Marine Pollution Bulletin 201 (2024) 116170

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Pollutant levels in the waters of the industrial area of North Aceh and Lhokseumawe Regency, Indonesia

Muliari Muliari [a,*], Mahdaliana [b], Irfannur Irfannur [c], Yusrizal Akmal [c], Agung Setia Batubara [d]

[a] Department of Marine Science, Faculty of Agriculture, Universitas Malikussaleh, Aceh Utara, Indonesia
[b] Department of Aquaculture, Faculty of Agriculture, Universitas Malikussaleh, Aceh Utara, Indonesia
[c] Department of Aquaculture, Faculty of Agriculture, Universitas Almuslim, Bireuen, Indonesia
[d] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, North Sumatra, Indonesia

ARTICLE INFO

Keywords:
Bicarbonate
Nitrite
Salinity
Alkalinity
ammonia

ABSTRACT

This research was conducted from June to August 2023. Data and samples were collected using an exploratory survey method in four locations around the industrial area, namely PT. ASEAN Aceh Fertilizer and PT. Kertas Kraft Aceh in North Aceh Regency, while PT. Pupuk Iskandar Muda and PT. Harun NGL in Lhokseumawe Regency, Indonesia. Observations of physico-chemical parameters including measurements of salinity, bicarbonate, calcium, magnesium, nitrate, nitrite, orthophosphate, total alkalinity, and total ammonia were analyzed in the Laboratory of PT Intraco Agroindustri, Langkat Regency, North Sumatra, Indonesia. Microplastic analysis was carried out at the Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, Indonesia. The biological parameters measured in this research include the chlorophyll concentration in the water locations observed. Based on the results of the analysis, it shows that the calcium, magnesium, orthophosphate content at the four research locations has exceeded the quality standards, while the nitrate content is only at PT. ASEAN Aceh Fertilizer and PT. Kertas Kraft Aceh that exceeds the quality standards. The bicarbonate, nitrite, salinity, total alkalinity, and total ammonia content at the four research locations were under normal conditions. The chlorophyll content in the four research locations was categorized as low fertility (oligotrophic). Based on the analysis, it also shows that the four research locations were contaminated with microplastics with a range of 2.78–5.49 particles/l.

1. Introduction

North Aceh and Lhokseumawe are regency in Aceh Province that has great potential in the marine and fisheries sector, both large and small pelagic fish. Small pelagic fish found in the waters of North Aceh and Lhokseumawe Regency, namely trevally, and mackerel (Shadiqin et al., 2018). Based on data from the North Aceh Maritime Fisheries Service, the total production of mackerel is 396.31 tons (BPS, 2016). North Aceh Regency is also one of the industrial areas in Aceh Province which consists of PT. ASEAN Aceh Fertilizer, and PT. Kertas Kraft Aceh, while Lhokseumawe Regency consists of PT. Pupuk Iskandar Muda and PT. Harun NGL. The development of massive industrial areas can increase pollution caused by the discharge of industrial factory waste (Dirgapraja et al., 2019). The waste produced is in the form of liquid waste which can pollute the environment, causing problems with water quality and aquatic life as well as damage to aquatic ecosystems (Parogay et al., 2021). Toxic wastewater from industrial areas will have a negative impact in terms of water ecology and the welfare of the community itself (Karri et al., 2021). Contamination of waste in water bodies can occur as a result of direct or indirect disposal (Muliari et al., 2019).

Research on industrial waste has become a global environmental issue so that several waste studies have been reported, such as the impact of acute and chronic exposure to different heavy metals on the main organs of fish (gills, liver, kidneys) including intestines, muscles, showing various types of pathology specific to internal organs (Shahjahan et al., 2022). Waste that has a high level of danger to the environment includes mercury (Hg), cadmium (Cd), lead (Pb) and microplastic (MP). Hg can cause gill damage and result in impaired osmotic regulation (Suseno et al., 2010), decreased Hepato Somatic Index (HSI) values, hemorrhage and hyperplasia of liver tissue (Zulfahmi et al., 2014), changes in the diameter and size of fish eggs (Ram and Sathyanesan, 1983). Exposure to Cd in fish can cause tissue

* Corresponding author.
E-mail address: muliari@unimal.ac.id (M. Muliari).

https://doi.org/10.1016/j.marpolbul.2024.116170
Received 9 December 2023; Received in revised form 13 February 2024; Accepted 14 February 2024

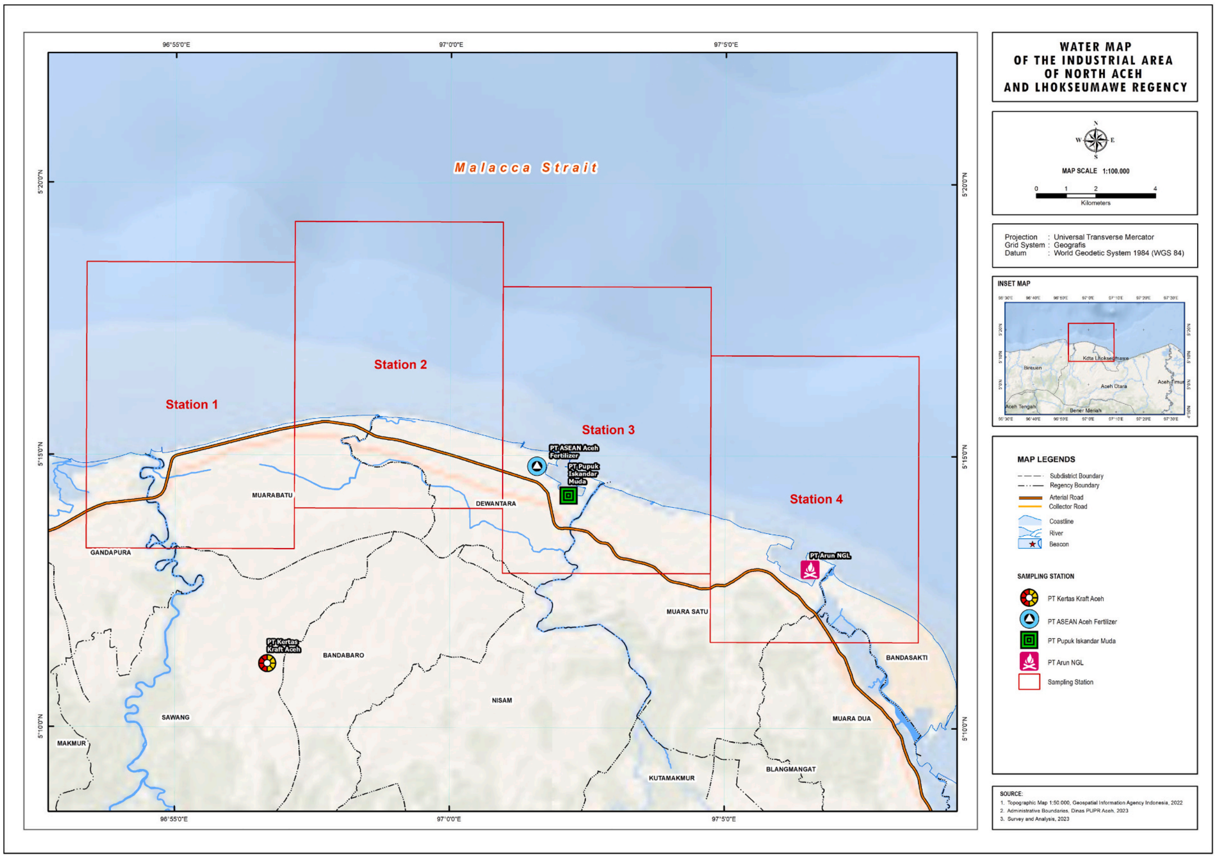

Fig. 1. Map of research location.

inflammation and gill capillaries to experience vasodilation (Garcia-Santos et al., 2006), disruption of the reproductive system, namely changes in the oogenetics of fish ovaries (Prado et al., 2011), goblet cell malformation, hemorrhage, atrophy of intestinal villi (Dane and Şişman, 2020), abnormality of erythrocyte cells (Witeska and Wakulesk, 2006), decreased number of leukocytes (Ghiasi et al., 2010). Exposure to Pb in fish can cause a decrease in the number and lifespan of erythrocyte cells (Harabawy and Mosleh, 2014), a decrease in hematocrit levels (Sahetapy, 2013), disruption of enzyme performance and activity (Rajamanicham and Musthuswam, 2008) and changes in fish morphology and behavior (Martinez et al., 2004). Furthermore, the physiological impacts of microplastics on aquatic organisms include blocked digestive tract, stunted growth, inhibiting egg hatching, liver toxicity and reproductive disorders (Jovanović, 2017; Menezes et al., 2019). The psychological impact of microplastics on aquatic organisms is in the form of changes in inherited behavior, eating preferences and death (Lönnstedt and Eklöv, 2016).

Waste pollution threatens the sustainability of coastal and marine ecosystems (Lu et al., 2018). Coral reefs are ecosystems that have a diversity of biota within them. The main causes of damage to coral reefs are natural and human factors (Wilkinson, 1996). The impact caused by heavy metal wastewater can have an impact on coral reefs, namely high temperatures and low salinity (Dzikrillah et al., 2022a, 2022b). As a result of the action of increasing water temperature, mortality increases (Saputra et al., 2021).

Coastal and marine areas with their natural resources are important for economic development (Nunes and Ghermandi, 2013). However, utilization practices that are not eco-friendly can have a negative impact on the environment in the form of environmental damage caused by pollution (Islam and Tanaka, 2004). Development in coastal areas must guarantee legal protection in the fair and sustainable use of marine resources for nature (Raymond et al., 2021). This can be seen from the behavior of the community in management (Masud et al., 2017). Impact on the development of socio-economic activities of communities in coastal areas for the development of tourism, trade and service activities (Prayogi and Asyiawati, 2021).

Based on the explanation above, it is necessary to carry out studies to solve and resolve problems. There are indications that there are levels of toxic pollution in coastal areas in the industrial areas of North Aceh and Lhokseumawe Regency, there have been mass deaths of fish in these waters. Therefore, it is necessary to conduct an analysis of the levels of toxic pollution in coastal areas of industrial areas to look at the water ecology regarding current issues. This research aims to analyze several chemical, physical and biological parameters to determine the level of water pollution around industrial areas in North Aceh and Lhokseumawe Regency, Aceh Province, Indonesia.

2. Method

2.1. Site and time

This research was conducted from June to October 2023. Data and samples were collected using an exploratory survey method in the coastal waters of North Aceh and Lhokseumawe Regency, Indonesia. The location points for data collection during the study were in location points around the industrial area, namely PT. ASEAN Aceh Fertilizer in Krueng Geukuh, and PT. Kertas Kraft Aceh in Jamuan, North Aceh Regency, Indonesia, while PT. Pupuk Iskandar Muda and PT. Harun NGL in Lhokseumawe Regency, Indonesia. Determination of sampling using purposive sampling method in four research locations where each area is divided into 25 stations based on the conditions of the industrial area (Fig. 1 and Table 1).

Table 1
Coordinate point for data collection in the waters of the North Aceh and Lhokseumawe Regency Industrial Areas, Indonesia.

No	Location	Longitude	Latitude	No	Location	Longitude	Latitude
1	PT. Kertas Kraft Aceh	96° 53′ 43.904″ E	5° 15′ 10.200″ N	51	PT. Pupuk Iskandar	97° 0′ 52.103″ E	5° 16′ 55.102″ N
2		96° 54′ 14.648″ E	5° 15′ 17.607″ N	52		97° 1′ 36.010″ E	5° 15′ 25.537″ N
3		96° 54′ 1.004″ E	5° 15′ 37.235″ N	53		97° 1′ 30.380″ E	5° 15′ 44.002″ N
4		96° 53′ 45.405″ E	5° 15′ 49.805″ N	54		97° 1′ 33.758″ E	5° 16′ 9.591″ N
5		96° 54′ 9.951″ E	5° 16′ 12.628″ N	55		97° 1′ 34.595″ E	5° 16′ 39.542″ N
6		96° 53′ 45.121″ E	5° 16′ 15.607″ N	56		97° 2′ 6.229″ E	5° 15′ 13.837″ N
7		96° 53′ 52.990″ E	5° 16′ 46.310″ N	57		97° 2′ 12.426″ E	5° 15′ 27.644″ N
8		96° 54′ 31.486″ E	5° 15′ 32.441″ N	58		97° 1′ 54.203″ E	5° 15′ 49.175″ N
9		96° 54′ 28.912″ E	5° 15′ 54.899″ N	59		97° 1′ 56.666″ E	5° 16′ 15.481″ N
10		96° 54′ 44.058″ E	5° 16′ 19.191″ N	60		97° 2′ 29.326″ E	5° 14′ 55.715″ N
11		96° 54′ 24.323″ E	5° 16′ 46.888″ N	61		97° 2′ 49.491″ E	5° 15′ 4.017″ N
12		96° 54′ 59.179″ E	5° 15′ 27.532″ N	62		97° 2′ 30.395″ E	5° 15′ 25.567″ N
13		96° 55′ 14.372″ E	5° 15′ 45.023″ N	63		97° 2′ 51.641″ E	5° 15′ 43.187″ N
14		96° 54′ 50.424″ E	5° 15′ 54.672″ N	64		97° 2′ 29.811″ E	5° 16′ 1.086″ N
15		96° 55′ 16.519″ E	5° 16′ 7.728″ N	65		97° 2′ 25.720″ E	5° 16′ 26.969″ N
16		96° 55′ 12.168″ E	5° 16′ 28.644″ N	66		97° 2′ 59.861″ E	5° 14′ 40.656″ N
17		96° 55′ 1.342″ E	5° 16′ 46.424″ N	67		97° 3′ 13.660″ E	5° 15′ 6.948″ N
18		96° 55′ 29.168″ E	5° 15′ 27.462″ N	68		97° 3′ 15.905″ E	5° 15′ 29.450″ N
19		96° 55′ 37.375″ E	5° 15′ 53.818″ N	69		97° 3′ 11.309″ E	5° 16′ 4.302″ N
20		96° 55′ 44.595″ E	5° 16′ 59.522″ N	70		97° 3′ 45.177″ E	5° 14′ 38.995″ N
21		96° 56′ 2.394″ E	5° 15′ 38.169″ N	71		97° 3′ 50.688″ E	5° 15′ 43.504″ N
22		96° 56′ 15.054″ E	5° 16′ 13.554″ N	72		97° 4′ 12.945″ E	5° 14′ 20.943″ N
23		96° 55′ 59.971″ E	5° 16′ 37.388″ N	73		97° 4′ 9.118″ E	5° 15′ 17.502″ N
24		96° 56′ 45.473″ E	5° 15′ 49.656″ N	74		97° 4′ 50.235″ E	5° 14′ 22.229″ N
25		96° 56′ 51.407″ E	5° 16′ 18.597″ N	75		97° 4′ 33.446″ E	5° 14′ 55.294″ N
26	PT. ASEAN Aceh Fertilizer	96° 56′ 41.193″ E	5° 16′ 44.210″ N	76	PT. Harun NGL	97° 4′ 54.144″ E	5° 15′ 22.347″ N
27		96° 56′ 32.790″ E	5° 17′ 8.282″ N	77		97° 5′ 14.793″ E	5° 14′ 2.169″ N
28		96° 57′ 14.661″ E	5° 15′ 52.157″ N	78		97° 5′ 26.670″ E	5° 14′ 47.156″ N
29		96° 57′ 14.327″ E	5° 16′ 45.916″ N	79		97° 6′ 2.547″ E	5° 13′ 36.270″ N
30		96° 57′ 10.856″ E	5° 17′ 15.805″ N	80		97° 5′ 44.792″ E	5° 13′ 38.938″ N
31		96° 57′ 45.686″ E	5° 15′ 58.355″ N	81		97° 5′ 42.542″ E	5° 14′ 12.962″ N
32		96° 57′ 33.148″ E	5° 16′ 24.680″ N	82		97° 5′ 58.536″ E	5° 14′ 59.474″ N
33		96° 57′ 59.446″ E	5° 16′ 56.619″ N	83		97° 6′ 26.838″ E	5° 13′ 22.579″ N
34		96° 57′ 44.274″ E	5° 17′ 22.099″ N	84		97° 6′ 27.992″ E	5° 13′ 52.525″ N
35		96° 58′ 25.714″ E	5° 15′ 59.157″ N	85		97° 6′ 9.111″ E	5° 14′ 16.092″ N
36		96° 58′ 5.491″ E	5° 16′ 17.472″ N	86		97° 6′ 23.199″ E	5° 14′ 37.992″ N
37		96° 58′ 33.864″ E	5° 16′ 44.375″ N	87		97° 7′ 8.571″ E	5° 13′ 5.409″ N
38		96° 58′ 34.636″ E	5° 17′ 26.743″ N	88		97° 6′ 49.507″ E	5° 13′ 17.173″ N
39		96° 58′ 49.685″ E	5° 16′ 9.656″ N	89		97° 6′ 52.358″ E	5° 13′ 41.435″ N
40		96° 59′ 0.475″ E	5° 16′ 33.398″ N	90		97° 6′ 50.589″ E	5° 14′ 5.046″ N
41		96° 59′ 3.483″ E	5° 16′ 55.397″ N	91		97° 7′ 8.874″ E	5° 14′ 34.871″ N
42		96° 59′ 27.074″ E	5° 16′ 12.149″ N	92		97° 6′ 45.729″ E	5° 15′ 0.291″ N
43		96° 59′ 38.986″ E	5° 16′ 56.976″ N	93		97° 7′ 16.596″ E	5° 12′ 44.707″ N
44		96° 59′ 23.792″ E	5° 17′ 26.570″ N	94		97° 7′ 25.623″ E	5° 12′ 55.628″ N
45		97° 0′ 0.264″ E	5° 15′ 53.504″ N	95		97° 7′ 41.423″ E	5° 13′ 16.193″ N
46		96° 59′ 50.568″ E	5° 16′ 34.538″ N	96		97° 7′ 23.706″ E	5° 13′ 35.180″ N
47		97° 0′ 12.031″ E	5° 17′ 11.730″ N	97		97° 7′ 21.701″ E	5° 13′ 56.732″ N
48		97° 0′ 25.840″ E	5° 16′ 26.675″ N	98		97° 7′ 38.317″ E	5° 14′ 38.717″ N
49		97° 0′ 47.890″ E	5° 15′ 44.048″ N	99		97° 8′ 6.400″ E	5° 13′ 45.853″ N
50		97° 1′ 4.364″ E	5° 16′ 14.945″ N	100		97° 7′ 49.336″ E	5° 14′ 0.572″ N

2.2. Data collection procedures

Water sampling was conducted at 100 stations (25 stations per location) from 4 research locations using a boat with a maximum distance of 4 miles from the beach to the sea (Table 1). Salinity measurements were carried out in situ using a Hand Refractometer (Atago Master-20M). 600 ml bottles were used to store water samples at each station, then the bottles were stored in a styrofoam box filled with ice with the aim of ensuring that there was no biochemical activity in the water samples. The styrofoam box was then sent to PT. Intraco Agroindustri, Langkat Regency, North Sumatra, Indonesia for measurements of bicarbonate, calcium, magnesium, nitrate, nitrite, orthophosphate, total alkalinity, and total ammonia. Water samples were taken to measure microplastics using a plankton net (mesh size 150 μm) by filtering 100 L of seawater. The filtered water samples were then stored in 100 ml bottles and given a 10 % KOH solution to degrade organic materials. Observations of microplastic samples were carried out at the Faculty of Marine and Fisheries, Syiah Kuala University, Banda Aceh, Indonesia using binocular (Zeiss Primo Star) and stereo microscopes (Meiji Techno EM-32). Chlorophyll measurements were carried out by taking 500 ml of seawater at each station, then putting the samples in a styrofoam box that had been given ice to inhibit biochemical processes in the water. The styrofoam box was then sent to PT. Logos Analitika Marinaterra, Langsa Regency, Indonesia for further analysis.

2.3. Research parameters

This study focused on physical, chemical and biological parameters. Observations of physico-chemical parameters including measurements of salinity was carried out in situ, then bicarbonate, calcium, magnesium, nitrate, nitrite, orthophosphate, total alkalinity, and total ammonia were analyzed in the PT Intraco Agroindustri, Langkat Regency, North Sumatra, Indonesia. Microplastic analysis was carried out at the Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, Indonesia. The biological parameters measured in this research include the chlorophyll concentration in the water locations observed.

Table 2
Results of analysis of pollutant levels in the waters of the North Aceh and Lhokseumawe Regency Industrial Areas, Indonesia.

No	Parameters	Research Locations			
		PT. Kertas Kraft Aceh	PT. ASEAN Aceh Fertilizer	PT. Pupuk Iskandar Muda	PT. Harun NGL
1.	Bicarbonate (HCO_3-) (mg/l)	130–136 (135.28 ± 1.99)[c]	98–188 (113.84 ± 20.78)[b]	68–73 (71 ± 2.5)[a]	68–73 (70.6 ± 2.55)[a]
2.	Calcium (Ca) (mg/l)	840–900 (869.6 ± 17.43)[a]	700–1020 (868.16 ± 93.51)[a]	840–920 (888 ± 40)[a]	840–920 (881.6 ± 40.79)[a]
3.	Chlorophyll (mg/m^3)	0.0018–0.0034 (0.0029 ± 0.0004)[b]	0.0009–0.0028 (0.0017 ± 0.0006)[a]	0.0018–0.0034 (0.0028 ± 0.0005)[b]	0.0011–0.0019 (0.0015 ± 0.0002)[a]
4.	Magnesium (Mg) (mg/l)	4720–4980 (4825.6 ± 67.70)[b]	4880–5460 (5074.88 ± 191.26)[c]	3620–4240 (3992 ± 310)[a]	3620–4240 (3942.4 ± 316.14)[a]
5.	Microplastics (particle/l)	0–6.67 (3.89 ± 3.43)[a]	0–13.33 (3.11 ± 4.27)[a]	0–6.67 (2.78 ± 3.43)[a]	0–20 (5.49 ± 6.34)[a]
6.	Nitrate (NO_3) (mg/l)	1–2 (1.6 ± 0.5)[b]	0–10 (6 ± 5)[c]	0[a]	0[a]
7.	Nitrite (NO_2) (mg/l)	0[a]	0–0.1 (0.028 ± 0.046)[b]	0[a]	0[a]
8.	Orthophosphate (PO_4) (mg/l)	0.1–0.15 (0.12 ± 0.025)[a]	0.25 (0.25 ± 0)[b]	0.25 (0.25 ± 0)[b]	0.25 (0.25 ± 0)[b]
9.	Salinity (‰)	32–33 (32.52 ± 0.51)[b]	31–33 (32.44 ± 0.58)[b]	31–32 (31.6 ± 0.5)[a]	31–32 (31.52 ± 0.51)[a]
10.	Total Alkalinity (mg/l)	134–140 (139.28 ± 1.99)[c]	100–122 (113.84 ± 7.95)[b]	68–73 (71 ± 2.5)[a]	68–73 (70.6 ± 2.54)[a]
11.	Total Ammonia (NH_4) (mg/l)	0[a]	0[a]	0–0.2 (0.056 ± 0.065)[b]	0–0.2 (0.084 ± 0.075)[c]

Note: Different superscripts indicate significant differences between the same lines.

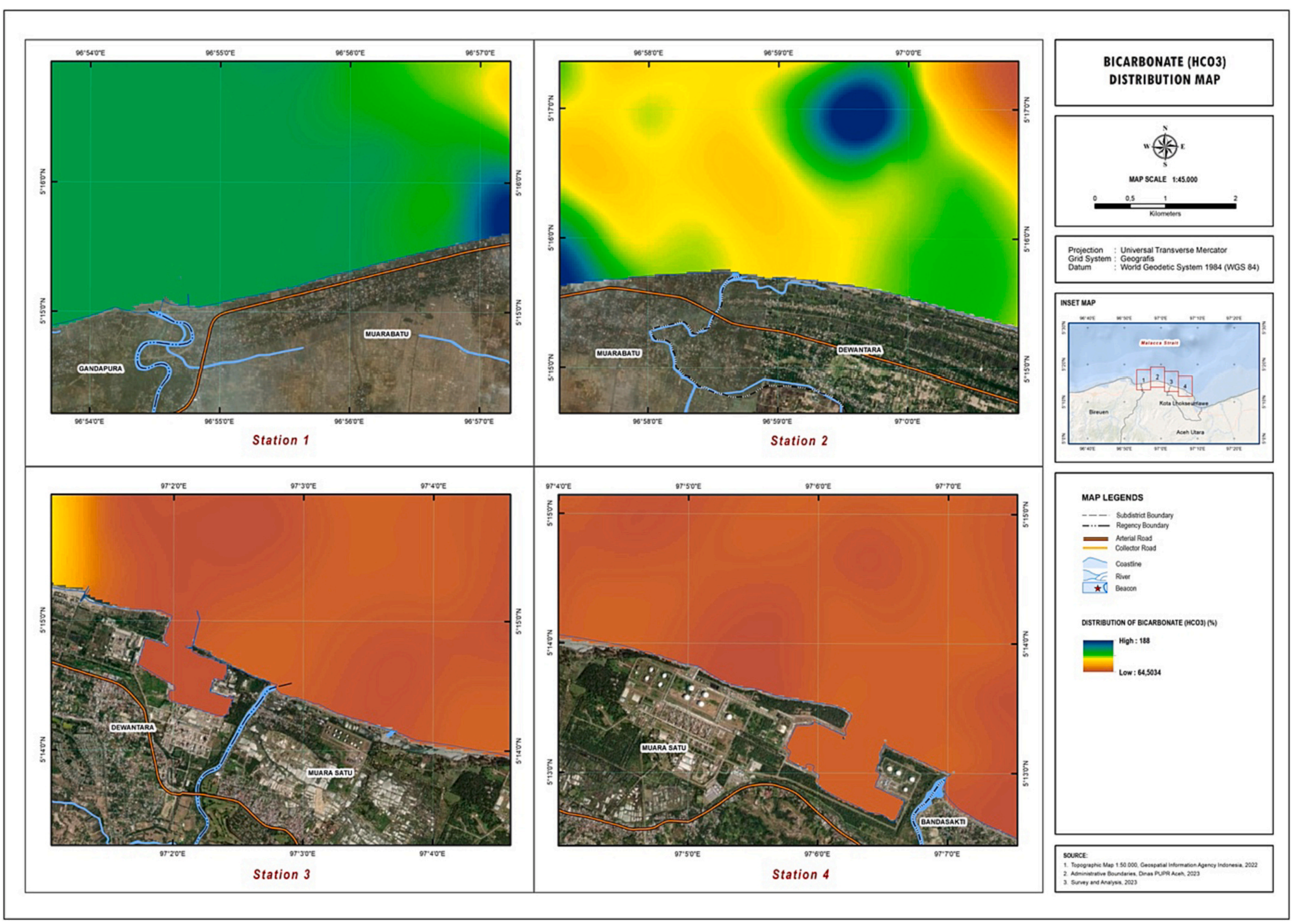

Fig. 2. Bicarbonate (HCO_3) level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

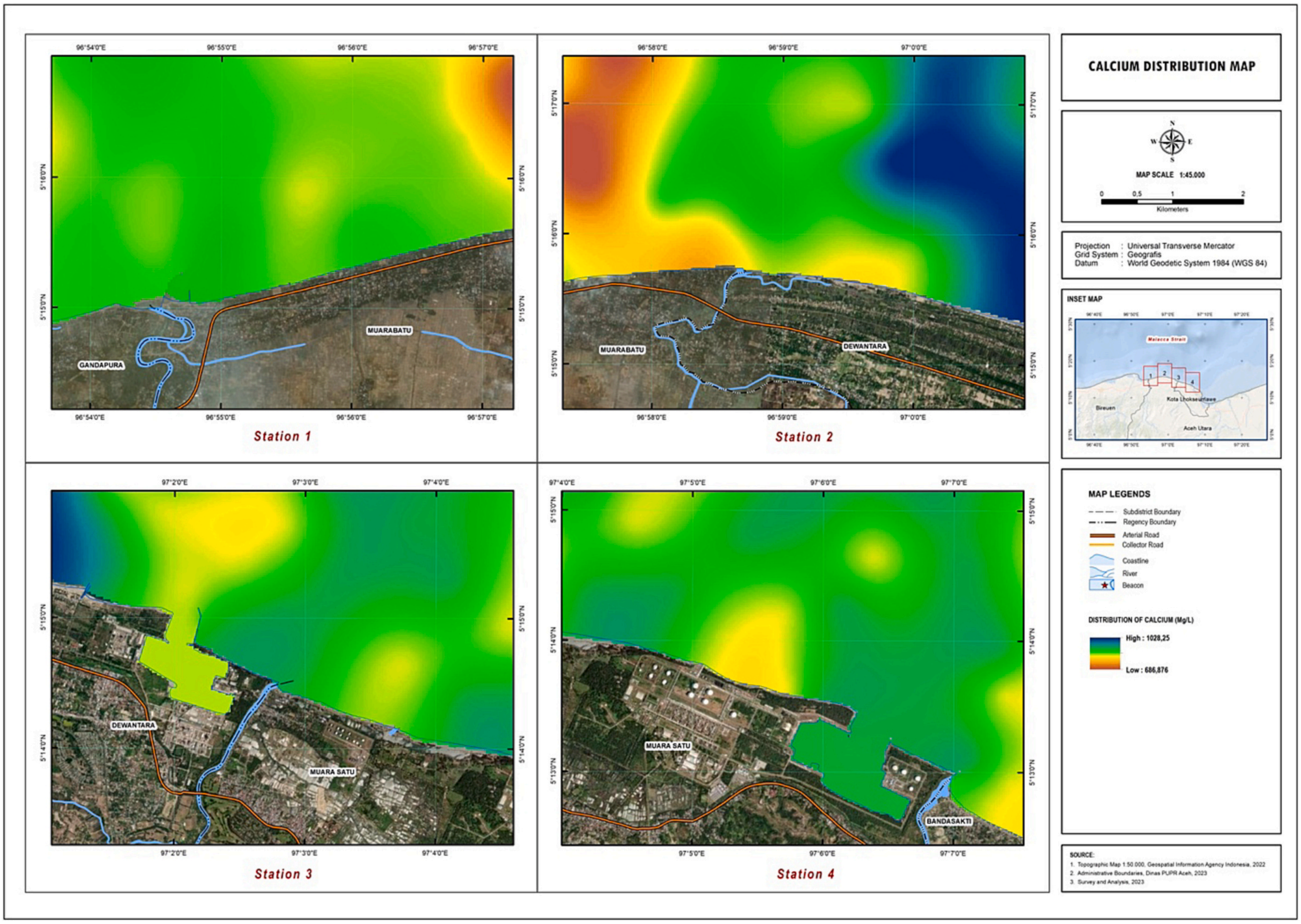

Fig. 3. Calcium level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

2.4. Data analysis

The data that has been obtained is then analyzed statistically (ANOVA) based on the research location. Furthermore, the data is also visualized using a map.

3. Results

The results of the analysis showed that the values of bicarbonate, chlorophyll, magnesium, nitrate, nitrite, orthophosphate, salinity, total alkalinity, and total ammonia were significantly different ($p < 0.05$) between the four research locations, while calcium and microplastics were not significantly different ($p > 0.05$). Based on research parameters, it shows that the highest average value of bicarbonate (HCO_3-), chlorophyll, salinity and total alkalinity are shown at the PT. Kertas Kraft Aceh with sequential values of 135.28 ± 1.99 mg/l, 0.0029 ± 0.0004 mg/m^3, 32.52 ± 0.51 ‰, and 139.28 ± 1.99 mg/l; the highest average value of calcium (Ca) value was at the PT. Pupuk Iskandar Muda (888 ± 40 mg/l); the highest average values of magnesium (Mg), nitrate (NO_3), and nitrite (NO_2) at the PT. ASEAN Aceh Fertilizer with sequential values of 5074.88 ± 191.26 mg/l, 6 ± 5 mg/l, and 0.028 ± 0.046 mg/l; the highest average value of microplastic and total ammonia (NH_4) values were at the PT. Harun NGL with sequential values of 5.49 ± 6.34 particles/l and 0.084 ± 0.075 mg/l. The average value of orthophosphate (PO_4) shows the location of PT. ASEAN Aceh Fertilizer, PT. Pupuk Iskandar Muda, and PT. Harun NGL has the same value reaching 0.25 ± 0 mg/l, while PT. Kertas Kraft Aceh 0.12 ± 0.025 mg/l (Table 2).

4. Discussion

Bicarbonate (HCO_3-) is the conversion of carbon dioxide (CO_2) in sea waters, where CO_2 enters sea waters through a diffusion process (Burkhardt et al., 2001). Bicarbonate is important for organisms to form calcium carbonate ($CaCO_3$) which functions to produce shells and the ontogenesis of organisms such as corals, bivalves, some protozoa and algae (Poloczanska et al., 2007; Reid et al., 2019). The highest average value of bicarbonate in this study was shown at the PT. Kertas Kraft Aceh reached 135.28 ± 1.99 mg/l, followed by PT. ASEAN Aceh Fertilizer 113.84 ± 20.78 mg/l, PT. Pupuk Iskandar Muda 71 ± 2.5 mg/l, and PT. Harun NGL 70.6 ± 2.55 mg/l (Fig. 2). Bicarbonate content >100 mg/l can increase microalgae biomass, but if it is >200 mg/l the opposite happens (Chiranjeevi and Mohan, 2016; Ye et al., 2019). Normally the bicarbonate content in sea waters is 140 mg/l (Štambuk-Giljanović, 2005).

The highest average value of calcium in this study was shown at the PT. Pupuk Iskandar Muda reached 888 ± 40 mg/l, and this value was not significantly different from other locations, namely 881.6 ± 40.79 mg/l at PT. Harun NGL, 869.6 ± 17.43 mg/l at PT. Kertas Kraft Aceh, and 868.16 ± 93.51 mg/l at PT. ASEAN Aceh Fertilizer (Fig. 3). The normal calcium value in sea waters is 420 mg/l (Khilchevskyi et al., 2018), but in this study the calcium value range was 868.16–888 mg/l,

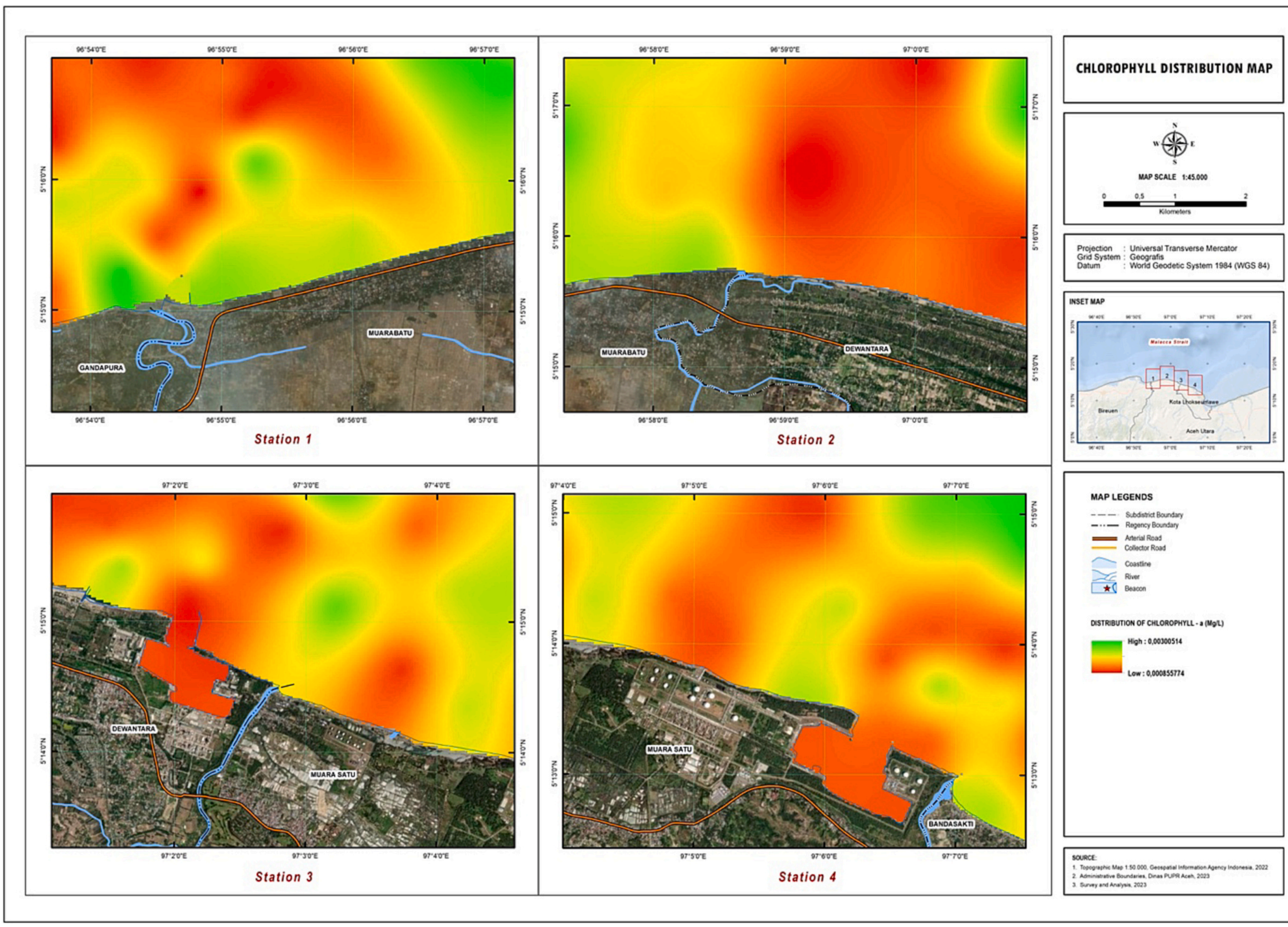

Fig. 4. Chlorophyll level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

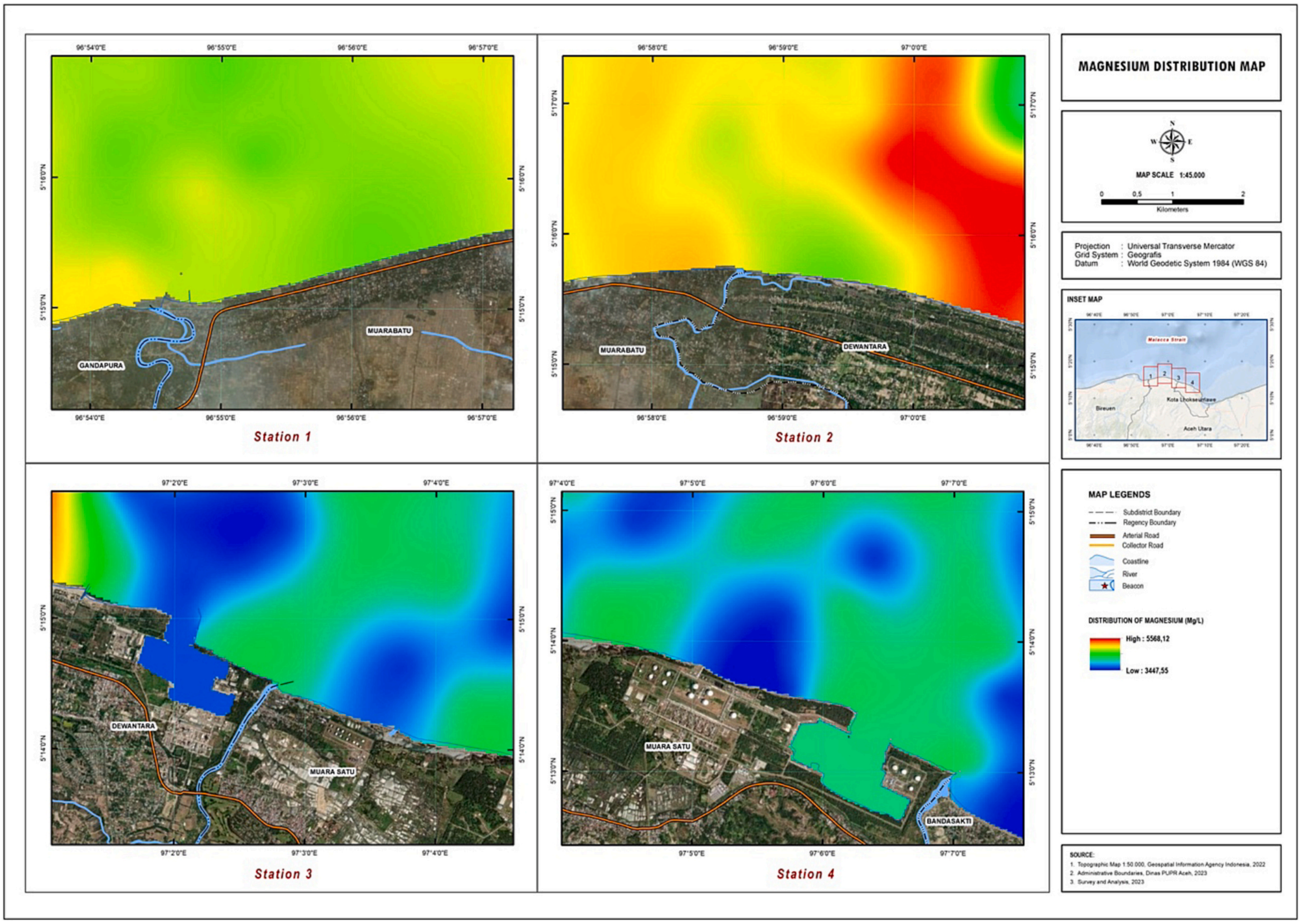

Fig. 5. Magnesium level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

so it was concluded that the calcium content had exceeded normal standards at all research locations. The function of calcium in marine ecosystems is to provide the needs of organisms in forming exoskeletons and bodies (Bentov et al., 2016), however if the calcium concentration is too low in the waters it will inhibit the development of corals, crustaceans and other aquatic organisms (Kurihara, 2008). Furthermore, if the calcium content is too high, the calcium will bind to carbonate and precipitate, making it unavailable to invertebrates and depleting the carbonate hardness (Dorozhkin, 2011).

The highest average value of chlorophyll in this study was shown at the PT. Kertas Kraft Aceh reached 0.0029 ± 0.0004 mg/m^3 and was significantly different ($p < 0.05$) from two other locations which reached values of 0.0017 ± 0.0006 mg/m^3 (PT. ASEAN Aceh Fertilizer), and 0.0015 ± 0.0002 mg/m^3 (PT. Harun NGL), and no significantly different ($p > 0.05$) from PT. Iskandar Muda Fertilizer (0.0028 ± 0.0005 mg/m^3) (Fig. 4). The chlorophyll content in this study showed a value between 0.0015 and 0.0029 mg/m^3, which indicates a low water fertility level (oligotrophic) (Felip and Catalan, 2000). Water fertility is influenced by the availability of nutrients in the water.

Magnesium is the most abundant element and makes up 2 % of the earth's crust (Prasad et al., 2022). Magnesium is an alkaline earth metal that is quite abundant in natural waters. The main source of magnesium in waters is ferrous magnesium and magnesium carbonate found in rocks (Stanienda, 2016). The highest average value of magnesium in this study was shown at the PT. ASEAN Aceh Fertilizer reached a value of 5074.88 ± 191.26 mg/l and was significantly different ($p < 0.05$) from other locations which reached a value of 4825.6 ± 67.70 mg/l (PT. Kertas Kraft Aceh), 3992 ± 310 mg/l (PT. Pupuk Iskandar Muda), and 3942.4 ± 316.14 mg/l (PT. Harun NGL)(Fig. 5). In sea waters, the magnesium content is normally at a level of 1300–1400 mg/l (Desai and Desai, 2012), but in this study it shows a range of 3942.4–5074.88 mg/l so it exceeds the normal standards.

The average value of microplastics at the four locations did not differ significantly with sequential values reaching 5.49 ± 6.34 particles/l (PT. Harun NGL), 3.89 ± 3.43 particles/l (PT. Kertas Kraft Aceh), 3.11 ± 4.27 particles/l (PT. ASEAN Aceh Fertilizer), and 2.78 ± 3.43 particles/l (PT. Pupuk Iskandar Muda). These results indicate that the waters at the four research locations have been polluted with microplastics. The types of microplastics found in this research include fiber, film, and fragment (Fig. 12). Microplastics that pollute waters can occur due to plastic waste that is physically and chemically fragmented (Andrady, 2017). Apart from that, the research location in the Malacca Strait could also be the cause of microplastics polluting these waters, where this strait is the busiest trade route in the world, making it possible for plastic waste to also come from ship waste that passes through these waters (Zaki et al., 2021). Furthermore, at this research location it has also been reported that microplastics have contaminated oysters (*Crassostrea gigas*) (Kasmini and Batubara, 2023).

Nitrate is the main form of nitrogen in water and is the most important nutrient required for plant and algae growth. Nitrate dissolves well in water and is stable (Fanning, 2000). High nitrate concentrations in water bodies can encourage the growth and development of aquatic organisms if nutrient availability is sufficient. The nitrification process, in which ammonia is oxidized to nitrite and nitrate, is an important

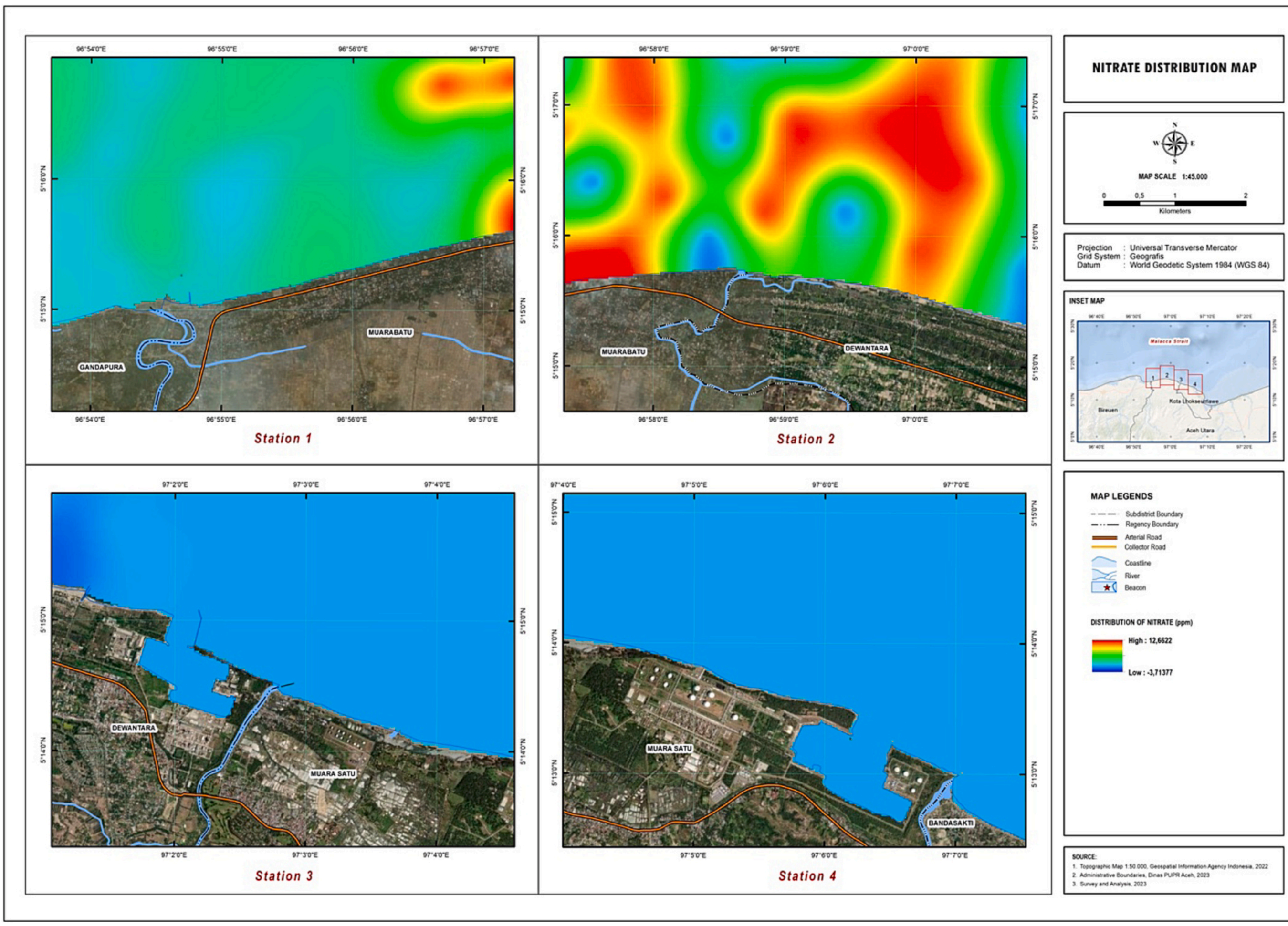

Fig. 6. Nitrate level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

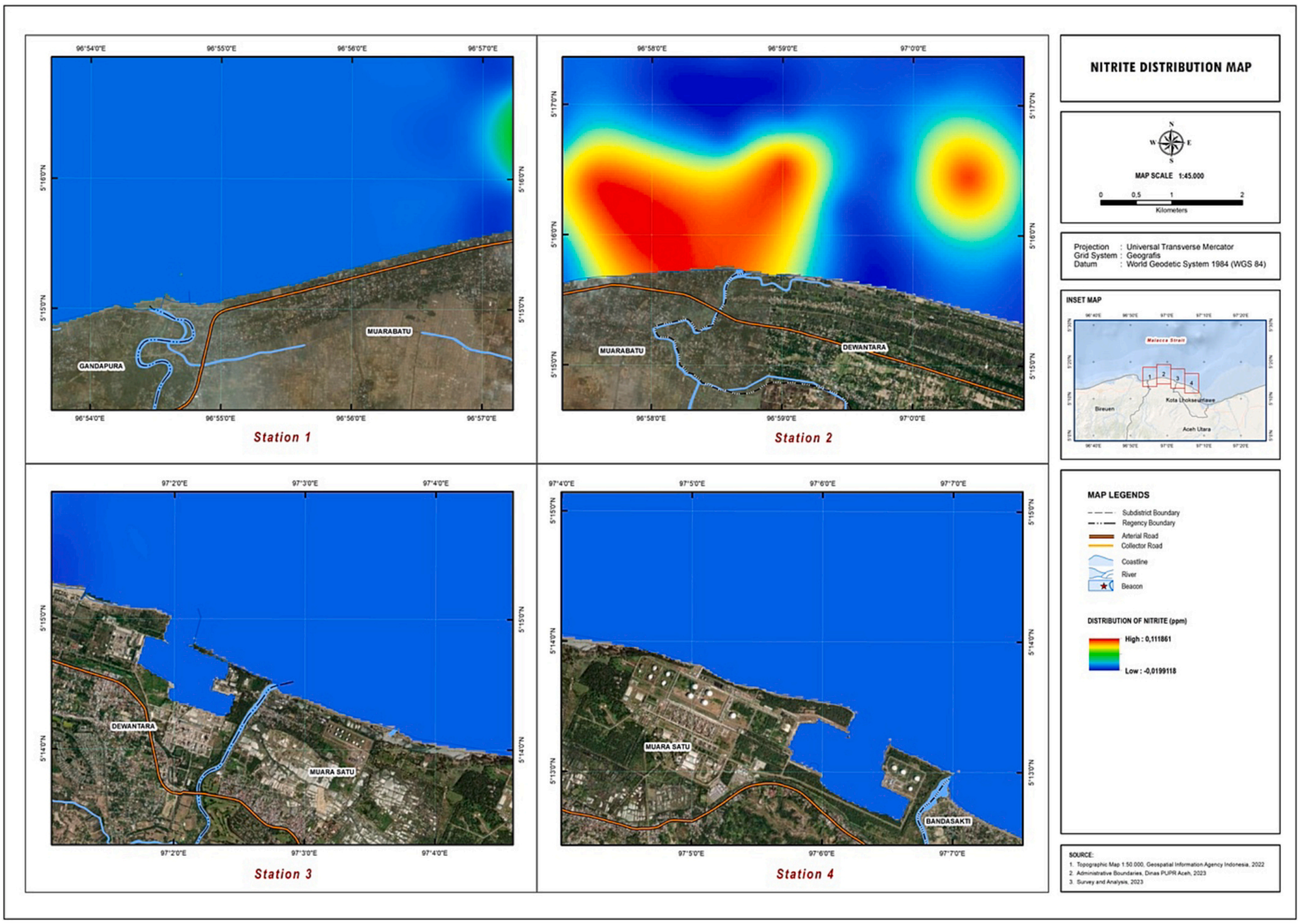

Fig. 7. Nitrite level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

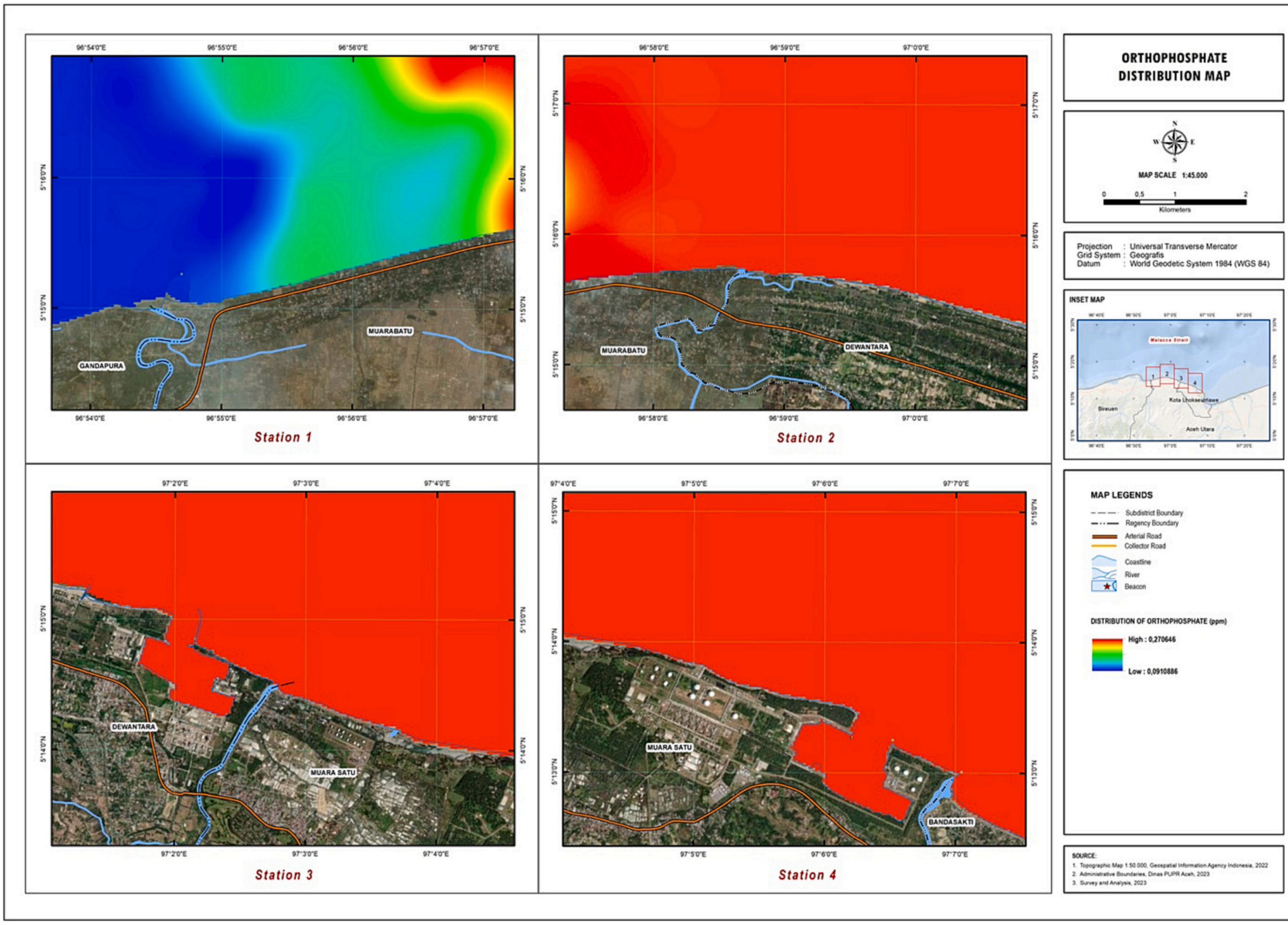

Fig. 8. Orthophosphate level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

process in the nitrogen cycle and occurs under aerobic conditions. Nitrosomonas bacteria oxidize ammonia to nitrite while Nitrobacter oxidize nitrite to nitrate (Noophan et al., 2009).

The average value of nitrate shows significant differences ($p < 0.05$) between the four locations, where the highest average value is shown at the PT. ASEAN Aceh Fertilizer reached 6 ± 5 mg/l, followed by PT. Kertas Kraft Aceh (1.6 ± 0.5), and nil at the PT. Pupuk Iskandar Muda and PT. Harun NGL (Fig. 6). Nitrate concentrations at PT. Pupuk Iskandar Muda dan PT. Harun NGL of 0 mg/l which still meet the quality standards stipulated in Republic of Indonesia Government Regulations No. 22, 2021, where the quality standard for nitrate concentration is 0.006 mg/l. However, the nitrate concentrations at the PT. ASEAN Aceh Fertilizer and PT. Kertas Kraft Aceh have exceeded the quality standards. This situation can pose a serious threat to marine biota, because nitrate concentrations above 0.2 mg/l can cause eutrophication of water bodies, which in turn can stimulate the rapid growth (blooming) of algae and aquatic plants (Nieder et al., 2018). The high levels of nitrate in coastal waters may be caused by the large input of organic matter from human activities, household waste, agricultural fertilizers, and other factors that mix with sea water (Kang and Xu, 2016).

The average value of nitrite shows significant differences ($p < 0.05$) between the four locations, where the highest value is shown at the PT. ASEAN Aceh Fertilizer reached 0.028 ± 0.046 mg/l and the other three locations were nil (Fig. 7). Nitrite is the oxidized form of nitrogen. Nitrite content has not been determined in seawater quality standards because it is unstable in seawater, nitrites in water are often found in small quantities because of their instability. Nitrite compounds present in water are the result of reduction of nitrate compounds by microbes or oxidation of ammonia and come from excretion of phytoplankton (Mudahayu and Djarot, 2012). According to Mbachu et al. (2020) degradation of organic materials caused by microorganisms requires large amounts of oxygen. When oxygen is insufficient, oxygen is taken from nitrate compounds, which are then converted into nitrate compounds. According to Ciji and Akhtar (2020) nitrite concentrations above 0.06 mg/l are toxic to aquatic organisms, so they can poison fish by binding to hemoglobin in the blood thereby inhibiting oxygen absorption. Based on the results of this research, all locations show average nitrite values under normal conditions.

Orthophosphate is one of the most important nutritional compounds. The average orthophosphate content of sea water is about 2 mg/l (Grasshoff et al., 2009). Orthophosphate is one of the nutrients needed for the growth and metabolic processes of phytoplankton and other marine organisms to determine the fertility of waters. The average value of orthophosphate shows that the three locations (PT. ASEAN Aceh Fertilizer, PT. Pupuk Iskandar Muda, and PT. Harun NGL) have the same value reaching 0.25 ± 0 mg/l, while PT. Kertas Kraft Aceh reached 0.12 ± 0.025 mg/l (Fig. 8). Based on the analysis results at the measurement location, the orthophosphate values ranged from 0.12 to 0.25 mg/l. This range has exceeded the quality standards set by Republic of Indonesia Government Regulations No. 22 of 2021 for orthophosphate, which is 0.015 mg/l. This condition can endanger marine biota in the waters because it can cause eutrophication. According to Anhwange et al. (2012) the highest recommended phosphate level for rivers and water bodies is 0.1 mg/l. Waters with a phosphate value of >0.1 mg/l are

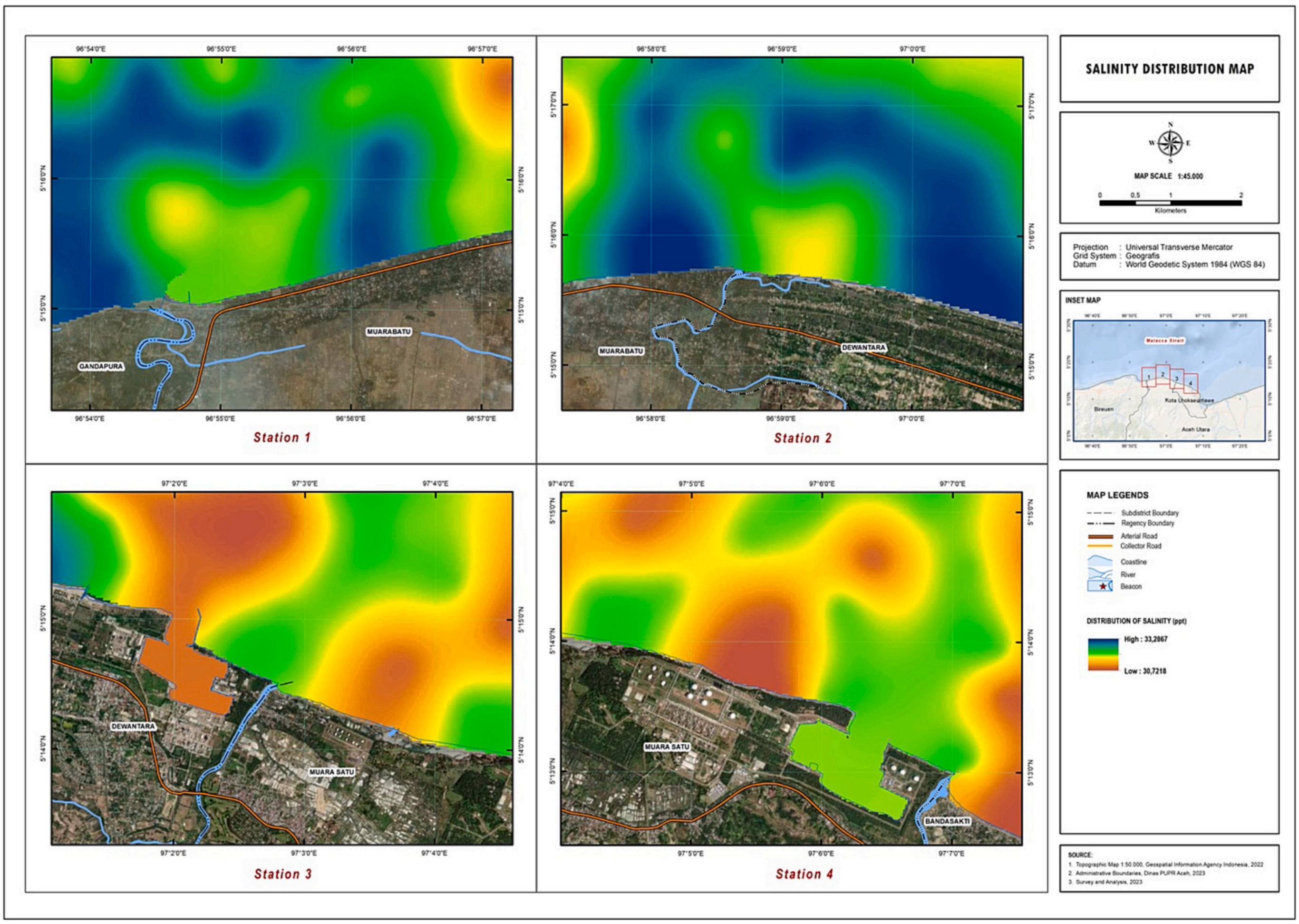

Fig. 9. Salinity level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

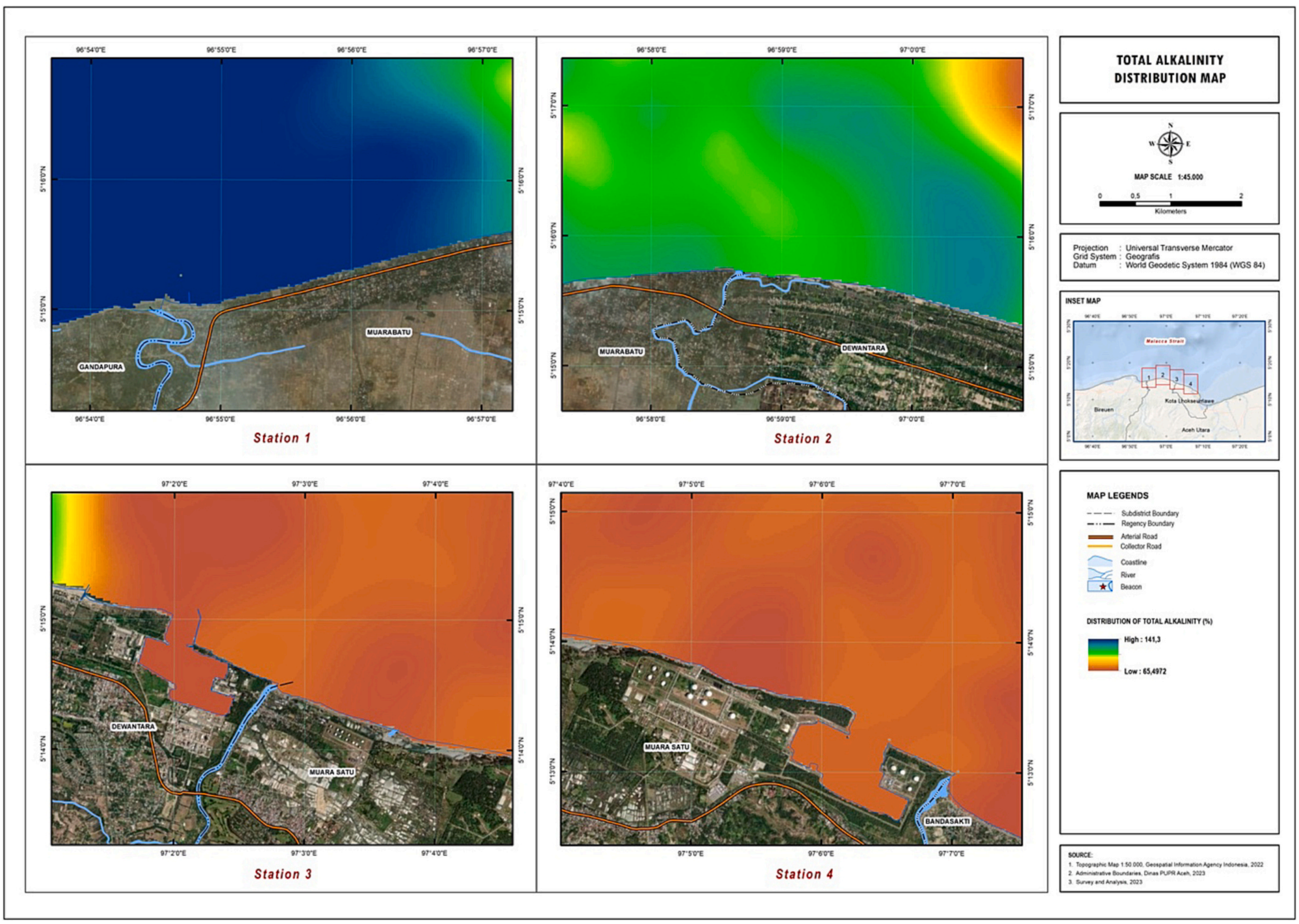

Fig. 10. Total alkalinity level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

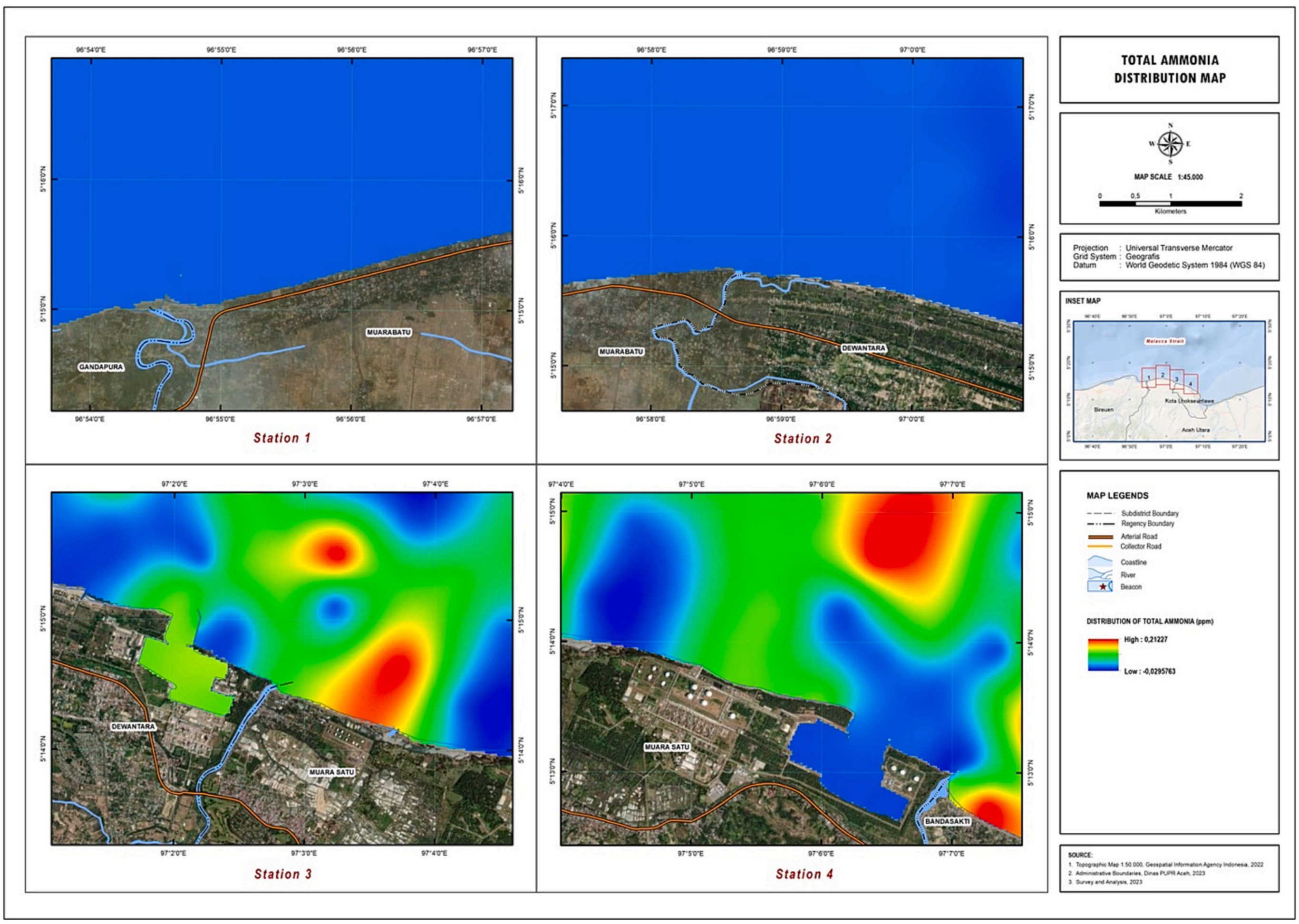

Fig. 11. Total ammonia level based on research locations, where Station 1 is PT. Kertas Kraft Aceh, Station 2 is PT. ASEAN Aceh Fertilizer, Station 3 is PT. Pupuk Iskandar Muda, and Station 4 is PT. Harun NGL.

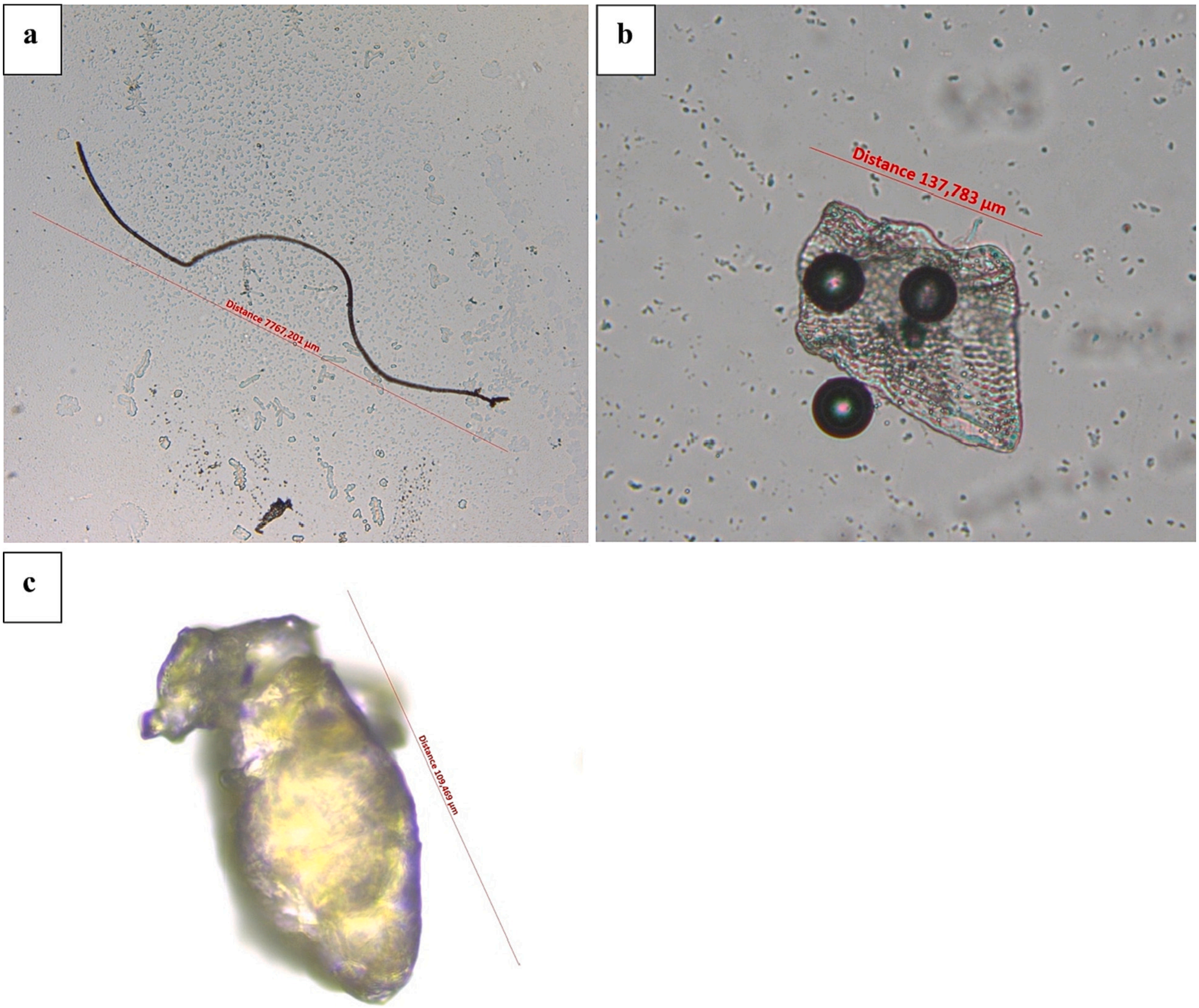

Fig. 12. Types of Microplastics that pollute the four research locations, where (a) fiber (range of 20–7767 μm), (b) Film (range of 127–579 μm), and (c) Fragment microplastics (range of 10–165 μm).

considered eutrophic waters, where phytoplankton explosions often occur (Imai et al., 2006). Phosphate concentrations in coastal waters are usually higher than in the open sea due to runoff from land and the influence of coastal upwelling (Satpathy et al., 2010).

Salinity is the total concentration of salt in sea water, and salinity affects the osmotic pressure of the water. The higher the salt concentration, the higher the osmotic pressure (Kim and Elimelech, 2013). Evaporation and fluctuations in rainfall can cause differences in salinity in sea water. The average value of salinity at PT. Kertas Kraft Aceh and PT. ASEAN Aceh Fertilizer is relatively the same with sequential values of 32.52 ± 0.51 and 32.44 ± 0.58 ‰ (parts per thousand), which is significantly different ($p < 0.05$) from PT. Pupuk Iskandar Muda and PT. Harun NGL with sequential values of 31.6 ± 0.5 ‰ and 31.52 ± 0.51 ‰ (Fig. 9). The results of salinity analysis at the measurement locations show that the salinity values between observation locations are not too different, ranging between 31.52 and 32.52 ‰. Based on the quality standards stipulated in Republic of Indonesia Government Regulations No. 22 of 2021, most of the salinity values at measuring stations still comply with quality standards. This salinity value is not much different from the average salinity of Indonesian waters which varies between 32 and 34 ‰ (Purba et al., 2021). Low salinity can be caused by the supply of fresh water from rivers that flow into sea water. According to Hong and Shen (2012) an estuary is an area where salinity decreases due to the influx of fresh water, which is also influenced by sea tides in the area. Variations in seawater salinity can affect aquatic organisms due to their ability to control specific gravity and adapt to changes in osmotic pressure.

Total alkalinity provides an overview of the amount of carbonate ions that buffer a water (buffer system) against changes in pH (Egleston et al., 2010). Total alkalinity is a component of the carbonate system which plays an important role in balancing carbonate concentrations in water (Sahabuddin et al., 2015). According to Boyd et al. (2016) apart from pH, total alkalinity is also influenced by mineral composition, temperature and ionic strength. The main cations in seawater are sodium and magnesium, the main anion is chloride. The highest average value of total alkalinity in this study was shown at the PT Kertas Kraft Aceh reached 139.28 ± 1.99 mg/l, which was significantly different ($p < 0.05$) from the other three locations which reached 113.84 ± 7.95 mg/l (PT. ASEAN Aceh Fertilizer), 71 ± 2.5 mg/l (PT. Pupuk Iskandar Muda), and 70.6 ± 2.54 mg/l (PT. Harun NGL) (Fig. 10). Based on the analysis results, it can be seen that the total alkalinity at the measurement location ranges from 70.6 to 139.28 mg/l, which can be said to be good when viewed from the total alkalinity level. The alkalinity value of natural waters almost never exceeds 500 mg/l. A good alkalinity value ranges from 30 to 500 mg/l. The alkalinity value in natural waters is 40 mg/L (Boyd, 1982).

Total ammonia is one of the organic pollution parameters of water bodies which is formed from the process of anaerobic decomposition of organic material (eutrophication) caused by microbes. The highest verage value of total ammonia (NH_4) in this study was shown at the PT. Harun NGL reached 0.084 ± 0.075 mg/l, and this value was significantly different ($p < 0.05$) from the PT. Pupuk Iskandar Muda (0.056 ± 0.065 mg/l), PT. Kertas Kraft Aceh (nil), and PT. ASEAN Aceh Fertilizer (nil) (Fig. 11). The results of total ammonia measurements at the measurement location showed an ammonia value of 0–0.084 mg/l. The ammonia concentration results still meet the quality standards based on Republic of Indonesia Government Regulations No. 22 of 2021, where the quality standard for ammonia concentration is 0.3 mg/l. According to Ayilara et al. (2020) most of the ammonia in water is the result of the metabolic processes of aquatic organisms and the decomposition of organic materials or organic waste such as household waste. Ammonia toxicity can increase suddenly due to changes in water quality factors such as pH, temperature, ion charge, salinity, and dissolved oxygen (DO) (Royan et al., 2019).

CRediT authorship contribution statement

Muliari Muliari: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mahdaliana:** Validation, Investigation, Formal analysis, Data curation. **Irfannur Irfannur:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Yusrizal Akmal:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Agung Setia Batubara:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

Acknowledgment

The author would like to thank the Ministry of Education, Culture, Research, and Technology of Indonesia who has funded this research through the "Skema Penelitian Fundamental - Reguler " scheme with the contract number: 132/E5/PG.02.00.PL/2023; 7/UN45.2.1/PT.01.03/VI/2023.

References

Andrady, A.L., 2017. The plastic in microplastics: a review. Mar. Pollut. Bull. 119, 12–22.
Anhwange, B.A., Agbaji, E.B., Gimba, E.C., 2012. Impact assessment of human activities and seasonal variation on River Benue, within Makurdi Metropolis. Int. J. Sci. Technol. 2, 248–254.
Ayilara, M.S., Olanrewaju, O.S., Babalola, O.O., Odeyemi, O., 2020. Waste management through composting: challenges and potentials. Sustainability 12, 4456.
Bentov, S., Abehsera, S., Sagi, A., 2016. Extracellular composite matrices in arthropods. Springer 137–163.
Boyd, C.E., 1982. Water Quality Management for Pond Fish Culture. Elsevier Scientific Publishing Co.
Boyd, C.E., Tucker, C.S., Somridhivej, B., 2016. Alkalinity and hardness: critical but elusive concepts in aquaculture. J. World Aquacul. Societ. 47, 6–41.
BPS (Central Bureau of Statistics), 2016. North Aceh in Numbers 2016. Central Bureau of Statistics, North Aceh, Indonesia.
Burkhardt, S., Amoroso, G., Riebesell, U., Sültemeyer, D., 2001. CO_2 and HCO_3^- uptake in marine diatoms acclimated to different CO_2 concentrations. Limnol. Oceanogr. 46, 1378–1391.
Chiranjeevi, P., Mohan, S.V., 2016. Critical parametric influence on microalgae cultivation towards maximizing biomass growth with simultaneous lipid productivity. Renew. Energy 98, 64–71.
Ciji, A., Akhtar, M.S., 2020. Nitrite implications and its management strategies in aquaculture: a review. Rev. Aquac. 12, 878–908.
Dane, H., Şişman, T., 2020. A morpho-histopathological study in the digestive tract of three fish species influenced with heavy metal pollution. Chemosphere 242, 125212.
Desai, B., Desai, H., 2012. Assessment of water quality index for the groundwater with respect to salt water intrusion at coastal region of Surat city, Gujarat, India. J. Environ. Res. Develop. 7, 607–621.
Dirgapraja, V.A., Poluan, R.J., Lakat, R.S.M., 2019. Pengaruh pengembangan kawasan industri terhadap Permukiman Kecamatan Madidir Kota Bitung. J. Spasial. 6, 282–290.
Dorozhkin, S.V., 2011. Calcium orthophosphates: occurrence, properties, biomineralization, pathological calcification and biomimetic applications. Biomatter 1, 121–164.
Dzikrillah, A., Fahriza, S.P., Lisana, R.N., Kisty, H.M., Yoga, M.I.A., Anzani, L., 2022a. Dampak Pencemaran Air Limbah PLTU Paiton terhadap Keberlangsungan Ekosistem Akuatik. J. Inconesian Conf. Mar. 1 (1), 26–32.
Dzikrillah, A., Fahriza, S.P., Lisana, R.N., Kisty, H.M., Yoga, M.I.A., Anzani, L., 2022b. Dampak pencemaran air limbah PLTU Paiton terhadap keberlangsungan ekosistem akuatik. Indo. Conf. Maritim. 1, 26–32.
Egleston, E.S., Sabine, C.L., Morel, F.M., 2010. Revelle revisited: buffer factors that quantify the response of ocean chemistry to changes in DIC and alkalinity. Glob. Biogeochem. Cycles 24, GB1002.
Fanning, J.C., 2000. The chemical reduction of nitrate in aqueous solution. Coord. Chem. Rev. 199, 159–179.
Felip, M., Catalan, J., 2000. The relationship between phytoplankton biovolume and chlorophyll in a deep oligotrophic lake: decoupling in their spatial and temporal maxima. J. Plankton Res. 22, 91–106.
Garcia-Santos, S., Fontaínhas-Fernandes, A., Wilson, J.M., 2006. Cadmium tolerance in the Nile tilapia (*Oreochromis niloticus*) following acute exposure: assessment of some ionoregulatory parameters. Environ. Toxicol. Int. J. 21, 33–46.
Ghiasi, F., Mirzargar, S.S., Badakhshan, H., Shamsi, S., 2010. Effects of low concentration of cadmium on the level of lysozyme in serum, leukocyte count and phagocytic index in cyprinus carpio under wintering conditions. J. Fish. Aquat. Sci. 5, 113–119.
Grasshoff, K., Kremling, K., Ehrhardt, M., 2009. Methods of Seawater Analysis. John Wiley & Sons.
Harabawy, A.S., Mosleh, Y.Y., 2014. The role of vitamins A, C, E and selenium as antioxidants against genotoxicity and cytotoxicity of cadmium, copper, lead and zinc on erythrocytes of Nile tilapia, *Oreochromis niloticus*. Ecotoxicol. Environ. Saf. 104, 28–35.
Hong, B., Shen, J., 2012. Responses of estuarine salinity and transport processes to potential future sea-level rise in the Chesapeake Bay. Estuar. Coast. Shelf Sci. 104, 33–45.
Imai, I., Yamaguchi, M., Hori, Y., 2006. Eutrophication and occurrences of harmful algal blooms in the Seto Inland Sea, Japan. Plankt. Benth. Res. 1, 71–84.
Islam, M.S., Tanaka, M., 2004. Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. Mar. Pollut. Bull. 48, 624–649.
Jovanović, B., 2017. Ingestion of microplastics by fish and its potential consequences from a physical perspective. J Integr. Environ. Asses. Manag. 13, 510–515.
Kang, P., Xu, S., 2016. The impact of mariculture on nutrient dynamics and identification of the nitrate sources in coastal waters. Environ. Sci. Pollut. Res. 23, 1300–1311.
Karri, R.R., Ravindran, G., Dehghani, M.H., 2021. Wastewater—sources, toxicity, and their consequences to human health. In: Soft Computing Techniques in Solid Waste and Wastewater Management. Elsevier, pp. 3–33.
Kasmini, L., Batubara, A.S., 2023. Microplastic contamination and growth pattern of oyster; *Crassostrea gigas* in a coastline. Glob. J. Environ. Sci. Manag. 9, 753–764.
Khilchevskyi, V.K., Kurylo, S.M., Sherstyuk, N.P., 2018. Chemical composition of different types of natural waters in Ukraine. J. Geol. Geograp. Geoecol. 27, 68–80.
Kim, Y.C., Elimelech, M., 2013. Potential of osmotic power generation by pressure retarded osmosis using seawater as feed solution: analysis and experiments. J. Membr. Sci. 429, 330–337.
Kurihara, H., 2008. Effects of CO_2^- driven ocean acidification on the early developmental stages of invertebrates. Mar. Ecol. Prog. Ser. 373, 275–284.
Lönnstedt, O.M., Eklöv, P., 2016. Environmentally relevant concentrations of microplastic particles influence larval fish ecology. J. Sci. 352, 1213–1216.
Lu, Y., Yuan, J., Lu, X., Su, C., Zhang, Y., Wang, C., Cao, X., Li, Q., Su, J., Ittekkot, V., Garbutt, R.A., Bush, S., Fletcher, S., Wagey, T., Kachur, A., Sweijd, N., 2018. Major threats of pollution and climate change to global coastal ecosystems and enhanced management for sustainability. Environ. Pollut. 239, 670–680.
Martinez, C.B.R., Nagae, M.Y., Zaia, C.T.B.V., Zaia, D.A.M., 2004. Acute morphological and physiological effects of lead in the neotropical fish *Prochilodus lineatus*. Braz. J. Biol. 64, 797–807.
Masud, M.M., Aldakhil, A.M., Nassani, A.A., Azam, M.N., 2017. Community-based ecotourism management for sustainable development of marine protected areas in Malaysia. Ocean Coast. Manag. 136, 104–112.
Mbachu, A.E., Chukwura, E.I., Mbachu, N.A., 2020. Role of microorganisms in the degradation of organic pollutants: a review. Energ. Environ. Eng. 7, 1–11.
Menezes, R., da Cunha-Neto, M.A., de Mesquita, G.C., da Silva, G.B., 2019. Ingestion of macroplastic debris by the common dolphinfish (*Coryphaena hippurus*) in the Western Equatorial Atlantic. Mar. Pollut. Bull. 141, 161–163.
Mudahayu, M., Djarot, S.W., 2012. Pengaruh limbah organik dan rasio n/p terhadap kelimpahan fitoplankton di kawasan budidaya kerang hijau Cilincing. J. Teknol. Pengel. Limb. 15, 51–64.
Muliari, M., Zulfahmi, I., Akmal, Y., 2019. Ekotoksikologi akuatik. Penerbit IPB Press, Bogor.
Nieder, R., Benbi, D.K., Reichl, F.X., Nieder, R., Benbi, D.K., Reichl, F.X., 2018. Soil components and human health. Springer 223–255.

Noophan, P.L., Sripiboon, S., Damrongsri, M., Munakata-Marr, J., 2009. Anaerobic ammonium oxidation by Nitrosomonas spp. and anammox bacteria in a sequencing batch reactor. J. Environ. Manag. 90, 967–972.
Nunes, P.A., Ghermandi, A., 2013. The economics of marine ecosystems: reconciling use and conservation of coastal and marine systems and the underlying natural capital. Environ. Resour. Econ. 56, 459–465.
Parogay, H., Sulistyawati, S., Fitriyani, F., 2021. Limbah cair industri tahu dan dampaknya terhadap kualitas air dan biota perairan. J. Pertan. Terp. 9, 53–65.
Poloczanska, E.S., Babcock, R.C., Butler, A., Hobday, A.J., Hoegh-Guldberg, O., Kunz, T. J., Matear, R., Milton, D., Okey, T.A., Richardson, A.J., 2007. Climate change and Australian marine life. Oceanogr. Mar. Biol. 45, 407.
Prado, P.S., Souza, C.C., Bazzoli, N., Rizzo, E., 2011. Reproductive disruption in Lambari Astyanax fasciatus from a Southeastern Brazilian reservoir. Ecotoxicol. Environ. Saf. 74, 1879–1887.
Prasad, S.S., Prasad, S.B., Verma, K., Mishra, R.K., Kumar, V., Singh, S., 2022. The role and significance of magnesium in modern day research-a review. J. Magnes. Alloys 10, 1–61.
Prayogi, W.A., Asyiawati, Y., 2021. Kajian kerentanan pantai terhadap pengembangan wilayah pesisir Pangandaran. J. Ris. Perencan. Wil. Kot. 1, 89–98.
Purba, N.P., Pranowo, W.S., Ndah, A.B., Nanlohy, P., 2021. Seasonal variability of temperature, salinity, and surface currents at 0 latitude section of Indonesia seas. Reg. Stud. Mar. Sci. 44, 101772.
Rajamanicham, V., Musthuswam, N., 2008. Effect of heavy metals induced toxicity on metabolic biomarkers in common carp (*Cyprinus carpio*.L). J. Mj. Int. Sci. Tech. 2, 192–200.
Ram, R.N., Sathyanesan, A.G., 1983. Effect of mercuric chloride on the reproductive cycle of the Teleostean fish *Channa punctatus*. Bull. Environ. Contam. Toxicol. 30, 24–27.
Raymond, D., Ma'rifah, M., Kalianda, K.H., 2021. Benefits of the utilization of coastal area justice based. J. De Jure Critic. Laws 2, 1–13.
Reid, G.K., Gurney-Smith, H.J., Marcogliese, D.J., Knowler, D., Benfey, T., Garber, A.F., Forster, I., Chopin, T., Brewer-Dalton, K., Moccia, R.D., Flaherty, M., 2019. Climate change and aquaculture: considering biological response and resources. Aquacul. Environ. Interact. 11, 569–602.
Republic of Indonesia Government Regulations No. 22, 2021. About Implementation of Protection and Management Environment. President of the Republic of Indonesia, Jakarta. https://jdih.setkab.go.id/PUUdoc/176367/PP_Nomor_22_Tahun_2021.pdf.
Royan, M.R., Solim, M.H., Santanumurti, M.B., 2019. Ammonia-eliminating potential of *Gracilaria* sp. and zeolite: a preliminary study of the efficient ammonia eliminator in aquatic environment. IOP Conf. Ser. Earth Environ. Sci. 236, 012002.
Sahabuddin, S., Jompa, J., Rukminasari, N., 2015. Increasing carbon dioxide concentration and temperature on growth and histopathology of tropic macroalgae *Halimeda* sp. J. Ilmu Teknol. Kel. Trop. 7, 98610.
Sahetapy, J.M.F., 2013. Dampak toksisitas sub kronis logam berat Timbal (Pb) terhadap respons hematologi dan pertumbuhan ikan kerapu macan (*Epinephelus fuscoguttatus*). J. Triton 8, 30–39.
Saputra, A., Permana, D.D., Cahyo, F.D., Arif, A., Wijonarko, E.A., 2021. Transplantasi terumbu karang *Acropora* spp, untuk rehabilitasi terumbu karang di Pulau Panjang, Teluk Banten. J. Kel. Per. Ter. 4, 105–115.
Satpathy, K.K., Mohanty, A.K., Natesan, U., Prasad, M.V.R., Sarkar, S.K., 2010. Seasonal variation in physicochemical properties of coastal waters of Kalpakkam, east coast of India with special emphasis on nutrients. Environ. Monit. Assess. 164, 153–171.
Shadiqin, I., Yusfiandayani, R., Imron, M., 2018. Produktivitas alat tangkap pancing ulur (*hand line*) pada rumpon *portable* di perairan Kabupaten Aceh Utara. J. Teknol. Per. Kel. 9, 105–113.
Shahjahan, M., Taslima, K., Rahman, M.S., Emran, M.A., Alam, S.I., Faggio, C., 2022. Effects of heavy metals on fish physiology – a review. Chemosphe 300, 1–18.
Štambuk-Giljanović, N., 2005. The quality of water resources in Dalmatia. Environ. Monit. Assess. 104, 235–268.
Stanienda, K.J., 2016. Carbonate phases rich in magnesium in the Triassic limestones of the eastern part of the Germanic Basin. Carbonates Evaporites 31, 387–405.
Suseno, H., Hudiyono, S., Budiawan, B., Wisnubroto, D.S., 2010. Effects of concentration, body size and food type on the bioaccumulation of Hg in farmed tilapia *Oreochromis mossambicus*. Austral. J. Bas. Appl. Sci. 4, 792–799.
Wilkinson, C.R., 1996. Global change and coral reefs: impacts on reefs, economies and human cultures. Glob. Chang. Biol. 2, 547–558.
Witeska, M., Wakulesk, M., 2006. The effect of heavy metal blood cells in vitro. J. Alternat. Lab. Anim. 35, 87–92.
Ye, Z., Abraham, J., Christodoulatos, C., Prigiobbe, V., 2019. Mineral carbonation for carbon utilization in microalgae culture. Energ. Fuels 33, 8843–8851.
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. Springer 1–16.
Zulfahmi, I., Ridwan, A., Djamar, T.F.L., 2014. Biometric condition of nile tilapia, *Oreochromis niloticus* (Linnaeus 1758) after mercury exposure. J. Iktiol. Indo. 14, 37–48.