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PROOF

RESEARCH PAPER

Spatial Analysis to Evaluate the Suitability of Seaweed Farming Site in Lampung Bay, Indonesia

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Abstract

Seaweed is a promising fishery product. Potential aquaculture of which in Lampung Province is estimated around 2260.5 ha. Several seaweed farming efforts have been carried out in Lampung Bay (Indonesia). However, they faced failure. Therefore, it is necessary to carry out spatial analysis to understand the level of seaweed farming suitability in the bay. This study was carried out in five observation site groups with total 20 sampling points and employed survey through spatial and temporal approaches as the study method. Geo-statistical model was used for earth surface mapping, both for biotic and abiotic components. Each station was then be given value to determine suitability class. The class was determined by making aquatic suitability matrix for each physical, chemical and biological parameter. Results acquired indicate that Lampung Bay area is not suitable as seaweed farming site. However the area is open for any suggestion.

Keywords: Geo-statistic, Lampung Bay, seaweed, suitability matrix.

Introduction

Seaweed is a fishery product with promising prospect, relatively fast growth and high adaptation ability against bad nutrient and environment conditions (Aitken, Bulboa, Godot-Faundez, Turrion-Gomez & Antizar-Ladislao, 2014; Jaap, Huijgen & Lopez-Contreras, 2014). In Indonesia, seaweed industry has been widely developed, among others are species *Kappaphycus alvarezii* (Doty) Doty ex P.C. Silva in Madura (Indriatmoko, Heriyanto, Limantara & Brotosudarmo, 2015), *K. alvarezii* and *Eucheuma denticulatum* (Burman) Collins & Hervey in North and Southeast Sulawesi (Sievanen, Crawford, Pollnac & Lowe, 2005; Aslan, Iba, Bolu, Ingram, Gooley & Silva, 2015; Puspawati, Wagiman, Ainuri, Nugraha & Haslianti, 2015) and *K. alvarezii* in Gorontalo (Fadilah, Alimuddin, Pong-Masak, Santoso & Parenrengi, 2016). The number of seaweeds export in Indonesia for 2015 reached 178280 tons (Ministry of Marine and Fisheries, 2015). In addition to being used as consumption material (Radulovich, Umanzor, Cabrera & Mata, 2015), seaweed also widely used as raw material for carrageenan extraction (De Ruiter & Rudolph, 1997; Imeson, 2009; Hernández-González, Buschmann, Cifuentes, Correa & Westermeier, 2007; Bulboa, Veliz, Saez, Sepulveda, Vega & Macchiavello, 2013), raw material for food, medicine, cosmetic and textile industries (Imeson, 2009; Dhargalkar & Verlecar, 2009; Nurjanah, Nurilmala, Hidayat & Sudirdjo, 2016). Seaweed also brings another benefit, i.e. as the source of biodiesel and bioenergy (Bruhn *et al*., 2011; Borines, de Leon & Cuello, 2013; Jaap *et al*., 2014; Bharathiraja *et al*., 2015; Ghadiryanfar, Rosentrater, Keyhani & Omid, 2016; Jiang, Ingle & Golberg, 2016). According to the result of the study, seaweeds of high economic value and is potential to be cultivated in Indonesian water as producers are among others *Gracilaria* as agarophyte producer, *Eucheuma* and *Kappaphycus* as carraginophyte producers, and *Sargassum* and *Turbinaria* as alginophyte producers (DoMF Sulteng, 2009).

Potential cultivation area in Pesawaran Lampung is around ± 3685.5 ha where 250 ha of which is for seaweed farming site (DoMF Pesawaran, 2010). In 2008, area utilization for seaweed was only 60 ha, i.e. in Padang Cermin and Punduh Pidada Sub-Districts (Indonesia). According to observation result, efforts to cultivate seaweed have been carried out in Tanjung Putus (Indonesia) and Harun Bay areas of Lampung Province (Indonesia) for *K. alvarezii.* However, such efforts faced failure. In seaweed farming efforts, determining culture site is one of the determining factors. Ecological aspect is the most important in determining such site. Aquatic environmental condition is highly important to assess prior to planning seaweed farming activities. Environmental factors that influence seaweeds growth are among others salinity, temperature, sunlight (Hernández-González *et al*., 2007; Kumar, Kumari, Reddy & Jha, 2014), nitrogen and organic carbon, as well as stable sea water pH (Friedlander & Levy,1995; Israel, Katz, Dubinsky, Merrill & Friedlander, 1999; Israel, Gavrieli, Glazer & Friedlander, 2005). This study aimed to analysis the suitability level of Lampung Bay (Indonesia) for seaweed farming based on ecosystem variables as well as to determine the zonation of sea farming suitable for seaweeds.

Materials and Methods

This study was carried out in April-May 2012 in Lampung Bay of Pesawaran District, Lampung Province, Indonesia. The determination of observation points was designed using purposive sampling method. Researcher chose five water area groups that have similarity with cultivane's ecological preference, i.e.:

Group 1 : Around Siuncal and Legundi Islands (station 1-4);

Group 2 : Around Pidada Bay (station 5-8);

Group 3 : Around Puhawang and Tegal Islands (station 9-12);

Group 4 : Around Maitem and Tegal Islands (station 13-16); and

Group 5 : Around Tegal Island to Hurun Bay (station 17-20).

For each area group, a total of four sampling stations were chosen by taking into account several aspects, among others spatial, security, time and possibility for farming construction. The sampling points were totally 20 stations (Table 1) and the map of which is shown in Figure 1.

Data Collection

This study employed primary and secondary data. Primary data was sample's water quality such as water's physical, chemical and biological parameters, while secondary data employed were earth surface map, imagery data, and other secondary data. Water quality sampling was carried out between 08.00 and 17.00 of Western Indonesia Time. Particularly for dissolved oxygen parameter, the data were taken twice a day, i.e. during daylight (noon-afternoon) and night (evening-morning). Water depth, clarity, temperature, current velocity, dissolved oxygen, pH and salinity were measured directly on the ground, following APHA method (1992). Phytoplankton, chlorophyll-a and nutrients were analyzed in Lampung Marine Aquaculture Development

Table 1. Sampling station

No. Station	Station	Coordinate (*degrees, minutes, seconds*)		Description of the Station
		Latitude	Longitude	
1	Siuncal	5º46'21.53"S	105º18'35.95"E	Around 1.2 km to the north from Siuncal Island's shoreline
2	Siuncal	5º47'7.62"S	105º18'21.90"E	In Labuhan Sawah area, around 0.4 km to the north from Siuncal Island's shoreline
3	Lesung	5º47'30.68"S	105º17'55.12"E	Located in the mouth of Siuncal Strait (strait between Siuncal and Legundi Islands)
4	Legundi	5º47'1.20"S	105º17'38.04"E	Around 1.2 km to the north from Legundi Island's shoreline
5	Punduh Pidada	5º44'19.89"S	105º11'33.21"E	In Punduh Pidada Bay
6	Tanjung Putus	5º44'25.93"S	105º13'20.91"E	To the south from Lalanggabalak Island, is ex-seaweed farming site
7	Punduh Pidada	5º45'29.82"S	105º11'35.97"E	In Punduh Pidada Bay
8	Punduh Pidada	5º45'30.53"S	105º13'30.01"E	In the mouth of Punduh Pidada Bay
9	Puhawang	5º42'59.50"S	105º13'40.57"E	To the north from Puhawang Island
10	Puhawang	5º41'38.32"S	105º12'14.48"E	To the northwest from Puhawang Island, there are several seaweed farming activities
11	Puhawang	5º41'36.81"S	105º13'38.43"E	In the middle of between Puhawang and Kelagian Islands
12	Puhawang	5º39'7.89"S	105º15'18.00"E	Around 2.5 km to the northeast from Puhawang Island
13	Maitem	5º35'30.91"S	105º15'27.94"E	To the north from Maitem Island
14	Maitem	5º34'50.00"S	105º15'49.95"E	In the middle of between Maitem and Tegal Islands
15	Tegal	5º34'46.96"S	105º17'11.23"E	To the southeast from Tegal Island
16	Tegal	5º34'2.69"S	105º17'23.83"E	To the east from Tegal Island
17	Tegal	5º33'5.12"S	105º17'14.39"E	To the north from Tegal Island
18	Kyoko	5º31'55.78"S	105º16'41.33"E	Seaweed farming site of PT Kyoko
19	Teluk Hurun	5º32'4.11"S	105º16'1.19"E	Grouper farming site
20	Ringgung	5º33'23.36"S	105º15'53.39"E	Grouper farming site

Agency's laboratory (*laboratorium* BBPBL Lampung), also following APHA method (1976; 1992). The list of measured parameters can be seen on Table 2.

Data Analysis

Contour Mapping and Spatial Modeling

Geo-statistic model was used for earth surface mapping (biotic and abiotic) through statistic application. This model development was based on geodetic/position data transfer (degree, minute, second or known as DMS), acquiring single value with formula as follow (Hartoko, 2000).

Numerical Value (Lat ; Long) = Degree + {Minute + (Second/ 60)} / 60

Ermapper 7.0 software was employed to process data, making layers for physical, chemical and biological parameter. The software also made contour using grid file as the base for its interpolation and extrapolation. In such process, it is as if point numbers were higher than the actual data figures. Kriging model was used in interpolation procedure (Budiyanto, 2005).

Analysis of Water Suitability for Aquaculture

Suitability rate was calculated following

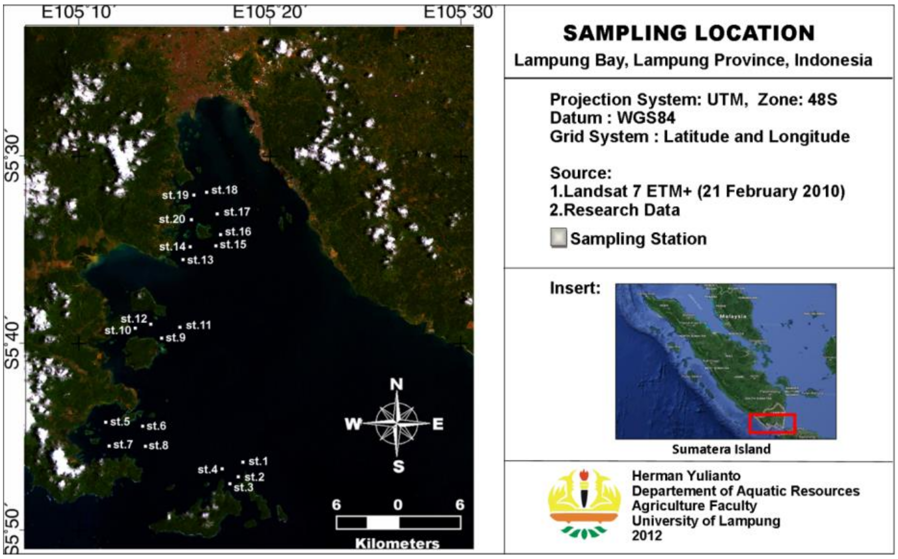

Figure 1. Map of sampling location.

Table 2. List of measured parameters

Measured parameter	Unit	Equipment	Location
Physical Parameter			
1. Coordinate	-	GPS	*In situ*
2. Depth	meter	Bathymeter	*In situ*
3. Clarity	meter	Secchi disk	*In situ*
4. Temperature	℃	Water quality checker	*In situ*
5. Current velocity	m/s	Current measurement tool	*In situ*
6. Waterbed substrate	-	Ekman Grab Sampler	*In situ*/Lab
7. Suspended Solid Material	mg/l	Millipore filter	Laboratory
Chemical Parameter			
1. Dissolved oxygen	mg/l	Water quality checker	*In situ*
2. pH	-	Water quality checker	*In situ*
3. Salinity	ppt	Water quality checker	*In situ*
4. Phosphate	mg/l	Spectrophotometer	Laboratory
5. Nitrate	mg/l	Spectrophotometer	Laboratory
Biological Parameter			
1. Phytoplankton	cell/l	Microscope, SRC	Laboratory
2. Chlorophyll-a	(mg/m^3)	Spectrophotometer	Laboratory

suitability matrix and was classed into four classes according to DoMF (2002), namely:

- Class S1: Highly Suitable. This area has no heavy boundary for a certain sustainable use or in the other word it only has a less meaningful boundary with no significant influence on the land productivity and does not add input from the land using. All environmental biophysical criteria reached the highest level (maximum).
- Class S2: Moderately Suitable. This area has a rather heavy boundary for a certain sustainable use. Such boundary will influence the productivity, and it is necessary to increase input to use the land.
- Class S3: Marginally Suitable. This area has really heavy boundaries. However, such boundaries still can be overcame and the condition can be improved into a suitable condition once improvement with higher level of technology introduction or cost-wise additional treatment is carried out.
- Class N: Not Suitable. This area has heavy, permanent boundaries, preventing any possibility for any additional treatment to the area.

Suitability matrix of the water was prepared through desk study and by taking into account aquaculture technic to make determining variables can be determined for references in valuing (Table 3). After all variable data obtained, correlation analysis among the variables was carried out. The relationship was analyzed using multiple regression mathematic model. Statistical Product and Service Solutions (SPSS) software was used as analysis tool. The suitability of the total scores obtained was then analyzed using Table 4.

Result and Discussion

Lampung Bay Environmental Condition

Lampung Bay has winding shoreline with several small bays (Hurun, Ratai and Pedada Bays) and the base of which is relatively sloping. The presence of Siuncal and Legundi Islands in the mouth of Lampung Bay (at the south part) serves as

Table 3. System of water suitability assessment for seaweed farming site

Parameter*	Range	Assessment Number** (A)	Value*** (B)	Score**** (AxB)
Nitrate (mg/l)	0.9 - 3.2	5		125
	0.7 - <0.9 & 3.2< -3.4	3	25	75
	<0.7 ; > 3.4	1		25
Phosphate (mg/l)	0.2 - 0.5	5		125
	0.1 - <0.2 & 0.5< - 1	3	25	75
	< 0.1 and >1	1		25
Depth (m)	1 - 10	5		25
	10< - 15	3	5	15
	< 1 and >15	1		05
Clarity (m)	> 3	5		125
	1 – 3	3	15	45
	<1	1		15
Current Velocity	20 - 30	5		50
(cm/sec)	10-<20 and 30< - 40	3	10	30
	< 10 and > 40	1		10
Suspended Solid	< 25	5		25
Material (mg/l)	25 – 50	3	5	15
	> 50	1		5
Salinity	32 - 34	5		25
(ppt)	30 - <32	3	5	15
	< 30 and > 34	1		5
Waterbed substrate	Coral	5		25
	Sand	3	5	15
	Sand/ Silt	1		5
Chlorophyll-a	> 10	5		25
(mg/m^3)	4 – 10	3	5	15
	< 4	1		5
Total Score:			(100%)	

Note:
*Criteria used to prepare the suitability matrix and valuation to determine seaweed farming suitability were modified by the researcher following criteria prepared by other researchers/agencies on marine farming (seaweed) by DoMF (2002), Radiarta, Wardoyo, Priono & Praseno (2003); Radiatra, Saputra & Priono (2004); Cornelia, Suryanto & Dartoyo (2005); Kangkan, Hartoko & Suminto (2007) and Hartoko & Kangkan (2010), as well as Decree of the Minister of Environment No. 51/2004 on Marine Water Quality Standard
**Assessment number based on DoMF (2002) guidance are as follow. 5: good , 3: medium, 1: bad
***Value based on references/taking into account dominant variable.
****Score is $\sum_{i=1}^{n} = A \times B$

protection for the water against threat from waves, both from Indian Ocean and Java Sea. The condition of the bay is adequately protected with high tide water level ranging 0.3-1.4 m (BMKG Lampung). Current velocity of which is ranging 10-30 cm s^{-1}, indicating that the water is relatively calm and can be used as mariculture site. The depth of the water is ranging 13-42.8 m. The difference in the depth indicates that the relief (topography) of the bay waterbed varies among sites.

According to water quality parameter data collected on the ground (Table 5), the clarity of the water ranged 5-16.5 m, indicating adequately high sunrays intensity penetrating the water. The temperature of which at two (2) m depth was relatively stable, i.e. ranging 28.9-31 ºC with mean value of 29.99 ºC. The salinity and pH of which also indicated that the water was adequately stable with pH ranging 8.02-8.64 and salinity around 33 ppt. In addition, nutrients such as nitrate and phosphate had a relatively low concentration with nitrate ranging 0.003-0.34 mg/l with mean value 0.06 mg/l, while phosphate (orthophosphate) ranging 0.01-0.48 mg/l with mean value 0.08 mg/l. The concentration of nitrate and phosphate levels have an impact on the growth of algae. Nitrate concentrations which optimum for the growth of algae by measuring the relative levels of chlorophyll is 9.61×10^{-4} and optimum phosphate concentration is 7.47×10^{-6} (Fried, Mackie, & Nothwehr, 2003). The results of physical parameter measurement obtained indicated that the water is supportive for mariculture activity. However, nutrients such as nitrate and phosphate indicated low suitability rate (Yulianto, 2013).

Seaweed Farming Suitability

After scoring process (Table 6), it was known that the waters of Lampung Bay (Indonesia) belonged to Not Suitable category when utilized for seaweed farming activity. Only station 2 and 10 belonged to Marginally Suitable. Score for Not Suitable category ranged 46-54%, while for Marginally Suitable ranged 70-74%. These data indicated that the existing ecosystem variables are not supportive for seaweed farming activity. The success of such activity highly depends on the supporting environmental factors. Main factors capable of influencing the success of seaweed culture are among others nutrient, clarity, water movement, salinity, depth and the presence of grazer (De San, 2012; Redmond, Green, Yarish, Kim & Neefus, 2014; Yang *et al*., 2015; Bharathiraja *et al.*, 2015).

Several physical parameters such as clarity and current velocity in this area were adequately suitable for seaweed farming activity with average clarity 11.32 m and average current velocity 20 cm s^{-1}. Light exposure takes part in photosynthesis process. In this study, light exposure was influenced with Suspended Solid Material where more material affects the light

Table 4. Evaluation of seaweed farming zonation suitability assessment

Total Scoring* (%)	Evaluation or Conclusion
>85 – 100	Highly Suitable
>75 – 85	Moderately Suitable
>65 – 75	Marginally Suitable
0 – 65	Not Suitable

Source: DoMF (2002).

*Total scoring obtained following formula: $\text{Total scoring} = \frac{\text{total score}}{\text{total maximum score}} \times 100\%$

Table 5. Range of water quality parameter in Lampung Bay

Parameter		Unit	Value
Temperature		ºC	29.99±0.50
Dissolved Oxygen	[A]*	mg/l	5.22±0.29
	[B]**	mg/l	5.63±0.42
Salinity		ppt	33.07±0.13
pH			8.16±0.12
Depth		m	26.99±6.53
Clarity		m	11.32±2.92
Current		cm/s	20.00±6.89
Suspended Solid Material		mg/l	47.05±18.02
Nitrate (NO_3)		mg/l	0.06±0.07
Phosphate (PO_4)		mg/l	0.08±0.09
Chlorophyll-a		mg/l	4.37±1.26
Plankton abundance		cell/l	89800.17±12447.56
Waterbed substrate			Sandy Coral

*Measurement at 00.00 to 06.00 Western Indonesia Time

**Measurement at 09.00 to 16.00 Western Indonesia Time

Table 6. Result of suitability scoring for each station

PARAMETER	SCORE MAX	SCORE (FIGURE X VALUE) OF EACH STATION																			
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
Salinity (ppt)	*25*	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Depth (m)	*25*	25	25	25	5	15	15	15	15	15	5	15	5	25	25	15	15	15	15	25	15
Clarity (m)	*75*	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Nitrate (NO_3) (mg/l)	*125*	25	125	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Phosphate (PO_4) (mg/l)	*125*	25	25	25	25	25	25	25	25	25	125	25	25	25	25	25	25	25	25	25	25
Suspended Solid Material (mg/l)	*25*	15	15	15	15	15	15	15	15	15	5	5	5	15	15	15	15	15	5	5	5
Chlorophyll-a (mg/l)	*25*	5	5	5	5	15	15	5	15	15	15	15	15	15	15	15	15	15	15	5	5
Current (cm/s)	*50*	30	50	30	50	50	50	50	50	50	50	50	30	30	30	50	50	50	30	50	30
Waterbed substrate	*25*	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
TOTAL	*500*	250	370	250	250	270	270	260	270	270	350	260	230	260	260	270	270	270	240	260	230
FINAL SCORE*		50	74	50	50	54	54	52	54	54	70	52	46	52	52	54	54	54	48	52	46

*Red means S1 (*Highly Suitable*); yellow means S2 (*Moderately Suitable*); green means S3 (*Marginally Suitable*); blue means N (*Not Suitable)* depth. Influence from light exposure and current velocity are important factors that can lead to difference in seaweed's biomass and frond size (Peteiro & Freire, 2012). On the other hand, suitable current velocity can increase nutrient load and eventually increase nutrient and carbon dioxide absorption by reducing diffusion on boundary layer around algae surface. Although extremely important, too fast current (more than 30 cm s^{-1}) leads to stress for several alga species (Peteiro & Freire, 2011).

Other aquatic factors, such as salinity, are also capable of influencing seaweed growth. According to the obtained data, salinity of Lampung Bay was of suitable range for seaweed farming area. Optimum salinity for seaweed growth is usually 25-35 ppt. However, each species may of different range (Kumar *et al*., 2014). Study by Pellizzari, Oliveira & Yokoya (2008) on *Gayralia* spp indicated that seaweed former growth drastically decreases in salinity of higher than 30 psu. However, there are several seaweed species such as *Gracilariopsis heteroclada* Zhang & Xia and *Gracilaria edulis* (Gmelin) P.C.Silva have wide range of tolerance against salinity (Carton, Caipang, Notoya & Fujita, 2011). In addition to salinity, depth also influences seaweed growth. In red alga *K. alvarezii*, the highest carrageenan is found in seaweed planted in deeper area (Wenno, Syamsuddin, Zainuddin & Ambo-Rappe, 2015).

Out of all the above mentioned factors, the main factor required by seaweed to grow is nutrient. In this study, analysis results indicated that nitrate and phosphate contents of Lampung Bay were really low. Such low nutrient content in the waters was presumably due to the condition of the substrate (sandy coral) that tended to lack of organic materials. Phosphate and nitrate in low concentration can be used as limiting factor in seaweed farming activity in Lampung Bay. According to Hernández-González *et al*. (2007), nutrient is an influencing factor for seaweed growth and chemical composition. Rydera *et al.* (2004) also stated that water movement and nutrient are important for *Gracilaria parvispora* Abbot initial growth. Nutrient becomes important for the growth of seaweed because high nutrient load will increase seaweed's growth and protein content (Msuya & Neori, 2008). Therefore, when seaweed is planted in really low nutrient content area, the growth rate of which will be hampered. That will become a disadvantage for seaweed farmers.

In seaweed farming activity, suitable conditions such as high light intensity, warm temperature and abundant nutrition supply will accelerate seaweed growth (Dhargalkar & Verlecar, 2009). Analyses on physical-chemical factors in planning fishery culture activity are important as such analyses relate to mariculture model that will be applied as well as supporting installation that will be used. According to Lehahn, Ingle & Golberg (2016), risks from clarity, nutrient and salinity can be overcame by selecting seaweed species that has specific tolerance against such environmental condition. According to the overall data obtained, it was known that Lampung Bay is not suitable for seaweed farming activity.

Seaweed Farming Zonation

Spatial model from mapping result showed that suitable area for seaweed farming location was extremely limited, i.e. only seashore area at the west of Puhawang Island and around Siuncal Island (Figure 2). This indicated that Lampung Bay is generally not suitable for seaweed farming activities. Different result was obtained for suitability analysis for pearl oyster farming. Yulianto, Hartoko, Anggoro & Delis (2016) reported that areas between Puhawang Island and Tegal Island as well as areas between Tegal

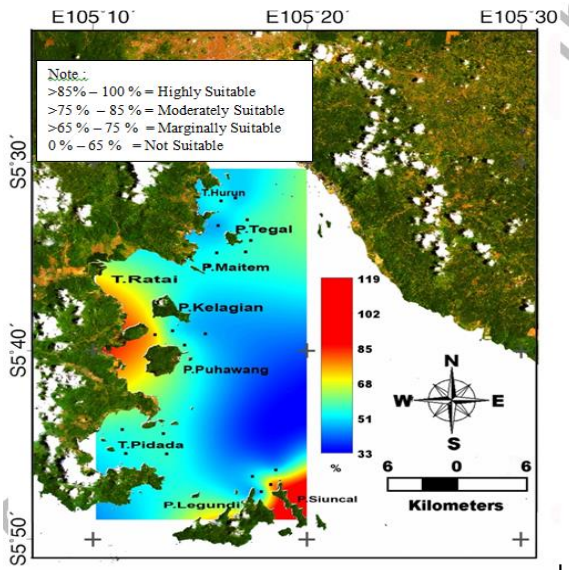

Figure 2. Zonation of water suitability for seaweed farming.

Island and Hurun Bay showed the highest value, indicating the areas are highly suitable for pearl oyster farming. Extremely low nitrate and phosphate concentrations are the limiting factors for seaweed farming activity, considering that nutrients are highly required for metabolism process. According to spatial model, it was known that of total study site area (33847.12 ha) water area that can be managed for seaweed farming with Highly Suitable (S1) rate was only 262.76 ha; Moderately Suitable (S2) 863.18 ha; Marginally Suitable (S3) 2503.47 ha and Not Suitable (N) 30217.71 ha.

Conclusion

Lampung Bay area showed not suitable condition as seaweed farming site. Analysis result indicated that of 33847.12 ha study site area, only 3629.41 ha of which was suitable for seaweed aquaculture that was divided into several suitability rates, i.e. Highly Suitable (S1) 262.76 ha; Moderately Suitable (S2) 863.18 ha; Marginally Suitable (S3) 2503.47 ha and Not Suitable (N) 30217.71 ha.

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