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Impact of Land Use on Oceanography Parameters and Quality of Seaweed *Kappaphycus alvarezii* in Coastal Waters of South Sulawesi, Indonesia

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ABSTRACT

This paper provides information on the influence of land use in South Sulawesi on the load of nitrate and phosphate nutrients in the water and its impact on the quality of *Kappaphycus alvarezii* seaweed grown in coastal areas. Data were collected at three coastal locations: Marang in Pangkajene Regency, Sanrobone in Takalar Regency, and Sajoanging in Wajo Regency, for three repetitions of nutrient loads. Oceanographic parameters were measured at nine points at each location, including temperature, salinity, pH, current waters, nitrate, phosphate, and total suspended solid (TSS). The quality of seaweed observed was chlorophyll-a, carrageenan content, water content, and ash content in seaweed reared in coastal waters. The research results show that land use is related to the amount of nutrient load; in the Sajoanging location, where agricultural land use is dominant, it produces high nitrate and phosphate loads, while in other locations, it is relatively lower. This nutrient content influences oceanographic conditions and the quality of cultivated *Kappaphycus alvarezii*.

Introduction

Population growth in an area is generally in line with increased development activities. However, this development process often has a negative impact on the environment, especially through excessive exploitation of natural resources. One of the impacts is the increasingly complex change in land use over time, which has the potential to result in land conversion and decreased environmental quality. These changes can directly or indirectly affect the ecological system, especially in coastal areas, through increased air pollution. Uncontrolled land use can cause pollutants to enter the air, such as nutrients [1] and heavy metals [2], which then have an impact on coastal aquatic ecosystems. Based on data from South Sulawesi Statistics in 2018, land use in this area is dominated by plantation, agricultural, residential, and forest activities. These activities, especially those that occur in river basins, contribute greatly to increasing nutrient loads in rivers, which then flow into coastal areas.

One of the main economic activities of the coastal communities of South Sulawesi is the cultivation of seaweed *Kappaphycus alvarezii*, which contributes almost 30% to global aquaculture production [3]. Seaweed cultivation is highly dependent on air quality, especially since cultivation systems such as the long-line method do not involve external nutrient addition [4]. Therefore, the supply of nutrients from land through rivers is very important for the success of this cultivation. Increased concentrations of nutrients such as nitrate and phosphate in waters can affect seaweed growth, both positively and negatively, depending on the concentration and ratio of these elements [5]. In addition, poor water quality also has the potential to increase epiphyte growth [6], which can interfere with seaweed growth. Other oceanographic factors such as suspended solids and air current speed also affect cultivation conditions. This is very important because the quality of carrageenan produced from *K. alvarezii* is highly dependent on the environmental conditions where the seaweed grows [7,8]. The physicochemical properties of carrageenan, which is a raw material in

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various food and non-food industries, are influenced by the biological structure of the organism and the quality of the cultivation waters [9].

Although numerous studies have explored the relationship between land use and air quality, as well as the impact of air quality on seaweed cultivation, there remain limited studies that specifically integrate these three aspects within the context of tropical coastal ecosystems, particularly in Indonesia. There are not many quantitative studies on changes in land use in the watershed area with coastal oceanographic parameters and the biological and chemical quality of cultivated *Kappaphycus alvarezii*. This study aims to fill this gap by analyzing the relationship between changes in land use, coastal water quality, and the quality of seaweed cultivation in South Sulawesi.

Materials and Methods

Study Area

This research was conducted in three regencies in South Sulawesi, each of which is a seaweed-producing area. These locations are Marang in Pangkep Regency (04°42'9.3"; 119°30'28.5"), Sanrobone in Takalar Regency (05°27'32.4"; 119°23'23.6"), and Sajoanging in Wajo Regency (04°00'7.6"; 119o21'29"). The sampling points are showed in Figure 1.

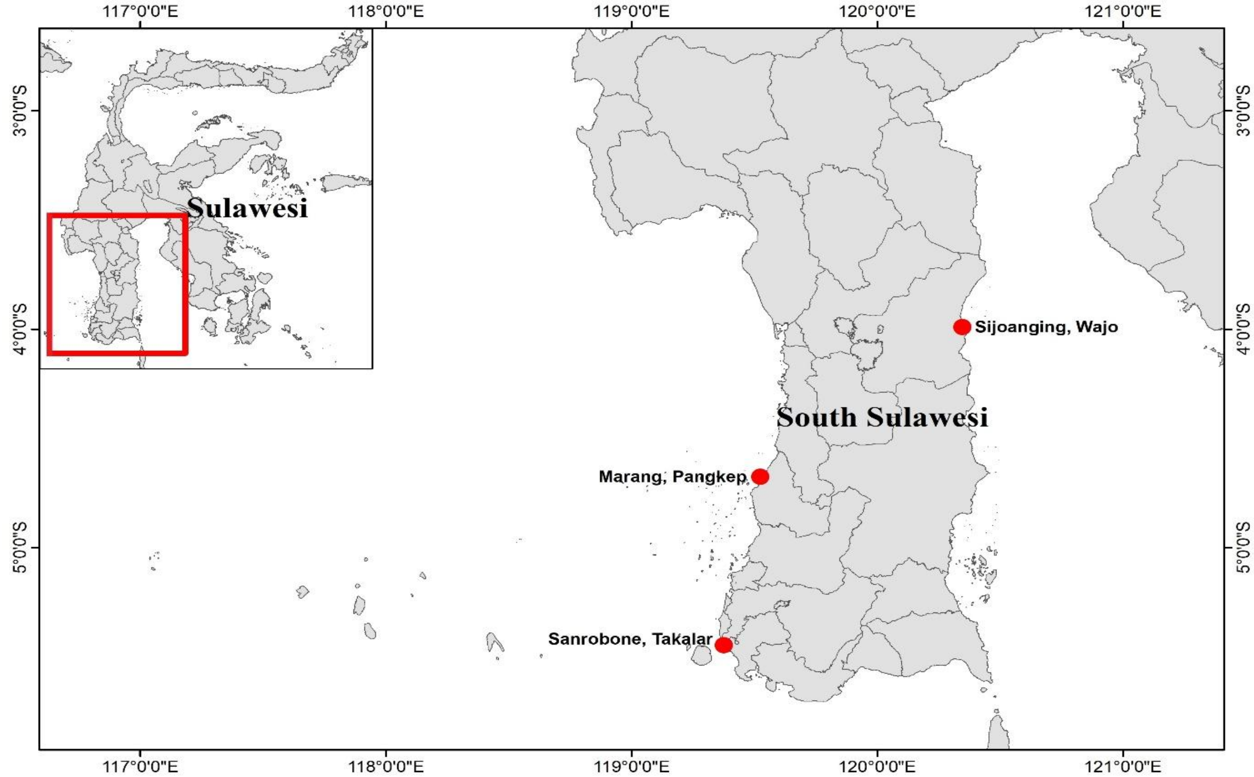

Figure 1. Site location.

Data Collection

The study analyzed the characteristics and area of land use at each location using ArcGIS and then presented them in the form of maps and tables of land use area. Sampling of seawater was performed using the Kemmerer Water Sampler with nine replications at each observation location. The seawater sample is put into a sample bottle and brought to the laboratory for analysis of oceanographic parameters for nitrate and phosphate nutrients, total suspended solids (TSS), used the APHA guidelines [10]. Oceanographic parameters, including temperature, salinity, and pH, were measured directly in the coastal waters at nine sampling points. Determination of the nutrient load originating from land via rivers to seawater was measured in triplicate in each river estuary by multiplying the river discharge (m^3/sec) by the nutrient concentration and TSS (mg/L). River discharge (Q) was measured using equation 1 and 2 [11]. Then, nutrients and TSS load is calculated using equation 3 with modification [12].

$$Q = V \times A \tag{1}$$

where: Q = River discharge (m^3/s); V = River flow velocity (m/s); A = River cross-sectional area (m^2).

$$A = W \times D \tag{2}$$

where: W = River width (m); D = river depth (m),

$$S = C \times Q \tag{3}$$

where:

S = Nutrient and TSS load from one river ($mg/m^3/s$)

C = Nutrient and TSS concentration at river estuaries (mg/L)

Q = River discharge (m^3/s)

The seaweed cultivation method applied in this research is the long-line method, which provides good growth of *Kappapicus alvarezii* seaweed [13]. The observed Seaweed quality parameters included chlorophyll-a content, which was analyzed in a previous study [14]. Carrageenan extraction. To obtain *Kappaphycus alvarezii* carrageenan, it was extracted using distilled water at 60 °C for 4 h with stirring. The product was filtered and precipitated in 85% isopropanol with a 0.2% KCl solution. The coagulum was then dried in an oven at 60 °C for 12 hours. The final carrageenan was refined to 250 µm [15]. After extraction to determine the carrageenan content, the equation 4 and 5 were used [16]. The equation used to calculate the ash content and water content of carrageenan is expressed in equation 6.

$$Chlorophyll\text{-}a\ (\mu g/g) = \frac{12.7\ x\ AB - 2.69\ x\ AC}{a\ x\ 1000XW}\ x\ V \tag{4}$$

where:

AB = Absorbance of wavelength A663

AC = Absorbance wavelength A645

V = Volume of solvent (mL)

a = Length of the cuvette path (1 cm)

W = Weight of seaweed thallus (g)

$$Carrageenan\ content = \frac{Wc}{Wm}\ x\ 100\% \tag{5}$$

where:

Wc = weight of extracted carrageenan (g)

Wm = weight of dried seaweed (g)

$$Ash\ content\ /\ water\ content = \frac{(Final\ weight\ of\ yield)}{(Initial\ weight\ of\ initial\ yield)}\ x\ 100\% \tag{6}$$

Data Analysis

Landuse analysis using Arc GIS and presented in map form. Differences in the quantity of seaweed carrageenan content at each research location were analyzed using the analysis of variance test. The quality of the carrageenan obtained was compared with the FAO standard [17], which ranged from 11 to 40%. Meanwhile, oceanographic parameters that characterize each observation station were analyzed using Principal Component Analysis (PCA).

Results

Land Use Area

The results of the classification of land use maps at the three observation locations were used to obtain the characteristics of land use, as shown in Figure 2. In the location of Marang District, the largest land use characteristic is fishponds, followed by shrubs and agriculture, while in Sanrobone District the largest use is agricultural land, fishponds, pastures, and settlements. In Sajoanging District, land use includes agricultural land, ponds, shrubs, and pastures. The areas of land use that influenced the nutrient loads are shown in Table 1.

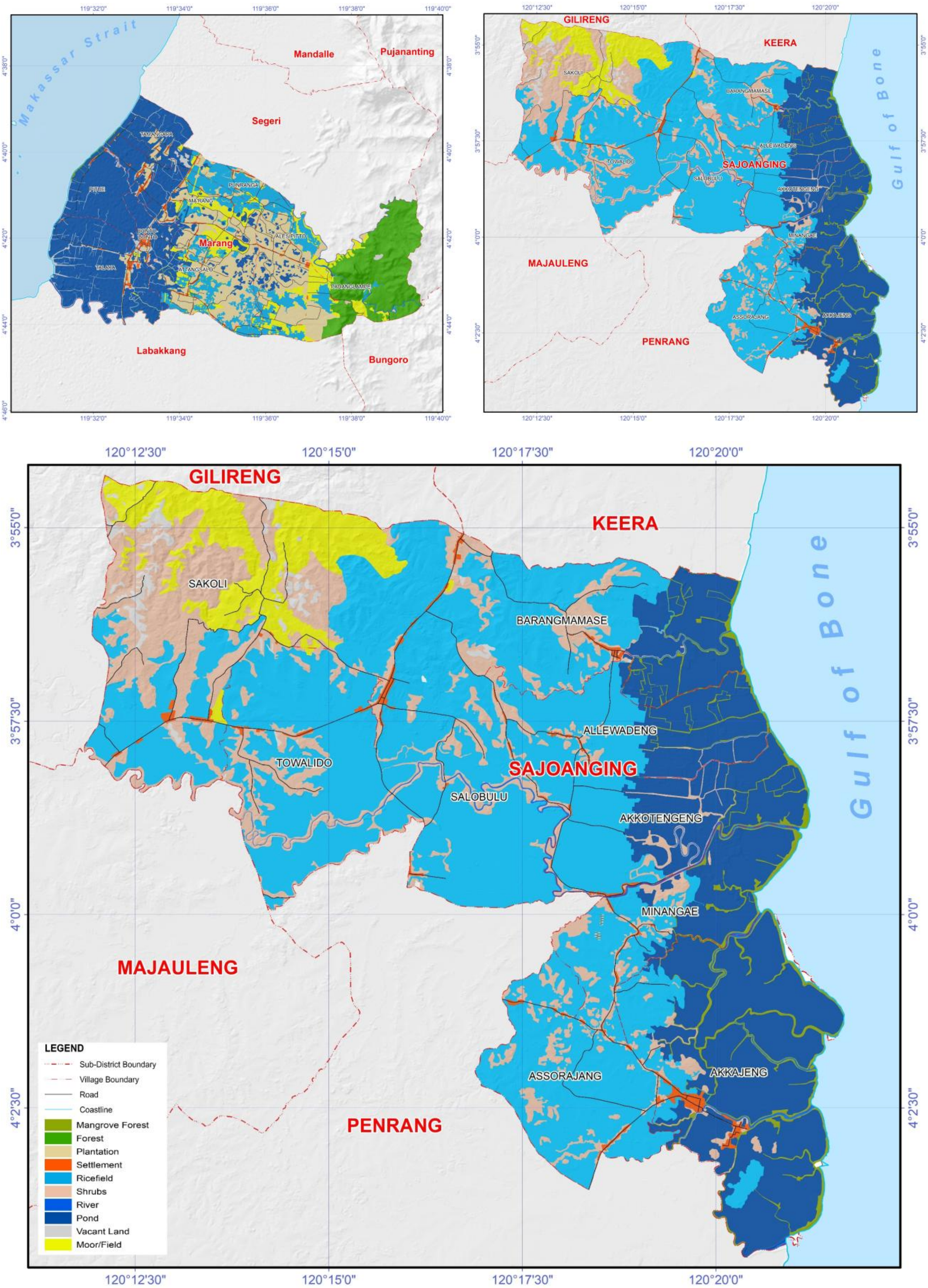

Figure 2. Land use at three observation locations.

The results of the analysis using Arch GIS of the area of each land use are shown in Table 1. Land use for rice fields accounts for the largest portion at each location, followed by land use for shrimp and milkfish ponds. In Sajoanging District, both land uses account for the largest share compared to other locations. This condition influences the amount of nutrient loading and suspended solids in the water (Table 2).

Table 1. Area of land use base on figure 2.

Land Use	Area (Ha)		
	Marang	Sanrobone	Sajoanging
Mangrove Forest	17.12	0.002	398.27
Forest	1,360.01	-	-
Plantation	1,946.18	5.57	-
Vacant Land	343.94	47.98	221.45
Settlement	172.29	62.40	182.88
Swamp	-	-	4.71
Rice field	1,221.59	902.44	8,318.52
Shrubs	2.85	34.74	3,016.52
River	51.96	40.97	142.20
Pond	3,671.40	393.71	4,201.81
Moor/Field	773.21	182.10	1,014.24
Total	9,560.56	1,669.95	17,500.60

Nutrient and TSS Load from River to Seaweed Cultivation Area

Based on the results of measurements of river flow velocity and the concentrations of nitrate and phosphate nutrients and TSS in three locations using Equations 1, 2, and 3, the nutrient load is shown in Table 2. The Ceppie River, located in Sajoanging District, produces the highest nutrient and TSS loads of any location. The inputs are nitrate at 1,446.78 m^3/year, phosphate at 158.7335 m^3/year, and TSS at 3,817,764.58 m^3/year.

Table 2. Results of the average nutrient and TSS load measurements at each source in the three locations.

Sources	Rate river current (m/s)	River wide (m)	River depth (m)	Concentration of materials (mg/L)			Materials load (m^3/year)		
				NO_3	PO_4	TSS	NO_3	PO_4	TSS
Limbangan River	0.082	94.86	1.5	0.029	0.013	30.46	120.57	53.8406	44,667.83
Takalar River	0.048	92.42	3	0.026	0.016	53.57	124.01	74.5092	139,044.78
Ceppie River	0.046	62.32	3.1	0.460	0.050	121.41	1,446.78	158.7335	3,817,764.58

Parameters of Oceanography at The Location of Seaweed Cultivation

The results of measuring oceanographic parameters of the coastal waters at locations affected by land use are presented in Table 3. The oceanographic parameters that showed differences were nitrate, phosphate, and TSS values. In the waters of Sajoanging District, these three parameters showed the highest values. These parameters influence the quality of cultivated seaweed.

The results of the variance analysis test of the Nitrate, Phosphate, and TSS variables at the three observation locations are shown in Table 4. The analysis shows that there are significant differences of nitrate, phosphate and TSS at the three seaweed cultivation locations ($P < 0.05$). For nitrate, the F-value is 30.417 with a Sig. of 0.000, indicating a strong difference in nitrate concentrations between the sites. Phosphate also shows a significant difference with an F-value of 7.776 and a Sig. of 0.002. Similarly, TSS has an F-value of 8.397 and a Sig. of 0.002, confirming significant variation across the locations.

Table 3. Parameter oceanography coastal waters in three location observations.

Parameter	Location		
	Marang	Sanrobone	Sajoanging
Temperature (°C)	32.5 ± 0.6	34.89 ± 2.0	29.98 ± 1.0
Salinity (ppt)	31 ± 3.7	33.9 ± 0.6	31.8 ± 1.5
Current flow (m/s)	0.082 ± 0.045	0.048 ± 0.024	0.093 ± 0.012
pH	8.07 ± 0.017	8.01 ± 0.03	8.03 ± 0.038
NO_3 (mg/L)	0.029 ± 0.014	0.026 ± 0.011	0.46 ± 0.023
PO_4 (mg/L)	0.013 ± 0.009	0.016 ± 0.012	0.05 ± 0.036
TSS (mg/L)	27.98 ± 4.62	39.75 ± 8.84	74.58 ± 42.29

Table 4. Test results of analysis of variance for the variables of nitrate, phosphate and TSS at 3 observation locations.

Variables		Sum of squares	df	Mean square	F	Sig.
Nitrate	Between Groups	1.120	2	0.560	30.417	0.000
	Within Groups	0.442	24	0.018		
	Total	1.562	26			
Phosphate	Between Groups	0.008	2	0.004	7.776	0.002
	Within Groups	0.012	24	0.000		
	Total	0.020	26			
TSS	Between Groups	10,570.977	2	5,285.489	8.397	0.002
	Within Groups	15,106.137	24	629.422		
	Total	25,677.114	26			

Quality of Seaweed *Kappaphycus alvarezii*

The results of the analysis of *Kappaphycus alvarezii* seaweed, including chlorophyll-a content, carrageenan content, moisture content, and ash content using Equation 4, 5, 6 from the three cultivation location (Figure 3 and 4). There are differences in chlorophyll-a concentrations in seaweed cultivated at different cultivation locations. The highest concentrations were found in Sajoanging District and the lowest in Marang District. This impacts the growth and quality of the cultivated seaweed. The quality of seaweed cultivated at the three locations showed the highest amount of carrageenan was found at the Sajoanging District location (Figure 4).

The results of the analysis of variance test for chlorophyll-a, carrageenan, water, and ash content showed differences between locations ($p < 0.05$) (Table 5). The results of the analysis of variance test for chlorophyll-a, carrageenan, water, and ash content showed significant differences between the three observation locations ($p < 0.05$) (Table 5). These findings suggest that the quality of *Kappaphycus alvarezii* varies according to the cultivation site, which may be influenced by differences in land use and the size of the surrounding area. The chlorophyll-a content showed a significant difference with an F-value of 14.534 ($p = 0.005$), while carrageenan content had an even stronger variation across sites ($F = 23.882$, $p = 0.001$). Water and ash contents also differed significantly, with F-values of 50.694 ($p = 0.000$) and 19.279 ($p = 0.002$), respectively. These variations reflect how local environmental conditions directly impact the biochemical composition and overall quality of seaweed.

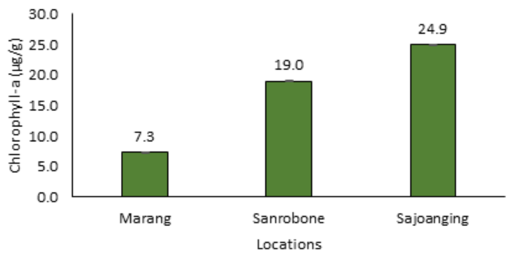

Figure 3. Chlorophyll-a content of seaweed *Kappaphycus alvarezii* from the three locations.

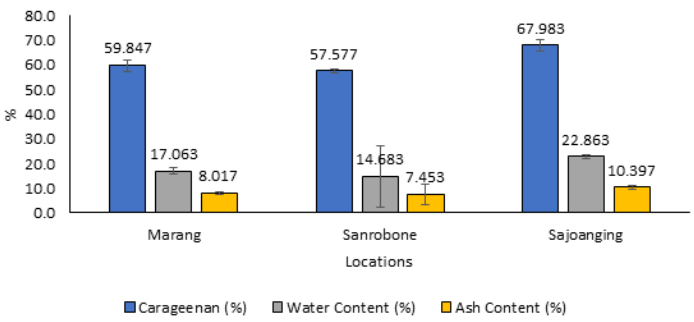

Figure 4. Carrageenan, water, and ash content of seaweed *Kappaphycus alvarezii* from the three locations.

Tabel 5. Test results of analysis of variance variable chlorophyll-a, carrageenan, water content, and ash content of *Kappaphycus alvarezii* at three observation locations.

Variables		Sum of squares	df	Mean square	F	Sig.
Chlorophyll-a Content	Between Groups	0.048	2	0.024	14.534	0.005
	Within Groups	0.010	6	0.002		
	Total	0.058	8			
Carrageenan Content	Between Groups	179.657	2	89.828	23.882	0.001
	Within Groups	22.568	6	3.761		
	Total	202.225	8			
Water Content	Between Groups	97.119	2	48.560	50.694	0.000
	Within Groups	5.747	6	0.958		
	Total	102.866	8			
Ash Content	Between Groups	246.698	2	123.349	19.279	0.002
	Within Groups	38.388	6	6.398		
	Total	285.087	8			

Oceanographic Parameters That Characterize Observation Locations

The results of the PCA show the parameters that characterize oceanography at three locations (Figure 5). PCA results showed that the waters of Sajoanging District with the best seaweed quality were characterized by relatively high nitrate, phosphate, and TSS levels, as well as currents compared to other locations. These parameters are location characteristics that influence the quality of cultivated seaweed.

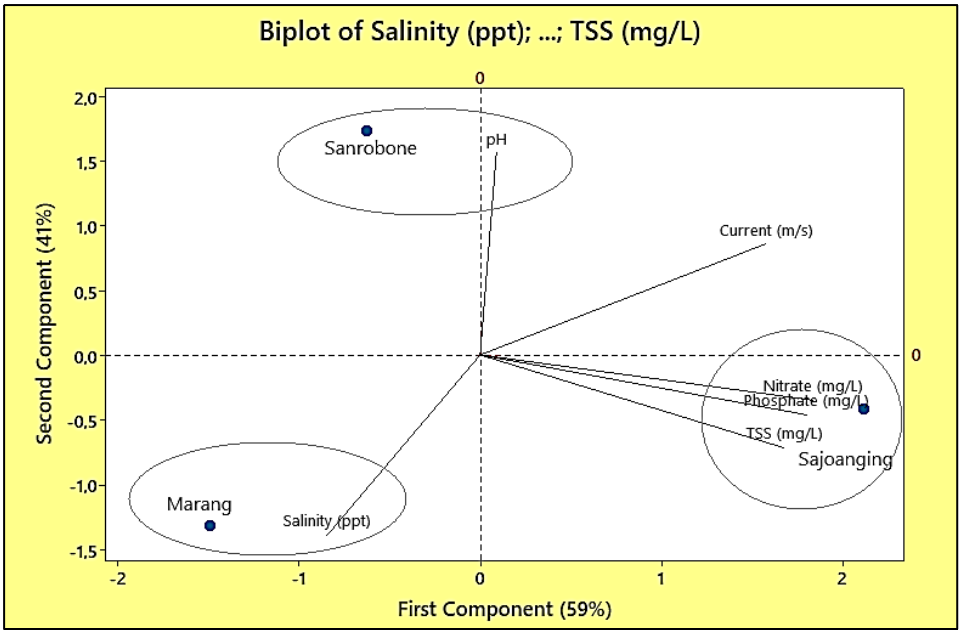

Figure 5. Characteristic parameters of oceanographic at the three observation locations.

Discussion

Based on Figure 2 and Table 1, the land use in the three locations was dominated by agricultural use and shrimp ponds. The largest use for agriculture is in the Sajoanging area, namely 8,318.52 ha, followed by Marang with 1,221.59 ha and Sanrobone with 902.44 ha. The highest land use for shrimp ponds is in the Sajoanging area (4,201.81 ha), followed by Marang (3,671.40 ha) and Sanrobone (393.71 ha). The sources of nutrients and suspended solids in river flow originate from agricultural and aquaculture activities. The use of fertilizers in agricultural activities contributes to nutrient accumulation through runoff and irrigation channels. Meanwhile, in aquaculture, the use of feed results in leftover organic waste entering the water and decomposing into nutrients and suspended solids. The amount of nutrients entering the water is thought to originate from land use activities for agriculture that use fertilizers [18].

Nitrate and phosphate nutrients and TSS loads to coastal waters are highest in the Sajoanging area, Wajo Regency, while low nutrient loads are observed in the Marang area, Pangkep Regency. This nutrient load is in accordance with the extensive use of land for agriculture, especially in the Sajoanging area. Rainwater that falls on agricultural areas causes soil erosion, and amounts of nitrogen and phosphorus into the river flow and reach the sea. The results of research by Räty et al. [19] explain that the erosion of agricultural land and forests contributes nitrogen and phosphorus to water. The results of Manninen et al. [20] explain that soil erosion by water in agriculture carries nitrogen and organic carbon through surface water. Nitrate and phosphate nutrient loads from river flows are distributed to *Kappapicus alvarezii* seaweed cultivation areas, as research has looked at the influence of the Bay of Bengal waters seasonally enriched with inorganic nutrients from the major rivers draining into it during monsoon and the transport of nutrients across the coastal waters by the coastal and tidal currents [21].

Based on the measurements of oceanographic parameters at the observation locations, the results are presented in Table 3, where the temperature parameter is at a natural value, supporting the growth of *Kappaphycus alvarezii* seaweed cultivated at the three locations. This condition is in accordance with the statement of the Indonesian National Standard [22] that seaweed growth requires an optimal temperature of 24 to 32 °C. While the appropriate salinity ranges from 28 to 33 ppt, water nitrate levels > 0.04 mg/L, phosphate levels > 0.1 mg/L, pH values range from 7 to 8.5, and TSS values < 25 mg/L. The highest concentration of nitrate was obtained in Sajoanging waters, in accordance with land use, which is mostly agricultural. The highest concentration of nitrate was found in Sajoanging waters, in accordance with the predominantly agricultural land use. However, this value is lower than that found in the waters of Panggang Island, namely 0.56 mg/L [23] and 1.07 mg/L in the waters of Laut Kota Baru Island [24]. Likewise, the highest phosphate concentration obtained in the Sajoanging waters was 0.05 mg/L. However, this value is still lower than that found in the coastal waters of Tarakan Island, North Kalimantan Province, which was 0.19 mg/L [25].

Based on the results of the analysis of variance test in Table 4, there were differences in oceanographic variables at three locations that were affected by land use, namely nitrate, phosphate, and TSS ($P < 0.05$). The results of the variance test showed differences in oceanographic parameters between the three locations, in line with the magnitude of material loading. The Sajoanging location had higher concentrations of nitrate, phosphate, and TSS than the Marang and Sanrobone locations. This is in line with the large amount of land use in the river basin at the Sajoanging location for agricultural and aquaculture activities, which provide large nitrate, phosphate, and TTS loads to the waters.

Chlorophyll-a in *Kappapicus alvarezii* seaweed plays a role in the photosynthetic process to form carrageenan. The higher the chlorophyll-a content, the greater the carrageenan yield. The three observation locations showed the highest chlorophyll-a values at the Sajoanging location (Figure 3), which is supported by the high concentration of nitrate in the water as a factor in the formation of chlorophyll-a. The chlorophyll-a concentration obtained was in the quite high category compared to research by Paransa et al. [26], ranging from 16.4 to 18.32 µg/g.

Analysis of the quality of *Kappaphycus alvarezii* seaweed (figure 4) from three locations generally complied with FAO standards [17], namely carrageenan of > 25%, moisture content of 15 to 40% and ash content of ≤ 12%. However, the Sanrobengi location has an ash content that exceeds the standard, ranging from 16.15 to 24.72%. Meanwhile, for the quality of seaweed at the three locations, the greatest difference in the yield of seaweed carrageenan was observed in Sajoanging waters, which had the best quality (Table 5). Carrageenan levels of 67.98% in seaweed from Sajoanging waters were quite high compared to those found in Pong-Masak and Sarira [27] in the waters of the coastal area of Doda Bahari Village, Sangia Wambulu Sub-district, Central Buton Regency, Province of Southeast Sulawesi, with a carrageenan content of 36.6%. Likewise, research conducted by Periyasamy et al. [28] when rearing *Kappapicus alvarezii* for 45 days yielded carrageenan levels of 35.1%. Table 5 shows that land use indirectly affects the content of chlorophyll-a, carrageenan, water, and ash in cultivated *Kappaphycus alvarezii*. The Sajoanging location, with the largest land use in the agricultural sector, had the highest carrageenan content compared to the other two locations. Kotiya et al. [29] explained that rearing location influences the growth of cultivated seaweed.

The results of the PCA in Figure 5 indicate that at the Sajoanging location, the oceanographic parameters that characterize the site are characterized by high values of nitrate, phosphate, and total suspended solids. The availability of nitrate and phosphate determines the suitability of marine waters for seaweed cultivation [30]. At the Sanrobengi location, the main identifying parameters were high temperature and salinity. Temperature and salinity influence the growth of *Kappapicus alvarezii* [31]. This analysis proves that the use of large agricultural land with artificial fertilizers can influence the chemical parameters of oceanography in coastal areas. Akib et al. [32] explained that water quality parameters greatly influence seaweed growth.

Conclusion

Land use for agriculture and shrimp farming contributes to the nutrient load of nitrate, phosphate, and TSS in coastal areas of South Sulawesi, thus affecting oceanographic conditions and the quality of cultivated seaweed *Kappaphycus alvarezii*. Sajoanging District, Wajo Regency, where most of the land is used for agriculture and shrimp farming, affects water quality and the cultivation of seaweed *Kappaphycus alvarezii* in coastal areas. This study proves that land use does not always have a negative impact on coastal areas, especially use for agriculture and shrimp farming in areas where seaweed cultivation occurs.

Author Contributions

MFS: Conceptualization, Methodology, Writing – review & editing; **ML**: Writing – review & editing– review & editing, Supervision; **FN**: Data curation, Formal analysis, Writing – review & editing; **AAP**: Formal analysis, Writing – review & editing; and **IK**: Data curation, Formal analysis.

Conflicts of Interest

There are no conflicts to declare.

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