SPATIAL CRITERIA FOR INDUSTRIAL AREA: SUSTAINABLE DEVELOPMENT STRATEGY IN SANGIRAN CULTURAL HERITAGE ZONE, GONDANGREJO DISTRICT

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ABSTRACT

Gondangrejo District is a suburb (peri urban) of Surakarta City with significant industrial growth in Karanganyar Regency. The driving factor of the development of the Gondangrejo District is the relocation of urban activities in Surakarta City. Gondangrejo District is an area of deconcentration of industrial activities because of its location directly adjacent to Surakarta City. A comprehensive site selection analysis is essential for industrial siting that supports sustainable builders. We select the optimal site for the industrial area by considering various criteria and inhibiting factors using GIS-based MCDA. Most suitable for industrial sites with GIS and AHP to build industries in The Gondangrejo District. This study aims to determine the most optimal industrial area by considering various appropriate criteria using multi-criteria decision analysis (MCDA) and geographic information system (GIS) methods. Based on the criteria used, namely proximity to roads, distance from rivers, distance from settlements, physiology, and population density with the same weight of 20%, a suitable location for the industrial area with a linear pattern or extending from east to west in the Gondangrejo District. Based on the same criteria with different weights from the results of the AHP analysis, suitable locations for industrial sites are Dayu Village, Rejosari Village, and Wonosari Village, which form a centering pattern. The study results found that the optimal industrial areas in Gondangrejo District are Dayu Village, Rejosari, and Wonosari. The results of the suitability of this industrial area can be used by decision-makers in the development planning of the Gondangrejo District.

Keywords: *Industrial area; MCDA; AHP.*

INTRODUCTION

Surakarta City impacts the surrounding area, including the Gondangrejo District. Characters of The peri-urban area is the change of non-built land into built-up land, so there is a crush on the city's physical appearance (Mataufani et al., 2020). Development in the Gondangrejo District area has led to excessive physical development since the start of the Solo-Kertosono Toll Road in 2013. The problem in the suburban area is incompatibility with spatial planning so that it becomes undirected and uncontrollable (Sari & Santoso, 2017). Undirected and uncontrolled development will be harmful to the preservation of nature.

Development in the Gondangrejo District area has led to excessive physical development since the start of the Solo-Kertosono Toll Road in 2013. The increase in industrial activity shows the development of the Gondangrejo District towards urban areas. The Planned of The Gondangrejo District is to become the Center of Trade and Industry of Karanganyar Regency (Rahmawati et al., 2019). Concentrated industry in The Gondangrejo District in the Solo-Purwodadi Road corridor and supported by a policy of allocating industrial locations in the western part (Sholihah et al., 2018). Industrial development is important to absorb the workforce (Nur, 2016). Industrial development is important to absorb the force. The main sector of the development of a region is through industrialization. Infrastructure investment is critical to successfully implementing change (Coutinho-Rodrigues et al., 2011). The Gondangrejo industrial area began to appear in the 1990s and started to overgrow in the 2000s, with the number of medium and large industries reaching 18 industries in 2003 and 42 industries in 2018 (Sholihah et al., 2018). Industrial growth is always accompanied by development in other sectors, so investment in the industry is a priority (Idrus & Hakim, 2018).

The development of industrial areas in the Gondangrejo District area began to be irregular, and not following the spatial allocation caused new problems that were quite complex. Industrial development in Gondangrejo District has led to the emergence of residential areas that are not only around the location but also around protected areas that have high accessibility (Sholihah et al., 2018). The solution to the problem of development irregularity is needed a system that can provide data cohesion where land is suitable for spatial data to be processed and perform analysis and calculations in helping to give decisions for the allocation of industrial spatial areas. Regional development must consider carefully and precisely in industrial location planning so that it is effective and efficient and considers existing factors to obtain an optimal location. (Idrus & Hakim, 2018).

Inhibiting factors are one of the factors in development planning. Disasters are one of the obstacles to development. Flooding is an obstacle to development in the Gondangrejo District. Population growth, economic development, and climate change will increase the impact of floods (Luu & von Meding, 2018). Development planning is needed to accommodate the growth of human activity so that it has resistance to flooding (Putra & Silfiana, 2020). A resilient city can adapt and or absorb disruption, and change, by reorganizing, maintaining the same basic structure, and providing the same services (Novita, 2020). Disaster risk is one of the considerations in development planning so that it can be prepared as a disaster-resistant building in the future.

This study aims to determine the most optimal location for industrial development in Gondangrejo District. The development of the industrial area is needed to encourage the growth of the industrial sector to become more focused, integrated and provide more optimal results. One way to determine industrial zones is to use Multi-Criteria Decision Analysis (MCDA). AHP uses a paired matrix to generate an appropriate alternative order of priorities (Han et al., 2020). Geographic Information Systems (GIS) emphasize inputs (data collection), process data, analysis, and outputs. GIS technology for planning is SDSS (Spatial Decision Support System) (Wibowo & Semedi, 2011). The core approach in this study is to integrate the Analytical Hierarchy Process (AHP) method with GIS mapping to determine MCDA to produce a map of the most suitable area for the industrial area. The combination will make the right decisions in spatial planning.

The balance of socioeconomic development and sustainable management of natural resources is one of the great challenges for science. As the urgency grows to balance and achieve the Sustainable Development Goals simultaneously, Effective strategies are needed to achieve food and water security, mitigate climate change, conserve biodiversity, and safeguard ecosystem services. The Karangnyar Regency Government needs to prepare an industrial site in the Gondangrejo

District with an optimal location for industrial sustainability.

MATERIALS AND METHODS

Method

GIS-MCDA is a widely used method for solving complex site selection problems. MCDA assists decision-makers by considering several criteria according to their importance. Site selection decisions made using GIS-MCDA are very suitable to be applied to industrial locations. GIS enables spatial decision-making using spatial analysis, such as proximity analysis and overlays. The MCDA method can also exclude unusable areas with limiting factors. The weighted sum method (WSM), as a simple method used in research, is applied by multiplying each raster layer by its specific weight and summing them (Kocabaldır & Yücel, 2023).

The MCDA technique determines the weight of the criteria in the overlay analysis. This study uses the AHP technique. AHP is widely used and easy to calculate (reference). Comparison of criteria in AHP applied by experts is by giving a number from 1 (same) to 9 (extreme), indicating one criterion's importance over another. The calculation of AHP will produce a weight. Illustrations of the GIS-MCDA workflow used in this study are served in **Figure 1.**

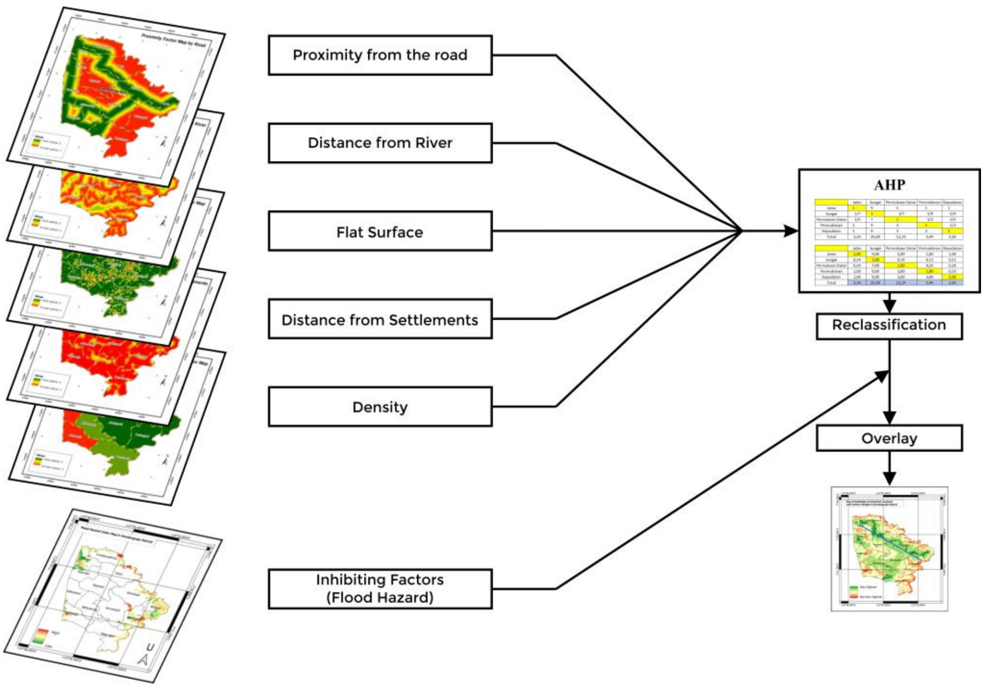

Figure 1. Research Method Flow

Data Collection Techniques

There are two types of data in the form of primary data and secondary data. Primary data is in the form of interviews with expert judgments from the Regional Planning Agency of Karanganyar Regency so that they are by existing conditions in the field. Secondary data from the image interpretation results in obtaining data on increasing land use (roads, rivers, and settlements), institutional data from the Central Statistics Agency (population density data), and flood hazard data from Inarisk. Details of the data used in this study are presented in **Table 1.**

Table 1. Data, Source, Resolution, and Type

Data	Source	Scale or Resolution	Type
Village Boundaries of Gondangrejo District	Digital Map of Indonesia	1:25.000	Vector/Line/Polygon
Land Use	Digital Map of Indonesia and Ikonos Imagery	1:25.000 and 10 meters	Raster/Vector/Polygon
Road Network	Digital Map of Indonesia and Ikonos Imagery	1:25.000 and 10 meters	Raster/Vector/Line
River Network	Digital Map of Indonesia and Ikonos Imagery	1:25.000 and 10 meters	Raster/Vector/Line
Slope	Hillshade Gondangrejo District	30 meters	Raster
Population	Badan Pusat Statistik	Jiwa	Number
Area	Badan Informasi Geospasial	Km^2	Number
Flood Hazard	Ina Risk	30 meters	Raster
Expert Judgement for Criterion Weighting	BAPPEDA Karanganyar Regency	-	Number

Criteria for Industrial Area

The data in this study were processed using QGIS software to conduct MCDA. The criteria are served in **Figure 2**. The following criteria used to determine industrial locations include:

Proximity from the Road: The road network is the main accessibility for industrial transportation in Gondangrejo (Sholihah et al., 2018).

Distance from River: The river border area is a protected area. Based on regulations, 50 meters on the left and right sides of the river are protected areas. The river functions for industry as a waste disposal site (Ulfa et al., 2017).

Flat Surface: Land suitable for industrial sites has a flat slope (Ulfa et al., 2017). Areas with slope data will be increasingly optimal for industrial sites.

Distance from The Settlements: Industry can potentially cause air pollution and confusion (Zaenuri, 2011). Industrial areas are more optimal to be built in locations far from settlements.

Density: Industrial locations far from densely populated areas can be an effort to reduce social conflicts that will occur (Wibowo & Semedi, 2011).

Inhibiting Factors (Flood Hazard): Industry must be free from flooding to minimize losses due to disasters. Industrial site planning is important to avoid potential disasters.

Each criterion for determining the location of the industry will be weighted using AHP. The study has two types of weighting: Uniform Weighting and Weighting using AHP. The weight is obtained through AHP using expert judgment, namely the Gondangrejo District Government. The following are the AHP calculation results and the normalization results of the five criteria that have been determined as industrial areas. The normalization results can be used to calculate CI and CR. Based on these five factors, it is known that the CI is 0.08325, and the CR is 0.0743. Based on this calculation, the data can be used because the CR is <0.1 or consistent. The weighting results using AHP are presented in **Table 2**.

Table 2. Criteria, Assumption, Uniform Weight, and Weighting Percentage.

Criteria	Assumption	Uniform Weight (%)	Weighting (%)
Proximity from the road	Locations close to roads have high industrial site potential, while locations far from the industry have no potential for industrial construction	20	30.598
Distance from River	The most optimal area to build an industrial area or have>100 meters from the river	20	2.2909
Flat Surface	The most optimal area is a relatively flat area and has a slope of <20%, while the least optimal area is an area with a relatively steep slope	20	22.261
Distance from Settlements	The farther the location of the industrial area from settlements, the more optimal it is for industrial construction	20	9.5807
Density	The most optimal area for industrial development is an area with a relatively low density	20	34.6503
Inhibiting Factors (Flood Hazard)	Areas with high flood hazards are increasingly not optimal for industrial areas.	Inhibiting Factor	Inhibiting Factor

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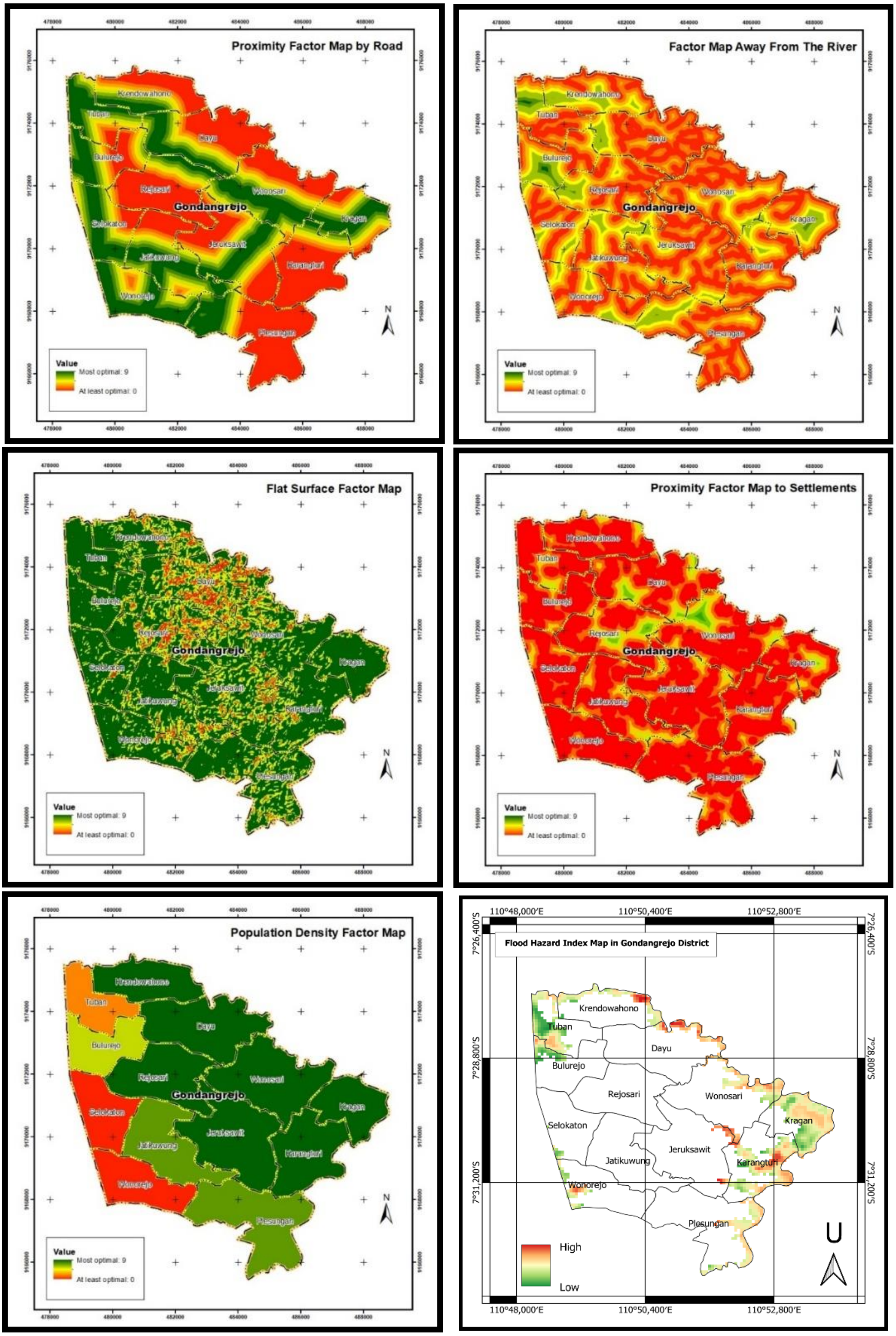

Figure 2. Criteria Map for Industrial Sites

RESULTS AND DISCUSSION

RESULTS

Suitability for Industrial Areas with Uniform Weighting

Suitability for industrial areas with a uniform weighting of Gondangrejo District is carried out with MCDA. The criteria used are Proximity from the road, Distance from the River, Flat Surface, Distance from Settlements, and Density of the same weight, which is 20%. There is an inhibiting factor, namely the danger of flooding. Inhibiting factors will reduce the optimization of industrial sites. Each of the weights for each criterion in the MCDA uniform weights is presented in **Table 2.**

The northern part is the optimal location distribution pattern for industries based on the data processing results in QGIS applications. Many factors make the suitability of industrial sites in the north optimal, including flat areas, far from rivers, far from settlements, and easy accessibility. The location pattern is optimal for the industry in Gondangrejo District, forming a linear or elongated pattern stretching from east to west in the north of Gondangrejo District. The optimal location distribution pattern is illustrated in Figure 3a. The extent of land suitability classes for the industry is presented in **Table 3.**

Table 3. Suitability for Industrial Sites in Gondangrejo District with Equal Weighting

No	Village	Suitability for Industrial Sites (ha)					Area (Ha)
		Very Not Optimal	Not Optimal	Medium	Optimal	Very Optimal	
1	Bulurejo	0	40.09	131.48	134.59	32.52	338.68
2	Dayu	9.57	83.80	256.05	155.61	95.43	600.46
3	Jatikuwung	0	8.21	158.05	322.80	7.14	496.19
4	Jeruksawit	0.18	13.37	260.73	378.12	12.85	665.25
5	Karangturi	7.46	178.41	192.60	82.20	14.06	474.73
6	Kragan	3.47	80.95	94.82	125.42	35.09	339.75
7	Krendowahono	14.43	74.01	123.76	124.81	46.51	383.52
8	Plesungan	33.55	172.48	279.29	136.60	46.28	668.19
9	Rejosari		14.13	242.03	224.71	25.33	506.19
10	Selokaton	0.0001	58.23	189.60	103.25	0.41	351.49
11	Tuban	1.16	77.85	127.31	83.43	6.87	296.62
12	Wonorejo	8.49	137.45	218.29	21.73	0.23	386.19
13	Wonosari	8.50	89.67	103.79	355.97	63.91	621.84
Total		86.81	1,028.65	2,377.79	2,249.25	386.62	6,129.12
Percentage (%)		1.42	16.78	38.80	36.70	6.31	100

Based on **Table 3,** The optimal location area for industry from MCDA results in Gondangrejo District is 6.31% or 386 ha spread across all villages in Gondangrejo District. The villages with the widest suitability for highly optimal industrial locations are Dayu Village (95.43 ha) and Wonosari Village (63.91 ha). The village that has no potential for industrial location is Plesungan Village, with a very non-optimal area of 33.55 ha and not an optimal area of 172.48 ha.

The medium class is dominated in The Gondangrejo District by the medium class to be industrial location, which is 2,377.79 ha (38.80%), and the optimal class is 2,249.25 ha (36.70%). The analysis results with uniform weighting show that Gondangrejo District can be used as an industrial location except in the periphery area because of the potential for flooding, making it less optimal for industrial sites.

Suitability for Industrial Areas with Weighting

The results of MCDA analysis for industrial sites in Gondangrejo District use different weights from uniform weightings. The distribution pattern of locations that are very optimal to be built has a centralized pattern where dominance only occurs in Dayu Village, Rejosari, and Wonosari. The distribution pattern is presented in **Figure 3b**.

Other districts also have optimal locations for industry, but only in a minimal area. The distribution of suitability for industrial sites that are not optimal in Gondangrejo District is in the suburbs and Selokaton Village. Villages in the south, namely Wonorejo and Plesungan Villages, also tend to be not optimal for industrial sites. The distribution of suitability of industrial sites in Gondangrejo District is presented in **Table 4.**

Table 4. Suitability for Industrial Sites in Gondangrejo District with Weighting

No	Village	Suitability for Industrial Sites (ha)					Area (Ha)
		Very Not Optimal	Not Optimal	Medium	Optimal	Very Optimal	
1	Bulurejo	0	81.55	163.11	94.02	0.00004	338.68
2	Dayu	0.76	64.19	274.14	197.13	64.25	600.47
3	Jatikuwung	0.001	71.49	142.47	279.17	3.07	496.19
4	Jeruksawit	0	7.74	343.14	309.59	4.79	665.25
5	Karangturi	0.48	189.44	222.44	57.37	5.02	474.73
6	Kragan	0.43	77.37	136.76	125.11	0.09	339.76
7	Krendowahono	7.72	91.73	159.63	123.75	0.69	383.53
8	Plesungan	46.39	325.24	145.06	151.46	0.05	668.19
9	Rejosari	0.001	3.80	347.71	123.18	31.50	506.19
10	Selokaton	8.70	104.47	238.21	0.11	0	351.50

No	Village	Suitability for Industrial Sites (ha)					Area (Ha)
		Very Not Optimal	Not Optimal	Medium	Optimal	Very Optimal	
11	Tuban	1.85	116.12	163.14	15.52	0.0001	296.62
12	Wonorejo	42.72	267.27	76.20	0.005	0	386.19
13	Wonosari	0.32	97.24	133.39	357.05	33.85	621.84
Total		109.37	1497.64	2545.39	1833.46	143.30	6129.15
Percentage (%)		1.78	24.43	41.53	29.91	2.34	100.00

The location is optimal for the industry by weighting based on **Table 4** in Gondangrejo District, only 2.34% of the area or 143 ha. The largest area is in Dayu Village, with 64.25 ha. Rejosari Village and Wonosari Village also have an optimal area of 31.50 ha and 33.85 ha. Factors that affect the optimal location are the dominance of proximity to roads and population density because these two criteria have the highest weight compared to other criteria (**Table 2**).

Comparison of Industrial Site Suitability with Uniform Weight and Weighting

Based on the results of the two simulations that have been carried out, there are very significant differences related to the distribution pattern of the suitability of industrial sites using uniform weights and weights. The results of the suitability of industrial locations with uniform weights in the Gondangrejo District tend to form a linear pattern or extend from east to west in the north for a very optimal location, while with weighting, a concentration pattern is obtained in Dayu, Rejosari, and Wonosari Villages (**Figure 3**).

The analysis results using uniform weights have a very optimal area wider than using weighting. Villages that have optimal classes for both simulations are Dayu Village and Wonosari Village.

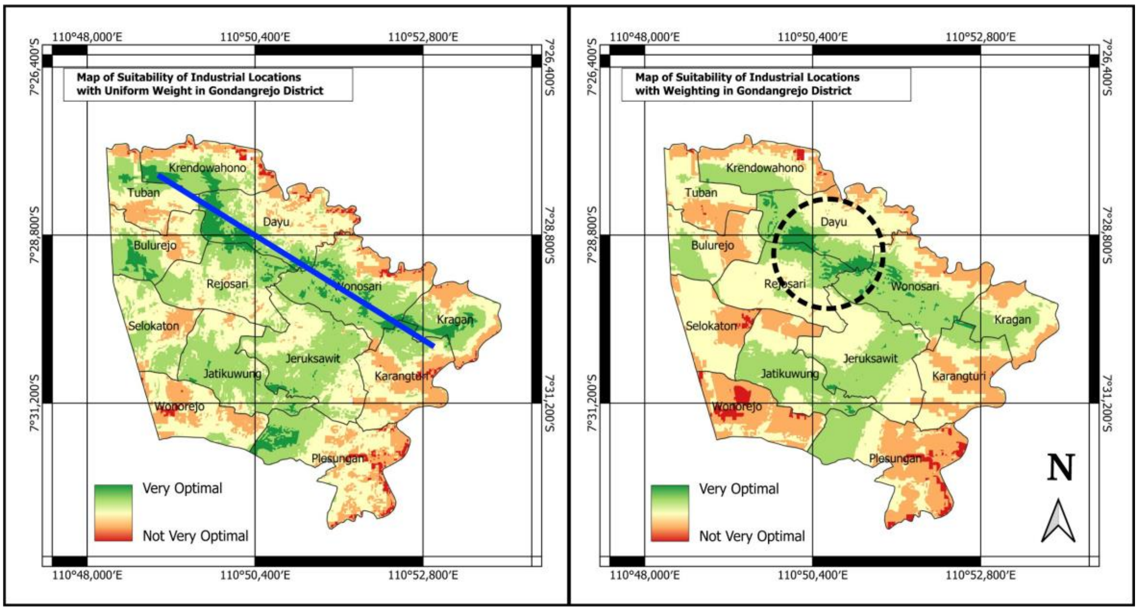

Figure 3. (a) Conformity Map for Industrial Site of Gondangrejo District with Uniform Weight; (b) Suitability Map for Industrial Site of Gondangrejo District with Weighting

DISCUSSION

Departing from a case study related to industrial area planning in the Gondangrejo district, an area affected by the development of Surakarta city, which highlights a new industrial area. The location of the new industry determination requires integration between SMCE and QGIS to get the most out of it.

Decentralizing industrial sites in peri-urban areas is a major challenge to achieving sustainable development in locations close to cultural heritage zones. This expansion requires technological knowledge, clear, comprehensive objectives, and correct governance schemes and monitoring protocols (Murcia et al., 2016).

The integration results will also be analyzed spatially to consider urban planning and obtain results in suitability maps to find optimal locations. Maps can communicate with various actors involved in decision-making. The decisions taken will also be more effective and efficient, and transparent. The MCDA method can provide alternative models and simulations that can provide confidence in the suitability of the region based on several aspects or factors (Wibowo & Semedi, 2011). MCDA can be a tool to evaluate or plan new industrial areas using existing criteria or add some new criteria in industrial area planning. Urban infrastructure investments are usually strategic and long-term. The benefits and costs of such investments are spatially distributed. Therefore, they affect various stakeholders differently (Coutinho-Rodrigues et al., 2011). Conformity maps can also be one solution related to differences of opinion of stakeholders where the language in the map is easily understood by anyone to resolve existing conflicts. The potential decrease in operational costs and the direct impact on decreasing demand is taken into account from other aspects (Feriyanto, 2017). The development of Gondangrejo industrial agglomeration is supported by several factors, including industrial location policy factors, ease of accessibility, support for regional infrastructure, labor accumulation, and proximity to market locations (Sholihah et al., 2018). The industrial agglomeration factor of Gondangrejo District is like determining the optimal location in the study, where controlling factors are used as the basis for determining the location of the industry.

CONCLUSIONS

Spatial Indicators of Priority Areas The industrial area system is an important tool to support, accelerate and scale industrialization in Gondangrejo District, which aims to prioritize areas for industrial locations considering the vulnerability of the natural environment of ecosystems in the implementation of development both as an instrument for economic growth and conservation of cultural heritage.

This study provides new insights on industrial siting in support of more integrative sustainable development between socioeconomic and environmental aspects.

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