Land suitability analysis for brackishwater aquaculture development in the coastal area of District West Halmahera, Indonesia

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Abstract. West Halmahera District is one of the areas that has great prospects for the development of brackishwater aquaculture. However, there are obstacles to the development of brackishwater aquaculture in West Halmahera District. This study aimed to determine the suitability of land for brackishwater aquaculture and its limiting factors, in order to increase the productivity and sustainability and to provide a general reference for policymakers in determining the Regional Spatial Plan in West Halmahera District. This study was conducted on brackishwater ponds in Jailolo Sub-District, West Halmahera District, North Maluku Province, Indonesia. Data on infrastructure, water quality, and soil parameters were collected and analyzed using the water and land suitability criteria, by establishing four classes, namely: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and non-suitable (N). The results of land suitability were then processed using spatial analysis in Geographic Information Systems. This study successfully revealed that Jailolo District, West Halmahera Regency, North Maluku Province, Indonesia is moderately suitable (S2) for brackish water aquaculture, with a land area of approximately 329.27 ha.
Key Words: coastal area, infrastructure parameters, suitability assessment, water quality parameters.

Introduction. Fisheries have become one of the most important sectors in the fulfillment of the global food demand. The Food and Agriculture Organization reported that the global fisheries production in 2020 reached 178 million tons. Of the total production, more than 157 million tons were used for human consumption. Furthermore, this fishery production comes from two leading sectors, namely the capture fisheries and aquaculture sectors (FAO 2022). The contribution of aquaculture to fisheries production in 2020 was 87.5 million tons (49%), better than in 2018 when it was of only 82.1 million tons (47%) (FAO 2020; FAO 2022). Indeed, aquaculture can contribute to people's income, employment, and potential foreign exchange earnings (Salayo et al 2022; Brugere et al 2023).

West Halmahera District is one of the areas that has great prospects for the development of freshwater aquaculture, brackishwater (ponds) and mariculture (Floating Net Cages-KJA and seaweed) with 2021 production reaching 192.71 tons and a production value of around 192 million dollars (KKP 2023). For developing the brackishwater aquaculture, the commodities commonly cultivated are *Penaeus vannamei* shrimp and *Chanos chanos* milkfish (Andriani et al 2022; Aris et al 2022). However, there are obstacles to the development of brackishwater aquaculture in West Halmahera District.

Land suitability analysis needs to be carried out for principle considerations in determining appropriate land use (Ghobadi et al 2021). Furthermore, land suitability analysis is a process of estimating land variability whenever it is used for specific purposes or as a method to explain or predict land use potential (Hossen et al 2021; Roy et al 2022). If land potential can be determined, then land use planning can be based on rational considerations (Calle-Yunis et al 2020). Thus, land suitability analysis is a strategic land

use planning tool that can predict the expected benefits and constraints of productive land use and the environmental degradation that may occur due to land use (Shunmugapriya et al 2021).

In aquaculture, the aspect of land suitability is the key that affects its success and sustainability (Watson et al 2022). Therefore, this study aimed to determine the suitability of land for brackishwater aquaculture and its limiting factors, in order to increase the productivity and sustainability and provide a general reference for policymakers in determining the Regional Spatial Plan in West Halmahera District.

Material and Method

Study area. This study was conducted in January 2024 in the existing brackishwater ponds in Jailolo Sub-District, West Halmahera District, North Maluku Province, Indonesia, which is located between latitude 1° 3′ 49′′ and 1° 3′ 16′′ N, and stretches between longitudes 127° 28′ 5′′ and 127° 29′ 44″ E. About 300 ha of the intertidal area is designated by the local government for fisheries development and some of it has been converted to aquaculture ponds. The existing brackishwater ponds are extensive and semi-intensive (Figure 1).

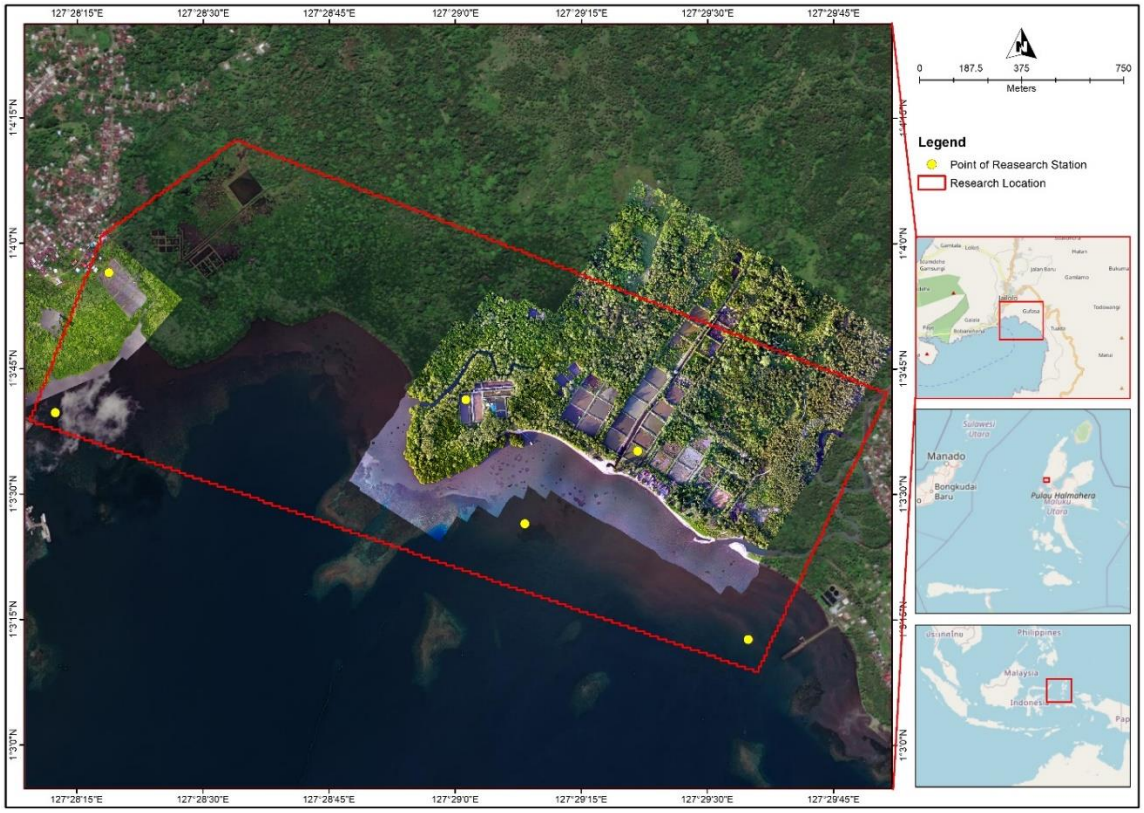

Figure 1. Location of study site in West Halmahera District, North Maluku Province.

Data collection. Data on infrastructure, water quality and soil parameters was collected. Infrastructure data are distance to market, distance to highway, and distance to hatchery which are observed in-situ (directly). Water quality parameter data observed were: water temperature, salinity, dissolved oxygen, water pH, total ammonia nitrogen (NH_3), nitrite (NO_2-), hydrogen sulfide (H_2S), mercury (Hg), lead (Pb), cadmium (Cd), and *Vibrio* sp. Data collection of temperature (using a thermometer), salinity (using a refractometer), dissolved oxygen (using a DO-meter), and water pH (using a pH meter) was done in situ, while data collection on NH_3, NO_2^-, H_2S, Hg, Pb, Cd (using a spectrophotometer), and *Vibrio* sp. bacteria (using thiosulfate citrate bile salt sucrose/TCBS agar media) was carried out ex-situ (laboratory). Soil parameter data observed included soil pH (using a pH meter) in-situ.

Data analysis. The data obtained were then analyzed using suitability analysis. The land suitability criteria in this study establish four classes, namely: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and non-suitable (N). The four classes were then given a score of 4 for S1, 3 for S2, 2 for S3, and 1 for N (Table 1). Furthermore, the scoring value of land suitability is then determined by the score range of each class. The total score of the S1 class is 326-400, the S2 class is 251-325, the S3 class is 176-250, and the N class is 100-175. The results of land suitability were then processed using spatial analysis in Geographic Information Systems following the methods developed by Abubakar et al (2024).

Table 1

The classification criteria of the land suitability analysis for brackishwater aquaculture development in the coastal area of West Halmahera District, Indonesia

Parameters		*Range*	*Score*	*References*
Infrastructure	Distance to road (km)	<2	4	Hadipour et al 2014
		2 – 3	3	
		3 – 5	2	
		>5	1	
	Distance to market (km)	<3	4	Hadipour et al 2014
		3 – 7	3	
		7 – 12	2	
		>12	1	
	Distance to hatcheries (km)	<3	4	Hadipour et al 2014
		3 – 7	3	
		7 – 12	2	
		>12	1	
Water quality	Water temperature (℃)	28 – 33	4	BSN 2014
		20 – 27 and 33 – 38	3	
		12 – 19 and 39 – 44	2	
		<12 and >44	1	
	Water salinity (ppt)	5 – 40	4	Indonesian Ministry of Marine Affairs and Fisheries 2016
		3 – 4 and 41 – 42	3	
		1 – 2 and 43 – 44	2	
		<0 and >45	1	
	Dissolved oxygen (mg L^{-1})	5 – 7	4	Indonesian Ministry of Marine Affairs and Fisheries 2016
		3 – 4 and 8 – 9	3	
		1 – 2 and 10 – 11	2	
		0 and 12	1	
	Water pH	7.0 – 8.5	4	BSN 2014
		6.0 – 6.9 and 8.6–9.5	3	
		4.0 – 5.9 and 9.6 – 11.0	2	
		<4 and >11	1	
	NH_3 (mg L^{-1})	<0.10	4	BSN 2014
		0.20 – 0.30	3	
		0.40 – 0.10	2	
		>1	1	
	NO_2- (mg L^{-1})	0 – 0.05	4	Kusuma et al (2017)
		0.06 – 0.09	3	
		1 – 1.4	2	
		>1.5	1	
	H_2S (mg L^{-1})	<0.01	4	Indonesian Ministry of Environment 2004
		0.02 – 0.20	3	
		0.21 – 0.40	2	

Parameters		*Range*	*Score*	*References*
		>0.41	1	
	Hg (mg L^{-1})	0 – 0.019	4	BSN 2009
		0.2 – 0.3	3	
		0.4 – 0.13	2	
		>1	1	
	Pb (mg L^{-1})	<0.1	4	BSN 2009
		0.1 – 0.2	3	
		0.2 – 0.4	2	
		>0.5	1	
	Cd (mg L^{-1})	0 – 0.016	4	BSN 2009
		0.2 – 0.3	3	
		0.4 – 0.13	2	
		>1	1	
	Vibrio sp.	Negative	4	Sarjito et al (2015)
		Negative and Positive	3	
		Positive and Negative	2	
		Positive	1	
Soil	Soil pH	6.5 – 8.5	4	Ikbal et al (2019)
		5.5–6.4 and 8.6–9.0	3	
		4–5.4 and 9.1–10	2	
		<4 and >10	1	

Results and Discussion. Current infrastructure factors greatly affect aquaculture operations (Subasinghe et al 2009). Infrastructure conditions are presented in Table 2. Good road infrastructure is an important prerequisite for farms as it contributes to mobility during production. Therefore, aquaculture development sites should be as close to the road system as possible. Observations of the distance to road parameter show values >5 km. A suitable distance to road for brackish water aquaculture is <2 km (Hadipour et al 2014). Brackish water aquaculture has become source of economically valuable, highly demanded commodities. Hence, pond development sites should be located in markets proximity. After harvesting, shrimp and fish need quick marketing so that their quality does not decline. Distance to market parameter observations indicate values >12 km with the target market being the local market in Ternate City (±31.56 km from the farm site). A distance to market <3 km is considered suitable for brackish water aquaculture (Hadipour et al 2014). When developing brackish water aquaculture, the source of fry must be secured, as it is susceptible to environmental conditions which may cause mortality. Based on these considerations, hatcheries should be close to the development site. Observations of the distance to hatcheries parameter showed that it was >12 km, measured from the hatchery unit of PT Esaputlii Prakarsa Utama (4° 8′ 38′′ S and 119° 36′ 54′′ E) in Barru District, South Sulawesi Province, Indonesia (±1.048 km from the pond site). Distance to hatcheries km which is suitable for brackish water aquaculture is <3 km (Hadipour et al 2014).

Environmental quality conditions, especially water and soil quality parameters, also greatly affect aquaculture operations (Mavraganis et al 2020). Water and soil quality conditions are presented in Table 2. Water temperature is one of the important environmental factors in aquaculture. Temperature changes can affect various aspects of the pond system, including the growth of cultured organisms and water quality. An optimal temperature can enhance the growth of organisms, as well as help spur production (Diana et al 2017). The observed water temperature was at 30℃. The optimal range of deep temperature for brackish water aquaculture is 28-33℃ (BSN 2014).

Salinity is the concentration of salt solution in seawater. Salinity in principle has a direct effect on the osmoregulation process of aquatic organisms which can affect the growth rate, feed consumption and survival of cultured organisms (Anufriieva & Shadrin 2023). Salinity observations were in the range of 18-27 ppt. The optimal range of salinity for brackish water aquaculture is 5-40 ppt (Indonesian Ministry of Marine Affairs and Fisheries 2016).

Dissolved oxygen is an important factor in aquaculture because it is closely related to the respiration process, which produces energy that can be used in various body maintenance activities, movement, feeding and biosynthesis processes (Ali & Anushka 2022). In addition, dissolved oxygen has an important role directly in the growth and production of cultured organisms. Salinity observations were in the range of 5.43-6.12 mg L^{-1}. The optimal range of salinity for brackish water aquaculture is 5-7 mg L^{-1} (Indonesian Ministry of Marine Affairs and Fisheries 2016).

Water pH is an important factor that can significantly affect brackish water aquaculture. The pH level of water directly affects the health and growth of aquatic organisms, as well as the overall water quality. If the pH level of the water is too acidic or too alkaline, it can be detrimental to the survival and development of brackish water species (Swain et al 2020). Water pH observations were in the range of 7.15-7.73. The optimal range of salinity for brackish water aquaculture is 7-8.5 (BSN 2014).

Table 2

Condition of infrastructure, water quality, and soil for existing brackishwater ponds West Halmahera District, Indonesia (n=6)

Parameters		*Minimum*	*Maximum*	*Average*
Infrastructure	Distance to road (km)	>5	>5	>5
	Distance to market (km)	>12	>12	>12
	Distance to hatcheries (km)	>12	>12	>12
Water quality	Water temperature (℃)	30.00	30.00	30.00
	Water salinity (ppt)	18.00	27.00	23.33
	Dissolved oxygen (mg L^{-1})	5.43	6.12	5.77
	Water pH	7.15	7.73	7.46
	NH_3 (mg L^{-1})	0.33	0.86	0.43
	NO_2^- (mg L^{-1})	0.02	0.02	0.02
	H_2S (mg L^{-1})	<0.001	<0.001	<0.001
	Hg (mg L^{-1})	0.0001	0.0004	0.0002
	Cd (mg L^{-1})	0.0013	0.0016	0.0014
	Pb (mg L^{-1})	0.0094	0.0102	0.0097
	Vibrio sp.	Positive	Positive	Positive
Soil	Soil pH	6.00	6.00	6.00

NH_3 and NO_2^- are related parameters because they are involved in the nitrogen cycle in water. Both compounds are toxic and poisonous to organisms, when ammonia levels in waters exceed the maximum threshold. In addition, NH_3 and NO_2^- play a role directly in the growth and production of cultured organisms (Zhao et al 2020). NH_3 observed values were in the range of 0.33-0.86 mg L^{-1}. The optimal range of NH_3 for brackish water aquaculture is <0.1 mg L^{-1} (BSN 2014). The NO_2^- value was 0.02 mg L^{-1}, while the optimal range for brackish water aquaculture is 0-0.05 mg L^{-1} (Kusuma et al 2017).

H_2S is one of the toxic gases formed in brackish water aquaculture ecosystems due to the decomposition process of organic matter carried out by anaerobic microorganisms. H_2S can negatively affect the growth and health of living organisms in the water (Rojas-Tirado et al 2021). H_2S observed values were <0.001 mg L^{-1}, while the optimal level for brackish water aquaculture is <0.01 mg L^{-1} (Indonesian Ministry of Environment 2004).

The presence of heavy metals in a water body greatly affects the survival rate of aquatic organisms. In addition, the accumulation of heavy metals in aquatic organisms will affect the food safety, including brackish water aquaculture commodities such as shrimp and fish (Arisekar et al 2022). The Hg observed values were in the range of 0.0001-0.0004 mg L^{-1}. The optimal range of Hg for brackish water aquaculture is 0-0.019 mg L^{-1} (BSN 2009). Cd was in the range of 0.0013-0.0016 mg L^{-1}. The optimal range of Cd for brackish water aquaculture is 0-0.016 mg L^{-1} (BSN 2009). Pb was in the range of 0.0094-0.0102 mg L^{-1}. The optimal value of Pb for brackish water aquaculture is <0.1 mg L^{-1} (BSN 2009). In addition to heavy metals, the presence of *Vibrio* sp. should also be observed in

aquaculture development areas. *Vibrio* sp. are gram-negative bacteria commonly found in estuary, coastal, and marine environments (Brumfield et al 2021). Understanding the genus *Vibrio* sp. is essential, considering the risks posed to the human health and the potential environmental and economic damage, therefore *Vibrio* spp. abundance must be observed (Purgar et al 2023). *Vibrio* sp. was found to be positive, which represents a threat to aquaculture production. The presence of *Vibrio* sp. should be negative (Sarjito et al 2015). Soil pH condition is also an important factor that can significantly affect brackish water aquaculture. Soil pH levels play an important role in the success of brackish water aquaculture (Bansode et al 2020). Maintaining an appropriate pH level in the soil is essential for successful brackish water aquaculture. The optimum range of deep salinity for brackish water aquaculture is 6.5-8.5 (Ikbal et al 2019).

These infrastructure, water quality and soil conditions will determine the suitability of brackish water aquaculture development in West Halmahera District. The development of an area for aquaculture must be evaluated based on the land suitability conditions (Mustafa et al 2022). This factor determines the success of production activities. Based on the results of the analysis, the brackish water aquaculture development land in Jailolo Sub-District, West Halmahera District, North Maluku Province, Indonesia, with a total area of 329.27 ha, is categorized as moderately suitable (S2) (Figure 2).

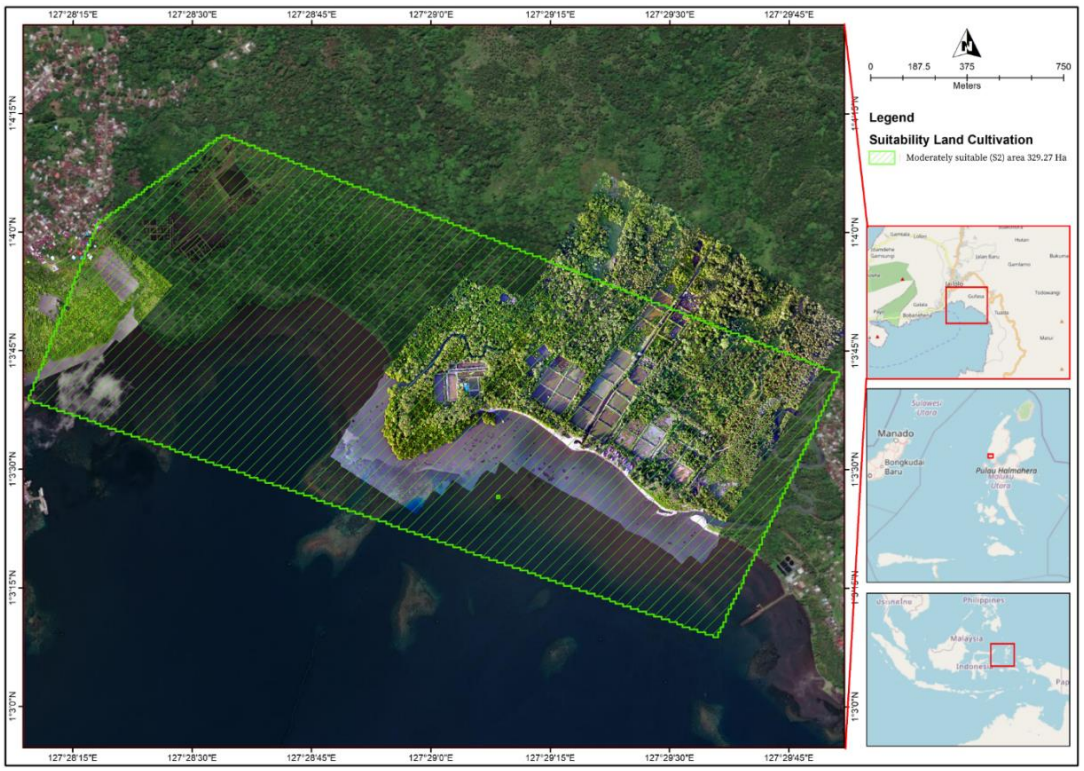

Figure 2. Land suitability map for brackishwater ponds in West Halmahera District, North Maluku Province.

Conclusions. A study on the suitability of brackishwater aquaculture based on infrastructure, water quality and soil parameters reveals that the coastal area of Jailolo Sub-District, West Halmahera District, North Maluku Province, Indonesia is moderately suitable (S2) for the development of brackishwater aquaculture, with a land area of 329.27 ha. This research can be an important reference for the development of brackishwater aquaculture in West Halmahera District, North Maluku Province, Indonesia.

Acknowledgements. The authors are grateful for the contribution of the North Maluku Provincial government and the West Halmahera District government in completing this research.

Conflict of interest. The authors declare no conflicts of interest.

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Received: 08 January 2024. Accepted: 15 February 2024. Published online: 28 February 2024.
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How to cite this article:
Tamrin T., Schaduw J. N. W., Sambali H., Wantasen A. S., Mantini D. M. H., Kepel R. C., Mingkid W. M., Kalesaran O. J., 2024 Land suitability analysis for brackishwater aquaculture development in the coastal area of District West Halmahera, Indonesia. AACL Bioflux 17(1):440-448.