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Research Article

Development of GIS-Based Pangasius Aquaculture Areas Using Analytical Hierarchy Process (AHP) in Tulungagung Regency, East Java, Indonesia

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Abstract

This study integrates Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) to assess the land suitability for pangasius aquaculture in Tulungagung Regency, East Java. The research, conducted from January to August 2022, evaluates water quality, soil characteristics, and infrastructure to identify suitable areas for sustainable aquaculture development. Using AHP, the study quantifies the relative importance of different parameters, and GIS is used to map the suitability categories. The findings reveal that 59% of the region's land is suitable or most suitable for aquaculture, with a total of 976,885.71 ha available for development. The study also identifies key challenges, such as the need to consider existing land uses (e.g., settlements, agriculture) in the planning process. By mapping the land suitability based on environmental and infrastructural factors, the research offers an innovative tool for policy makers and aquaculture practitioners to prioritize areas for expansion while ensuring the sustainability of the aquaculture industry. The study provides valuable insights for the future development of pangasius farming in Tulungagung and sets a precedent for similar applications in other regions.

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1. Introduction

Aquaculture has become the fastest-growing food production system, experiencing a 122% growth rate since 1990. Currently, over 50% of the fish consumed globally is sourced from aquaculture (FAO, 2021). The development of aquaculture brings numerous benefits, including providing healthy food, boosting economic growth, increasing income, creating jobs, and generating foreign exchange earnings through exports (Belton and Thilsted, 2014; Filipski and Belton, 2018; Brugere *et al*., 2021). However, if aquaculture development is not carefully managed, it can lead to negative impacts, such as alterations to mangrove ecosystems and agricultural land (Murray *et al*., 2018; de Lacerda *et al*., 2021).

Proper planning is essential for aquaculture expansion, as not all areas are suitable for its development. It is crucial to conduct studies that assess the suitability of potential aquaculture sites based on location, production capacity, and environmental factors. This helps minimize negative impacts and potential conflicts over land use (Jayanthi *et al*., 2020).

Land suitability analysis is a valuable tool for evaluating existing aquaculture land or identifying new areas with optimal environmental carrying capacity. One commonly used tool for this analysis is the Geographic Information System (GIS) (Izawa *et al*., 2019). GIS provides spatial data on land characteristics, including land use and land cover, allowing for a detailed description of aquaculture site potential (Wirosoedarmo *et al*., 2014; Saing *et al*., 2021). It can also be used to assess the carrying capacity of aquaculture areas based on factors such as water quality, soil quality, and infrastructure (Nayak *et al*., 2018; Riyanto *et al*., 2020). Previous studies have explored various parameters for determining land suitability, categorizing them into biophysical, economic, and accessibility factors (Puniwai *et al*., 2014). Other research has highlighted the importance of land cover in assessing suitability (Kaliraj *et al*., 2017). Commonly used parameters for assessing land carrying capacity include water quality, soil quality, and infrastructure (Nayak *et al*., 2018; Jayanthi *et al*., 2020; Ghobadi *et al*., 2021).

The weight of the parameter values determines the level of accuracy of the research results. Several methods of determining the weights include using a paired comparison scale or the Analytical Hierarchy Process (AHP) (Dedeoğlu and Dengiz, 2019; Jayanthi *et al*., 2020). Determination of weights using AHP can be done by the researchers themselves, but this has a high level of subjectivity. In the determination of weights in the AHP method, some researchers usually use references and expert opinions to avoid subjectivity (Nayak *et al*., 2018; Odu, 2019). The use of the AHP method in assessing the suitability of aquaculture has also been carried out by several researchers but has not been specifically carried out on certain commodities. It is necessary to test the use of the AHP method in determining land suitability for specific commodities, such as Pangasius aquaculture.

Pangasius, also known as dory, is a public favorite and is always present in dishes in restaurants and hotels. Pangasius is widely distributed in Bangladesh, Java, Myanmar, India, Vietnam, Thailand, and Pakistan (Khalid *et al*., 2022). In recent years, Tulungagung Regency has become known for its pangasius aquaculture industry and has a number of fish farms that specialize in pangasius aquaculture. The industry has provided employment opportunities for many people in the regency, particularly in rural areas. Currently, 60-70% of Pangasius production has met the export fish fillet standard (high grade), including white flesh without blood, no soil smell, and the same size (East Java Provincial Government, 2019). In 2019, Tulungagung Regency received market demand from exporting Pangasius fillets to Abu Dhabi and the United Arab Emirates (East Java Provincial Government, 2019). However, this export demand cannot be fulfilled continuously; the export market demand reaches 225,000 tons per year, and the consumption of pilgrims is 300,000-400,000 tons per year while the production of pangasius in 2019 is only 50 tons per day or 18,000 tons per year (Daniarto, 2019). The high demand for exports spurred the people and government of Tulungagung Regency to develop pangasius aquaculture areas. This will have a negative impact if carried out without a land suitability assessment. So, it is necessary to have a land suitability analysis to minimize land use conflicts and optimize the production of pangasius aquaculture. Several factors cause an aquaculture area to not be optimal, including no infrastructure, no zoning and regional spatial plan (*RTRW/Rencana Tata Ruang Wilayah*), biophysical damage to aquaculture areas, and low productivity supporting the aquaculture industry (Safitri *et al*., 2019).

This study introduces a novel approach by combining Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) to assess the land suitability for pangasius aquaculture in Tulungagung Regency, East Java. While both AHP and GIS have been widely used in land suitability analysis separately, their integration specifically for pangasius farming in a regional context like Tulungagung remains underexplored. This research fills the gap by applying these techniques together to

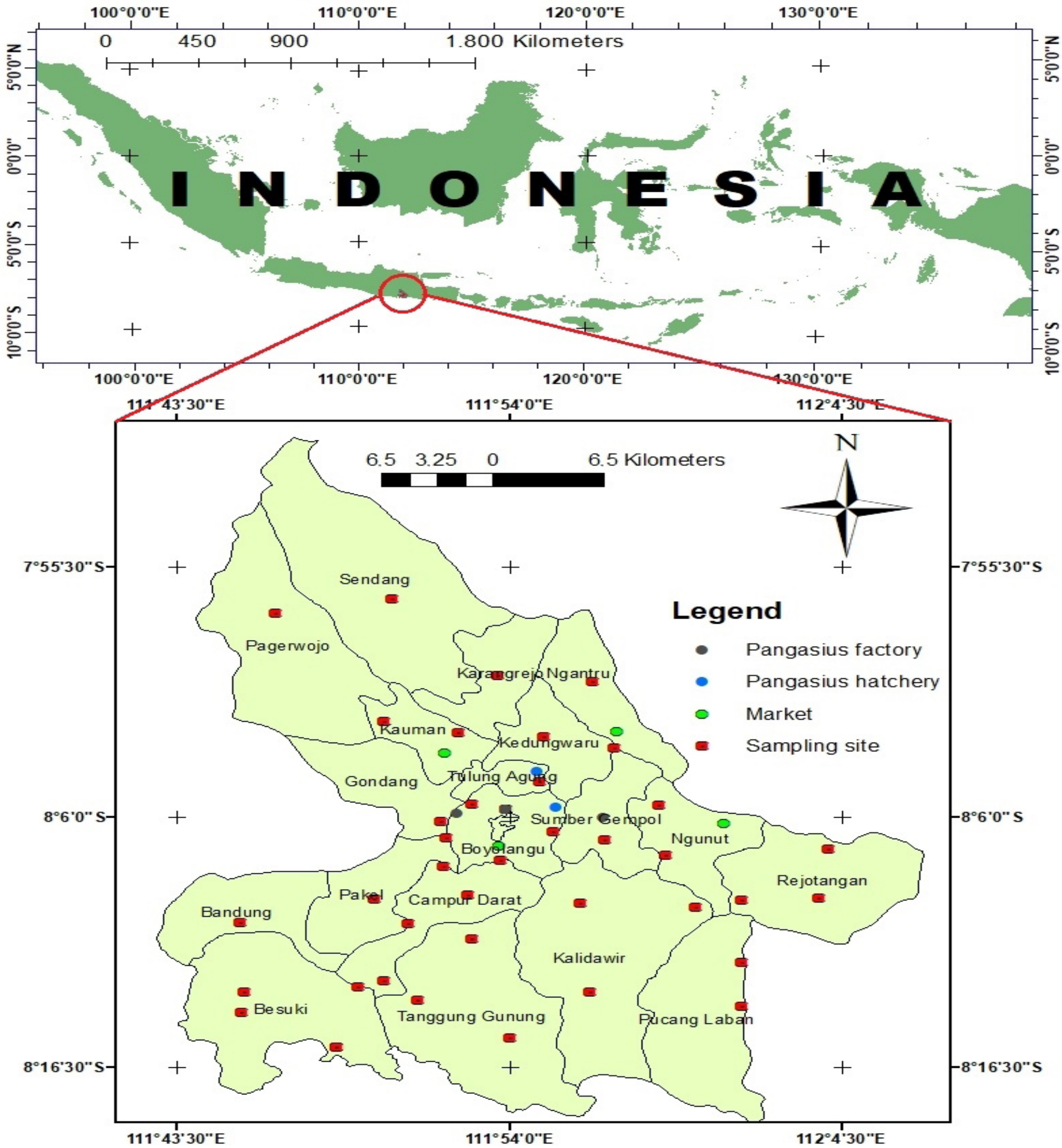

Figure 1. Study area. Tulungagung Regency consists of 19 districts and 271 villages. The research samples were taken at 39 sampling points spread throughout the districts in Tulungagung Regency.

evaluate aquaculture land suitability, offering a more comprehensive and localized method for site selection. Additionally, this study incorporates economic and infrastructure factors, such as proximity to roads, markets, hatcheries, and fillet factories, which are often overlooked in previous land suitability models focused primarily on biophysical parameters like soil and water quality. The incorporation of infrastructure considerations in aquaculture land suitability analysis is a significant gap in existing literature, particularly in developing regions where infrastructure plays a crucial role in the feasibility of aquaculture operations. Furthermore, this research explores the impact of natural resource diversity such as variations in water quality, soil fertility, and local biodiversity on site selection, a factor that has received limited attention in past studies. By considering these ecological and infrastructure variables alongside traditional biophysical factors, this study proposes a more holistic approach to identifying optimal aquaculture sites, thus contributing to more sustainable aquaculture development strategies.

2. Materials and Methods

2.1 Material

2.1.1 Study area

This research was conducted in Tulungagung Regency, East Java Province, Indonesia, with a geographical position of 111°43' - 112°07' E and 7°51' - 8°18' S (Figure 1). To the north, Tulungagung Regency is bordered by Kediri Regency, to the east by Blitar Regency, to the south by the Indian Ocean, and to the west by Trenggalek Regency. The research area is 115469.1 ha, consisting of land, mountainous areas, and coastal areas. Tulungagung Regency has various potential resources, such as food crops, plantations, and fisheries. Administratively, Tulungagung Regency is divided into 19 sub-districts, and 271 villages. It is also divided into three plains, namely high, medium, and low. The lowlands cover all villages except for some of the Pagerwojo sub-district (four villages) and part of the Sendang sub-district (four villages). The plains cover part of Pagerwojo District (six villages) and part of Sendang District (five villages). The highlands cover part of Pagerwojo District (one village) and part of Sendang District (two villages) (Central Bureau of Statistics, 2020).

Tulungagung Regency has aquaculture areas, especially freshwater fisheries. The area of aquaculture in Tulungagung Regency in 2014 was 299.56 ha and continued to increase until 2019, reaching 392.72 ha (Central Bureau of Statistics, 2020). Aquaculture production has also increased; in 2017, aquaculture production was 28395 tons (Ministry of Marine and Fisheries, 2017), and in 2019, aquaculture production reached 39073.78 tons (Central Bureau of Statistics, 2020). Tulungagung Regency has facilities to support pangasius aquaculture activities, such as the availability of seeds, feed, markets, and laboratories. The fish seeds used by Tulungagung fish farmers came from Bogor, with a size of 3/4 inch. The feed used is branded Japfa, CV Prima, Matahari Sakti, and Menara (local), harvesting with a time of seven to eight months. Tulungagung Regency has an experimental pangasius breeding laboratory which is a collaboration between the Fisheries Agency (DKP) of Tulungagung and the Fish Breeding Research Institute (BPPI) of Sukamandi and is located at the Tulungagung Office. BPPI Sukamandi provides superior pangasius *jambal* parent seeds. Superior pangasius *jambal* parent seeds can be bred with pangasius *siam* in Tulungagung and produce superior pangasius *Pasupati* seeds. This superior pangasius *Pasupati* can be raised in Tulungagung well. Therefore, there is no need to take superior seeds from Sukamandi anymore (Yulisti and Putri, 2013).

2.1.2 Sampling and data collection

Research data consists of water quality, soil quality, and infrastructure. Assessment of water and soil quality is carried out by taking water samples from water sources, and soil samples are taken at the observation point. Observation points were carried out at 39 points spread throughout the Tulungagung Regency area with a purposive sampling method. Water samples were taken in January, April, and August, where the pangasius aquaculture period started in January and ended in August. Several water quality parameters were measured, including DO, temperature, TDS, ammonia, and nitrate. Each tool and material used follows the Standard Operating Procedure (SOP) of SNI 8037.1:2014. DO and the temperature were measured using a dissolved oxygen meter (AZ 8402). TDS was measured using a TDS and EC meter (hold), and the pH of the water was measured using a pH meter (ATC). Ammonia and nitrate were measured using the API Freshwater Master Test Kit. Soil quality parameters consist of the slope, soil pH, and soil texture. The slope was measured using Google Earth 7.3 software, soil pH was measured using a soil pH meter (VT-05), and soil texture was measured using a measuring cylinder. The infrastructure parameters consist of the distance to the road, the distance to the market, the distance to the hatchery, and the distance to the pangasius factory. Distance measurements on infrastructure parameters were carried out using ArcGIS 10.3 software and the coordinates of the location points of each infrastructure parameter were taken using Garmin GPSMAP 65s.

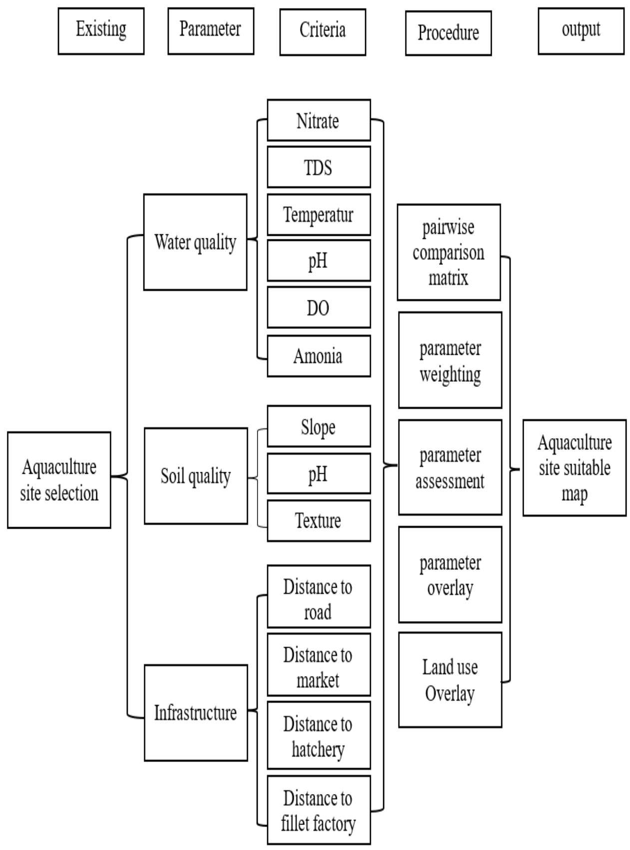

Figure 2. Schematic diagram of determining procedure for development of pangasius aquaculture area

2.1.3 Land cover and land use

Land cover and land use are two things that are interrelated in regional development planning. Land cover can be interpreted as the appearance of physical material on the earth's surface (Sampurno and Thoriq, 2016), and land use is a regulation on land use where human resources and natural resources are needed (Susanti *et al*., 2017). Land-used data was obtained through the official website of One Data Indonesia in 2022 with a spatial resolution of 5 meters (https://tanahair.indonesia.go.id/portal-web/). There are many interests in land use in Tulungagung Regency, so not all areas can be used for aquaculture area development. So, in addition to paying attention to the level of land suitability, it is also necessary to pay attention to the use of the land. Land that can be used in the development of pangasius aquaculture areas is unused or unutilized land, such as shrubs or vacant land. The procedure followed in modeling the land suitability for fisheries development is presented in Figure 2.

2.2 Method

2.2.1 Land suitability class

The determination of the land suitability class began with compiling a suitability matrix containing the parameters that were the conditions for the growth and development of pangasius that were farmed in terms of the quality of the soil, water sources, and the environment. Then determine the value limits for each parameter that meet the requirements of pangasius culture. The weighting of each parameter was determined based on the dominance of these factors in an allotment of the feasibility of pangasius aquaculture land. Each parameter, weighting, and class score are determined based on a literature study and justification from competent experts in the field of pangasius aquaculture through questionnaires. Parameters that can have a stronger influence were given a higher weight than those with a weaker influence. To determine class intervals and land suitability values, the following equation can be used (Noor, 2015):

$$I_{ks} \frac{\sum N\,max - \sum N\,min}{\sum k}$$

Where:

I_{ks} = Class interval

k = Number of land suitability classes

N max = Maximum final score

N min = Minimum final grade

2.2.2 Identification of land suitability criteria assessment

Water quality is important to pay attention to in pangasius aquaculture (Minggawati and Saptono, 2012). Poor water can make fish susceptible to disease. In the management of aquaculture, it is the main factor in determining the good or bad of aquaculture. Various kinds of research related to aquaculture have never escaped the observation of water quality. Generally, there are several important variables related to water quality, including temperature, pH, DO, ammonia, nitrite, and TDS (Abedin *et al*., 2017), (Sanou *et al*., 2022).

The temperature of a water body is influenced by the seasons, latitude, altitude above sea level (altitude), time of day, air circulation, cloud cover, and the flow and depth of water bodies. Temperature changes affect the physical, chemical, and biological processes of water bodies. Temperature also plays a very important role in controlling the condition of aquatic ecosystems. Aquatic organisms have a certain temperature range (upper and lower limits) that is preferred for their growth (Effendi and Wardiatno, 2015). The metabolic rate of fish is closely related to the temperature of the water. The higher the water temperature, the greater the metabolic rate. In natural habitats, fish can easily tolerate seasonal changes in temperature, decreasing in winter to 0°C and increasing in summer to 20-30°C. Temperature varies with season, time of day, water depth, and meteorological conditions. Temperature is also related to other factors, especially the dissolved oxygen content. There is an inverse relationship between dissolved oxygen and water temperature; it is also closely related to air temperature. In aquaculture ponds, the water temperature at the bottom of the pond will be lower than the temperature at the pond surface (Abedin *et al*., 2017).

pH is the concentration of hydrogen ions (H+) present in culture water as a measure of acidity or alkalinity. The pH scale extends from 0 to 14, with 0 being the most acidic and 14 being the most basic. pH 7 is a state of neutrality and normally occurs in the range of 7.0 to 9.0 (optimal 7.5 to 8.5). At higher temperatures, fish are more sensitive to changes in pH. Changes in pH in water are mainly affected by carbon dioxide and the ions in equilibrium with it. Carbon dioxide is acidic and lowers the pH of the water (Abedin *et al*., 2017).

Dissolved oxygen in water comes from air diffusion and the results of the photosynthesis of chlorophyll organisms that live in water, which is needed by organisms to oxidize nutrients that enter their bodies (Simanjuntak, 2007). Dissolved oxygen (DO) is needed by all living organisms for respiration, metabolic processes, or the exchange of substances that then produce energy for growth and reproduction. In addition, oxygen is also needed for the oxidation of organic and inorganic materials in aerobic processes. The main source of oxygen in waters comes from a diffusion process from free air and the results of the photosynthesis of organisms that live in these waters (Salmin, 2005). Several things that affect water oxygen include photosynthesis, phytoplankton, plant respiration, fish respiration, sediment oxygen consumption, and diffusion (Jescovitch and Boyd, 2017). The need for oxygen for organisms to live in water should not be below 3 mg/l (Boyd *et al*., 2018).

Ammonia is the second-most important water quality parameter for aquaculture after dissolved oxygen (DO) and has a significant effect on aquaculture production. High ammonia levels can occur due to overfeeding. The protein-rich feed can eventually decompose to release toxic ammonia gas. This ammonia, along with fish waste, can accumulate to very dangerous levels under certain conditions. In water, ammonia is present in molecular and ionic forms. The ratio between these two forms depends on the pH and temperature of the water. It is mainly found as an ammonium ion and is formed through bacterial protein breakdown, bacterial de-nitrification, and N2 fixation by certain bacterial molds and blue-green algae (Abedin *et al*., 2017). Good waters for pangasius

Table 1. Land suitability parameter metrics. The land suitability parameter consists of 3 parameters, i.e., water, soil, and infrastructure quality which are classified as most suitable, suitable, moderately suitable, and not suitable.

No	Parameters	Suitable classes				Reference
		Most suitable	Suitable	Moderately suitable	Not suitable	
	-Water Quality					
1	Temperature (°C)	28 – 30.9	25-27.9 or 31-33.9	22-24.9 or 34-36	< 22 and > 36	Abedin *et al.* (2017)
2	pH	7-8.5	6 - 7	5.5-<6 or 8.6-10	<5.5 and >10	Ghobadi *et al.* (2021)
3	DO (mg/l)	>5	4-5	3.5-4	<3.5	Boyd *et al.* (2018)
4	Ammonia (mg/l)	<0.3	0.3 -0.7	0.7-1	>1	Abedin *et al.* (2017)
5	Nitrate (mg/l)	<1	1-1.49	1.5-2	>2	Ghobadi *et al.* (2021)
6	TDS (mg/l)	90-150	>60. <90 and >150. <200	30-60 and 200-300	<30 and >300	Ghobadi *et al.* (2021)
	-Soil Quality					
7	Texture (% clay)	>35	25-35	18-24.9	<18	Ghobadi *et al.* (2021)
8	pH	7.1-8.5	6.5-7	5.5-6.4 or 8.6-9	<6.5 and >9	Hong *et al.* (2018)
9	Slope (%)	<15	15-19.9	20-25	25<	Putra and Apriani *et al.* (2018)
	- Infrastructure					
10	Distance to the road (m)	<500	500-1000	1000-2000	>2000	Hadipour *et al.* (2015)
11	Distance to market (km)	<3	3-7	7.1-12	12<	Hadipour *et al.* (2015)
12	Distance to the hatchery (km)	<3	3-7	7.1-12	12<	Hadipour *et al.* (2015)
13	Distance to fillet factory (km)	<3	3-7	7.1-12	12<	Hadipour *et al.* (2015)

aquaculture are those that contain ammonia less than 0.1 ppm or 0.1 mg/l. While a concentration of ammonia of greater than 0.1 can cause the death of pangasius. However, for the conditions of life, pangasius is more tolerant of ammonia when compared to other types of cultured fish (Abedin *et al*., 2017).

Nitrate is a macronutrient that controls primary productivity in the euphotic zone of water. The main source of nitrate can be household and agricultural waste, including waste from animals and humans. The best nitrate value for aquaculture is less than 0.2 ppm (Jayanthi *et al*., 2020), and the worst value is more than 2 ppm (Abedin *et al*., 2017).

Dissolved solids, or total dissolved solids (TDS), are solids that have a smaller size than suspended solids. Dissolved materials in natural waters are not toxic, but if the amount is excessive, this can increase the value of turbidity, which will inhibit the entry of sunlight into the water body and, of course, affect the process of photosynthesis in the waters (Kustiyaningsih and Irawanto, 2020). The best-cultured TDS value for aquaculture is 90 to 150 mg/l, and the worst is in the range of less than 30 mg/l or more than 300 mg/l (Ghobadi *et al*., 2021).

Soil quality is an indicator used to assess the good or bad condition of the soil. Some soil qualities that can be used as indicators of whether or not the soil is good for aquaculture include soil texture, pH, and organic matter (Nayak *et al*., 2018). Another important parameter to be taken into account as an indicator is the slope of the soil. Soil slopes are grouped into three categories: flat (slope less than15%), gentle (slope 15 to 25%), and steep (slope more than 25%). (Putra and Apriani, 2018).

Texture is one of the most important and frequently measured parameters in soil science. It is common knowledge among experienced soil scientists in the field that soil texture can be well estimated in the field manually through the sense of taste. However, there is no systematic evaluation assessing the precision and accuracy of field-based soil texture compared to laboratory tests (Vos *et al*., 2016). Soil texture consists of grains that differ in size and shape, so special terms are needed that provide clues about their physical properties. For this, class names such as sand, dust, clay, and clay are used (Mutiara and Rusli, 2019).

The pH of the soil is determined by the nature of the acidity and alkalinity of the soil, also known as the soil reaction. Lawrence and Hemingway (2003), classified soil acidity into three groups, namely: a) soil pH below 4.5 (soil is very acidic), b) soil pH between 6.6-7.3 (soil is neutral), c) soil pH between 7.9-8.4 (soil is slightly alkaline). Good soil for aquaculture has a pH of about 6.5-8.5. Soil pH regulates soil biogeochemical processes and has a tiered effect on the structure and function of terrestrial ecosystems (Huang *et al*., 2018).

In addition to water and soil quality parameters, infrastructure parameters also play a very large role in supporting the success of aquaculture. Poor infrastructure will hamper the aquaculture production process. In determining the suitability of aquaculture land based on infrastructure parameters, several things are assessed, including roads, markets, hatcheries, and fillet factories (Hadipour *et al*., 2015). The closer to the infrastructure, the easier it will be for the production process of pangasius aquaculture (Jayanthi *et al*., 2020). In determining the level of land suitability, researchers usually determine the distance between the aquaculture location and the available infrastructure facilities (Ghobadi *et al*., 2021). Based on the existing references, a metric is made that is used to assess the level of land suitability of a research parameter (Table 1).

2.3 Analysis Data

The Analytical Hierarchy Process (AHP) is the most widely used method for determining weights. Several studies using AHP have been conducted by Hossain *et al.* (2009), Hossain and Das (2010), and Rahman *et al.* (2019). It is very important to determine the weight of each parameter. Inaccuracy in determining parameter weights will result in inaccurate land suitability analysis results as well. The determination of the weight begins with determining the respondents. Respondents selected in this study were among experts in pangasius aquaculture, totaling three people. According to Saaty (1993), the determination of respondents is based on quality, not quantity, with a minimum number of two respondents. Bouzon *et al.* (2016) used 16 respondents for each expert in their research using AHP. Respondents must have the same scientific background to avoid inconsistencies. The responders in this study were pangasius aquaculture professionals with over 5 years of research experience.

In filling out the questionnaire, respondents were asked to choose the position on the scale that best represented their interests and preferences from the nine

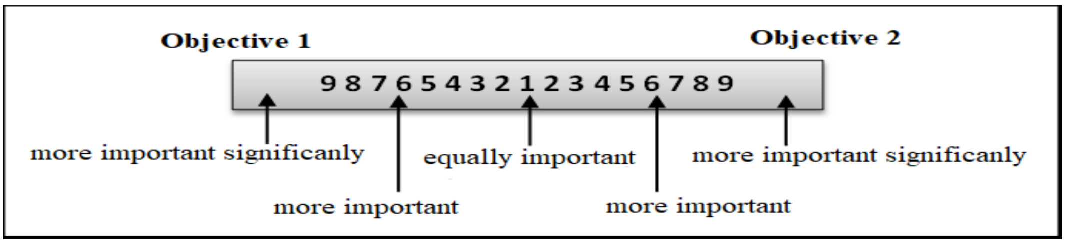

Figure 3. Example of a 9-point pairwise comparison scale. The scale starts from an equally important scale with a value of 1 to significantly more important with a value of 9.

available scales (Figure 3). The scale starts from an equally important scale with a value of 1 to a significantly more important scale with a value of 9 (Morgan, 2017). A metric comparison of each parameter in this study has been made; the comparison includes parameters of water quality, soil quality, and infrastructure. Normalization is obtained by dividing the grid value by the sum of each metric column. The weight was obtained by taking the average of the number of normalized values. The grid value of each parameter is multiplied by its weight value, calculated by pairwise metric comparisons, and assessed to produce a grid result=∑ (gridi x weighti). Pairwise comparison metrics of pangasius aquaculture parameters have been made (Table 2, Table 3, Table 4, and Table 5). The eigenvalues (λmax), and consistency index (CI) were calculated based on previous studies (Sambah and Miura, 2014), (Hadipour *et al.*, 2015), (Dedeoğlu and Dengiz, 2019), and (Jayanthi *et al.*, 2020), as seen below:

$$\lambda_{max} = \sum \text{(average weight by row X column total of the same criteria)}$$

$$CI = (\lambda_{max} - n) / (n-1)$$

The consistency ratio (CR) value was obtained based on the division between the consistency index (CI) and index random consistency (IR) values (CR=CI/IR). The CR value should be no more than 0.10, which means that the comparisons made are consistent with each parameter. The next step is to calculate the land suitability grid value, the value of which is derived from the calculation of the water, soil, and infrastructure quality parameter grids.

Water quality parameters consist of DO, temperature, TDS, pH, ammonia, and nitrate. These parameters are considered to affect the survival and growth of pangasius. The weight values of these parameters are sequentially starting from temperature (0.44), pH (0.20), ammonia (0.12), DO (0.09), and nitrate (0.07). The weight and criteria of water quality parameters (equation 1) showed a good CR value of 0.08 (Table 2).

$$Grid_{water} = Grid_{temperature} \times 0.44 + Grid_{pH} \times 0.20 + Grid_{ammonia} \times 0.12 + Grid_{DO} \times 0.09 + Grid_{nitrate} \times 0.08 \quad (1)$$

Soil quality parameters consist of soil texture, soil pH, and soil slope. These parameters are considered very influential in pangasius aquaculture. Sequentially, the weight values of soil quality parameters are slope (0.72), pH (0.19), and soil texture (0.08). The weight and soil quality criteria (equation 2) obtained the CR value of the soil quality parameter, which is still in good condition, namely 0.10 (Table 3).

$$Grid_{soil} = Grid_{slope} \times 0.72 + Grid_{pH} \times 0.19 + Grid_{texture} \times 0.08 \quad (2)$$

The infrastructure parameters consist of the distance to the road, the distance to the market, the distance to the hatchery, and the distance to the pangasius fillet factory. These parameters support the implementation of pangasius aquaculture. Sequentially, the value of infrastructure weights starts with the distance to the road (0.58), the distance to the market (0.28), the distance to the pangasius fillet factory (0.08), and the distance to the hatchery (0.07). The weights and infrastructure parameters (equation 3) obtained a good CR value of 0.06 (Table 4).

$$Grid_{infrastructure} = \text{Grid distance to road} \times 0.58 + \text{Grid distance to market} \times 0.28 + \text{Grid distance to Factory} \times 0.08 + \text{Grid distance to hatchery} \times 0.07 \quad (3)$$

The determination of land suitability for pangasius aquaculture was carried out based on water, soil, and infrastructure quality parameters. These parameters are generally used in land suitability assessments. Water and soil quality parameters have the same value (0.45) or are equally important, while infrastructure has the smallest weight value (0.09). The weight and land suitability parameters (equation 4) obtained a very good CR value, namely 0 (Table 5).

$$Grid_{suitability} = Grid_{Water} \times 0.45 + Grid_{soil}\ 0.45 + Grid_{infrastructure} \times 0.09 \quad (4)$$

Table 2. Pairwise comparison matrix for water quality. Comparison values were calculated as normalized values to determine weight values (Wt), eigenvalues (λmax), consistency index (CI), random consistency index (IR), and Consistency Ratio (CR)

Criteria	Parameter						Normalization						Wt	λ_{max}	CI	IR	CR
Water	DO	TM	TDS	pH	AM	NT	DO	TM	TDS	pH	AM	NT					
D0	1	1/5	1	1/3	1/3	3	0.08	0.09	0.08	0.06	0.04	0.19	0.09	6.50	0.100	1.24	0.08
TM	5	1	5	3	5	5	0.38	0.47	0.42	0.51	0.54	0.31	0.44				
TDS	1	1/5	1	1/3	1	1	0.08	0.09	0.08	0.06	0.11	0.06	0.08				
pH	3	1/3	3	1	1	5	0.23	0.16	0.25	0.17	0.11	0.31	0.20				
AMN	3	1/5	1	1	1	1	0.23	0.09	0.08	0.17	0.11	0.06	0.12				
NTT	1/3	1/5	1	1/5	1	1	0.03	0.09	0.08	0.03	0.11	0.06	0.07				

DO-Dissolved oxygen; TM-Temperature; TDS- Total Dissolved Solids; AM-Ammonia; NT-Nitrate; Wt-Weight

Table 3. Pairwise comparison matrix for soil quality. Comparison values were calculated as normalized values to determine weight values (Wt), eigenvalues (λmax), consistency index (CI), random consistency index (IR), and Consistency Ratio (CR).

Criteria	Parameter			Normalization			weight	λ_{max}	CI	IR	CR
Soil	Texture	pH	Slope	Texture	pH	Slope					
Texture	1	1/3	1/7	0.09	0.05	0.11	0.08	3.11	0.056	0.58	0.10
pH	3	1	1/5	0.27	0.16	0.15	0.19				
Slope	7	5	1	0.64	0.79	0.74	0.72				

Table 4. Pairwise comparison matrix for infrastructure. Comparison values were calculated as normalized values to determine weight values (Wt), eigenvalues (λmax), consistency index (CI), random consistency index (IR), and Consistency Ratio (CR).

Criteria	Parameter				Normalization				weight	λ_{max}	CI	IR	CR
Infrastructure	DRD	DMR	DHC	DFC	DRD	DMR	DHC	DFC					
DRD	1	3	7	7	0.62	0.67	0.44	0.58	0.58	4.17	0.058	0.90	0.06
DMR	1/3	1	7	3	0.21	0.22	0.44	0.25	0.28				
DHC	1/7	1/7	1	1	0.09	0.03	0.06	0.08	0.07				
DFC	1/7	1/3	1	1	0.09	0.07	0.06	0.08	0.08				

DRD-Distance to road: DMR-Distance to market; DHC-Distance to hatchery; DFC-Distance to Factory

3. Results and Discussion

3.1 Results

3.1.1 Water quality assessment

Water quality parameters are one of the references in assessing the suitability of Pangasius aquaculture land. The water quality parameter has an important role in determining the success of pangasius aquaculture. The results of the assessment of all parameters consisting of water quality, soil, and infrastructure are presented in Table 6. The distribution of the area and percentage of land suitability ranging from the most suitable to suitable to moderately suitable (Table 7). The results of the spatial water quality assessment consisting of DO, temperature, pH, ammonia, nitrite and TDS can be seen in Figure

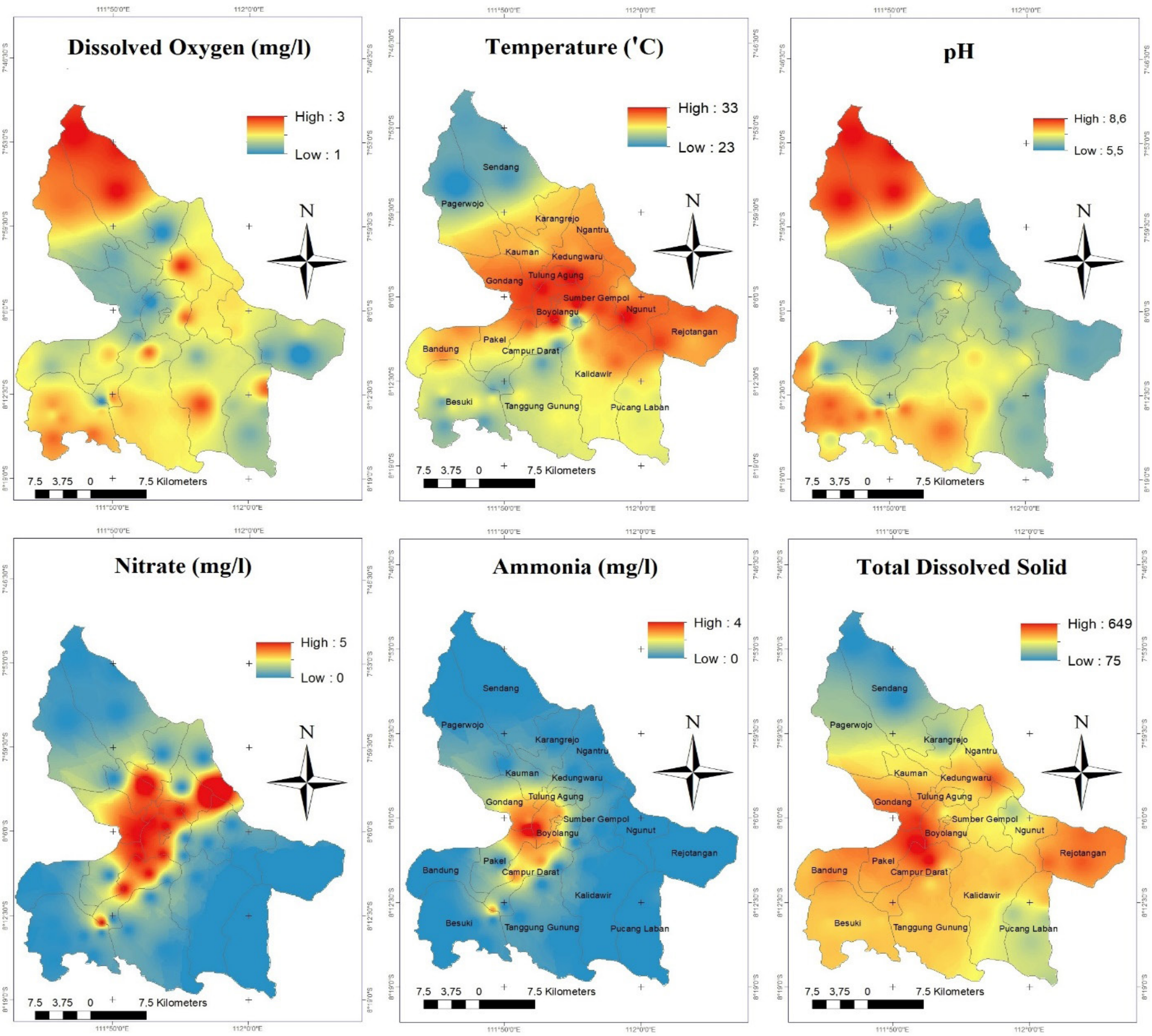

Figure 4. Distribution of water quality parameters values. The value of each water quality parameter was displayed from the lowest to the highest.

4. Each quality parameter of water has various values and distributions. DO shows that 100% of research water sources are included in the unsuitable category. The low DO value is because the sample is taken from well water with a depth of 3-15 m, which is used as a source of aquaculture. The condition of the narrow and dark surface of the well causes very limited oxygen from the atmosphere and the photosynthesis process (Trisnawulan *et al*., 2007). The temperature has a dominant distribution of 44.15, and 44.11% is the most suitable and appropriate; the remaining 11.17% is quite suitable. Similar to temperature, the pH value is also dominated by very suitable and suitable values of 36.8 and 50.78%, while the remaining 12.41% is quite suitable. Most of the TDS values of 71.89% are the most suitable, and the remaining 15.4, 6.51, and 6.21% are appropriate, quite suitable, and not suitable. Likewise, with ammonia, most of the values obtained 74.05% are the most suitable, and the remaining 13.62, 3.1, and 9.23% are suitable, quite suitable, and not suitable. Most of the nitrate values of 81.87 were the most suitable, and the remaining 4.59, 4.42, and 9.12% were suitable, quite suitable, and not suitable. The results of overlaying all water quality parameters obtained three land suitability classes, namely the most suitable, suitable, and quite suitable. Most of the research areas have a water quality class that corresponds to the percentage reaching 60%. The rest are the most suitable at 8% and moderately suitable at 32% (Figure 5).

3.1.2 Soil quality assessment

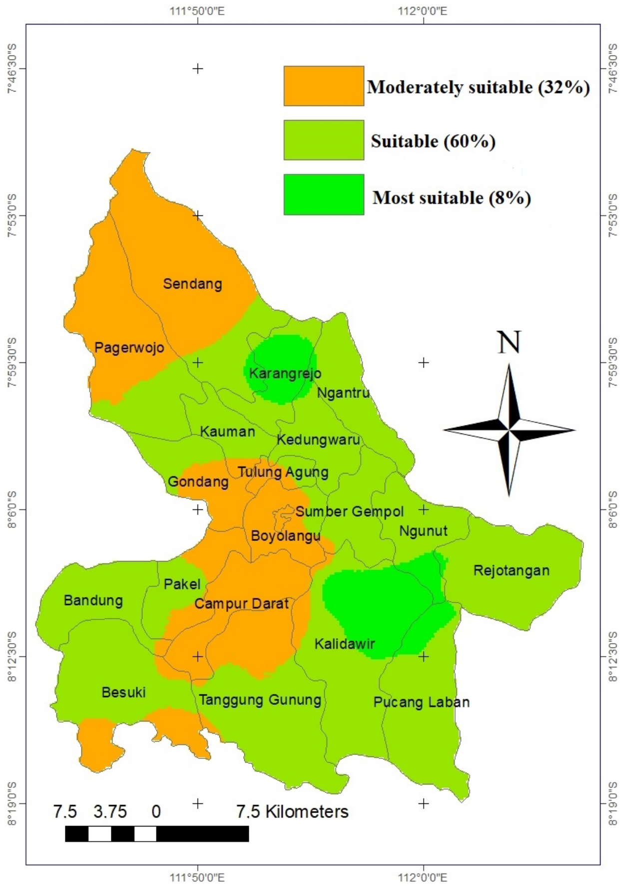

Figure 5. Land suitability level of water quality parameters. There were three land suitability classes for water quality parameters, i.e., most suitable, suitable, and moderately suitable.

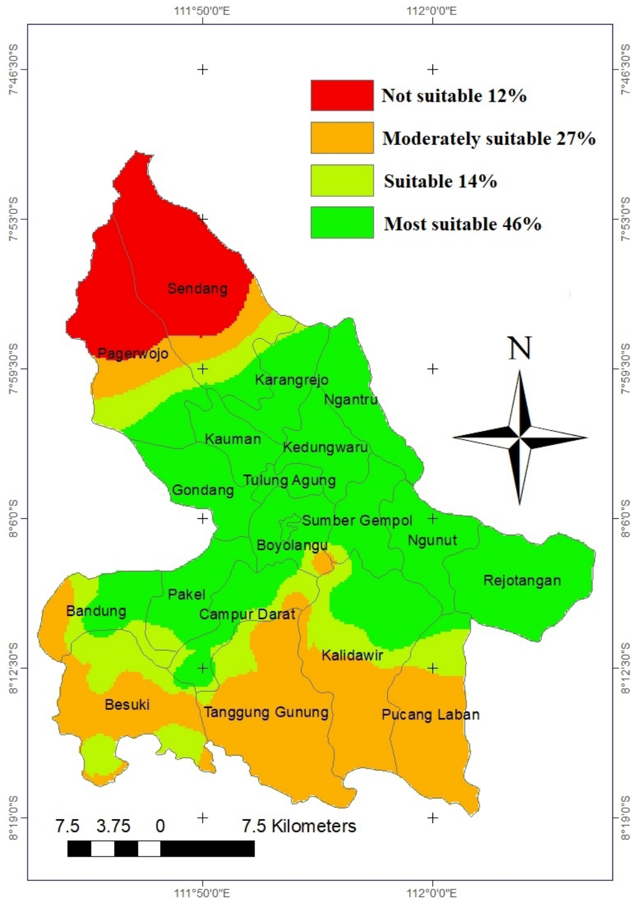

Figure 7. Land suitability level of soil quality parameters. There were four land suitability classes for water quality parameters, i.e., most suitable, suitable, moderately suitable, and not suitable.

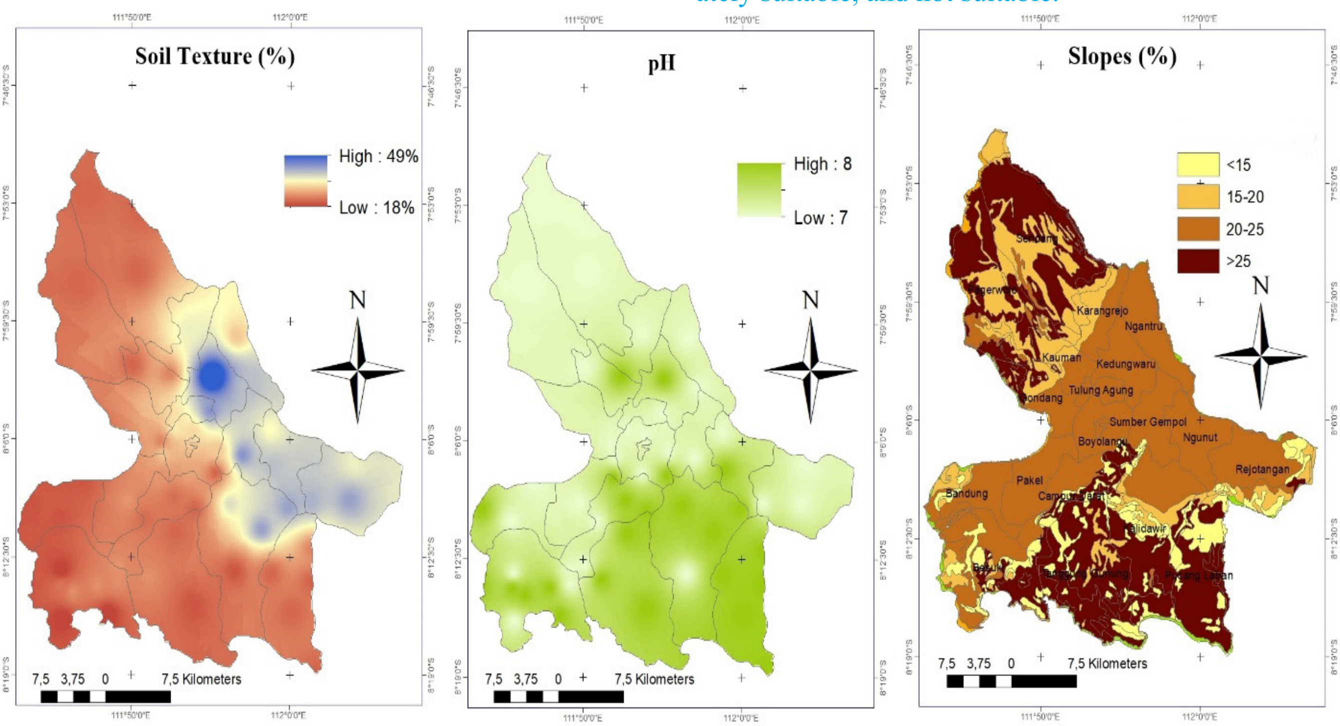

Figure 6. Distribution of soil quality parameter values. The value of each soil quality parameter was displayed from the lowest to the highest.

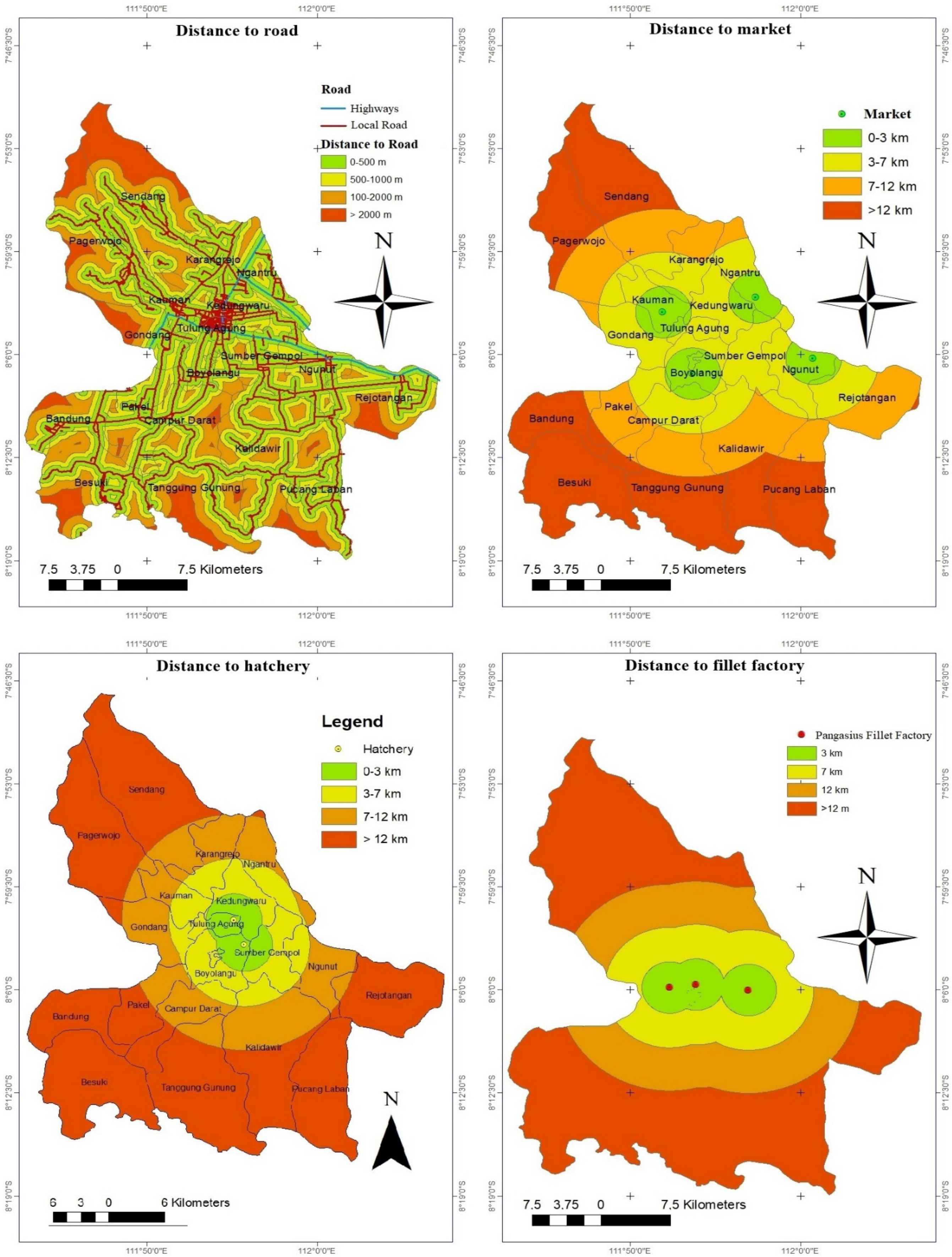

Figure 8. Distribution of Infrastructure parameter values. The value of each infrastructure parameter was displayed from the lowest to the highest.

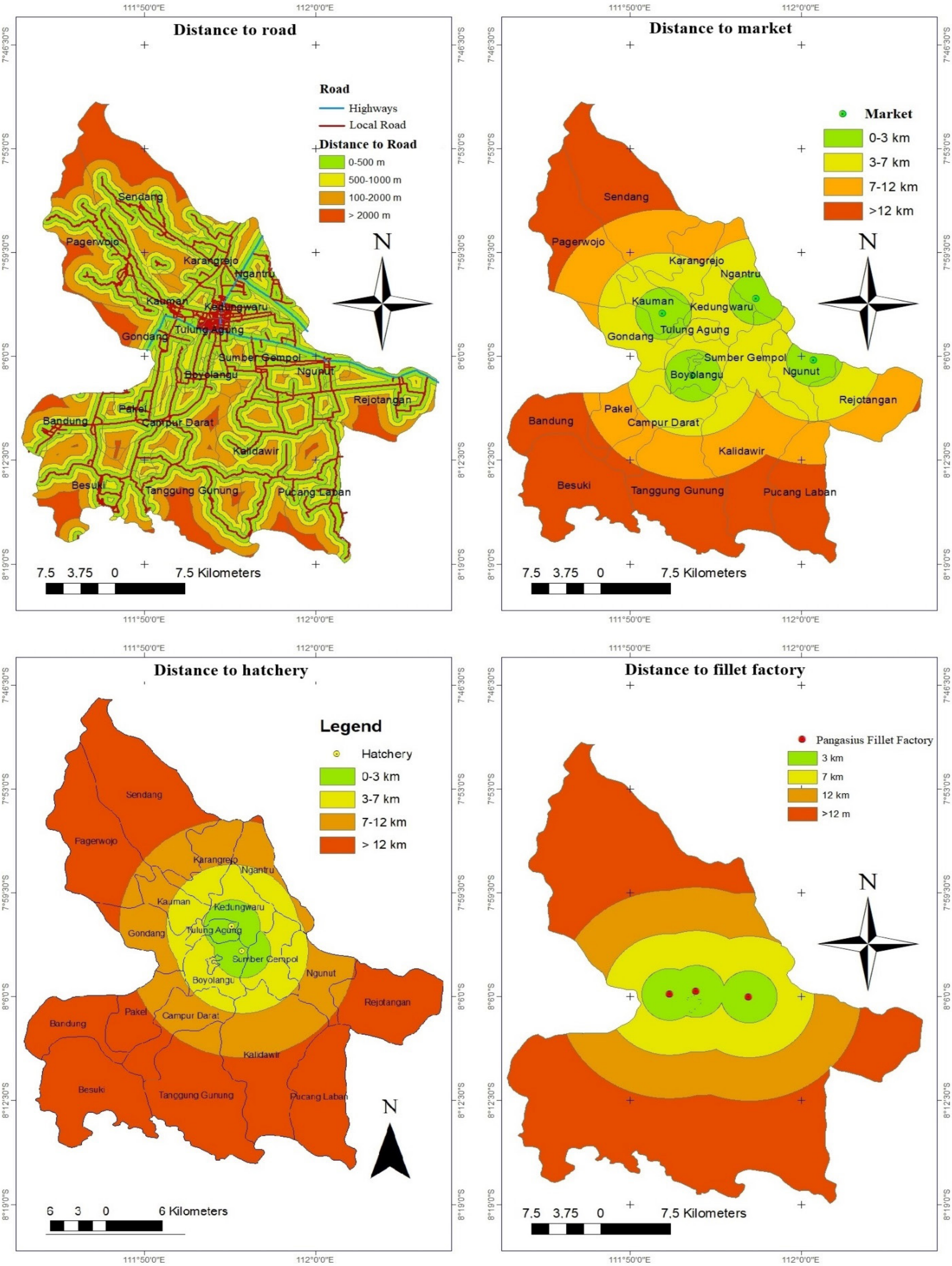

Figure 9. Land suitability level of infrastructure parameters. There were three land suitability classes for water quality parameters, i.e., most suitable, suitable, and moderately suitable.

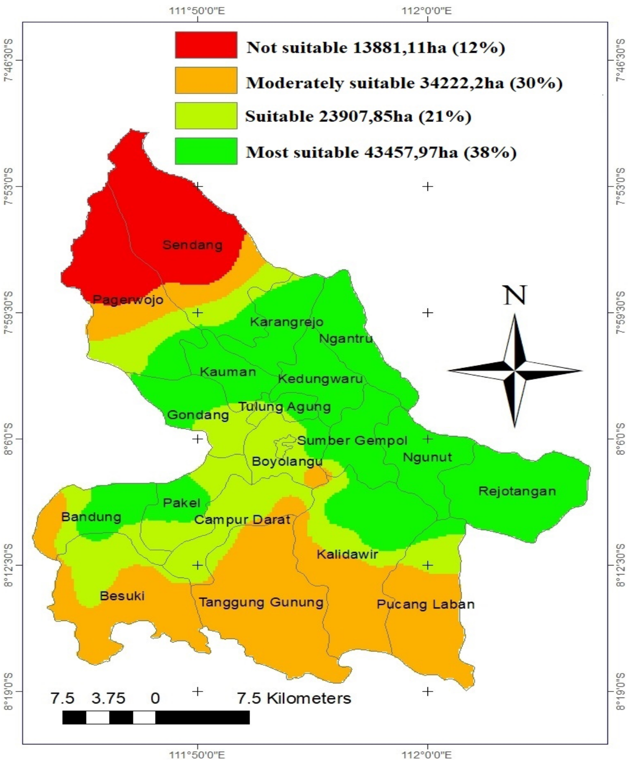

Figure 10. Level of the suitability of pangasius aquacultureland. There were four land suitability classes for pangasius aquacultureland, i.e., most suitable, suitable, moderately suitable, and not suitable.

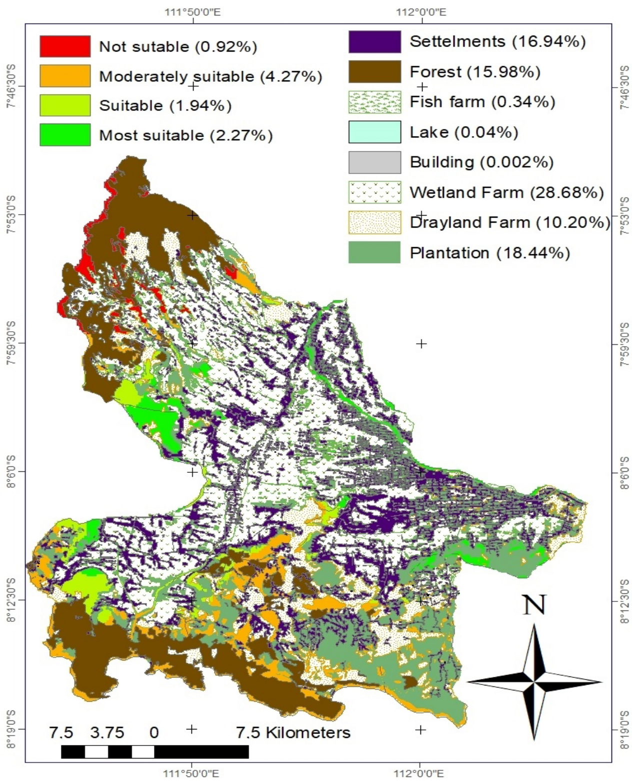

Figure 11. Land use of Tulungagung Regency. Land use in Tulungagung Regency consists of shrubs, meadow, settlements, lake, wetland farm, dryland farm, plantation, forest, fish farm, and building.

The results of the assessment of soil quality, such as slope, soil texture, and soil pH, are depicted spatially (Figure 6). The slope has a percentage of 50.17% most suitable, 13.4% suitable, 22.38% quite suitable, and 14.06% not suitable. Overall, pH is 100% in the most suitable category. Soil texture is dominated by 62.91%, which is most suitable, and only a small part (0.02%) is not suitable; the remaining 13.4 and 22.38% are suitable and quite suitable. The results of the overall overlay of soil quality parameters obtained four land suitability classes, including not suitable, quite suitable, and very suitable, the unsuitable class has the smallest percentage with only 12% of the total research area, this class is geographically located in mountainous areas. For the class with the highest percentage, the most appropriate category is 46% (Figure 7).

3.1.3 Infrastructure assessment

Infrastructure was assessed based on the distance to the aquaculture site. The assessment includes the distance to the road, the distance to the market, the distance to the hatchery, and the distance to the pangasius fillet factory. The distance to the road has various values; most of them, 43.85%, are most suitable, and the rest, 24.1, 21.09, and 10.96%, are

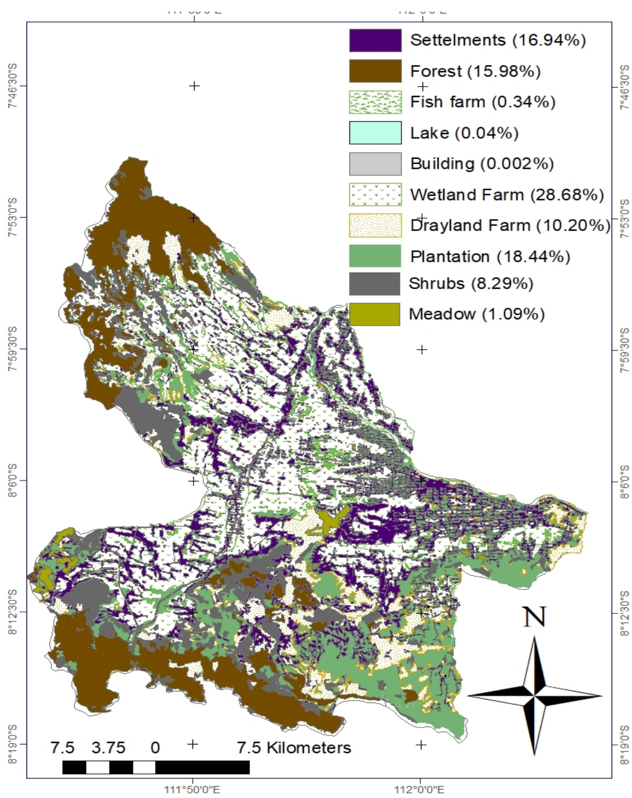

Figure 12. Pangasius aquaculture potential. The land potential for the development of pangasius aquaculture is 8.84% consisting of most suitable, suitable, and moderately suitable.

appropriate, quite appropriate, and not appropriate, respectively. The distance to the market was found to be 8.65, 25.78, 25.63, and 39.94%, indicating the most suitable, suitable, moderately suitable, and not suitable, respectively. The distance to the hatchery was mostly dominated by 61.14% not suitable, with the remaining 3.94, 12.99, and 21.93%, being the most suitable, suitable, and moderately suitable, respectively. The distance to the fillet factory is also dominated by 54.81% not suitable, with the remaining 6.3, 15.38, and 23.52%, being most suitable, suitable, and quite suitable, respectively (Figure 8). The results of the infrastructure parameter overlay are obtained from the distribution of infrastructure suitability. The distribution of the greatest infrastructure suitability is in the adequate category, with a percentageof 42%. The next category is based on the percentage of 38% and the most appropriate 20% (Figure 9).

3.1.4 Land suitability assessment

Land suitability was determined based on the results of the assessment of water, soil, and infrastructure quality parameters. These parameters are then overlaid to obtain an overview of the suitability of the pangasius aquaculture land spatially. The results of the overlay show that most of the Tulungagung Regency areas are in the most suitable, suitable, and moderately suitable category according to the area of 43,457.97, 23907.8, and 34,222.2 ha with percentages of 38, 21, and 30%, respectively. Meanwhile, only a small part of the area in the not suitable category is 13,881.11 ha or 12%. Based on these results, Tulungagung Regency has a total area of 101,588.02 ha, or 88% moderately suitable, suitable, and most suitable (Figure 10). This total area can be used as a basis for reference in developing aquaculture areas in Tulungagung Regency.

3.1.5 Land use and potential for developing aquaculture areas

In planning the development of aquaculture areas, it is crucial not only to assess the land suitability levels but also to consider the existing land uses, such as agriculture, residential zones, and forests, to prevent conflicts with aquaculture activities. The land use types in Tulungagung Regency include settlements (16.94%), lakes (0.04%), wetland farms (28.68%), dryland farms (10.20%), plantations (18.43%), forests (15.98%), fish farms (0.34%), and buildings (0.002%). Each land use type serves a specific function, which limits the areas available for aquaculture development. Areas such as shrubs and meadows are identified as suitable for aquaculture, covering a total area of 10,835.13 ha (9.38%) (Figure 11). These areas are then overlaid with the land suitability map, which categorizes the land as most suitable (2,619.35 ha, 2.27%), suitable (2,235.74 ha, 1.94%), moderately suitable (4,913.77 ha, 4.26%), and unsuitable (1,066.27 ha, 0.92%) (Figure 12). The total area available for aquaculture development is therefore 976,885.71 ha, which constitutes 8.46% of the total area of Tulungagung Regency.

3.2 Discussion

Planning for the development of pangasius aquaculture areas through geospatial means has an important role in determining the sustainability of the aquaculture business (Jayanthi *et al*., 2020). Geospatial data can be used to analyze land suitability for aquaculture and minimize adverse impacts on the environment (Vafaie *et al*., 2015). Land suitability analysis is needed in the selection of aquaculture sites. The selection of aquaculture sites affects success and sustainability and can resolve conflicts between various activities in land use. Previous studies only paid attention to aspects of existing resources (Pourebrahim *et al*., 2011; Vafaie *et al*., 2015; Hadipour *et al*., 2015) but did not include other land uses.

Table 5. Pairwise comparison matrix for suitability. Comparison values were calculated as normalized values to determine weight values (Wt), eigenvalues (λmax), consistency index (CI), random consistency index (IR), and Consistency Ratio (CR).

Criteria	Parameter			Normalization			Weight	λmax	CI	IR	CR
Suitability	Water	Soil	Infrastruc-ture	Water	Soil	Infrastructure					
Water	1	1	5	0.45	0.45	0.45	0.45	3	0	0.58	0
Soil	1	1	5	0.45	0.45	0.45	0.45				
Infrastructure	1/5	1/5	1	0.09	0.09	0.09	0.09				

This study estimates the potential areas in Tulungagung Regency for pangasius aquaculture development using AHP and based on GIS. If the aquaculture area is to be developed in a small area, land suitability testing can be done directly; however, Tulungagung Regency has a large area, and this will be a separate obstacle in determining the level of land suitability. The use of GIS in determining the level of land suitability provides many conveniences and advantages (Hossain *et al*., 2009). GIS can interpolate the area for which data is not collected and can estimate the condition of the area (Ghobadi *et al*., 2021). This will be more efficient in all respects of determining land suitability.

This study minimizes land use change so that the planning for the development of pangasius aquaculture areas is only focused on unutilized lands such as shrubs or grasslands. Pangasius aquaculture factors are grouped to make it easier to analyze the level of land suitability. Several researchers who have grouped aquaculture factors include Hossain *et al*. (2009), Puniwai *et al*. (2014), and Rahman *et al*. (2019).

Table 6. Results of the assessment of all land suitability parameters. Land suitability parameter values consist of water quality, soil, and infrastructure which are the range of values in each district.

No	Sub-district	Water Quality						Soil Quality			Infrastructure			
		DO (PPM)	Temperature (°C)	pH	Amonia (ppm)	Nitrat (ppm)	TDS	Slope (%)	pH	Soil Texture (%Liat)	Highway Distance (m)	Market Distance (km)	Seeding Distance (km)	Fish Management Distance (km)
1	Bandung	1.66±0.29	29.8±1.50	5.9±0.12	0.0±0.00	0.0±0.00	459±64.47	1.0±0.70	7.2±0.29	20±0.82	100±24.5	18.77±4.88	20.1±3.96	22.5±2.65
2	Besuki	2.71±0.09	24.5±0.85	6.8±0.23	1.3±0.58	0.8±1.44	378±12.53	15.9±4.70	7.7±0.58	18±0.62	600±20.4	23.16±5.69	20.7±4.14	23.4±3.23
3	Boyolangu	2.75±0.17	32.3±1.06	6.5±0.21	1.2±0.76	3.5±1.32	335±31.19	0.4±0.30	7.0±0.50	27±1.41	100±32.7	5.72±4.22	4.8±3.89	1.8±1.47
4	Campur Darat	2.54±0.20	24.9±2.70	6.3±0.38	1.7±0.58	2.5±2.50	402±6.56	1.2±0.20	7.2±0.29	23±1.63	100±24.6	16.56±5.38	16.5±8.44	17.91±8.59
5	Gondang	1.33±0.32	31.3±1.69	6.0±0.10	1.7±0.58	2.5±0.50	540±32.79	0.7±0.40	7.2±0.76	23±2.16	50±16.3	4.92±1.79	6.5±2.58	9.3±5.33
6	Kalidawir	1.98±0.28	30.4±0.75	7.1±0.21	0.0±0.00	0.0±0.00	390±21.79	1.7±0.70	7.8±0.29	36±2.16	50±4.7	14.23±7.20	11.3±4.98	8.9±2.14
7	Karangrejo	1.16±0.06	28.6±0.58	5.7±0.20	0.0±0.00	0.0±0.00	158±39.95	1.6±0.60	7.2±0.29	31±0.82	400±40.8	7.02±3.66	7.7±3.70	12.4±4.29
8	Kauman	1.71±0.15	28.1±1.80	5.9±0.17	0.25±0.25	3.2±0.76	342±12.29	0.7±0.60	8.0±0.00	23±1.63	150±4.1	2.01±1.65	5.4±1.87	10.5±5.64
9	Kedungwaru	2.98±0.20	29.2±1.08	5.8±0.12	0.0±0.00	2.7±2.52	401±11.53	0.4±0.30	7.8±0.29	49±4.08	400±20.4	2.03±0.71	2.7±1.80	7.2±3.23
10	Ngantru	2.13±0.35	29.2±1.18	5.5±0.10	0.0±0.00	0.0±0.00	304±13.00	0.8±0.70	7.0±0.50	27±1.63	100±8.2	7.03±4.11	7.5±2.79	10.4±2.16
11	Ngunut	2.23±0.10	28.9±0.96	5.9±0.23	0.0±0.00	0.0±0.00	219±17.78	0.3±0.20	7.2±0.29	30±1.41	200±16.5	8.77±1.65	6.2±1.91	3.9±3.18
12	Pagerwojo	2.69±0.12	23.4±0.50	8.6±0.10	0.0±0.00	0.0±0.00	198±22.07	26.5±6.00	7.2±0.29	21±0.82	700±12.2	14.78±5.97	19.3±6.96	24.5±9.49
13	Pakel	2.34±0.39	28.4±1.31	5.8±0.15	0.0±0.00	2.5±2.50	412±6.93	0.4±0.30	7.0±0.00	24±1.63	50±8.2	11.49±0.90	12.4±4.14	14.6±8.39
14	Pucang Laban	2.79±0.17	27.7±1.23	5.9±0.06	0.2±0.14	0.0±0.00	395±11.36	18.0±8.00	7.8±0.29	23±1.41	450±40.8	19.29±5.72	15.8±2.96	13.4±2.07
15	Rejotangan	1.97±0.22	30.8±1.73	5.9±0.06	0.0±0.00	0.0±0.00	479±6.00	0.5±0.40	7.0±0.00	31±0.82	150±4.1	19.06±5.67	16.3±5.80	13.5±2.74
16	Sendang	3.07±0.26	24.2±0.31	8.6±0.12	0.0±0.00	0.0±0.00	75±8.72	26.7±1.70	7.0±0.50	21±1.41	700±8.2	12.67±1.69	15.7±6.84	20.8±8.52
17	Sumbergempol	2.16±0.16	31.2±2.03	6.5±0.40	0.0±0.00	0.0±0.00	324±9.00	0.5±0.30	7.2±0.29	37±2.92	800±10.3	6.86±0.77	3.6±2.77	1.7±1.39
18	Tanggung Gunung	2.38±0.39	27.9±1.40	8.0±0.06	0.0±0.00	1.8±1.61	360±18.03	21.7±1.70	7.8±0.29	23±2.16	850±16.3	13.9±2.86	16.1±5.14	18.2±7.76

Table 7. Distribution of area and percentage of land suitability. The area and the percentage of areas were calculated based on land suitability criteria, namely, very suitable, suitable, quite suitable, and not suitable.

Parameter		The extent of suitability (ha)				Percentage of Suitability (%)			
		Most suitable	Suitable	Moderately suitable	Not suitable	Most suitable	Suitable	Moderately suitable	Not suitable
Water	DO	0	0	0	115469.1	0	0	0	100
	temperature	50975.95	50927.87	13565.31	0	44.15	44.11	11.75	0
	pH	42498.04	58636.27	14334.83	0	36.80	50.78	12.41	0
	TDS	83005.05	17783.42	7511.396	7169.261	71.89	15.40	6.51	6.21
	Ammonia	85499.98	15732.13	3575.709	10661.31	74.05	13.62	3.10	9.23
	Nitrate	94540.28	5300.152	5101.63	10527.06	81.87	4.59	4.42	9.12
Soil	Slope	57926.31	15474.4	25836.34	16232.08	50.17	13.40	22.38	14.06
	pH	115469.1	0	0	0	100	0	0.00	0.00
	Texture	3513.382	39217.37	72645.23	27.86705	3.04	33.96	62.91	0.02
Infrastructure	Distance to road	50632.04	27829.75	24348.48	12658.86	43.85	24.10	21.09	10.96
	Distance to market	9989.685	29767.16	29591.32	46120.97	8.65	25.78	25.63	39.94
	Distance to Hatchery	4545.154	15005.2	25318.58	70600.21	3.94	12.99	21.93	61.14
	Distance to Factory	7270.722	17754.41	27158.96	63285.05	6.30	15.38	23.52	54.81

The opportunity for the government of Tulungagung Regency to develop a pangasius aquaculture area is very large; the total area that can be used to develop a pangasius farm area is 976885.71ha. Based on land use data from One Data Indonesia in 2022, the area of the Tulungagung Regency aquaculture area is 396.41ha, meaning that the existing potential has only been utilized at 3.9%. This study recommends that the development of pangasius aquaculture areas be prioritized in the most suitable category area, with an area reaching 2619.35 ha or 25.77% of the total potential. After that, it can be developed into areas with suitable categories that have a potential of 21.99% and are moderately suitable to the potential of 48.34%.

In general, most of the Tulungagung Regency area is 59% in the suitable and most suitable category for pangasius farming; this is one of the reasons why the current pangasius aquaculture has good quality (Tulungagung Regency Government, 2019). This is also supported by previous research on pangasius in Tulungagung, the results of which are very feasible for development (Yulisti and Putri, 2013). Additionally, the ongoing pangasius farming business in Tulungagung Regency has shown an increase in profits every year (Primyastanto *et al.,* 2020; Supriyadi *et al.,* 2022). Recent research conducted on the sustainability of pangasius cultivation in Tulungagung Regency has indicated that the area has a sustainable status (Asro *et al.,* 2024).

The development of pangasius aquaculture areas is highly recommended to increase pangasius production. Of course, this will not necessarily increase the output of pangasius aquaculture if there is no follow-up. This research can be used as a basis for determining the area of reference in the selection of a good pangasius aquaculture location. Multi-line collaboration is needed to follow up on the results of this research. The next aspect that needs to be studied are the social and economic aspects. Both aspects will cover the potential of natural resources and human resources. The formulation of policy strategies can also be carried out by following up on the results of this study. The formulation of the policy strategy will be applied directly by the government of Tulungagung Regency.

Table 8. Area and percentage of land use. Land use in Tulungagung Regency consists of shrubs, meadow, settlements, lake, wetland farm, dryland farm, plantation, forest, fish farm, and building.

No	Land use	Area (ha)	Percentage
1	Shrubs	9575.23	8.29%
2	Meadow	1259.90	1.09%
3	Settlements	19559.37	16.94%
4	Lake	50.28	0.04%
5	Wetland farm	33118.51	28.68%
6	Dryland farm	11773.15	10.20%
7	Plantation	21286.64	18.43%
8	Forest	18446.88	15.98%
9	Fish farm	396.41	0.34%
10	Building	2.76	0.00%
Total		115469.1	100%

4. Conclusion

This study successfully integrates Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) to assess the land suitability for pangasius aquaculture in Tulungagung Regency, East Java. The analysis reveals that the majority of land in the region (approximately 59%) falls within the suitable and most suitable categories for aquaculture, providing significant potential for expanding pangasius farming. With a total of 976,885.71 ha identified for aquaculture development, the study highlights the critical factors influencing land suitability, such as water quality, soil quality, and infrastructure. This research provides a comprehensive land suitability map that can serve as a valuable resource for policy makers and industry stakeholders in making informed decisions about the future of pangasius aquaculture in the region. The study's results underscore the need for a balanced approach to land use, taking into account both environmental sustainability and the socio-economic potential of aquaculture in Tulungagung Regency.

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Authors' Contributions

The contributions of each author are as follows: Asro; Collect data, data analysis, original manuscript drafting, graphical abstract design. Aida; conceptualization, funding acquisitions, data acquisitions, supervision, writing review, and editing. Mimit, and Maheno; designed the main conceptual idea and critical revision of the article. Lugu and Andra; provided research facilities and accommodation. All authors discussed the research results and contributed to the final manuscript. However, this research is limited in its assessment of water and soil fertility levels, making it crucial for future research to focus on these parameters for further development.

Conflict of Interest

The authors declare that they have no competing interests.

Declaration of Artificial Intelligence (AI)

The author(s) affirm that no artificial intelligence (AI) tools, services, or technologies were employed in the creation, editing, or refinement of this manuscript. All content presented is the result of the independent intellectual efforts of the author(s), ensuring originality and integrity.

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