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GIS-Based Weighted Overlay Analysis for Assessing the Potential of Bioretention and Rain Gardens for Stormwater Management

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ABSTRACT

The increase in built-up areas in the Dr. Cipto Mangunkusumo Street Corridor in Cirebon City has caused a lack of water absorption areas, thus increased surface runoff and potentially caused puddles. This condition indicates the need for the implementation of green infrastructure as an effort to manage rainwater sustainably. This study aims to analyze the potential for implementing Bioretention and Rain Garden based on the level of land suitability in the research area. The method used is a spatial quantitative method with primary data from field observations and secondary data obtained from BPBD, PUPR, and BIG. The analysis was carried out using a Geographic Information System (GIS). Land suitability analysis uses the Weighted Overlay method based on land use parameters, soil type, and slope gradient. The results show that the Dr. Cipto Mangunkusumo Street Corridor in Cirebon City is dominated by trade and service areas with a fairly high level of runoff. Based on the Weighted Overlay analysis, most of the research area is included in the suitable class for the implementation of Bioretention and Rain Garden. The application of both types of green infrastructure has the potential to reduce surface runoff, increase infiltration and support sustainable urban drainage management in Cirebon City.

1. Introduction

Although numerous studies have investigated the application of bioretention systems and rain gardens for urban stormwater management, most have primarily focused on evaluating their hydrological performance or engineering design [1], [2], [3]. Studies that specifically assess land suitability for their implementation using a Geographic Information System (GIS)-based Weighted Overlay approach remains limited, particularly at the urban



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corridor scale in Indonesia [4], [5]. Furthermore, no previous study has comprehensively integrated land use, soil type, and slope to identify priority locations for implementing these green infrastructure practices along the Dr. Cipto Mangunkusumo Street Corridor in Cirebon City [5], [6].

The Dr. Cipto Mangunkusumo Street Corridor was selected as the study area because it is one of the city's principal urban corridors, characterized by intensive commercial, residential, educational, and public service activities. Rapid urban development has increased the proportion of impervious surfaces, reduced natural infiltration capacity and contributed to higher surface runoff and recurring waterlogging during rainfall events [7], [8], [9], [10]. These characteristics make the corridor an appropriate case study for evaluating the spatial potential of green infrastructure to support sustainable stormwater management.

This study contributes by integrating land use, soil type, and slope within a GIS-based Weighted Overlay framework to produce a spatial land suitability assessment for bioretention systems and rain gardens. The resulting suitability map provides a scientific basis for identifying priority locations for green infrastructure implementation and offers spatial decision-support information for sustainable urban stormwater management in Cirebon City [5], [6].

2. Research Method

This study employed a quantitative research approach supported by spatial analysis using a Geographic Information System (GIS) as the primary analytical tool [4], [5]. Primary data were collected through field observations to verify existing site conditions, while secondary data consisted of Google Earth imagery (2026), soil type data from the Geospatial Information Agency (BIG), drainage and supporting spatial data from the Cirebon City Public Works and Spatial Planning Agency (PUPR).

All spatial datasets were projected using the WGS 1984 UTM Zone 48S coordinate system to ensure spatial consistency. Prior to the analysis, the datasets underwent preprocessing, including image interpretation for land use mapping, clipping to the study area boundary, coordinate system standardization, raster conversion, and reclassification based on the predefined scoring criteria. Land suitability was subsequently assessed using the Weighted Overlay method by integrating land use, soil type, and slope parameters according to their assigned scores and weights [5]. The resulting weighted overlay values were then classified into land suitability classes to identify priority locations for implementing bioretention systems and rain gardens within the study area [2], [6].

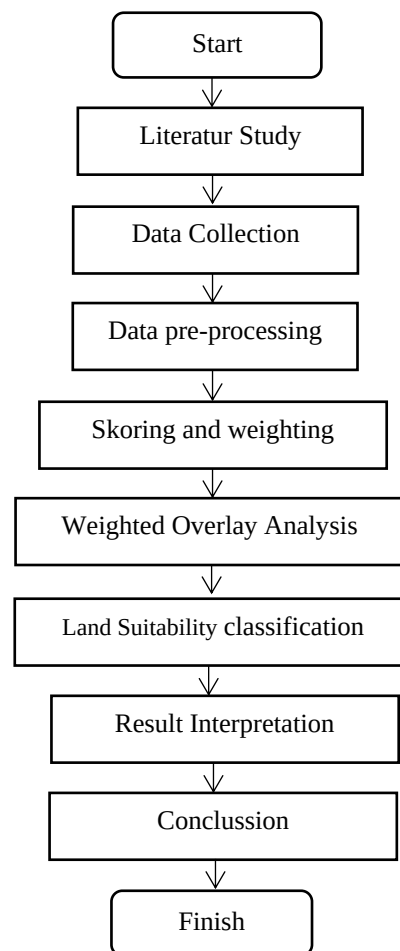


Figure 1. Research Flowchart

3. Description and Technical

1. Population and Samples.

The study area covered the Dr. Cipto Mangunkusumo Street Corridor in Cirebon City, extending approximately 1.8 km. For spatial analysis, the corridor was divided into three segments based on differences in land use characteristics and existing site conditions. Each segment served as the spatial unit of analysis for evaluating land suitability for bioretention systems and rain gardens.

2. Sampling Techniques.

The study area was selected using purposive sampling, a non-probability sampling technique that allows researchers to intentionally select locations with characteristics relevant to the research objectives [11]. The Dr. Cipto Mangunkusumo Street Corridor was selected based on the following criteria: (1) the corridor frequently experiences waterlogging during rainfall events, (2) it is characterized by intensive urban land use, including commercial, residential, educational, and public service activities, (3) it contains a high proportion of impervious surfaces that increase surface runoff, and (4) it provides representative physical characteristics for evaluating the spatial suitability of bioretention systems and rain gardens [11], [9].

3. Operational Definition of Variables

The operational variables used in this study consisted of land use, soil type, and slope. Each variable was represented by specific indicators and assigned suitability scores based on

established criteria. The variables were subsequently weighted according to their relative influence on the implementation of bioretention systems and rain gardens. The operational definitions, indicators, scoring system, weighting scheme, and corresponding references are presented in Table 1.

The weighting scheme was adopted from the Sustainable Technologies Evaluation Program (STEP) – Low Impact Development Stormwater Management Planning and Design Guide and adapted to the physical characteristics of the study area. Soil type was assigned the highest weight (40%) because it directly controls infiltration capacity. Slope was assigned a weight of 35% due to its influence on runoff velocity and infiltration potential, while land use was assigned 25% because it affects the extent of impervious surfaces and the availability of space for implementing bioretention systems and rain gardens.

Table 1. Scoring and Weighting of suitability parameters [12] [13].

Parameter	Criteria	Score	Weight
Land Use	Dense residential	1	25%
	Sparse settlement / mixed area	2	
	Parking area	3	
	Minimal green open space	4	
	Open green space	5	
Soil Type	Regosol, Litosol, Organosol, Renzina	1	40%
	Andosol, Laterit, Grumosol, Podsolik	2	
	Brown Forest Soil, Non-Calcic	3	
	Brown, Mediteran	4	
	Aluvial, Tanah Gleii, Planosol,	5	
Slope	>45%	1	35%
	25-45%	2	
	15-25%	3	
	8-15%	4	
	0-8%	5	

Source: Adapted and processed by the author based on Presidential Decree of the Republic of Indonesia No. 32 of 1990 concerning Management of Protected Areas, Sustainable Technologies Evaluation Program (STEP) – LID SWM Planning and Design Guide

Table 2. Land Suitability classification for the Implementation of Bioretention System and Rain Gardens

Score Range	Suitability Class
4,2 – 5,0	Highly Suitability
3,4 – 4,1	Suitable
2,6 – 3,3	Moderately Suitable
1,8 – 2,5	Less Suitable

Source: Sustainable Technologies Evaluation Program (STEP) — LID SWM Planning and Design Guide[14]

Land suitability classes were established using the Equal Interval classification method. This approach divides the range of Weighted Overlay scores into four classes with equal interval widths, ensuring a consistent and systematic classification of land suitability. Based on the resulting score distribution, the suitability values were classified into Less Suitable (1.8–2.5), Moderately Suitable (2.6–3.3), Suitable (3.4–4.1), and Highly Suitable (4.2–5.0). The Equal Interval method was selected because it provides a simple, objective, and consistent framework for interpreting land suitability levels derived from the Weighted Overlay analysis, thereby facilitating the identification of areas with varying potential for the implementation of bioretention systems and rain gardens.

4. Instrument Analysis Tool.

Spatial analysis was performed using ArcGIS 10.8 and the Weighted Overlay method. The analysis was supported by land use maps, soil type maps, slope maps, field observation data, and field documentation [5].

5. Data Analysis Techniques.

Land suitability was evaluated using the Weighted Overlay method within a Geographic Information System (GIS) [5]. The analysis integrated three parameters land use, soil type, and slope to determine their combined influence on the suitability of bioretention systems and rain gardens. Scores and weights were assigned to each parameter according to their contribution to rainwater infiltration [2]. The resulting suitability map was classified into four categories: unsuitable, less suitable, suitable, and highly suitable. These categories were used to identify areas with the greatest potential for implementing bioretention systems and rain gardens along the Dr. Cipto Mangunkusumo Street Corridor in Cirebon City [6].

4. Result and Discussions

Land use analysis revealed that the Dr. Cipto Mangunkusumo Street Corridor is predominantly occupied by commercial and service areas, residential neighborhoods, educational facilities, and public facilities. The predominance of built-up land reduces the natural infiltration capacity of the area, thereby increasing the potential for surface runoff during rainfall events [7], [8]. Field observations also identified several locations experiencing temporary waterlogging during periods of intense rainfall, indicating the need for improved urban stormwater management to address existing drainage issues [9], [10], [15].

As presented in Table 3, the Suitable class constitutes the largest proportion of the City of Cirebon, accounting for 69.10% (2,727.65 ha) of the total area. The Highly Suitable class covers 765.93 ha (19.40%), while the Moderately Suitable and Less Suitable classes represent 11.14% (439.68 ha) and 0.37% (14.42 ha), respectively. This distribution indicates that the physical characteristics of most areas within the city are favorable for the implementation of bioretention systems and rain gardens, thereby providing substantial opportunities for the development of green infrastructure to support sustainable stormwater management.

To further assess the study area, the city-wide land suitability map was evaluated within a 100 m buffer on both sides of the Dr. Cipto Mangunkusumo Street Corridor. The results indicate that the entire corridor, covering 41.17 ha, is classified as Suitable, representing 100% of the study area. This demonstrates that the corridor possesses appropriate physical conditions for implementing bioretention systems and rain gardens, particularly with respect to land use compatibility, soil characteristics, and relatively gentle slopes. Consequently, the corridor represents a promising location for the application of green infrastructure to enhance urban stormwater management.

Overall, the findings demonstrate that integrating land use, soil type, and slope through the Weighted Overlay approach provides a reliable basis for identifying suitable locations for green infrastructure development [6], [16]. These findings are consistent with previous studies demonstrating that Geographic Information Systems (GIS) integrated with

multi-criteria spatial analysis provide an effective framework for identifying suitable sites for green infrastructure development [5], [17]. Therefore, the outcomes of this study may serve as a scientific basis for supporting planning decisions related to the implementation of bioretention systems and rain gardens along the Dr. Cipto Mangunkusumo Street Corridor, contributing to more sustainable urban stormwater management.

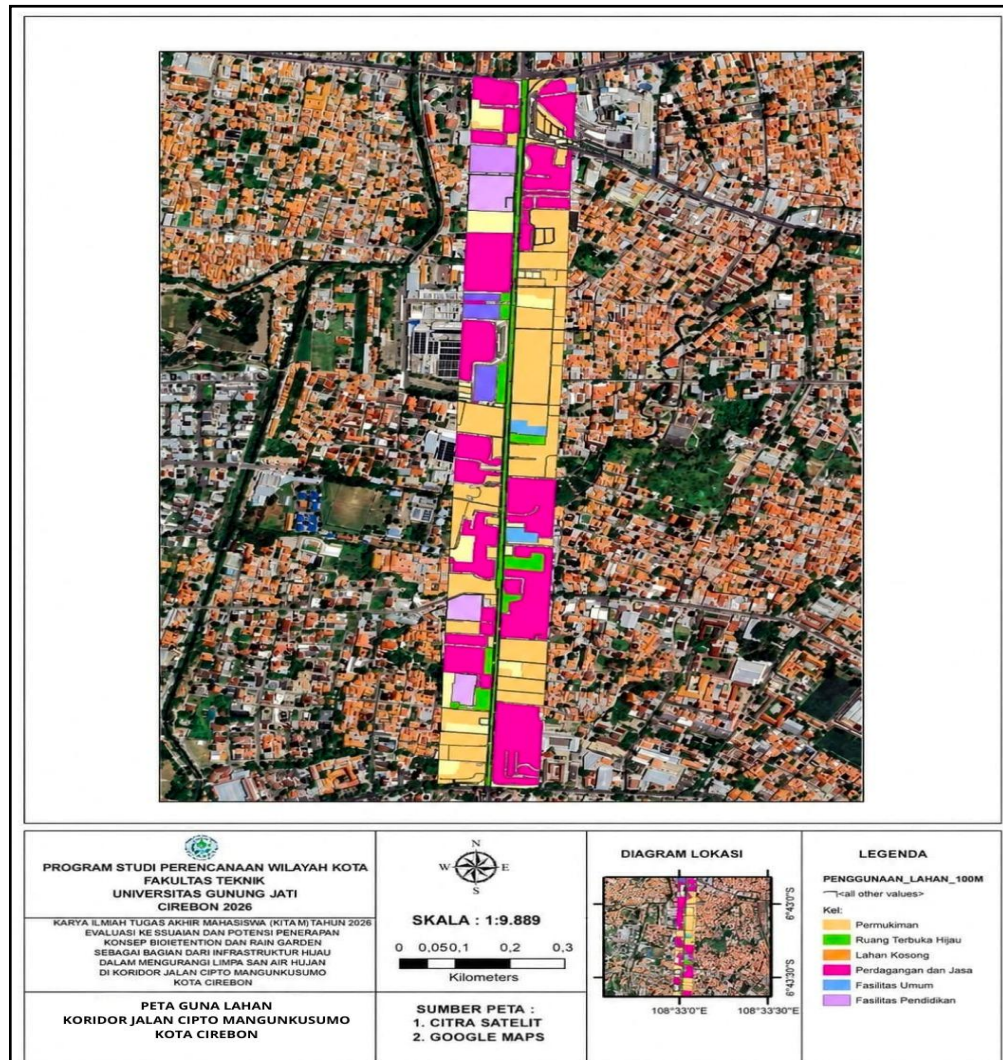


Figure 2. Land Use Map of the Dr. Cipto Mangunkusumo Street Corridor, Cirebon City

Based on Figure 1, land use within the Dr. Cipto Mangunkusumo Street Corridor is predominantly characterized by commercial and service areas, residential neighborhoods, educational facilities, and public facilities [18]. The predominance of built-up land reflects the high intensity of urban activities within the corridor, which has consequently reduced the extent of permeable surfaces available for rainwater infiltration. As a result, the area is more susceptible to surface runoff during rainfall events, particularly in locations dominated by impervious surfaces.

Despite the high proportion of built-up land, several sections of the corridor still contain open spaces that may accommodate the implementation of bioretention systems and rain gardens. Accordingly, land use was considered one of the key parameters in the land suitability assessment using the Weighted Overlay method. The results of this analysis were

subsequently integrated with soil type and slope data to determine the overall land suitability for the proposed green infrastructure within the study area.

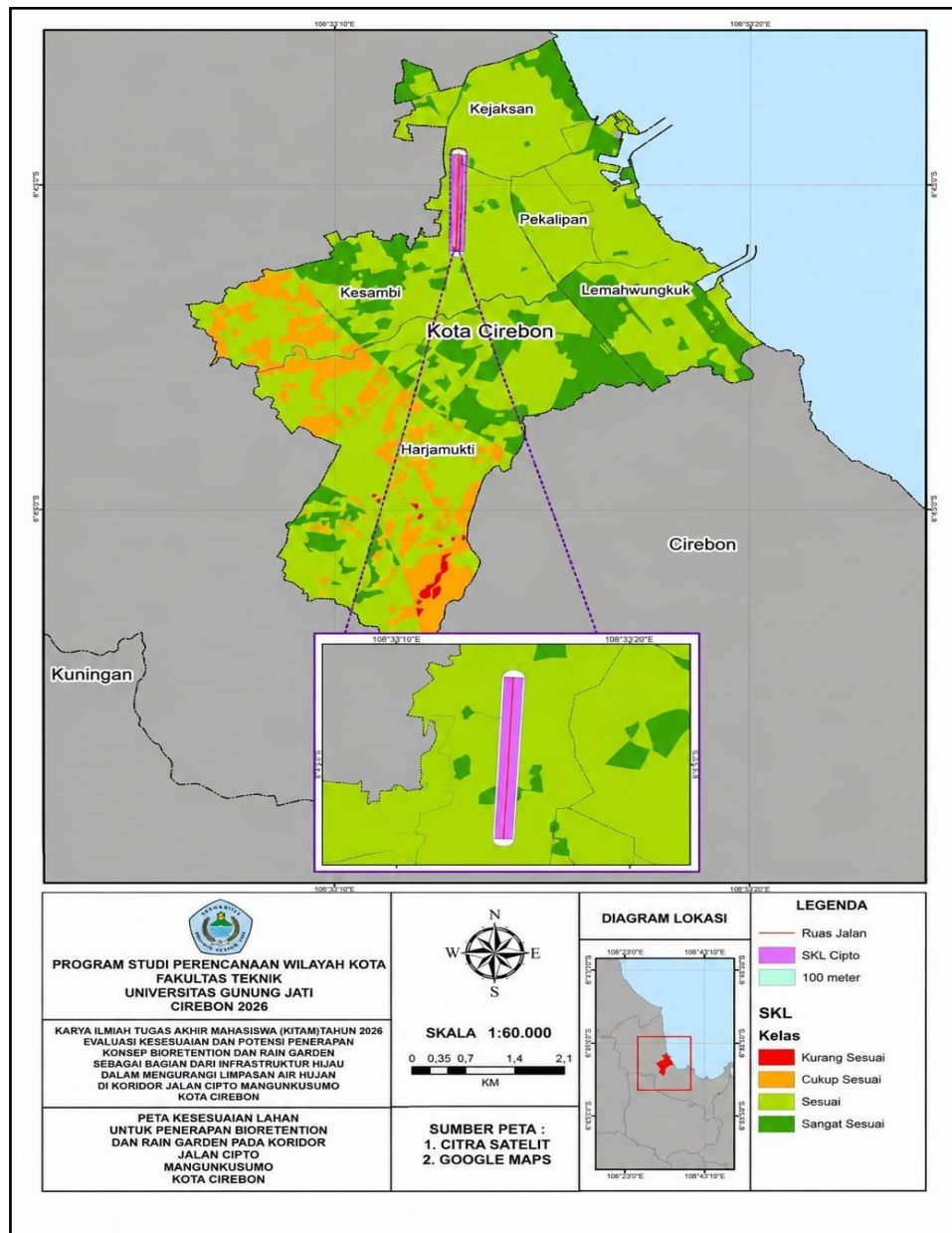


Figure 3. Land Suitability Map for the Implementation of Bioretention and Rain Gardens

Table 3. Land Suitability Classification in the city of Cirebon

Suitability Class	Area (Ha)	Percentage (%)
Highly Suitable	765.93	19.4
Suitable	2727,65	69.1
Moderately Suitable	439,66	11.14
Less Suitable	14,42	0.37
Total	3947.68	100

Source: Sustainable Technologies Evaluation Program (STEP) — LID SWM Planning and Design Guide)[14]

Based on Figure 2, the Weighted Overlay analysis identified several land suitability classes for the implementation of bioretention systems and rain gardens along the Dr. Cipto Mangunkusumo Street Corridor. The suitability classification was derived by integrating three key parameters land use, soil type, and slope each of which was assigned a score and a weight according to its contribution to rainwater infiltration.

The analysis indicated that most of the study area falls within the suitable category, while several locations were classified as less suitable or highly suitable. These variations reflect the differences in the physical characteristics of each location. Areas with more open land, favorable soil conditions, and relatively gentle slopes generally exhibited higher suitability than locations dominated by dense built-up areas or constrained by less favorable physical conditions[7]. These findings suggest that several parts of the corridor offer promising opportunities for the implementation of bioretention systems and rain gardens to enhance rainwater infiltration, reduce surface runoff, and support more sustainable urban drainage management [2], [12].

These findings indicate that land suitability is influenced by the combined effects of land use, soil type, and slope conditions within the study area [19]. Areas classified as suitable and highly suitable provide more favorable conditions for the implementation of bioretention systems and rain gardens due to their greater potential to enhance rainwater infiltration and reduce surface runoff [1], [12], [15]. Therefore, the land suitability map generated through the Weighted Overlay analysis can serve as a reference for identifying priority locations for green infrastructure implementation along the Dr. Cipto Mangunkusumo Street Corridor. The application of these practices is expected to improve urban stormwater management while supporting a more sustainable and resilient urban environment [20].

5 Conclusion and Suggestion

5.1 Conclusion

This study demonstrates that a GIS-based Weighted Overlay approach provides a systematic and reliable framework for evaluating land suitability for the implementation of bioretention systems and rain gardens in urban environments. By integrating land use, soil type, and slope as key physical parameters, the approach generates spatial information that can support evidence-based planning and decision-making for green infrastructure development.

Beyond its methodological contribution, this study also offers practical value for urban planning. The findings may serve as a reference for the Government of Cirebon City in identifying priority locations for the implementation of bioretention systems and rain gardens as part of sustainable stormwater management strategies. The proposed approach can support efforts to improve urban drainage performance, reduce surface runoff, and strengthen the integration of green infrastructure into future urban development.

Nevertheless, several limitations should be acknowledged. The land suitability assessment was based solely on three physical parameters, namely land use, soil type, and slope. Other factors that may influence the effectiveness of green infrastructure, including drainage capacity, groundwater conditions, and hydrological characteristics, were beyond the scope of this study. Therefore, the results should be interpreted as an assessment of physical land suitability rather than a direct evaluation of hydrological performance.

Future research should incorporate hydrological modeling, such as the Storm Water Management Model (SWMM), to assess the effectiveness of bioretention systems and rain gardens under different rainfall conditions. Integrating additional hydrological parameters, including rainfall characteristics and drainage capacity, would provide a more comprehensive basis for planning and implementing green infrastructure in urban areas.

5.2 Suggestion

Future studies are recommended to validate the land suitability results through field verification and hydrological simulation using the Storm Water Management Model (SWMM) to evaluate the effectiveness of bioretention systems and rain gardens in reducing surface runoff. In addition, integrating rainfall characteristics, drainage network capacity, and other hydrological parameters into the GIS-based Weighted Overlay analysis would provide a more comprehensive assessment of suitable locations. Such improvements are expected to support more effective planning and implementation of green infrastructure in Cirebon City.

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