Journal of Marine Research Vol 15, No. 3 Agustus 2026, pp. 623-632 DOI : 10.14710/jmr.v15i3.54399
EISSN: 2407-7690
https://ejournal3.undip.ac.id/index.php/jmr

Analysis of Dissolved Nitrogen and Its Spatial Distribution in Galesong Waters for Seaweed Cultivation

Nur Halizah Roebetho[1], Putri Sakinah Resman[1], Rahmat Pratama Putra[1], Andi Alya Yusriyyah[2] Amanda Pricella Putri[1], Asmi Citra Malina[1], Nita Rukminasari[1], Joeharnani Tresnati[1], Jamaluddin Fitrah Alam[2]*
[1]Departemen Perikanan, Fakultas Ilmu Kelautan dan Perikanan, Universitas Hasanuddin
[2]Departemen Kelautan, Fakultas Ilmu Kelautan dan Perikanan, Universitas Hasanuddin
Jl. Perintis Kemerdekaan Km.10 Tamalanrea, Makassar, Sulawesi Selatan 90245 Indonesia
Corresponding author, e-mail: alamjamaluddin@unhas.ac.id

ABSTRACT: This study evaluated dissolved inorganic nitrogen concentrations in Galesong Waters, Takalar Regency, South Sulawesi, Indonesia, in relation to aquaculture water-quality criteria and described the horizontal distribution of ammonium (NH_4^+) and nitrate ($NO_3^−$). Sampling was conducted from 23 April to 25 May 2025 at five purposively selected stations representing nearshore, farming-area, and offshore conditions. Surface seawater samples were analyzed spectrophotometrically for NH_4^+ and $NO_3^−$, while temperature, pH, dissolved oxygen, and salinity were measured in situ. Spatial distribution was visualized using ArcMap 10.3. Measured environmental conditions were generally suitable for seaweed cultivation, with temperature ranging from 29.6 to 29.9 °C, pH from 7.92 to 7.95, dissolved oxygen from 4.66 to 4.95 mg $L^{−1}$, and salinity from 28.32 to 28.98 ppt. Ammonium remained below the analytical detection limit at all stations throughout the six-week observation period. Nitrate was consistently detected, with mean concentrations ranging from 0.017 ± 0.012 to 0.023 ± 0.015 mg $L^{−1}$, and declined from week 1 to week 6. Spatially, nitrate was highest at the nearshore station and lowest within active seaweed farming plots. These findings indicate low dissolved inorganic nitrogen availability rather than evident nitrogen enrichment and suggest that nitrogen limitation may constrain seaweed productivity if cultivation intensity increases without adequate nutrient replenishment.

Keywords: ammonium; dissolved inorganic nitrogen; nitrate; seaweed cultivation; water quality

INTRODUCTION

Nutrients are essential resources that support metabolism and growth of aquatic organisms. In the water, nutrients are commonly grouped into macronutrients and micronutrients; among macronutrients, nitrogen (N), phosphorus (P), and potassium (K) play central roles in regulating productivity (Meirinawati *et al*., 2021). In the nitrogen pool, ammonium (NH_4^+) and nitrate ($NO_3^−$) are key dissolved inorganic forms. Nitrate is a highly soluble, oxidized species that often dominates natural waters, whereas aquatic primary producers and many heterotrophs readily take up ammonium (Prakash & Khanam, 2021).

Nitrogen enters coastal ecosystems via natural processes, weathering and decomposition of organic matter and through land-based inputs associated with agriculture, livestock, and domestic wastewater (Muhaemin *et al*., 2023). Atmospheric exchange and runoff-derived organic matter also contribute external loads (Howarth *et al*., 2021). Microbial mineralization of organic inputs supplies dissolved nutrients, notably $NO_3^−$ and phosphate, that fuel phytoplankton growth. Because phytoplankton respond rapidly to nutrient availability, their biomass and composition are widely used as indicators of trophic status and water quality (Liu *et al*., 2021; Marsela *et al*., 2021).

Ammonium (NH_4^+) and nitrate ($NO_3^−$) are fundamental substrates for protein synthesis and cellular metabolism, thereby supporting the productivity of autotrophs such as phytoplankton and benthic algae. Balanced nitrogen availability enhances primary production, which forms the base of aquatic food webs and directly supports the sustainability of fish resources in coastal areas

Diterima : 26-11-2025 ; Diterbitkan : 20-08-2026

(Trommer *et al.*, 2020). However, excessive nitrogen enrichment can trigger eutrophication, leading to phytoplankton blooms whose decomposition consumes dissolved oxygen and creates hypoxic conditions (Liu *et al.* 2021). These conditions can lead to mass fish mortality and shifts in fish community structure, ultimately reducing fisheries productivity (Zamora-López *et al.*, 2025). Conversely, nitrogen limitation suppresses primary production and reduce food availability for higher trophic levels (Howarth *et al.*, 2021). Therefore, effective management requires site-specific understanding of nitrogen sources, concentrations, and distribution in relation to water quality and coastal fisheries sustainability.

Galesong Waters, located on the western coast of Takalar Regency and directly bordering the Makassar Strait, receive multiple nutrient inputs from small coastal streams, surface runoff, and intensive coastal use, including fish and shrimp farming. Dense coastal settlements add domestic waste loads that may alter local biogeochemistry. The area is a major center for seaweed cultivation particularly *Kappaphycus alvarezii* and *Eucheuma denticulatum* which has expanded markedly over the past decade (Akmal *et al.*, 2017; Prajogo *et al.*, 2023) In this context, fluctuations in nitrogen concentrations play a critical role, as they not only influence water biogeochemistry but also directly determine nutrient assimilation efficiency, growth, and overall harvest success of cultivated seaweeds. Consequently, variability in nitrogen availability can drive spatial and temporal differences in growth performance and harvest quality, ultimately affecting production outcomes in coastal aquaculture systems (Barillé *et al.*, 2025; Oort *et al.*, 2025).

Recent studies in Indonesian coastal systems reveal pronounced spatial variability in dissolved inorganic nitrogen and water-quality parameters related to coastal activities, providing baseline information for evaluating aquaculture related impacts (Hendrayana *et al.*, 2022; Akbar *et al.*, 2023). Other investigations underscore the value of nitrogen-based assessments for siting and managing coastal farming zones (Gainaugasiray *et al.*, 2024; Pariakan *et al.*, 2019). This is further supported by findings from Wafi *et al.* (2021), who demonstrated that spatial variation in dissolved inorganic nitrogen strongly influences the suitability of sites for seaweed cultivation. In addition, Cahyadi *et al.* (2025) reported that seasonal fluctuations in ammonium and nitrate significantly affect chlorophyll-a dynamics, highlighting the critical role of dissolved inorganic nitrogen in sustaining the photosynthetic capacity and overall productivity of *Kappaphycus*. In addition, nutrient limitation has been reported as a practical constraint in seaweed-farming areas of South Sulawesi, indicating that nutrient assessment is necessary not only from an environmental perspective but also for improving aquaculture management and production efficiency (Alam *et al.*, 2025). However, limited studies have specifically assessed nitrogen concentrations and their spatial distribution in Galesong Waters in relation to aquaculture water-quality standards. This highlights the need for site-specific evaluation of dissolved inorganic nitrogen (NH_4^+, NO_3^-) to support sustainable seaweed aquaculture management in the region.

This study aims to: (i) evaluate nitrogen concentrations in Galesong Waters against Indonesia's water-quality criteria for aquaculture as specified in Government Regulation No. 22 of 2021; and (ii) describe the horizontal distribution of dissolved inorganic nitrogen (NH_4^+, NO_3^-). The findings are intended to inform sustainable water-quality management and support the environmental suitability of seaweed aquaculture in the region.

MATERIALS AND METHODS

The study was conducted from 23 April to 25 May 2025 in coastal waters off Aeng Batu-Batu Village, North Galesong Subdistrict, Takalar Regency, South Sulawesi, Indonesia (5°14′10″ S, 119°22′53″ E). Site selection followed a purposive approach to represent nearshore areas potentially influenced by land-based activities and offshore waters less affected by coastal inputs. Five stations were established based on local hydrogeomorphic characteristics (Figure 1). Station 1 was in the intertidal zone adjacent to residential housing, approximately 30 m from shore. Stations 2–4 were located within active seaweed farming plots, with ~5 m spacing between stations. Station 5 was positioned ~120 m southwest of the shoreline.

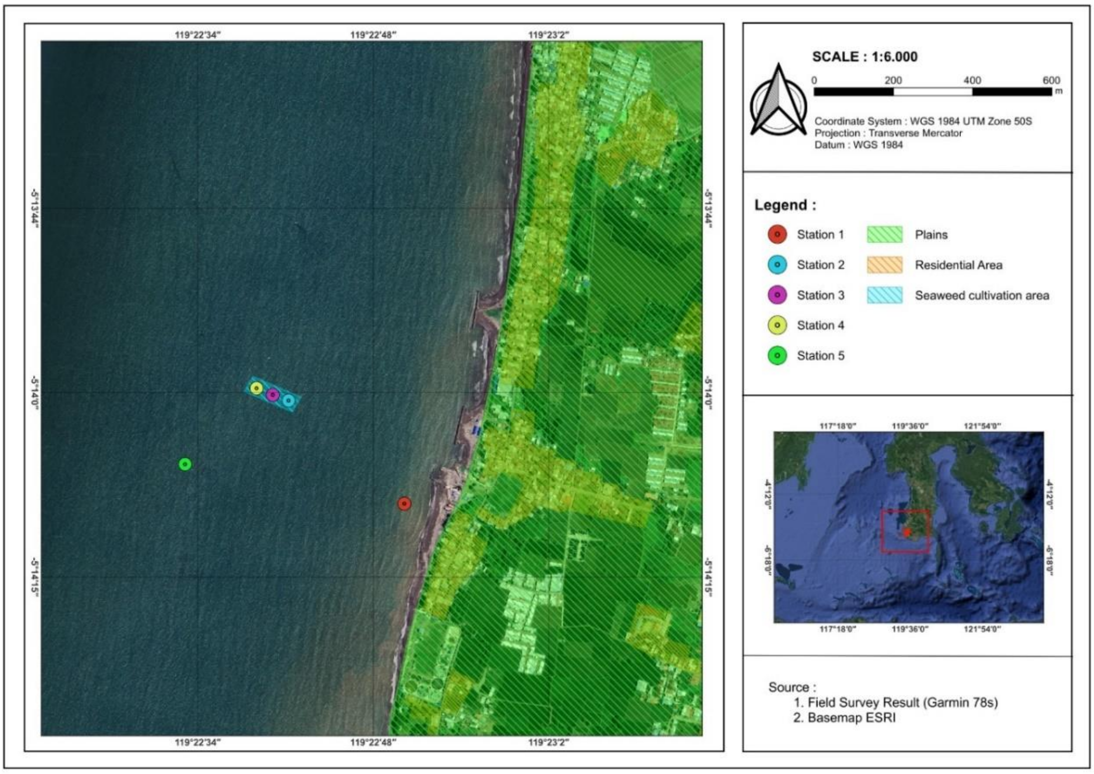

Figure 1. Map Sampling Locations in Galesong Waters

Surface seawater samples were collected at each station between 07:00 and 10:00 WITA at a depth of 0.5 m below the surface. Samples were stored in 500 mL bottles in an insulated cool box and transported to the laboratory for nutrient analysis. In situ measurements of dissolved oxygen, pH, and temperature were obtained using a portable multiparameter meter (Toa DKK WQC-24, Japan). Nitrogen analyses were performed at the Water Quality Laboratory, Faculty of Marine Science and Fisheries, Hasanuddin University. Ammonium (NH_4^+) and nitrate (NO_3^-) concentrations were measured spectrophotometrically (model DREL 2800). Prior to analysis, 25–50 mL aliquots were filtered: 0.45 µm membrane filters (Millipore) for NH_4^+ and Whatman No. 42 ashless cellulose filters for NO_3^-. For NH_4^+, 5 mL of 5 % phenol solution and 5 mL sodium nitroprusside catalyst were added to the sample, followed by 3 mL alkaline oxidizing reagent. After 60 min color development, absorbance was read at 640 nm. For NO_3^-, 5 mL of filtered sample was mixed with 0.5 mL brucine solution, allowed to stand for 2–4 min, then 5 mL concentrated H_2SO_4 was added, the mixture was homogenized, cooled to room temperature, and measured at 410 nm. Results are reported as mg L^{-1}.

Absorbance values were converted to concentrations in Microsoft Excel using laboratory calibration curves, and station coordinates with corresponding NH_4^+ and NO_3^- values were imported into ArcMap 10.3 for spatial analysis (Puspitasari *et al*. 2021). Nitrogen concentrations were evaluated descriptively against Indonesia's aquaculture water-quality standards in Government Regulation No. 22/2021, alongside contemporaneous oceanographic conditions in Galesong Waters.

RESULTS AND DISCUSSION

Measured environmental parameters for the five stations are summarized in Table 1. Seawater temperature ranged from 29.6–29.9 °C, meeting the aquaculture water-quality criterion of 26–32 °C under Government Regulation No. 22/2021 and falling within the commonly reported optimal range for *Kappaphycus alvarezii* cultivation of 20–30 °C (Astriana *et al*., 2024). Within this near-optimal window, photosynthetic activity and protein synthesis in seaweeds are generally sustained, which can increase cellular nitrogen demand and facilitate more efficient uptake of dissolved inorganic nitrogen by photosynthetic organisms. This interpretation is consistent with Nikhlani & Kusumaningrum (2021), who noted that optimal temperatures enhance photosynthesis and nutrient absorption in *K. alvarezii*. Conversely, departures from the optimal range can lead to thallus discoloration (pale yellowing) and may depress growth and survival when temperatures are excessively high or low (Afifah *et al*., 2025).

Measured pH ranged from 7.92–7.95, within the Government Regulation No. 22/2021 criterion of 7.0–8.5 and suitable for seaweed growth. Consistent with Zakariah *et al*. (2023), slightly alkaline conditions (> 7) favor *Kappaphycus* cultivation. Deviations toward more acidic or highly alkaline waters can induce physiological stress in seaweeds (Nikhlani & Kusumaningrum, 2021). In coastal systems, pH reflects the balance of photosynthesis, respiration, and organic-matter decomposition; the relatively higher pH observed in farming plots likely reflects seaweed photosynthesis lowering CO_2 and elevating pH (Alamrousi *et al*. 2022).

Dissolved oxygen (DO) concentrations were 4.66–4.95 mg L^{-1}, meeting the Government Regulation No. 22/2021 (4–8 mg L^{-1}). These values are generally sufficient for aquatic metabolism and support nitrification of NH_4^+ to NO_3^-. Wafi *et al*. (2021) reported that DO of ~4–6 mg L^{-1} is adequate for biochemical processes and the nitrogen cycle, whereas DO < 4 mg L^{-1} can indicate thermal stress, elevated community respiration, or organic loading. Potential drivers of low DO include high temperature, weak currents, and decomposition of organic matter none appeared limiting at the time of sampling. (Mahaffey *et al*. 2020).

Salinity ranged from 28.32–28.98 ppt (mean ~28–29 ppt). This range aligns with seaweed farming guidance (28–34 ppt; Muliyadi, 2024) but is slightly below the salinity criterion in Government Regulation No. 22/2021, which sets an acceptable range of 33–34 ppt. The modest depression in salinity likely reflects tidal mixing with freshwater from nearby small streams (Azhikodan *et al*., 2021). Large departures from the optimal salinity window can disrupt cellular osmoregulation and impede

Table 1. In-situ environmental parameters at five stations in Galesong Waters. Values are reported as mean ± SD

Parameters	Sampling Point					Quality standards	Reference
	1	2	3	4	5		
Temperature (°C)	29.9 ± 0.685	29.9 ± 0.769	29.6 ± 1.031	29.9 ± 0.784	29.8 ± 0.649	20 – 30 °C.	Government Regulation No. 22 of 2021; Astriana *et al*., 2023
pH	7.92 ± 0.074	7.94 ± 0.057	7.95 ± 0.023	7.95 ± 0.042	7.94 ± 0.119	pH 7.0–8.5	Government Regulation No. 22 of 2021; Zakariah *et al*., 2023
Dissolved Oxygen (mg/L)	4.81 ± 0.823	4.95 ± 1.441	4.93 ± 1.327	4.71 ± 1.252	4.66 ± 0.982	4 – 8 mg/L	Government Regulation No. 22 of 2021; Wafi *et al*., 2021
Salinity (ppt)	28.32 ± 1.776	28.90 ± 1.218	28.62 ± 1.272	28.92 ± 1.358	28.90 ± 1.468	28-34 ppt	Government Regulation No. 22 of 2021; Mulyadi, 2024

Note: (±) standard deviation; St 1 = near settlement; St 2–St 4 = seaweed farming area; St 5 = ~120 m southwest from shoreline.

nutrient uptake, reducing *Kappaphycus alvarezii* growth (Aris *et al*., 2021). Thus, while salinity remained broadly supportive of cultivation during the study, maintaining stable salinity conditions would help sustain optimal productivity.

Ammonium (NH_4^+) concentrations remained extremely low, consistently approaching zero or falling below the analytical detection limit across all five stations throughout the six-week observation period (Table 2 and Figure 2). These near-nondetectable values easily meet the Indonesian marine water quality criterion for aquaculture (≤ 0.3 mg L^{-1}) under Government Regulation No. 22/2021, indicating an absence of inorganic nitrogen pollution from anthropogenic organic waste.

Ecologically, this persistent depletion is driven by two main factors: rapid biological uptake and active biogeochemical processing. As the most energetically favorable form of dissolved inorganic nitrogen, NH_4^+ is preferentially and rapidly assimilated by autotrophs, particularly the cultivated *Kappaphycus alvarezii* (Muhaemin *et al*., 2023; Syamsuddin, 2024) Furthermore, any remaining ammonium in the water column is likely subjected to efficient microbial nitrification, rapidly converting it to nitrite (NO_2^-) and ultimately nitrate (NO_3^-) (Surya *et al*., 2024). Similar oligotrophic conditions and rapid ammonium depletion have been documented in other tropical coastal aquaculture systems, where the high biological demand of dense macroalgal cultivation outpaces the natural supply of dissolved ammonium (Smart *et al.*, 2022). While these low levels reflect excellent environmental conditions in terms of pollution control, they fall below the optimal range of 0.01–3.50 mg L^{-1} recommended for *K. alvarezii* growth (Abbas *et al*., 2021). Consequently, this sustained scarcity implies that ammonium is a limiting nutrient in Galesong Waters, forcing the cultivated seaweed to rely almost entirely on nitrate to sustain their protein synthesis and growth.

Nitrate (NO_3^-) concentrations exhibited a distinct temporal decline across all stations from week 1 to week 6 (Figure 3). Initially, NO_3^- ranged from ~0.025 to 0.045 mg L^{-1}, but experienced a sharp drop by week 4 (reaching ~0.005–0.015 mg L^{-1}) before stabilizing. This depletion aligns with the exponential growth phase of *Kappaphycus alvarezii*, where thalli actively acquire nitrogen for protein and photosynthetic pigment synthesis (Narvarte *et al*. 2022). Overall, the average NO_3^- concentrations (0.017–0.022 mg L^{-1}) were well below the Indonesian marine quality threshold of ≤ 0.06 mg L^{-1} (Government Regulation No. 22/2021). While these levels indicate unpolluted conditions, they fall slightly below the highly optimal range for *K. alvarezii* cultivation (> 0.04 mg L^{-1}; Khasana *et al*., 2025). However, as demonstrated by Kasim *et al*. (2019) in other Indonesian coastal waters, seaweeds can still maintain basal growth at concentrations of 0.02–0.04 mg L^{-1}, though maximum productivity might be constrained.

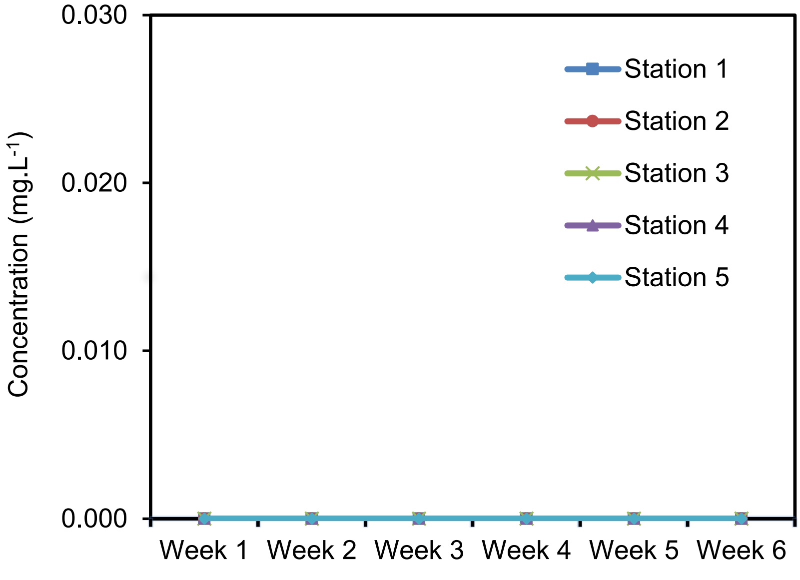

Figure 2. Average ammonium concentration in Galesong Waters

Journal of Marine Research Vol 15, No. 3 Agustus 2026, pp. 623-632

Table 2. Average concentrations of dissolved inorganic nitrogen across five stations in Galesong Waters during the six-week observation period

Parameters	Sampling Point					Quality standards
	1	2	3	4	5	
Nitrate (mg/L)	0.023 ± 0.015	0.020 ± 0.014	0.017 ± 0.012	0.020 ± 0.010	0.023 ± 0.014	0.04 – 0.06 mg/L
Ammonium (mg/L)	ND	ND	ND	ND	ND	0.01 – 3.50 mg/L

Note: (±) standard deviation; St 1 = near settlement; St 2–St 4 = seaweed farming area; St 5 = ~120 m southwest from shoreline. ND = Not Detected (below the analytical limit of detection).

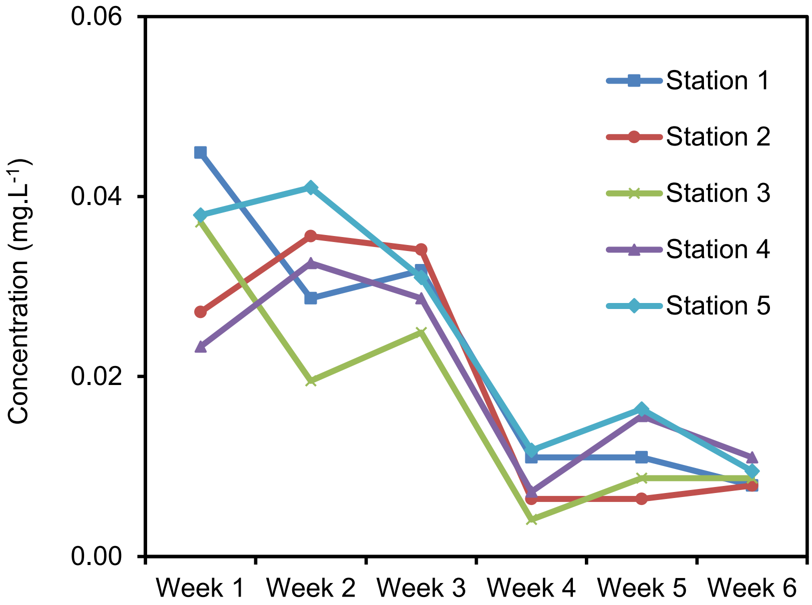

Figure 3. Average nitrate concentrations in Galesong Waters

Spatial analysis further elucidated the environmental drivers of nitrogen distribution (Figure 4). The weekly spatial maps reveal a pronounced nearshore-to-offshore gradient. Nitrate concentrations were consistently highest at the nearshore site (Station 1), particularly during the first three weeks, likely driven by terrestrial runoff and domestic wastewater discharge from coastal settlements in Aeng Batu-Batu Village. Conversely, the active seaweed farming plots (Stations 2–4) exhibited the lowest NO_3^- levels, creating a localized zone of nutrient depletion. This spatial gradient confirms the role of *K. alvarezii* as an effective . Station 5, located further offshore (~120 m), maintained intermediate-to-high nitrate levels, reflecting reduced biological drawdown and the influence of offshore hydrodynamic mixing. Similar spatial dynamics have been reported in other tropical coastal systems in Indonesia (Hendrayana *et al*., 2022; Akbar *et al*., 2023), where intensive cultivation significantly lowers ambient nutrients compared to uncultivated adjacent waters. By week 4, corresponding with the sharp decline in overall concentration, the spatial distribution became significantly more homogenous across the entire study area, indicating that localized seaweed uptake is a powerful regulator of nitrate bioavailability during the critical growth period. However, because hydrodynamic exchange, water residence time, and nutrient fluxes were not measured directly in this study, the relative contribution of terrestrial input, uptake by seaweed, and physical mixing cannot be separated quantitatively. The spatial pattern should therefore be interpreted as a descriptive indication of local nitrogen variability rather than definitive proof of causation.

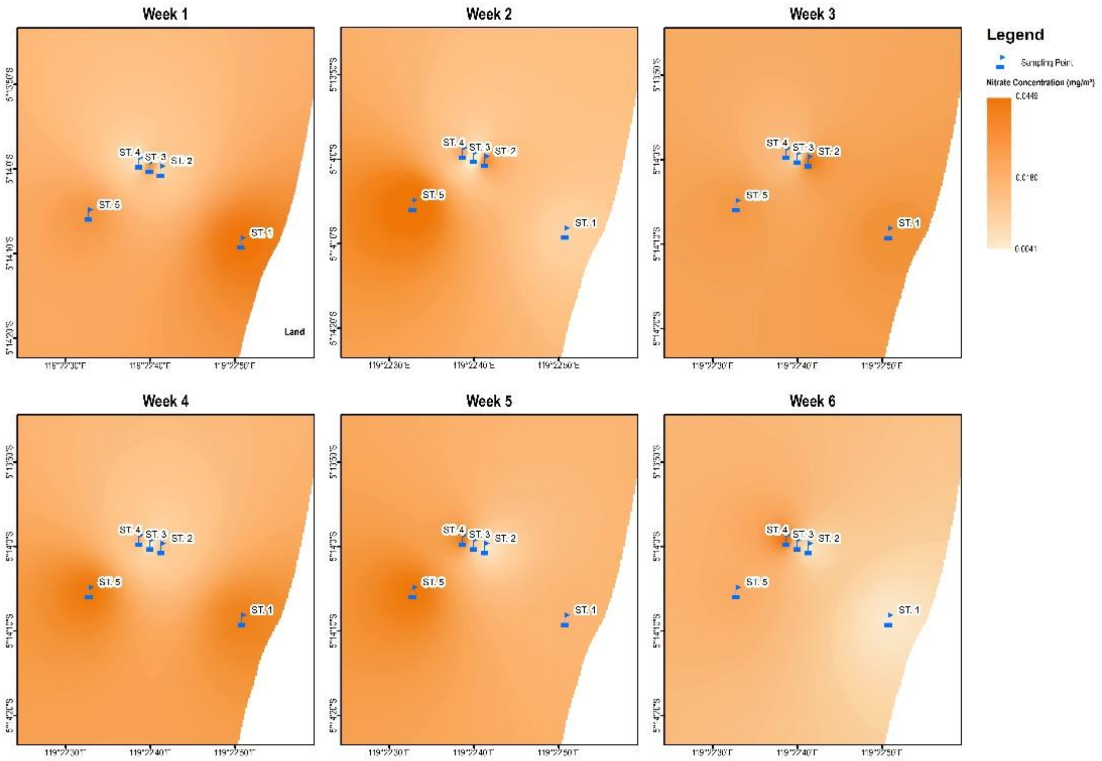

Figure 4. Distribution of nitrate concentrations in Galesong Waters

From an ecological and fisheries management perspective, the persistently low ammonium and nitrate levels in Galesong Waters underscore a critical implication. While the local water quality is excellent and free from eutrophication risks, the system is fundamentally nitrogen-limited. The environmental context (temperature 29.6–29.9 °C, pH 7.92–7.95, and salinity 28–29 ppt) is highly supportive of biogeochemical processing, but the absolute lack of dissolved inorganic nitrogen means the carrying capacity for seaweed aquaculture in this specific coastal zone may be approaching its upper limit. Unregulated expansion or increasing the density of seaweed longlines could exacerbate nutrient competition, potentially leading to stunted growth, thallus discoloration, and increased susceptibility to diseases due to nutritional stress. These findings also have broader implications for coastal resource management. In seaweed-producing areas such as Galesong, water quality assessment should not be limited to the detection of pollution thresholds alone but should also consider whether nutrient availability is sufficient to support sustainable cultivation. The present results suggest that farm expansion or excessive planting density may intensify nutrient competition within the farming area, particularly during active growth phases when nitrogen demand is high. Therefore, adaptive management measures such as maintaining adequate spacing between farm plots, aligning planting schedules with periods of greater nutrient replenishment, and conducting routine nutrient monitoring would be beneficial for sustaining productivity. Although this study did not directly measure fishery response, maintaining balanced nutrient conditions in coastal waters remains relevant not only for aquaculture performance but also for broader ecosystem productivity and fisheries support, as nitrogen availability influences primary production at the base of the food web.

CONCLUSION

This study indicates that, during the observation period, Galesong Waters generally met the applicable marine water-quality criteria for aquaculture under Government Regulation No. 22 of

2021, with temperature, pH, dissolved oxygen, and salinity remaining within or close to ranges considered suitable for seaweed cultivation; however, dissolved inorganic nitrogen availability was low, as shown by ammonium concentrations below the analytical detection limit and nitrate concentrations of 0.017–0.023 mg L^{-1}, suggesting that the system was not experiencing evident nitrogen enrichment but may be characterized by limited nitrogen availability for optimal seaweed growth. The observed nitrate pattern, with relatively higher concentrations at the nearshore station and lower concentrations within active farming plots, suggests the combined influence of land-based inputs near the coast and biological drawdown in cultivated areas, although these mechanisms were not directly quantified. Therefore, while the waters remain suitable for current seaweed farming, low dissolved inorganic nitrogen availability may become a constraint if cultivation intensity increases without adequate nutrient replenishment. This conclusion should be interpreted with caution because the study was based on a limited sampling period, a small number of stations, and a restricted set of measured variables, without direct assessment of hydrodynamics, nutrient fluxes, chlorophyll-a, or seaweed growth response. Future studies should expand spatial and seasonal coverage and integrate additional environmental and biological variables to better resolve nitrogen dynamics and provide a stronger basis for evaluating aquaculture sustainability and carrying capacity in Galesong Waters.

ACKNOWLEDGMENTS

The authors thank Universitas Hasanuddin for financial support through the PDPU Research Grant for Fiscal Year 2025 (Contract No. 01260/UN4.22/PT.01.03/2025). We also thank Dg. Sila for assistance with field sampling and all contributors whose support enabled the completion of this study.

REFERENCES

Abbas, N., Syamsuddin, R. & Dh. Trijuno, D. 2021. The Seaweed Kapppaphycus alvarezii cultivation from different aquatic activity locations. *International Journal of Scientific and Research Publications,* 11(7): 9–15. DOI: 10.29322/ijsrp.11.07.2021.p11503

Afifah, A.N., Abdunnur & Efendi, M. 2025. Comparison of water quality in coral reef ecosystem waters inside and outside the conservation area Bontang City, East Kalimantan. *Jurnal Laot Ilmu Kelautan*, 7(1): 80–85. DOI: 10.35308/jlik.v7i1.12348

Akbar, R.N.F., Kartika, A.G.D., Pratiwi, W.S.W. & Effendy, M. 2023. Distribusi nitrogen anorganik terlarut di perairan Padelegan, Kecamatan Pademawu, Kabupaten Pamekasan. *Buletin Oseanografi Marina*, 12(2): 261–269. DOI: 10.14710/buloma.v12i2.50156

Akmal, Gafur, A., Sudrajat, I., Haruna & Hasbullah, D. 2017. Kualitas karagenan, gel strength, viskositas Kappaphcus alvareziidibudidayakan bersama Eucheuma denticulatum pada perairan yang sama. *Jurnal Perekayasaan Budidaya Air Payau*, 2(1): 1–6.

Alam, J. F., Kasmiati, K., Fachrudin, L., Umar, W., Mulyani, A., Said, R. D., Suryani, S., & Alimin, A. W. F. 2025. The application of slow-release solid organic fertilizer on *Kappaphycus alvarezii* in a low nutrient conditions seaweed farming area. *Fisheries and Aquatic Sciences,* 28(10): 677–686. DOI: 10.47853/FAS.2025.e57

Alam, J.F., Yamamoto, T., Umino, T., Nakahara, S. & Hiraoka, K. 2020. Estimating nitrogen and phosphorus cycles in a timber reef deployment area. *Water (Switzerland)*, 12(9): 2515. DOI: 10.3390/w12092515

Alamrousi, A., Casais, E., García-Cardesín, É., Masaló, I., Pintado, J. & Cremades, J. 2022. Influence of pH, N, P, N: P ratio, and dissolved inorganic carbon on Ulva ohnoi growth and biomass quality: Potential implications in IMTA-RAS. *Aquaculture Journal*, 2(4): 285–301. DOI: 10.3390/aquacj2040017

Aris, M., Muchdar, F. & Labenua, R. 2021. Study of seaweed Kappaphycus alvarezii explants growth in the different salinity concentrations. *Jurnal Ilmiah Perikanan dan Kelautan*, 13(1): 97–105. DOI: 10.20473/jipk.v13i1.19842

Astriana, B.H., Cokrowati, N. & Putra, A.P. 2024. Analisis tingkat pencemaran perairan di lokasi budidaya rumput laut, Labuhan Sangoro, Teluk Saleh Kabupaten Sumbawa. *Jurnal Perikanan Unram*, 13(3): 744–754. DOI: 10.29303/jp.v13i3.617

Azhikodan, G., Hlaing, N.O., Yokoyama, K. & Kodama, M. 2021. Spatio-temporal variability of the salinity intrusion, mixing, and estuarine turbidity maximum in a tide-dominated tropical monsoon estuary. *Continental Shelf Research*, 225: .104477. DOI: 10.1016/j.csr.2021.104477

Barillé, L., Paterson, I.L.R., Oiry, S., Aris, A., Cook-Cottier, E.J. & Nurdin, N. 2025. Variability of Kappaphycus alvarezii cultivation in South-Sulawesi (Indonesia) related to the monsoon shift: Water quality, growth and colour quantification. *Aquaculture Reports*, 40: 102557. DOI: 10.1016/j.aqrep.2024.102557

Cahyadi, J., Prayitno, S.B., Desrina, D. & Purwanti, F. 2025. Distribusi musiman nitrat dan fosfat serta pemodelan klorofil-a sebagai indikator ekologis keberlanjutan budidaya Kappaphycus alvarezii di Pulau Tarakan. *Jurnal Kelautan Tropis*, 28(2): 175–184. DOI: 10.14710/jkt.v28i2.24784

Gainaugasiray, A.J., Tuhumury, S.F. & Pattinasarany, M.M. 2024. Analisis kesesuaian lokasi budidaya rumput laut dalam meningkatkan produksi di Desa Kumul Kecamatan Aru Utara Timur Batuley. *Indonesian Journal of Sustainable Aquaculture*, 1(2): 47–61. DOI: 10.30598/aquaculture.1.2.47-61

Hendrayana, H., Raharjo, P. & Samudra, S.R. 2022. Komposisi nitrat, nitrit, amonium dan fosfat di perairan Kabupaten Tegal. *Journal of Marine Research*, 11(2): 277–283. DOI: 10.14710/jmr.v11i2.32389

Howarth, R.W., Chan, F., Swaney, D.P., Marino, R.M. & Hayn, M. 2021. Role of external inputs of nutrients to aquatic ecosystems in determining prevalence of nitrogen vs. phosphorus limitation of net primary productivity. *Biogeochemistry*, 154(2): 293–306. DOI: 10.1007/s10533-021-00765-z

Kasim, M., Marlia, Abdullah, Balubi, A.M. & Djalil, W. 2019. Succession of epiphyte on thallus of Kappaphycus alvarezii (Rhodophyta) in horizontal net cage culture. *ACCL Bioflux*, 12(5): 1710–1716.

Khasana, U., Retno Iriani, V. & Bidayani, E. 2025. Regenerasi mikropropagul menjadi plantlet rumput laut Kappaphycus alvarezii di Balai Besar Perikanan Budidaya Laut Lampung. *Amreta Meena*, 2(1): 25–31. DOI: 10.33019/am.v2i1.5901

Liang, Z., Wang, W., Liu, L., Li, G. & Xia, B. 2022. Influence of commercial-scale seaweed cultivation on water quality: A case study in a typical laver culture area of the Yellow Sea, North China. *Journal of Marine Science and Engineering*, 10(5). DOI: 10.3390/jmse10050681

Liu, L., Wang, Z., Wang, C., Li, W. & Nie, X. 2021. Effects of nitrogen sources and concentrations on the growth of different phytoplankton taxa. *Journal of Ocean University of China*, 20(3): 721–728. DOI: 10.1007/s11802-021-4564-z

Mahaffey, C., Palmer, M., Greenwood, N. & Sharples, J. 2020. Impacts of climate change on dissolved oxygen concentration relevant to the coastal and marine environment around the UK. *MCCIP Science Review 2020*: 31–53. DOI: 10.14465/2020.arc02.oxy

Marsela, K., Hamdani, H., Anna, Z. & Herawati, H. 2021. The relation of nitrate and phosphate to phytoplankton abundance in the upstream Citarum River, West Java, Indonesia. *Asian Journal of Fisheries and Aquatic Research*, 1(5): 21-31. DOI: 10.9734/ajfar/2021/v11i530216

Meirinawati, H., Prayitno, H.B. & Wahyudi, A.J. 2021. Nutrient distribution in eastern Indonesian waters. *IOP Conference Series: Earth and Environmental Science*, 934(1): 012052. DOI: 10.1088/1755-1315/934/1/012052

Muhaemin, M., Alfya Rahmadita, D., Suwiryono, J. & Mayaguezz, H. 2023. Variabilitas konsentrasi dan sebaran N-anorganik (amonia, nitrit, dan nitrat) terlarut di perairan Kalianda dan perairan Anyer-Panimbang. *Journal of Marine Research*, 12(4): 737–745. DOI: 10.14710/jmr.v12i4.38566

Muliyadi. 2024. Kajian kualitas air terhadap pertumbuhan rumput laut Eucheuma cottonii; studi kasus di Desa Tapi-tapi Kec. Marobo Sulawesi Tenggara. *Jurnal Perikanan Unram*, 13(3): 682–689. DOI: 10.29303/jp.v13i3.605

Narvarte, B.C.V., Genovia, T.G.T., Hinaloc, L.A.R. & Roleda, M.Y. 2022. Growth, nitrate uptake kinetics, and biofiltration potential of eucheumatoids with different thallus morphologies. *Journal of Phycology*, 58(1): 12–21. DOI: 10.1111/jpy.13229

Nikhlani, A. & Kusumaningrum, I. 2021. Analisa parameter fisika dan kimia perairan Tihik Tihik Kota Bontang untuk budidaya rumput laut Kapphaphycus alvarezii. *Jurnal Pertanian Terpadu*, 9(2): 189–200. DOI: 10.36084/jpt..v9i2.328

Oort, P.A.J., Julianto, B., Latama, G., Siradjuddin, I., Rukminasari, N., Walyandra, Z.Z., Ibrahim, I.A., Verhagen, A. & van der Werf, A.K. 2025. Yield determinants of Kappaphycus alvarezii seaweed in South Sulawesi, Indonesia. *Journal of Applied Phycology*, 37(2): 1153–1170. DOI: 10.1007/s10811-025-03446-8

Pariakan, A., Mustafa, A. & Indrayani. 2019. Karakteristik oseanografi kimia Selat Tiworo Utara sebagai daya dukung lingkungan dalam penentuan lokasi budidaya rumput laut (Eucheuma cottonii). *Journal of Fisheries and Marine Research*, 3(3): 390–399. DOI: 10.21776/ub.jfmr.2019.003.03.15

Prajogo, D., Alam, J.F., Malina, A.C., Kasmiati, Alhaqqi, M.S. & Mustava, M.D. 2023. Seaweed trade: Unleashing Australia-Indonesia seaweed industry's trade potential.

Prakash, A. & Khanam, S. 2021. Nitrogen pollution threat to mariculture and other aquatic ecosystems: An overview. *Journal of Pharmacy and Pharmacology*, 9(12): 428-433. DOI: 10.17265/2328-2150/2021.12.005

Puspitasari, A.A., Zinuri, M., Setiyono, H., Wulandari, S.Y. & Maslukah, L. 2021. Analisa sebaran kandungan fosfat di Muara Sungai Bodri, Kendal Jawa Tengah. *Indonesian Journal of Oceanography*, 3(1): 120–127.

Smart, J.N., Schmid, M., Paine, E.R., Britton, D., Revill, A. & Hurd, C.L. 2022. Seasonal ammonium uptake kinetics of four brown macroalgae: Implications for use in integrated multi-trophic aquaculture. *Journal of Applied Phycology*, 34(3): 1693–1708. DOI: 10.1007/s10811-022-02743-w

Surya, A.T.J., Sasongko, A.S. & Cahyadi, F.D. 2024. Kandungan amonia, fosfat, nitrat dan nitrit air laut di perairan pesisir Desa Lontar. *Juvenil: Jurnal Ilmiah Kelautan dan Perikanan*, 5(3): 238–245. DOI: 10.21107/juvenil.v5i3.23089

Syamsuddin, R. 2024. Seaweed Kappaphycus alvarezii cultivation for seagrass ecosystem conservation. In: A.M. Gonçalves (ed.), *Marine Ecosystems*. IntechOpen. DOI: 10.5772/intechopen.106762

Trommer, G., Poxleitner, M. & Stibor, H. 2020. Responses of lake phytoplankton communities to changing inorganic nitrogen supply forms. *Aquatic Sciences*, 82(2): 22. DOI: 10.1007/s00027-020-0696-2

Wafi, A., Ariadi, H., Khumaidi, A. & Muqsith, A. 2021. Pemetaan kesesuaian lahan budidaya rumput laut di Kecamatan Banyuputih, Situbondo berdasarkan indikator kimia air. *Jurnal Ilmu Perikanan*, 12(2): 170–179. DOI: 10.35316/jsapi.v12i2.1346

Zakariah, M.I., Koto, S., Irsan & Fesanrey, W. 2023. Analisis kualitas perairan budidaya rumput laut di Dusun Saliong Desa Batu Boy sebagai dampak gagal panen. *Biopendix: Biologi Pendidikan dan Terapan*, 10(1): 91–101. DOI: 10.30598/biopendixvol10issue1page91-101

Zamora-López, A., Guerrero-Gómez, A., Torralva, M., Zamora-Marín, J.M. & Oliva-Paterna, F.J. 2025. Eutrophication-induced shifts in fish assemblages from a Mediterranean coastal lagoon. *Science of The Total Environment*, 1004: 180765. DOI: 10.1016/j.scitotenv.2025.180765