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Evaluating Optimal Cultivation Sites for Microalgae Based on Dairy Farm Wastewater using Analytical Hierarchy Process and Geographic Information System Techniques

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ABSTRACT

Dairy farm wastewater contains high BOD, COD, and TSS, thus harming the environment if discharged without proper treatment. However, it is rich in nutrients, primarily nitrogen and phosphorus, which are needed by microalgae to grow and synthesis useful and high-value organic compounds. Microalgae biomass can be generated from a cultivation system that is integrated with wastewater sources efficiently. Selecting a suitable location is thereby crucial for the sustainable development of microalgae cultivation. This study aimed to select suitable locations in Cangkringan District, Indonesia for microalgae cultivation sites using the analytical hierarchy process (AHP) method integrated with geographic information system (GIS) and weighted overlay analysis (WOA). AHP helped determine the relative weights of the relevant factors, including dairy farm wastewater, temperature, land use, land elevation, and land slope in the study area. These weights were subsequently applied in WOA to determine locations that were most suitable for microalgae cultivation sites. The results of WOA, presented in the form of a land suitability map, showed that 0.1% (0.04 km^2) of the studied areas is highly suitable for the development of microalgae cultivation and that a significant portion, approximately 67.2% (29.75 km^2), is not suitable.

Keywords: dairy farm wastewater, microalgae, Cangkringan, AHP, GIS.

INTRODUCTION

Dairy farm wastewater comes from livestock cleaning, milking, and cage flushing (Ding et al., 2015; Hawke and Summers, 2006). It comprises liquid (99.9%) consisting of urine, water and feces mixed with urine and solids (0.1%) in the form of solid suspension mixed with organic and inorganic matter (Rivas Lucero et al., 2018; Shams et al., 2018). Containing chemical oxygen demand (COD), phosphorus, and nitrogen in fairly high concentrations, it is considered as a high-level pollutant that can result in eutrophication of water bodies, contamination of groundwater, and air pollution by evaporation of ammonia (Cui et al., 2020; Daneshvar et al., 2019; Fridrich et al., 2014). However, it is potential to be a cost-effective source of nutrients for microalgae cultivation. It can also increase lipid content and remove about 98% of pollutants in wastewater (Hena et al., 2015, 2018). These excellences can enhance the economic value of dairy farming activities (Labbé et al., 2017). Microalgae as photosynthetic microorganisms utilize sunlight, CO^2, and about 50% of atmospheric oxygen to produce biomass rich in lipids (3–20% dry weight), carbohydrates, and proteins (Liyanaarachchi et al., 2021; Russell et al., 2022; Suganya et al., 2016). Such a substantial amount of lipids, along with other valuable compounds like polyunsaturated fatty acids and carotenoids, offers opportunities for utilization in the production of bioenergy, especially biodiesel (El-Haji et al., 2023; Elshobary et al., 2022; Pawar, 2016), and applications in the fields of bioremediation, pharmaceuticals, and nutraceuticals (Bhatt et al., 2022; Spolaore et al., 2006). Effective cultivation of microalgae requires suitable climatic conditions, land characteristics, and nutrient availability. Climatic factors such as high solar radiation and optimal temperatures are indispensable (Brusca et al., 2017; Dalgleish, 2017; Sarker & Salam, 2019), while wastewater serves as an effective source of phosphorus and nitrogen that are useful in the growth of microalgae and their metabolic activity (Prasad et al., 2014; Yaakob et al., 2021).

The use of geospatial technology such as GIS along with the analytical hierarchical process (AHP) method can support the selection of locations for cultivation sites by considering eco-climatological factors and nutrient sources. GIS allows the analysis of variables using various layers of data, including drainage, geology, elevation, land use, rainfall, and soil, while AHP aids in decision-making by calculating the weights of each factor or criterion (Avdullahi and Hajra, 2023; Razak et al., 2015). This decision-making process is based on the calculation of each factor/criterion's and sub-criterion's weights, following the AHP method developed by Saaty (Saaty, 2008). In practice, each factor/criterion or sub-criterion used is determined based on the opinions of experienced experts in the relevant field (Ariff et al., 2012; Ismail et al., 2024). Research have been performed on the utilization of GIS for determining locations suitable for microalgae cultivation sites in various countries with their respective climate and land characteristics, including in Australia (Boruff et al., 2015; Prasad et al., 2014), Canada (Klise et al., 2011), Italy (Brusca et al., 2017), Pakistan (Arsalan and Iqbal, 2023), Mexico (Lozano-Garcia et al., 2019), India (Milbrandt and Jarvis, 2011), Chile (Bravo-Fritz et al., 2015), and the United States (Quinn et al., 2012; Wigmosta et al., 2011; William et al., 2017). Most of the areas studied were in countries with four seasons. In this case, tropical countries, especially Indonesia, have not been explored massively; A study identified the potential for microalgae cultivation in Eastern Indonesia (Citra Permata Kusuma Anggraini et al., 2018), but did not yet integrate more specific natural resource considerations.

This study was performed to evaluate the potential of wastewater generated by dairy farms in Cangkringan District, Indonesia for microalgae cultivation sites. The evaluation was carried out by considering the climate, land, and source of nutrients from livestock waste, with the ultimate goal of determining locations that meet the requirements for microalgae growth. The results are expected to provide useful information for decision-making in the development of sustainable microalgae cultivation sites in the area.

METHODOLOGY

This study combined multi criterion decision making (MCDM) and weighted overlay analysis (WOA) in a geographic information system (GIS). Among the various MCDM method, AHP has been widely used in numerous fields (Ferliandi et al., 2022; Hanene et al., 2024; Pramanik, 2016). The implementation of these methods is highly effective and promising in the process of assessing the suitability of land for cultivating microalgae (Khahro et al., 2014). WOA works based on parameters that are set and reclassified by paying attention to the percentage of influencing factors obtained from AHP calculations (Hazini et al., 2015). Integrating AHP and WOA with the local environmental conditions can help determine locations with high potential for microalgae cultivation sites (Hossain et al., 2020; Sedghamiz, 2017). WOA is constructed using land use maps, land slope maps, land elevation maps, temperature maps, and maps of dairy farm locations distribution. The results of AHP and WOA can generate a recommended map indicating the suitability of lands for the microalgae cultivation sites with nutrients from dairy farm wastewater.

Study area

Cangkringan district (Fig. 1) located 25 km northeast of the capital city of Sleman Regency, Yogyakarta was chosen to be the study area. The region is geographically situated at 7°33'3" to 7°41'2" S and 110°25'4" to 110°28'35" E, on the southern slopes of Mount Merapi, in the form of a plateau covering villages spread from top to

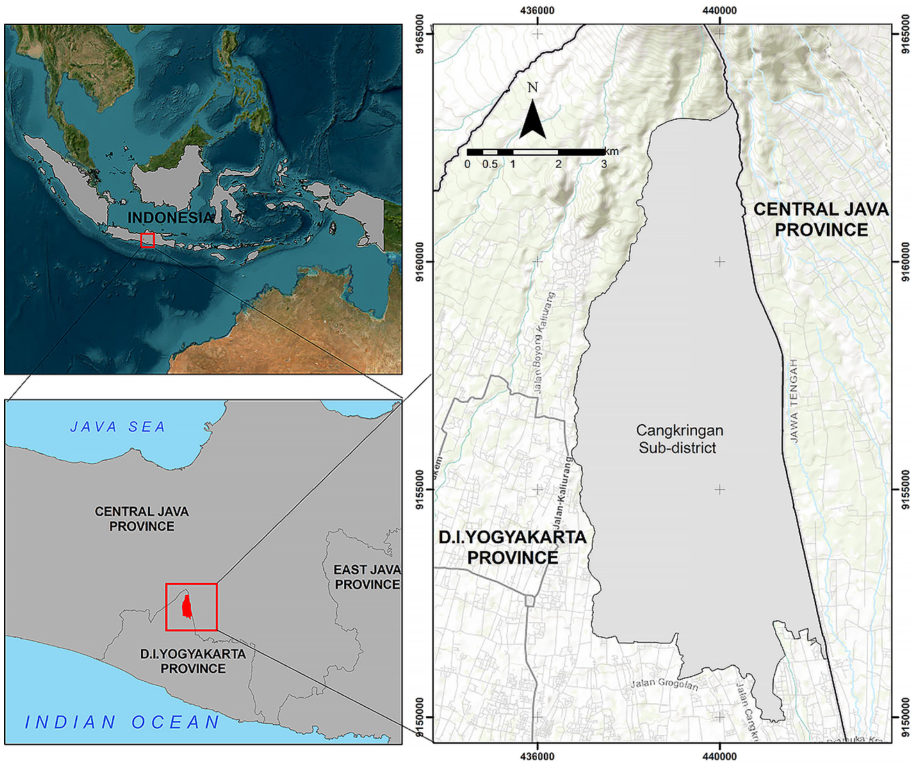

Figure 1. Study site

bottom. Administratively, the district is divided into 5 kelurahans, namely Argomulyo, Wukirsari, Umbulharjo, Kepuharjo, and Glagaharjo, covering an area of 4799 km^2. The district capital has an altitude of 400 meters above sea level. The region's climate is typical of highland tropical areas, characterized with cool weather. The highest temperature recorded therein ranges from 25.5 to 25.5 °C. The terrain consists of undulating land and hills.

Data and sources

The data employed were sourced from numerous sources. Solar radiation data was derived from satellite imagery. Land use, land slope, and land elevation data were collected from *DEMNAS* data provided by the geospatial information agency (BIG) of Cibinong, Indonesia. Temperature, location, and livestock populations data were obtained from direct location surveys. The details data sources are written in Table 1.

Mapping method

Generation of criterion maps using geospatial techniques

The thematic maps used in this study were created using ArcGIS 10.3. Land elevation maps and land slope maps were made based on digital elevation model (DEM) data from DEMNAS with a resolution of 8.1 meters. Land use maps

Table 1. The data sources for datasets used in the microalgae cultivation land sutability

Parameter	Detail or source	Period	Data link
Solar radiation	All sky surface shortwave downward irradiance (kW-hr/m^2/day)	2019–2023	https://power.larc.nasa.gov/#resources
Landuse	RBI Map Scale 1:25.000 page 1408–241, 1408–223, and 1408–244	2019	https://tanahair.indonesia.go.id/unduh-rbi/
Elevation and slope	DEMNAS (Spatial resolution 0.27-arcsecond with vertical datum EGM2008)	2019	https://tanahair.indonesia.go.id/demnas/
Dairy farm sites	Global positioning system (GPS)	2023	–
Livestock populations	Field survey activities	2023	–
Temperature	Field survey activities	2024	–

were obtained from the indonesian terrain map (RBI) scaled 1:25,000. Temperature maps were made based on sampling location points in the field using a 1×1 kilometer grid and interpolated with the help of the inverse distance weighting (IDW) method. The maps of dairy farm sites were obtained from field data. During field survey activities, global positioning system (GPS) recipients functioned in checking the fields and determining the geographic coordinates for geo-coding in GIS-based data analysis (Chukwuma et al., 2021) The stored data (tracking and waypoints) was used as a reference in making maps or mapping processes.

Standardization

The operation of WOA needs the uniformity of units across all predetermined criteria, requiring conversion and standardization. This standardization technique converts the measurement into a uniform unit, resulting in scores that lose their original dimensions and units of measurement for all criteria (Effat and Hassan, 2013). Input parameters that are still in the form of vector data (land use maps and dairy farm location points) are converted into raster form in ArcGIS Ver 10.3 with a spatial resolution of 8.1 m using the 'vector to raster conversion' technique. Subsequently, the raster layer is reclassified as input data in the WOA method in ArcGIS. The reclassification method on the Arc-GIS software Spatial Analyst Toolbox standardizes the values of all criteria to enable comparison.

Analyzing locations optimal for microalgae cultivation sites should be based on the microalgae's requirements and living conditions, with adjustments to potential natural resources and local geographical conditions. The initial phase of such an analysis involves the determination of parameters and criteria that are expected to influence land suitability for microalgae growth. These criteria have different levels of importance. Three parameters consisting of land parameters, climate parameters, and nutrient parameters are used to classify the criteria. Microalgae cultivation necessitates a site with appropriate temperature and light, non-residential and non-productive agricultural land, and land conditions that facilitate the circulation of microalgae growth medium. To determine the most promising locations, favorable climate conditions and nutrient-rich sources of nitrogen and phosphorus must be aligned with existing land characteristics such as land slope, land elevation, and land use.

Climate characteristics, particularly temperature, significantly affect microalgae productivity (Prasad et al., 2014). Land parameters include land slope, land elevation, and land use, the latest of which can limit the placement of microalgae cultivation ponds due to high land conversion costs. Non-productive land may be more economically viable for microalgae biomass production (Lundquist et al., 2010). Since the study area was a mountainous area, the land elevation and slope were crucial to identify land suitable for microalgae cultivation sites. Degrees of land slope recommended for technology development are below 15% (Bennett et al., 2014). Land elevation, to avoid excessively low environmental temperatures, should be below 900 meters, since elevation affects regional temperatures (Arsalan and Iqbal, 2023). Nutrient availability relates to the availability of waste sources from dairy farms, with criteria based on the number of livestock. All criteria were considered during the analysis process in the selection of suitable locations. The criteria were reclassified into five different categories, with a scale of 1–5, where 1 indicated the highest level of importance and 5 meant the lowest level of importance. The criteria were scored according to the level of contribution of each criterion to the suitability of the land for microalgae cultivation. The scoring was carried out by considering the opinions of experts, the study area characteristics, and the results of previous studies. Table 2 displays the quantitative distribution of the criteria used.

Determination of weights using AHP

AHP has been implemented to address many problems involving multiple criteria at different hierarchical levels, in which interactions between these criteria usually occur (Feizizadeh et al., 2014). This process works on a set of criteria or sub-criteria to form a hierarchical structure by assigning weight to each criterion in the decision-making process (Kiker et al., 2005). In this research, AHP functioned to determine the weights of the criteria (Manoj et al., 2022). It helped determine the influencing factors in the different input hierarchies selected in WOA and to assign weights of each of these factors. The technique used was a pairwise comparison matrix on a 1–9 scale (Saaty, 2008) The stages in the implementation of AHP carried out by previous researchers (Elaalem et al., 2011) are as follows:

Table 2. Criteria distribution in the study area

Parameter	Criteria	Classification	Score
Climate	Temperature (°C)	29.37–30.42	5
		28.35–29.36	4
		27.75–28.34	3
		26.72–27.54	2
		25.50–26.71	1
Nutrient availability	Availability of local wastewater (cow populations)	≥20	5
		5–19	3
		1–4	1
Land	Land slope (%)	<5	5
		<8	4
		<15	3
		<20	2
		<30	1
	Land use	Shrubs	5
		Meadow	5
		Moor/Farm	4
		Plantation	3
		Paddy	2
		Residential land	1
	Land elevation (asl)	<300 m	5
		300–500	4
		500–700	3
		700–900	2
		>900 m	1

- Determination of factors or criteria relevant to the research
- Determination of the weights or relative significances of all factors or criteria using a pairwise comparison matrix by considering the opinions of experts and literature studies.
- Evaluation of the consistency levels.

For determining the parameters' weights based on the AHP preference scale, a pairwise comparison matrix was created by paying attention to the level of importance of one criterion relative to other criteria in a pair. The number 1 indicates an equal level of importance, and the number 9 suggests that one constituent is more important than the other. Meanwhile, the inverse values from 1 to 9 (1/1 and 1/9) indicates that one element is less important than the other (Table 3). The suitability and importance ratings for the criteria were defined based on literature studies and the opinions of 5 experts. The creation of a pairwise comparison matrix should be followed by checking the matrix consistency. A comparison matrix is declared consistent if the value of the Consistency Ratio (CR) is ≤ 0.1. If the CR value is > 0.1, the comparison matrix is considered inconsistent and should be re-examined (Saaty and Vargas, 2012). The CR value is the ratio of the consistency index (CI) and the ratio index (RI) expressed by Equation 1:

$$CR = \frac{C1}{R1} \tag{1}$$

while C1 can be determined through Equation 2:

$$C1 = \frac{\lambda_{average} - n}{n-1} \tag{2}$$

where: CR – consistency ratio, C1 – consistency index, R1 – ratio index, λ – eigenvalue. RI stands for the average of the consistency index whose value is correlated to the number of n or criteria used (Saaty and Vargas, 2012) that has shown in Table 4. After ensuring the consistency of the entire pairwise comparison matrix, the next step is to calculate the vector eigenvalue (w) (Citra Permata Kusuma Anggraini et al., 2018). The eigenvector variable (w) value reflects the weight of each criterion. In determining the weights using the eigenvalue method and the eigenvector method (exact method), the requirement is that the sum of the values of each weight must be equal to 1.

Site suitability model for microalgae cultivation using weighted overlay analysis in GIS

The site suitability model was created by combining all thematic maps and performing a weighted overlay analysis (WOA) process using ArcGIS 10.3 software. WOA can help researchers solve spatial complexity in suitability analysis and select sites based on the application of a uniform

Table 3. Intensity of importance scale

Rating for pairwise comparison according to Saaty	Numerical value	Opposite value
Equal importance	1	1
Equally to moderately	2	1/2
Moderate importance	3	1/3
Moderately to strong	4	1/4
Strong importance	5	1/5
Strongly to very strong	6	1/6
Very strong importance	7	1/7
Very strong to extremely	8	1/8
Extreme importance	9	1/9

Table 4. Random inconsistency indices (RI) for n = 10

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,46	1,49

value scale to different and diverse inputs (Kuria et al., 2011) Furthermore, to apply the weighted overlay technique, all the developed thematic layers are integrated within GIS (Mishra et al., 2015) Map overlay is the process of merging the geometry and attributes of two or more thematic maps to generate an overlay output. It creates a new spatial dataset by integrating data from multiple input layers into a single output layer.

RESULTS AND DISCUSSION

The weighted values of the selected criteria calculated in AHP were used in the WOA ArcGIS stage to produce land suitability in microalgae cultivation in the study area. There were 5 levels of site suitability: 1) very high, 2) high, 3) moderate, 4) low, and 5) very low. By employing the WOA approach based on the AHP process, the site suitability for microalgae cultivation can been determined.

AHP results

Three factors have been estimated to affect site suitability, including land characteristics, climate, and nutrient availability. Climate involves temperature, land is characterized by its slope, elevation, and use, while nutrient availability is related to the availability of wastewater from dairy farms. After the calculation of the pairwise comparison matrix, the weights or relative eigenvectors are calculated using the Saaty method. The results of the pairwise comparison calculation are shown in Table 5 and 6. In this study, the CR value obtained was 0.062. From the calculation results, the CR value obtained was ≤ 0.1, then the comparison matrix was deemed consistent. Subsequently, calculated weight values are converted into percentages for weighted overlay analysis in GIS.

The outcomes of weighting of criteria with the AHP method are shown in Table 6. In terms of selecting the most suitable locations in the study area for microalgae cultivation sites, it was found that nutrient availability had the highest priority weight of 45.30% because nutrients are the primary need that can affect the microalgae biomass production process. Besides, nutrients are the main consideration for both the source and the composition, as they can affect the total cost that must be incurred for large-scale microalgae cultivation. In terms of temperature and land use, land elevation, and land slope, each had a decreasing priority weight. Specifically, land use had a higher priority compared to land elevation and land slope, indicating its more important role in the process of selecting locations for microalgae cultivation sites.

Microalgae cultivation site selection criteria maps

Meeting the required land characteristics, nutrient availability, and climate conditions is necessary for effective microalgae cultivation. High solar radiation and ideal temperatures are critical climatic considerations. Temperature, in particular, is a key factor in controlling the metabolism and photosynthetic activity of microalgae in both open and closed environments. Data collected through field surveys showed that in the study area, temperatures ranged from 25.4900 °C to 30.4199 °C (Fig. 2). The gradient of increasing temperature from dark blue (north) to light blue (south) is shown in the map. The northern region borders Mount Merapi, so the further north, the cooler the air temperature is because it is closer to the slopes of Mount Merapi. Thus, in terms of

Table 5. Pairwise comparison matrix for multi-criteria decision problems

Criteria	Land use	Land slope	Land elevation	Nutrient availability	Temperature
Land use	1	5	3	1/3	1/3
Land slope	1/5	1	1/3	1/7	1/9
Land elevation	1/3	3	1	1/7	1/5
Nutrient availability	3	7	7	1	3
Temperature	3	9	5	1/3	1

Table 6. The synthesized matrix for multi-criteria decision making

Criteria	Penggunaan Lahan	Land slope	Land elevation	Nutrient availability	Temperature	Weights	Weight (%)	Eigen value
Land use	0,132743363	0,2	0,183673469	0,170731707	0,071770335	0,151783775	15.19	5,195194551
Land slope	0,026548673	0,04	0,020408163	0,073170732	0,023923445	0,036810203	3.68	5,077140941
Land elevation	0,044247788	0,12	0,06122449	0,073170732	0,043062201	0,068341042	6.83	5,152018708
Nutrient availability	0,398230088	0,28	0,428571429	0,512195122	0,645933014	0,452985931	45.3	5,551238894
Temperature	0,398230088	0,36	0,306122449	0,170731707	0,215311005	0,29007905	29	5,410327695
Total	1	1	1	1	1	1		5,277184158

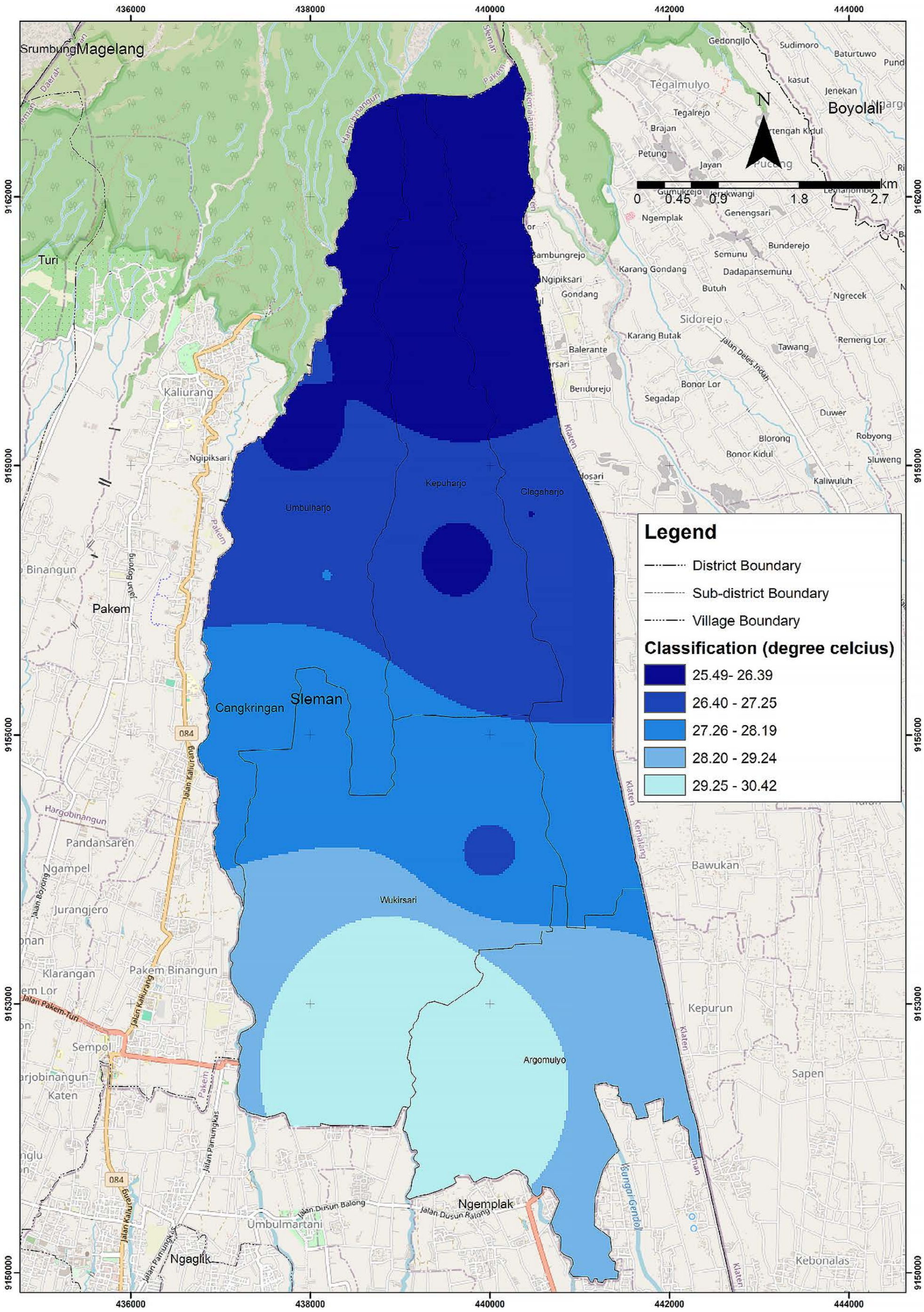

Figure 2. Temperature map

temperature, such area is suitable for microalgae cultivation. The existing temperature range provides good suitability for microalgae growth and can be used to improve biomass yield and algae productivity (Wen and Johnson, 2023). Microalgae cultivated on a large scale are able to grow optimally at temperatures ranging from 20 °C to 35 °C (Lundquist et al., 2010)

Land parameters that include land elevation, land slope, and land use are vital to consider. Figures 3, 4 and 5 show the land use, land slope, and land elevation of the study area, respectively. Figure 3 visualizes that the type of land use varied from north to south. The area's northern part had shrubs, grasslands, fields, gardens, several residential land. Such diversity provided potential locations for microalgae cultivation sites. Meanwhile, the southern region was predominantly agricultural land and residential land, making it less suitable for microalgae cultivation sites. The basic case, also known as the barren case, is defined as a situation in which the cultivation of microalgae is only allowed in areas with land designated as barren (Maxwell et al., 1985; Quinn et al., 2012). Another important factor in determining the cultivation area is land

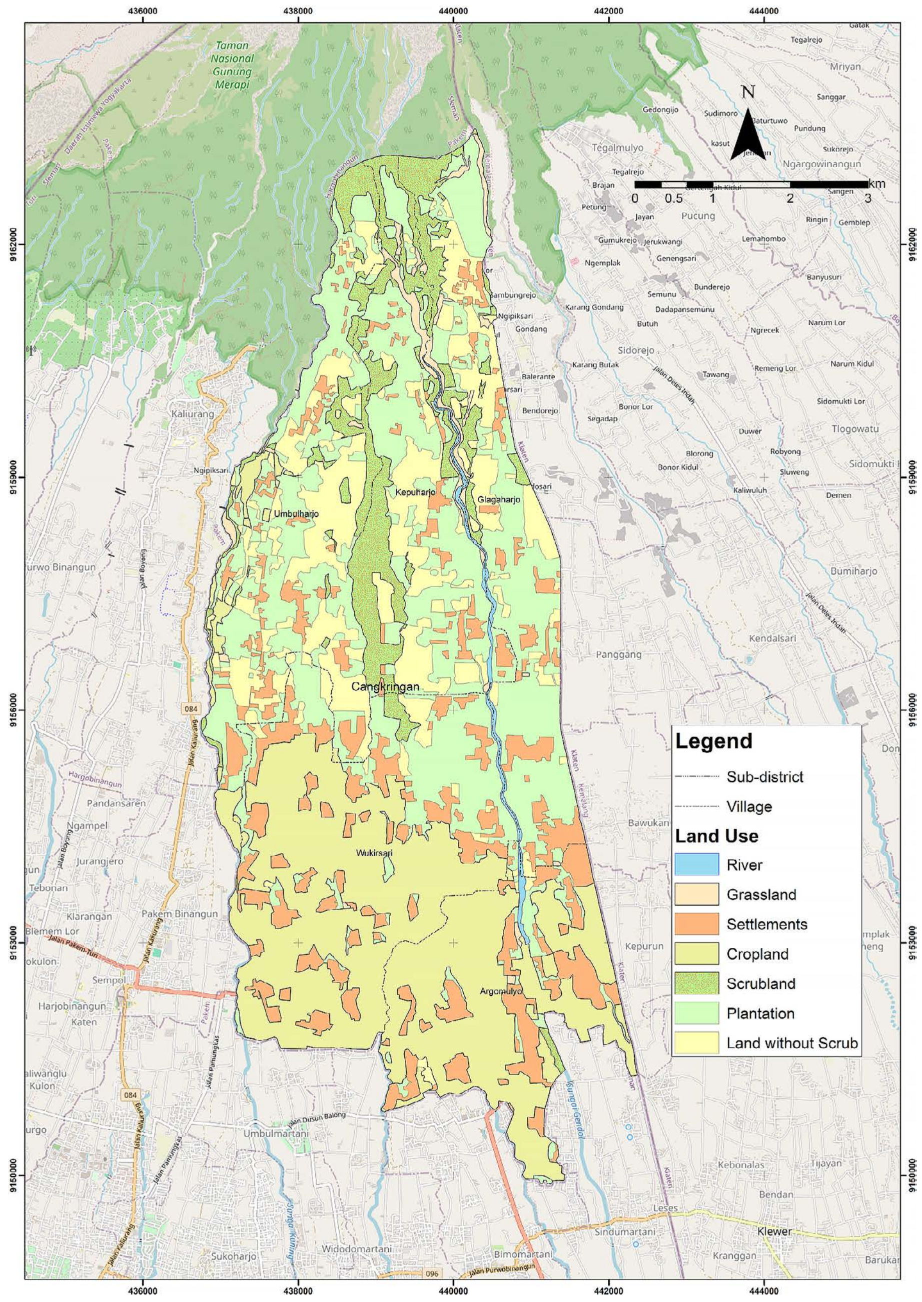

Figure 3. Land use map

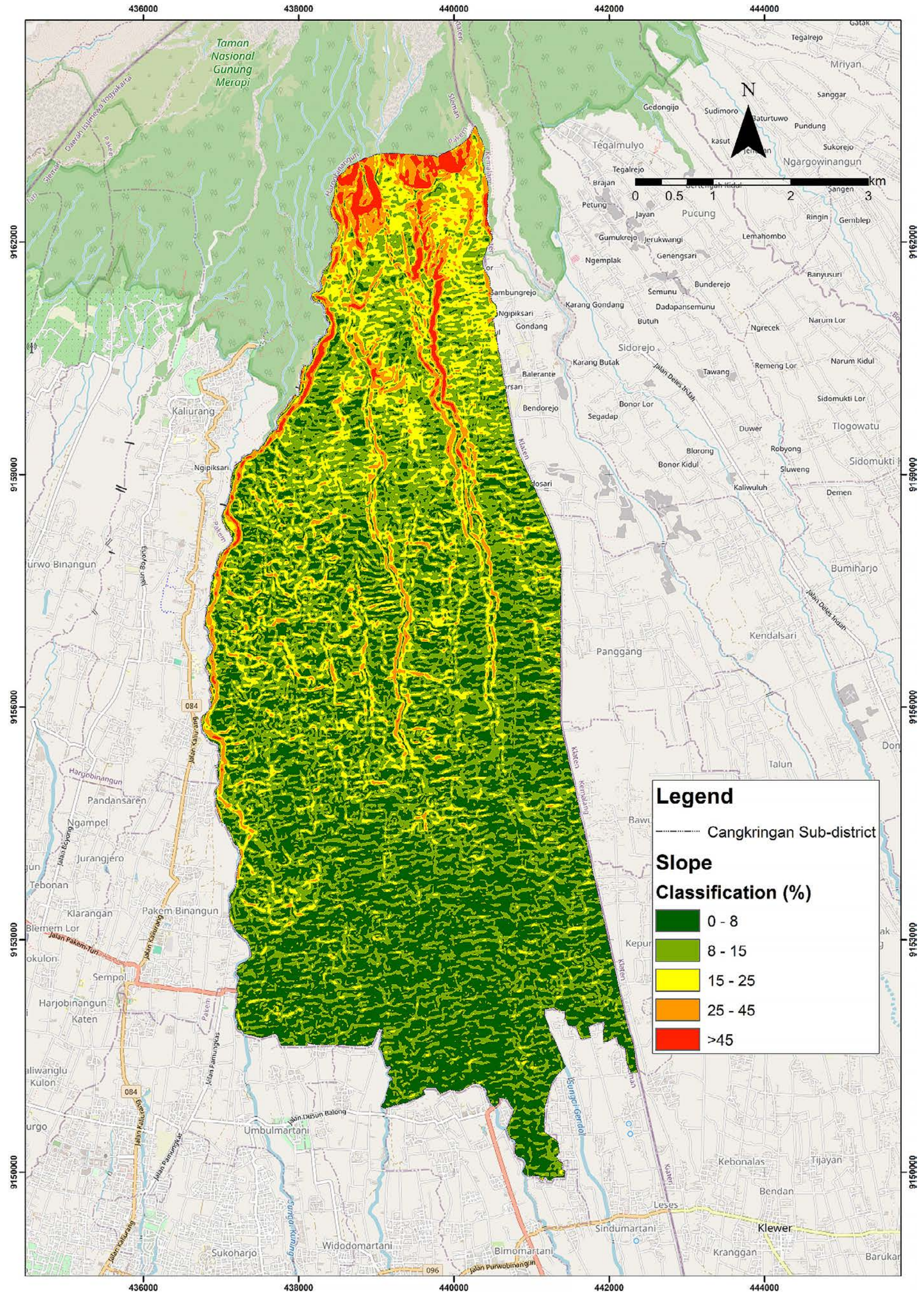

Figure 4. Land slope map

slope. The slope in the study area varied significantly, from flat to steep terrain. The distribution of these values is shown in Figure 4. Land with a minimum slope, namely less than 15%, is deemed the most suitable for microalgae cultivation. Slopes with values of 0–8%m are indicated with dark green, while those with values of 8–15% are indicated with light green. The slope map suggests that the area has a hilly and mountainous topography. As one moves further north, the terrain becomes steeper, with slopes between 25–45% shown in orange and slopes above 45% depicted in red.

Digital elevation maps were created to illustrate the variation in elevation across the study area. Figure 5 shows that the land elevation varied from 298 m to 1399 m, with elevation decreasing from the north to the south. The northern part (red) has an elevation above 1050 meters above sea level, while the southern part (dark green) has an elevation of between 298 and 450 meters above sea level. For ensuring that the temperature remains conducive for microalgae cultivation, the assessment only covered areas with elevation levels below 900 meters above sea level. Elevation significantly

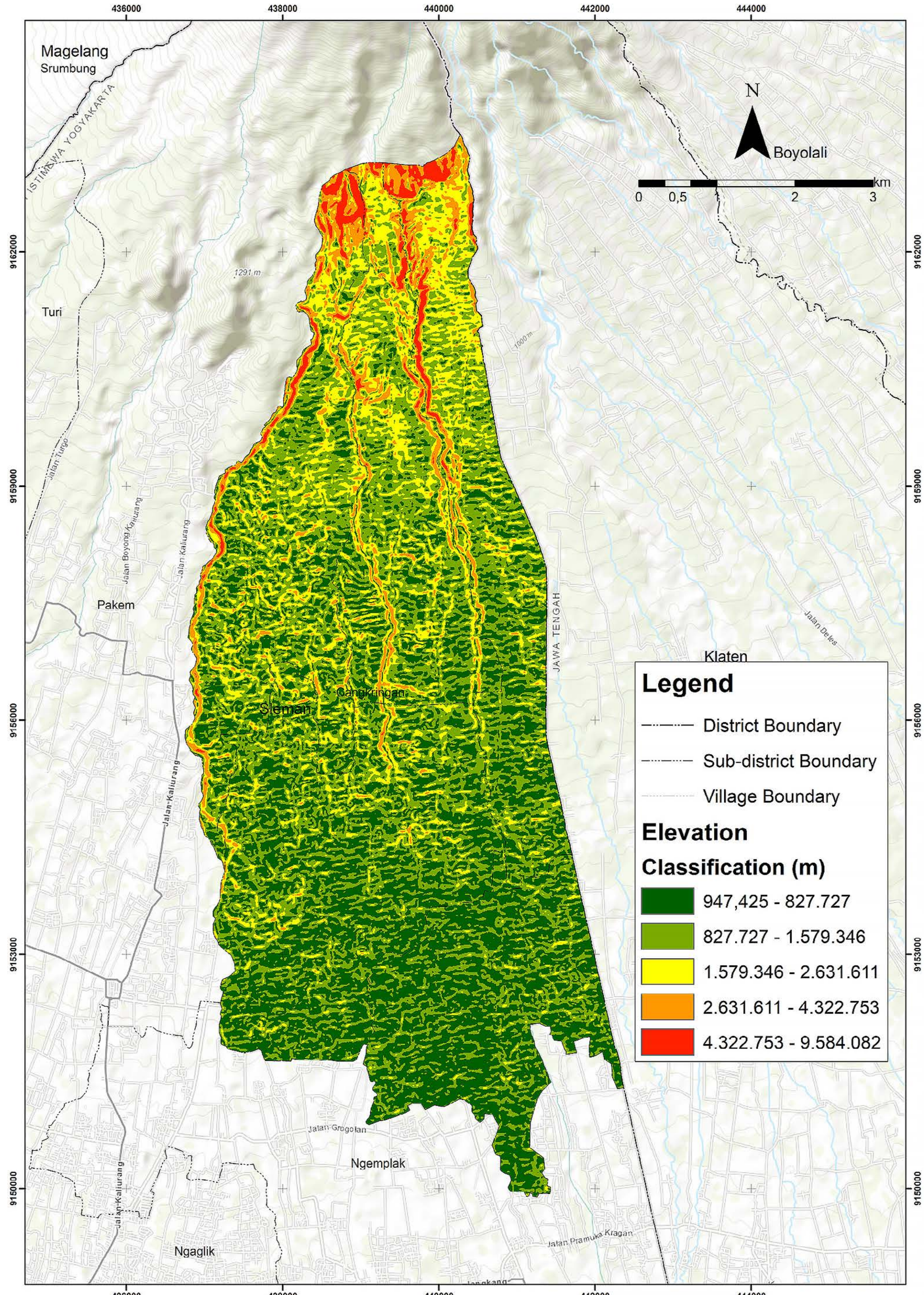

Figure 5. Land elevation map

affects a site's microclimate, which includes precipitation, temperature, and wind patterns (Li et al., 2008; Wang, 2013). Therefore, land elevation is an important factor that needs to be considered when determining the location of microalgae cultivation. Research suggested that locations with lower elevations are increasingly favored for microalgae cultivation sites since they have easier access to water sources and higher temperatures (Chisti, 2007; Li et al., 2008). Nutrients play a crucial role in supporting the growth of microalgae and can be obtained from either commercial or non-commercial sources. In this study, dairy farming is considered as a non-commercial source of nutrients. The spatial distribution of dairy farm locations in the study area is shown in Figure 6. Dairy farms, based on the number

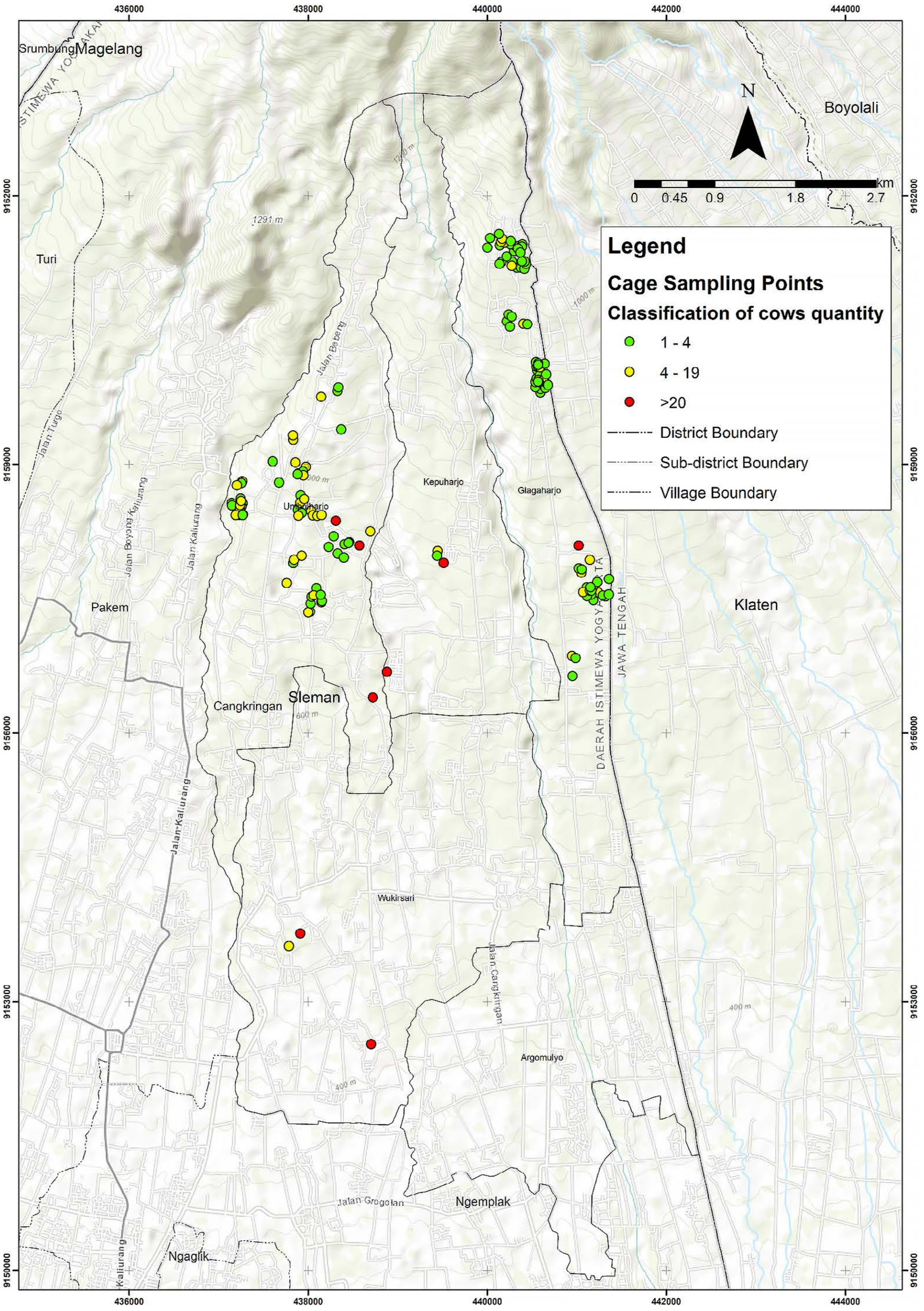

Figure 6. Map of the dairy farm locations in Cangkringan

of cows, are categorized into three: category I (1–4 cows) has 102 locations (green), category II (5–19 cows) has 45 locations (yellow), and category III (more than 20 cows) has 8 locations (red). Data on the number of dairy cows was obtained through interviews with farmers and direct surveys. Farms with more than 20 cows were given the highest scores.

Generation of land suitability map for microalgae cultivation sites

Figure 7 depicts the map of land suitability for microalgae cultivation sites. The statistical results for each suitability class, including the area and percentage of the total area assigned to each class, are shown in Table 7. The assessment was carried out by categorizing the suitability of land

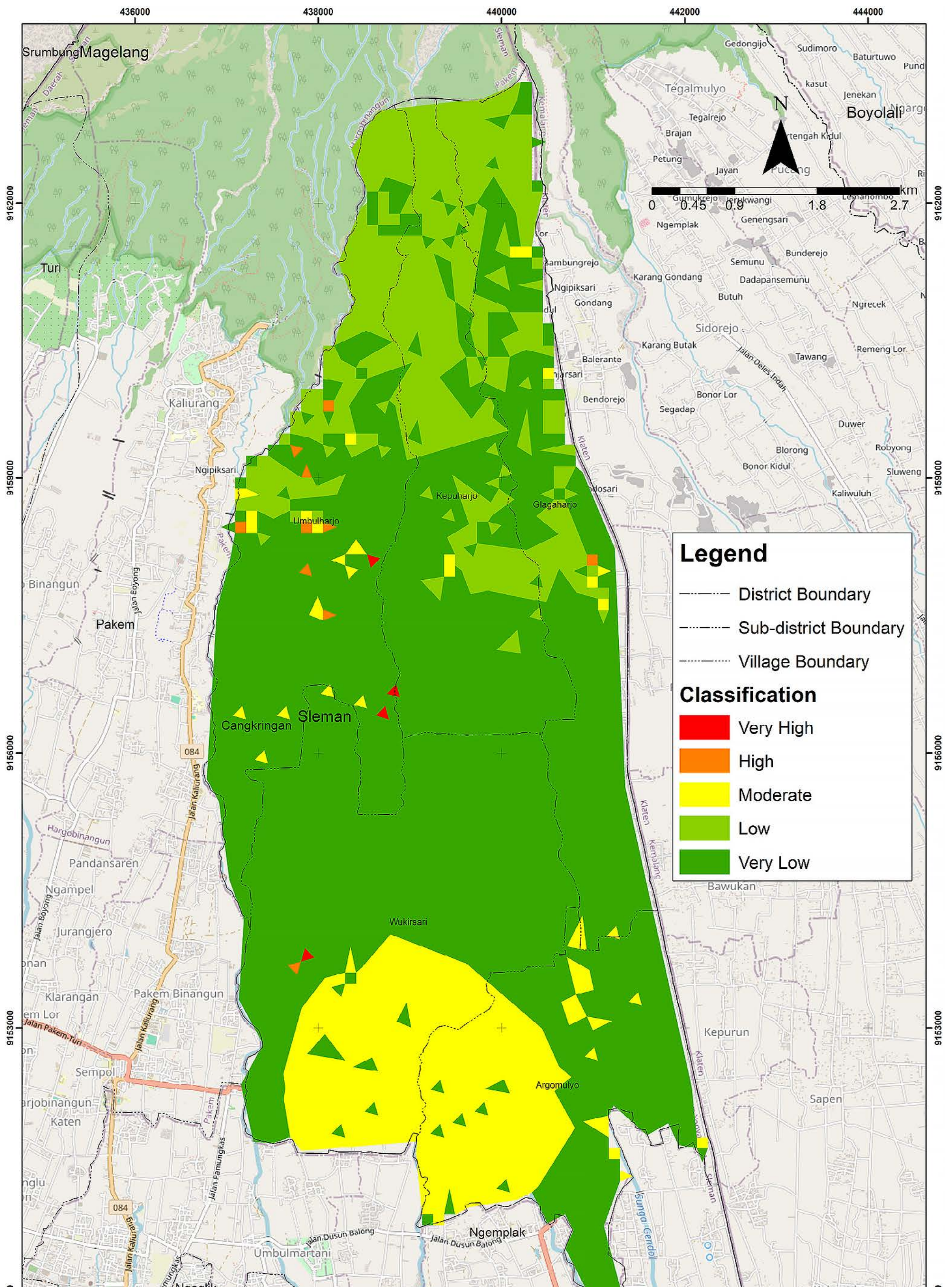

Figure 7. Suitable locations for microalgae cultivation sites

for microalgae cultivation into five classes, spanning from highly suitable to least suitable. The results showed that of the total area studied, 0.1% (0.04 km^2) had very high suitability, 0.3% (0.11 km^2) had high suitability, 15.3% (6.78 km^2) had moderate suitability, 17.2% (7.62 km^2) had low suitability and 67.2% (29.75 km^2) had very low suitability. Figure 8 shows that 0.4% (0.14 km^2) of the area studied had very high and high potentials for being microalgae cultivation sites.

The red area is considered having very high potential for the existence of dairy farms, each with more than 20 cows, making it a viable source of nutrients for microalgae. In terms of land use, the red area is predominantly composed of moors/fields and shrubs, allowing for microalgae cultivation without disturbing the interests of agriculture and residential land. Meanwhile, the land elevation varies and is categorized into three: 300–500, 500–700, and 700–900 meters. Locations below

Table 7. Results of WOA of land suitability for microalgae cultivation sites

Class	Color	Area (km²)	Area (%)
Very low	Dark green	29.75	67.2
Low	Light green	7.62	17.2
Moderate	Yellow	6.78	15.3
High	Orange	.11	.3
Very high	Red	.04	.1

900 meters are still possible for microalgae cultivation because the ambient temperature is not too low for microalgae growth. The terrain slope varies from flat to gently sloping or below 15%. Land with a minimal slope is taken as the most suitable and given the highest grade, i.e. land with a slope between 0–15%. Some larger slope values are studied to accommodate the potential for technological advances that allow production on steeper inclines (Lundquist et al., 2010).

Locations with very high potential (red) are considered candidate zones for microalgae cultivation sites with dairy farm wastewater as nutrient supplier. Environmental factors in such locations, such as sufficient sunlight, comfortable temperatures, and available sources of nutrients and suitable land, are favorable. The results showed that the study area has an area with very favorable climatic conditions, thus being the best location for the development of microalgae. This finding is in line with previous research using environmental and geographical factors (Chiu and Wu, 2013; Orfield et al., 2014; Prasad et al., 2014) The factors worked in identifying locations suitable for cultivation sites include temperature, land elevation, land slope, land use, and nutrient availability.

Parts with very low potential (dark green) are not suitable for microalgae cultivation due to several factors. The areas have active agricultural and residential zones. In addition, there is only a few sites having a population of 1–4 cows. This condition causes insufficient dairy farm-based nutrient sources for large-scale microalgae production. Moreover, lands above 900 meters with varied slopes, from flat to steep, make these areas not suitable for microalgae cultivation.

The main obstacle to microalgae cultivation in the study area comes from the variation of land slope and elevation. Both factors need to be considered as they can elevate the production costs, especially the construction costs. Photobioreactor technology serves as another approach to alleviate construction costs and high slopes (Skarka, 2012). Another strategy that also can be considered to reduce production costs substantially is the utilization of wastewater, as opposed to the addition of minerals or nutrients through growth media (Roostaei et al., 2018). In addition to providing for water needs, wastewater also contains important nutrients for microalgae growth. Cultivating microalgae using wastewater can lower the cost of procuring fresh water as a medium and nutrients (Pawar, 2016). The use of barren land is a suitable choice for microalgae cultivation sites, while fertile land and residential land are not recommended (Jonker and Faaij, 2013).

The results found in this study are expectedly useful in determining the optimal location to build an environmentally friendly and economically viable biofuel production system, especially for stakeholders such as entrepreneurs, investors, and researchers. Future researchers should expand the research scope by including additional factors such as labor availability, social acceptance, economic feasibility, and a representation of the road network for the transportation of biofuels from cultivation sites. The cultivation technology used, namely the use of photobioreactors or openponds, needs further investigation.

CONCLUSIONS

This research has evaluated a suitable location for microalgae cultivation in Cangkringan, Indonesia using the AHP GIS method. The MCDM technique with the GIS-based AHP method has been proven to be effective in solving complex decision-making, taking into account important factors relevant to microalgae cultivation sites. The study area consists of undulating land and hills area, its requires a rigorous land selection process. Using the AHP and GIS methods, it is possible to identify any location in Cangkringan, Indonesia that were most suitable for microalgae cultivation sites, which has never been done before. The abundant source of dairy farms wastewater in the research area is used as one of the location selection criteria, i.e. as a cost-effective source of nutrients for microalgae cultivation. The process is expected to be able to produce biomass with more value at once as an energy-efficient wastewater treatment effort.

The results of the analysis showed that about 0.1% or 0.04 km² of the studied areas is very suitable for developing cultivation sites. It spread across several villages without being concentrated in a single area, providing opportunities for various regions to develop microalgae cultivation as a transition to more environmentally friendly energy. Since this study only included physical parameters, future research needs to include social and economic aspects and use high-resolution satellite data for more detailed analysis. Prior to practical implementation, field verification is required to ensure the accuracy of the identified zones, taking into account additional local parameters. The methods and findings of this study are not only useful for assessing suitable land in hilly areas, but also provide insight into the potential for the formation of microalgae industrial ecology in non-urban areas. Similar research methods are applicable in other regions, taking into account local geographical conditions and resources available therein.

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