Landscape Suitability Analysis for Developing a Framework of Green Infrastructure Protection in Bandung Basin Area, Indonesia

Widyastri A. Rahmy[1], Thomas Hoctor[2]

[1]University of Florida, Florida/USA · wrahmy@ufl.edu
[2]University of Florida, Florida/USA

Abstract: GIS-based landscape suitability analysis is a useful approach in the practices of urban design, planning, and management, especially for developing future land use, which includes the identification of land suitable for green infrastructure protection. We explored applying a multi-criteria decision analysis through GIS-based suitability tools to create a combined criteria map for developing a green infrastructure protection plan in Bandung Basin Region, Indonesia. We used two overlay techniques, the Weighted Sum Overlay and the Fuzzy Overlay. Both approaches aided the land suitability identification process for developing a green infrastructure plan in the region based on proposed objectives. Results showed that both cities of the region were predominantly built areas while the other three regencies were mostly vegetated open space, which suggested that the outer urban areas offered more opportunities to develop a green infrastructure protection plan. We also identified the key issues for future improvement of the overlay techniques application to help inform the planning and design process.

Keywords: Landscape suitability, geodesign, green infrastructure, urban greenspace protection, bandung basin

1 Introduction

Urbanization, followed by loss of greenspace and other natural or semi-natural areas, has altered the urban environment's quality through an extensive land cover conversion. A predominantly impervious surface, as well as poorly connected urban natural or semi-natural patches, significantly degraded the quality and services provision of urban ecosystems. This was especially true regarding the water cycle and urban micro-climate regulation, pollution and flooding control, urban wildlife habitat provision, and cultural services such as recreation, education, and social functions of greenspace. These changes challenged the urban environment's resilience and brought up questions about how landscape planning and design could help mitigate such effects through green infrastructure planning (BENEDICT and MC MAHON 2006, MELL 2014). Green infrastructure is defined as a network of connected greenspaces to serve both ecological and social functions (BENEDICT and MC MAHON 2006). This concept had often been identified as an approach to integrating conservation and development in landscape planning. It can be applied at various spatial scales, from urban to regional landscapes (BENEDICT & MC MAHON 2006).

In this paper, we aim to explore and report on the application of landscape suitability analysis and interpretation as part of the foundation for developing future green infrastructure planning scenarios for the study region. It is part of a research project focusing on integrating green infrastructure protection in land-use plans at the scale of urban regions. Green infrastructure protection, which consists of conservation of existing greenspace and, whenever possible, provision of new greenspace, is a critical approach to conservation and development balance (BENEDICT & MC MAHON 2006, GORDON et al. 2009) to enhance the resilience of

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urban landscape. However, this approach's integration in the urban plans needs further exploration, especially for application in rapidly changing and high-density urban regions. It becomes necessary to assess future green infrastructure protection opportunities beyond administrative boundaries to develop an integrated green infrastructure planning framework that ensures future conservation of the urban regions.

The concept of urban regions (FORMAN 2008) is adopted to identify potential greenspace patches, corridors, and matrices within the study region and assess them as the base elements for developing future green infrastructure protection scenarios. The evolving geodesign framework (STEINITZ 2012) and GIS technology (MALCZEWSKI 2004) allow us to explore the application of multi-criteria decision analysis (ROMANO et al. 2015). We utilized the GIS-based suitability functions using two overlay techniques (MALCZEWSKI 2004): Weighted Sum Overlay and Fuzzy Overlay. We then interpreted what the results might inform the green infrastructure planning and design process.

2 Methods, Analysis, and Results

2.1 Study Region and Materials

The study region of this research is Bandung Basin Area, or also known as Bandung Metropolitan Region, in Indonesia. The region (Fig. 1) consists of two cities: Bandung City and Cimahi City as the central urban areas. The region also includes three regencies: Bandung Regency, West Bandung Regency, and parts of Sumedang Regency as the outer urban (suburban and rural) areas. All data used in this study were retrieved from the Indonesia Geospatial Portal website (https://tanahair.indonesia.go.id, accessed June 6, 2019) in the form of a GIS-based shapefile format. Each administrative area has its own large sets of raw data, therefore a series of data cleaning and grouping was required. The process included projection, merging each data from all five regions into one dataset of the overall study region, data conversion to raster-based format, and data features recategorization. While the datasets were digitized based on the mapping process in 1998, they were visually verified using the region's latest aerial maps provided by ArcGIS. A general field survey of Bandung City in 2019 was used as a reference for other areas outside the city.

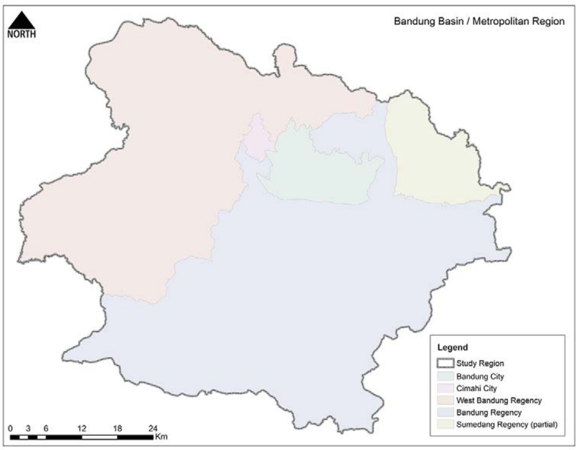

Fig. 1: Study Region

Five maps were used as base data for analysis, including elevation map and slope map (generated from DEM of the region), land cover map and surface water body map (generated from geomorphology map of the region), and roads and railways maps. These maps were included since representing the region's main physical, ecological, and urban characteristics: a basin surrounded by mountains and formed by multiple watersheds and a rapidly urbanized metropolitan. Using these basic maps to create multi-criteria suitability surfaces, we expected to identify potential areas to develop future green infrastructure and protect existing ones.

2.2 Suitability Maps for Green Infrastructure Protection Objectives

The first step of analysis was to create individual suitability maps based on selected green infrastructure protection objectives. The first objective was to conserve areas with an elevation of 750 meters and higher per regional rule. The second objective was to protect areas with a slope of 30% or higher. The third objective was to protect existing greenspace such as forests, parks, and other vegetated areas, also to seek potential areas to develop new green infrastructure. The fourth objective was to protect and conserve buffer areas or floodplains of water bodies, including dams and lakes, rivers, and creeks. The fifth objective was to protect buffer areas of main roads and railways as potential street trees and open space corridors. The datasets were analyzed using ArcGIS functions, including slope, distance, and reclassification, to assess their suitability value in terms of the objectives. The results were then reclassified into a range of values between 1 (one) to 9 (nine), with nine being the most suitable and one being the least suitable for the objectives (Table 1).

Table 1: Suitability scale of each dataset for the green infrastructure protection objectives

No	Objectives	Approach	Scale
1.	To protect areas with an elevation of 750 meters and higher	Reclassification	9: > 1,500 meters (m); 7: 750-1,500 m; 5: 625-750 m; 3: 500-625 m; 1: < 500 m
2.	To protect areas with a 30% slope or higher	Slope	9: > 30%; 7: 15-30%; 5: 8-15%; 3: 2-8%; 1: 0-2%
3.	To protect existing greenspace and seek potential areas for new green infrastructure	Reclassification	9: Forest Area; 7: Non-forest Vegetated Area; 5: Agriculture Area; 3: Water Surface; 1: Built Area / Sand Surface
4.	To protect surface water buffer or floodplain	Distance Reclassification	Dams and big rivers: 9: 100 m; 8: 200 m; 7: 300 m; 1: >300 m Small rivers: 9: 50 m; 8: 100 m; 7: 150 m; 1: >150 m Creeks: 9: 30 m; 8: 60 m; 7: 90 m; 1: >90 m
5.	To protect main roads and railways buffer areas	Distance Reclassification	Railway buffer: 9: < 50 m; 1: > 50 m Roads buffer: 9: < 25 m; 1: > 25 m

The next step was to combine the individual suitability maps into one map. We explored two approaches in creating the combined suitability surfaces for the overall suitability value to develop a green infrastructure plan: (1) the Weighted Sum Overlay approach and (2) the Fuzzy Overlay approach. Both techniques were performed in ArcGIS.

2.3 Combined Suitability Map with Weighted Sum Overlay Analysis

Weighted Sum Overlay analysis allows us to combine multiple rasters (or objectives) with specifically assigned weights for each to create an overall suitability surface. This analysis applied five alternatives to weight values assignment with the total value of all objectives equal to 1 (Table 2). The first alternative was an equal weight of 0.20 across all five objectives (Figure 2). The second alternative was weighted more towards protecting surface water buffer or floodplain with weight 0.40. The third alternative was weighted more towards the protection of existing greenspace. The fourth alternative was weighted more towards the topography-based (elevation and slope) area conservation with a total weight of 0.55. The fifth alternative was weighted more towards the protection of roads and railways buffer areas.

Table 2: Weighted value assignment for the Weighted Sum Overlay alternatives

No	Objectives	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5
1.	Protection of areas with elevation of 750 meters and higher	0.20	0.15	0.15	0.275	0.15
2.	Protection of areas with 30% slope or higher	0.20	0.15	0.15	0.275	0.15
3.	Protection of existing greenspace and potential provision of new green infrastructure	0.20	0.15	0.40	0.15	0.15
4.	Protection of surface water bodies buffer or floodplain	0.20	0.40	0.15	0.15	0.15
5.	Protection of main roads and railways buffer areas	0.20	0.15	0.15	0.15	0.40

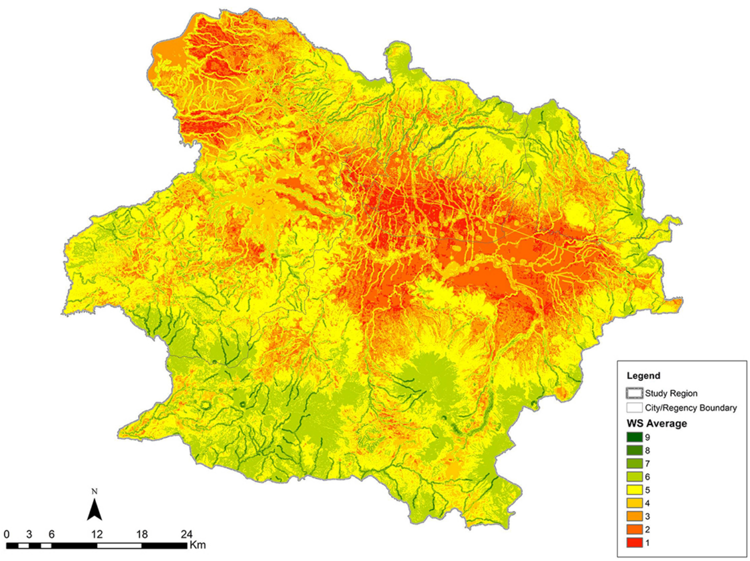

Fig. 2: Combined suitability map using Weighted Sum Overlay approach with an equal weight of 0.20 for each of five objectives (Alt. 1)

The combined suitability surface with equal weights (Figure 2) showed that the higher priority (value range 7-9) was located on some segments of the surface water buffer areas. A more moderate priority (value range 5-6) was located on existing mountainous areas and agricultural lands. A large portion of the study region can be considered less or not suitable (value range 1-4) for developing a green infrastructure plan. As a comparison, the map on the left in Figure 3 illustrates the Weighted Sum Overlay result for the second alternative weighting. A higher priority was given to all buffer areas of the surface water bodies. The map on the right in Figure 3 illustrates the third alternative weighting result in which a higher priority was more equally distributed to existing forests, other vegetated areas, partial agricultural lands, and surface water buffers.

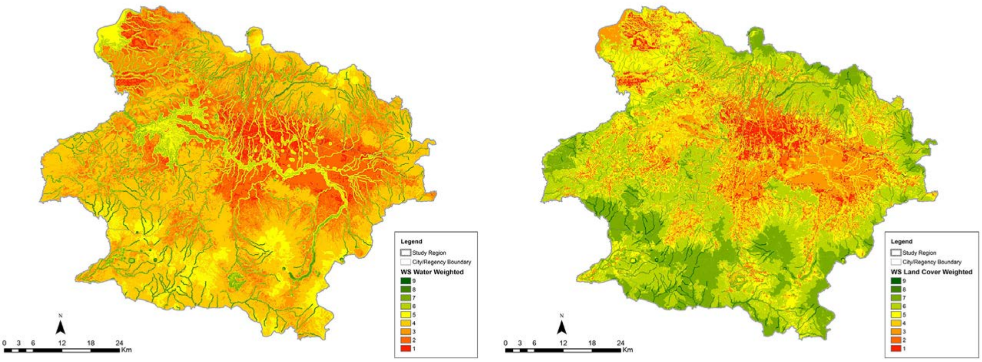

Fig. 3: Comparison of combined suitability map using Weighted Sum Overlay approach with weighted towards Objective 4 (Alt. 2 – left); and weighted towards Objective 3 (Alt. 3 – right)

2.4 Combined Suitability Map with Fuzzy Overlay Analysis

Besides applying the Weighted Sum Overlay analysis, we also explored the possibility of using Fuzzy Overlay analysis to generate a better-combined suitability map of multiple objectives. The traditional suitability approach assigned the weights of objectives in a numerical form, which often disregarded the level of importance of the objectives themselves (MALCZEWSKI 2004). The fuzzy logic approach offered a way to address this issue and gave place for imprecision in the land-use suitability analysis (MALCZEWSKI 2004). In this paper, the Fuzzy Gamma method was used to combine all objectives in five alternatives with Gamma values of 0.10, 0.25, 0.50, 0.75, and 0.90 assigned for each. Before applying the Fuzzy Overlay function, we first transformed each objective-based suitability model with the Fuzzy Membership function to rescale the value of 1-9 into 0-1. However, the Fuzzy binary value range works opposite to the objective-based suitability value range. In the objective-based suitability models, the value of 9 indicates the most suitable, while 1 indicates the least suitable instead of the other way around. Therefore, in the Fuzzy Membership models, the value of 1 implies the least suitable instead of being the most suitable.

After having all objective-based suitability models transformed into Fuzzy Membership models, we performed the Fuzzy Overlay analysis to combine all of the outputs using the Gamma method. We generated seven models by applying Gamma values of 0.00, 0.10, 0.25, 0.50, 0.75, 0.90, and 1.00. In this case, the model with a Gamma value of 0.00 showed the 'total' suitability values of all combined criteria, while the model with a Gamma value of 1.00 showed the 'multiplied' values of all combined criteria, therefore less than any of the input criteria. The model with a Gamma value of 0.50 represented equal importance of relationship among all combined criteria. This model (Figure 4) showed the higher priority (smaller values) to be distributed on some segments of surface water buffer areas, followed by the buffer area of roads and railways, and lastly the green areas on mountains. As a comparison, Figure 5 showed the models with Gamma values 0.10 (left) and 0.90 (right). The model with Gamma value 0.10 showed a higher priority to be more expansively distributed, including on the area of surface water bodies and their surroundings. Conversely, the model with Gamma value 0.09 showed a higher priority to be less distributed throughout the region, while areas with lower priority or less suitability were more expanded.

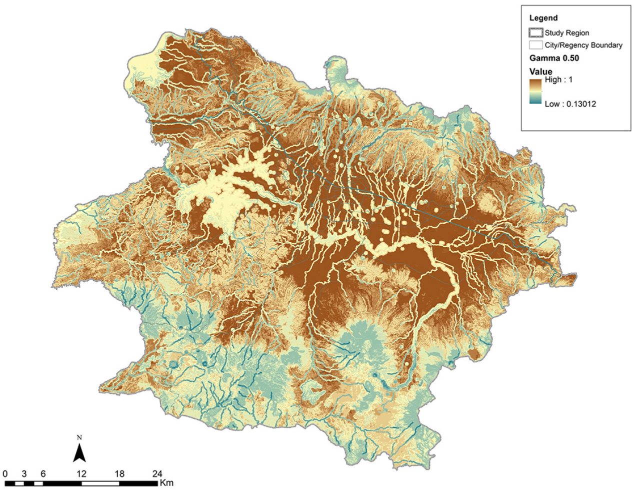

Fig. 4: Combined suitability map using Fuzzy Overlay approach with a Gamma value of 0.50, representing equal importance across all objectives

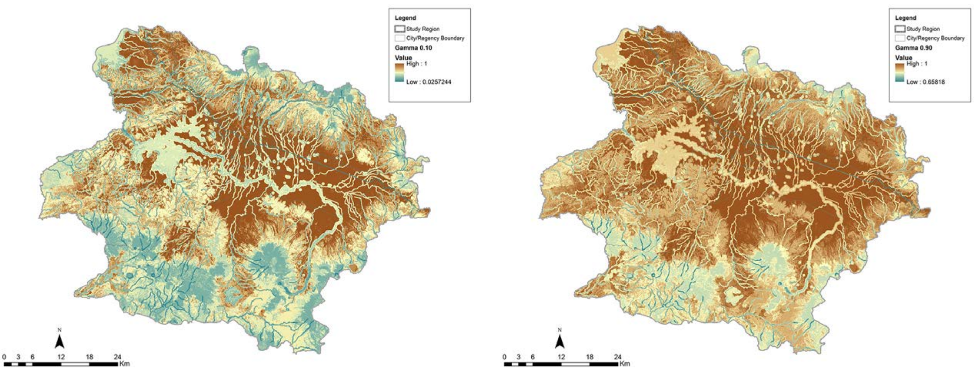

Fig. 5: Comparison of combined suitability maps using Fuzzy Overlay approach with Gamma values of 0.10 (left) and 0.90 (right)

3 Discussion

The purpose of having the GIS-based suitability analysis performed using the overlay functions reported in this paper was to explore its application in creating a combined criteria map for developing a green infrastructure plan, particularly in the Bandung Basin Region. A multi-criteria analysis approach was considered useful for this goal as it could provide relatively objective reasoning to determine priority for future green infrastructure planning. Two key issues for discussion were identified through performing the overlay approaches:

1) In the Weighted Sum Overlay analysis, each criterion's weighting factors must be carefully determined while creating the combined output. There was no universal consensus on assigning a set of weighting factors towards the criteria included in the suitability analysis (MALCZEWSKI 2004). It was most likely to depend on our specific goals and objectives of planning and the number of criteria to be counted. One basic approach to use is by assigning an equal weighting factor for each criterion. Another approach is assigning more weighting factors toward a criterion we consider as more important, with a clear reasoning, and then giving an equal factor for the rest. In addition, there is also an expert opinion approach or a stakeholder approach, where we survey related experts or stakeholders to get their opinion on the weighting factors, which then can be averaged or determined by a discussion and consensus approach (MALCZEWSKI 2004). We will explore these options in a follow-up research.
2) The Fuzzy Overlay analysis offers a different way of creating a combined criteria map through its five methods, including the Gamma method applied in this study. The Gamma value suggests the probability of a region meeting all the criteria instead of weighting each criterion's influence towards the combined model. However, there is one critical issue from the technical aspect in this process, as reported in the Method Section 2.4. We need to reverse the individual objective-based suitability model's values before processing with the Fuzzy Membership function to generate the suitability models for the Fuzzy Overlay analysis. They need to be changed from 9 (nine) being the most suitable and 1 (one) being the least suitable to 1 (one) being the most suitable and 9 (nine) being the least suitable. The individual suitability models used in the Weighted Sum Overlay analysis cannot be directly used in the Fuzzy Membership operation as it will reflect an opposite suitability value. While the results can be read in reverse, it contradicts the concept of what the binary value of Fuzzy Overlay output represents.

The outputs from both approaches increased awareness of the region's landscape characteristics regarding its suitability for developing a green infrastructure plan. All results showed that both cities of the region (Bandung and Cimahi) were predominantly built areas. The other three regencies were mostly open space with vegetation ranging from wildwood/forest, parks/gardens, fields, and rice fields. These interpretations suggested a challenge in proposing a green infrastructure protection plan in the central urban area, but more opportunities were identified in the outer urban (suburban-rural) areas. There is a possibility to have green infrastructure networks of different scale or structure in the rural areas versus urban areas. The green infrastructure network in the urban areas may be limited to pocket parks, stormwater parks, urban gardens including food producing or wildflower gardens, green streets, green roofs, bioswales, and rain gardens. The surface water greenway was identified as a prominent feature to connect large greenspace patches in the surrounding regencies and small greenspace patches in the central urban area. The riparian greenway was also considered extremely important for protecting water quality and wildlife habitat/corridors. A separate analysis is needed to assess the value of connectivity and its integration in the suitability models.

4 Conclusion and Recommendation

GIS-based landscape suitability analysis is a useful approach in urban design, planning, and management practices, especially for developing future land-use visioning and plans (MALCZEWSKI 2004). This approach includes identifying land suitable for green infrastructure planning, which was explored in this study using Weighted Sum and Fuzzy Overlay techniques. Both techniques were considered helpful in aiding the identification process as part of developing a framework to propose future green infrastructure planning scenarios. The suitability modeling can be applied at multiple scales, providing opportunities to identify areas with potential suitability regardless of the administrative boundaries.

The landscape suitability models need to be more actively incorporated in planning and design and spatial planning-related policy development processes to better inform decision making (GORDON et al. 2009). The scale of suitability criteria should be carefully determined in alignment with the resolution of the spatial analysis. One key area of improvement is to develop a more appropriate approach in determining the weighting factors or Gamma value associated with a more adaptive future green infrastructure planning (AHERN et al. 2014).

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