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Affordable Housing, Urban Analytics, and Inclusive Infrastructure Planning

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ABSTRACT

Affordable housing, particularly in developing countries such as Indonesia, has become a major government priority through the Ministry of Housing and Residential Areas of the Republic of Indonesia. Adequate housing does not function in isolation but must be supported by complementary infrastructure such as commercial areas, roads, transportation networks, healthcare facilities, and other public service centers. Housing development should therefore be inclusive by adopting a mixed-use development approach and avoiding overly rigid zoning systems, since each land-use category is interconnected with and dependent on other land-use types. To address this challenge, urban analytics is required. This study applies land-use optimization based on four key objectives: compactness, compatibility, dependency, and suitability. By implementing clustering techniques, several potential central nodes were identified as suitable hubs for specific land-use types, including commercial centers, vertical residential districts, and industrial zones.

1. Introduction

In its early urban development, Indonesia largely adopted a tree-structure planning model, in which urban functions were spatially separated into rigid and hierarchical zones. Residential areas, for example, were concentrated in specific locations that were often far from workplaces, schools, markets, and even major road networks (Sadewo et al., 2021). This pattern created a fragmented urban form where daily activities depended heavily on long-distance travel between isolated zones (Firman, 2004; Newton, 2000). The resulting impacts were diverse, ranging from chronic traffic congestion and inefficient mobility to widening socio-spatial inequality, as elite residential enclaves became increasingly segregated from middle- and lower-income settlements (Hasic, 2000; Newton, 2000; Surya et al., 2021). In extreme cases, such divisions contributed to broader social tensions, which culminated during the May 1998 riots (Himawan et al., 2022).

The tree-structure concept had long been criticized by Christopher Alexander, who argued that the proper urban form is a lattice structure, where urban functions overlap and interact rather than remain rigidly separated (Alexander, 1966). Recent empirical evidence confirms Alexander's proposition that urban districts with semilattice-like street networks are more conducive to urban life than rigid tree-like structures (Huang et al., 2022). In the modern era, the United Nations introduced the Sustainable Development Goals (SDGs), a set of global development goals established by the United Nations in 2015 under the 2030 Agenda for Sustainable Development, one of which focuses on cities (Almulhim et al., 2024). Another goal is SDG 10, which focuses on reducing inequalities in income, opportunities, and access to essential services. In Indonesian urban areas, such as the peri-urban areas of the Jakarta Metropolitan Area (Jabodetabek), the issue is evident in several ways, including clear differences between rich and poor neighborhoods, limited access to education, healthcare, and jobs, as well as housing areas that are located far from workplaces and city centers.

The advancement of GIS and the increasing accessibility of satellite imagery have enabled urban researchers and planners to apply modern technologies for planning, analysis, and the prediction of land-use change. Planning based

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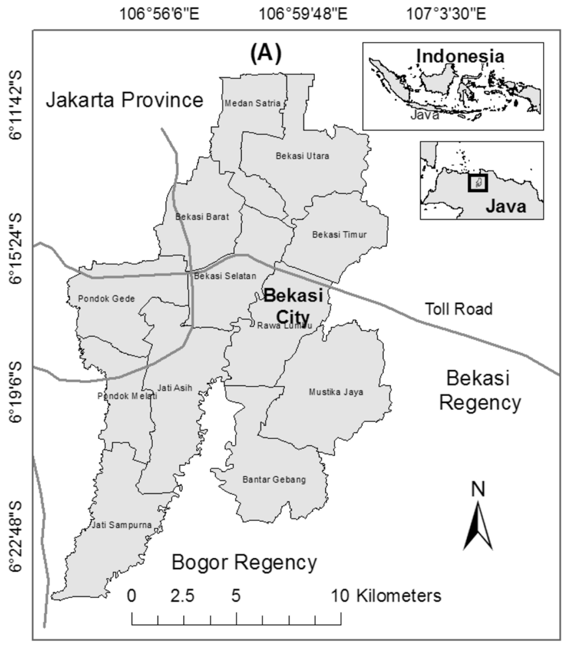

Figure 1: Bekasi City, Indonesia.

on a mixed-use development concept requires more complex analysis than conventional zoning approaches; however, recent progress in urban analytics has significantly improved this process (Handayanto et al., 2017; Masoomi et al., 2013). Today, deep learning methods are increasingly being adopted, supported by more accurate datasets and high-resolution multispectral spatial data (Herlawati et al., 2023). One of the key factors supporting the implementation of urban analytics is data availability. Since 2019, Indonesia has implemented the One Data Indonesia Policy through Presidential Regulation No. 39 of 2019, aimed at creating accurate, integrated, interoperable, and publicly accessible government data. One important component of this initiative is spatial planning data, which are now increasingly available through official platforms, including detailed spatial plans (Rencana Detail Tata Ruang / RDTR) accessible via the GISTARU Portal (`https://gistaru.atrbpn.go.id/`).

2. Urban Analytics

Government provision of data is very important, considering that in geospatial studies there are the terms land cover and land use. Land cover refers to the physical material or natural and built features present on the Earth's surface, such as vegetation, water bodies, bare soil, or built-up areas, while land use refers to how the land is utilized or managed by humans, such as for residential, commercial, governmental, educational, or industrial purposes (Longley et al., 2007). Satellite imagery is generally only able to distinguish types of land cover, for example built-up areas, but cannot reliably differentiate whether those areas are residential neighborhoods, business districts, government facilities, schools, or industrial zones. Therefore, the availability of government-provided data is highly valuable in supporting analysis conducted by urban planners.

Previous studies have tended to discuss cities in general, such as Jakarta (Firman, 2004, 2009), Bandung (Tarigan et al., 2016), and other urban areas. Therefore, this article focuses on a more specific topic, namely urban analytics and residential settlements. This article discusses urban analytics for urban spatial planning, particularly in the Bekasi area, with a focus on residential development. Bekasi serves as a peri-urban buffer zone for Jakarta, where many residents who work in Jakarta choose to live.

The rest of the paper discusses the techniques used to evaluate and optimize the current spatial structure by applying the concepts of compact city and eco-city through appropriate objective functions. It further examines the optimal allocation of land for future development. In addition, clustering of specific land-use types is analyzed to determine the most suitable locations for high-density residential areas through vertical settlements such as apartments and public housing blocks. Figure 1 shows the study area.

Urban areas are the primary focus of researchers, considering that these areas consume the greatest number of resources and generate large amounts of waste (Doran et al., 2023; Jabareen, 2006; Lu et al., 2024). Urban areas are dominated by residential settlements, ranging from elite neighborhoods to slum areas. Their management requires careful attention, as even small mistakes can have serious consequences, particularly for the people who live there (Alvarez, 2016; Edwards, 2001). The concept of sustainable urban form refers to an urban spatial structure and physical development pattern that supports environmental protection, economic efficiency, and social well-being over the long term. It emphasizes creating cities that use land, energy, water, and other resources efficiently while minimizing pollution, waste, and ecological degradation. At the same time, it seeks to provide accessible housing, transportation, public services, and economic opportunities for residents. Sustainable urban form is commonly associated with characteristics such as compact development, mixed land use, efficient public transport, walkability, green spaces, and balanced urban growth (Chen et al., 2008; Skovbro, 2017; Williams et al., 2000).

2.1. Land Use Optimization

Land use optimization aims to determine the most appropriate locations among several land use types in order to achieve an optimal fitness score. The current fitness score adopts a multi-objective approach, aiming to identify trade-offs among different objectives by applying evolutionary algorithms such as Particle Swarm Optimization (PSO), Genetic Algorithms (GAs), and others (Handayanto et al., 2017; Ma et al., 2011; Masoomi et al., 2013; Masoumi et al., 2019; Sellappan et al., 2025).

From the compact city concept, three objectives are derived: compactness, compatibility, and dependency. Compactness is intended to reduce fuel consumption by encouraging locations to be situated closer to one another. Compatibility indicates whether adjacent land use types do not negatively affect each other (negative avoidance), while dependency shows whether neighboring land use types mutually require or support one another (positive attraction) (Skovbro, 2017). Meanwhile, from the eco-city concept, a fourth criterion is adopted, namely suitability, which indicates how appropriate a particular land use type is for a specific area. Equations (1)–(4) present the objective functions used to calculate the total fitness score.

$$F_1 : \text{Maximize} \left[\frac{1}{n} \sum_{i=1}^{n} \text{Compactness}_i \right] \tag{1}$$

$$F_2 : \text{Maximize} \left[\frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{n_i} \sum_{j=1}^{n_i} \text{Comp}_{ij} \right) \right] \tag{2}$$

$$F_3 : \text{Maximize} \left[\frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{n_i} \sum_{j=1}^{n_i} \text{Dep}_{ij} \right) \right] \tag{3}$$

$$F_4 : \text{Maximize} \left[\frac{1}{n} \left(\sum_{i=1}^{n} \text{Suitability Score} \right) \right] \tag{4}$$

where n is the number of LUs in the study area, and i and j are the current land use and its neighbours, respectively. The constraints are defined such that candidate locations must be within the study area and within designated allowable locations. By applying weighting factors in the calculation, the following objective function is maximized:

$$F = \max \sum_{i=1}^{k} w_i F_i(x) \tag{5}$$

$$H = \text{Inside Allowable Location} \tag{6}$$

Compactness is the tendency of one land use type to attract the same type of land use, for example residential areas attracting other residential areas, while dissimilar land use types are not attracted. This concept helps reduce urban sprawl as much as possible and is formulated into the following equation (Torrens and Alberti, 2000):

$$\text{Compactness} = \frac{1}{h} \sum_{i=1}^{n} I_i \tag{7}$$

Meanwhile, compatibility and dependency use scores derived from surveys of environmental experts, regional planners, and related researchers. Using the Delphi technique (Masoomi et al., 2013; Skulmoski and Hartman, 2007), scores were obtained that represent the relationship between one land use type and other land use types. The land use classes include commercial, elementary school, industrial, middle school, college, medical, sport, park, low-density residential area, and high-density residential area.

The selection of land use types is essential in achieving a sustainable urban form, particularly in fostering a compact city through the integration of various land uses. This approach supports SDG 11: Sustainable Cities and Communities, which emphasizes inclusive, safe, resilient, and sustainable urban development (Jabareen, 2006; Skovbro, 2017), and also contributes to SDG 4: Quality Education by ensuring better accessibility to educational facilities within urban areas, as reflected in land use types such as elementary, middle schools and colleges (Siva Kumar et al., 2026).

Table 1 presents both the compatibility and dependency scores derived from expert survey data processed using the Analytic Hierarchy Process (AHP). The survey was conducted in two rounds using the Delphi method, an iterative process that gathers and refines expert judgments through multiple rounds to achieve consensus. Subsequently, the value of each relationship between land uses is converted into a numerical scale ranging from 0 to 1 based on the AHP scale, where very low, low, medium, high, and very high correspond to 0.041, 0.081, 0.176, 0.275, and 0.428, respectively.

Previous studies have indicated the maximum distance at which one land use type is influenced by another land use type (Figure 2). In this study, the values of R_1 and R_2 are set at 5 km and 15 km, respectively (Stead et al., 2000). Beyond 5 km, the influence decreases gradually.

Finally, the suitability score indicates how appropriate a particular land use type is when located in a specific region, whether it falls into high suitability, medium suitability, or

Table 1

Compatibility and dependency scores from the expert survey. Com: commercial; El Schl: elementary school; Ind: industrial; Mid Schl: middle school; Colg: college; Med: medical; LowRes: low-density residential; HighRes: high-density residential. The symbols ++, +, 0, −, and −− represent very high, high, medium, low, and very low, respectively.

A. Compatibility (Comp)

LU Class	Com	El Schl	Ind	Mid Schl	Colg	Med	Sport	Park	LowRes	HighRes
Commercial	++	−−	+	−	+	−	++	++	++	++
Elementary school		−−	−−	++	++	++	++	++	++	++
Industrial			++	−−	+	++	++	++	−−	−−
Middle school				0	++	++	++	++	++	++
College					0	++	++	++	++	++
Medical						−−	−−	++	++	++
Sport							−−	++	++	++
Park								++	++	++
Low Resident									++	++
High Resident										−−

B. Dependency (Dep)

LU Class	Com	El Schl	Ind	Mid Schl	Colg	Med	Sport	Park	LowRes	HighRes
Commercial	++	−−	++	−	+	++	++	++	++	++
Elementary school		−−	−−	++	+	++	++	++	++	++
Industrial			++	+	++	++	0	++	−	−−
Middle school				−−	++	++	++	++	++	++
College					−−	++	++	++	++	++
Medical						++	++	++	++	++
Sport							−−	++	++	++
Park								++	++	++
Low Resident									−−	++
High Resident										−−

low suitability categories, which are then converted into corresponding numerical values.

The following equation presents this relationship in the form of a fuzzy set (Zadeh, 1965):

$$\mu_A(d_{ij}) = \begin{cases} 1, & d_{ij} \leq d_{ij}^{\min} \\ \left(\dfrac{d_{ij}^{\max} - d_{ij}}{d_{ij}^{\max} - d_{ij}^{\min}} \right)^{\beta}, & d_{ij}^{\min} \leq d_{ij} \leq d_{ij}^{\max} \\ 0, & d_{ij} \geq d_{ij}^{\max} \end{cases} \quad (8)$$

To determine regional suitability, a GIS-based suitability analysis was applied, specifically using the Weighted Overlay method in ArcGIS (Khouni et al., 2021). Figure 3 shows the block diagram for determining the suitability score, which was then implemented in ArcGIS.

In the computation process, the in-polygon function is required to determine whether a land use type is located within an area of high, medium, or low suitability (Hormann and Agathos, 2001). Of course, the optimization process cannot be carried out manually, as it involves a large number of land use points to be calculated. To simplify the analysis, each land use point in this study represents an area of approximately 50 to 100 meters.

Several optimization models can be used, such as Particle Swarm Optimization (PSO) (Ma et al., 2011), Genetic Algorithms (GAs) (Albadr et al., 2020), and similar approaches. In this study, the optimization model is applied for both current optimization and allocation, where new land uses are assigned to the most suitable candidate locations. In practice, allocation plays the more important role, considering that relocating an existing land use type to another area is very difficult to implement in Indonesia.

Therefore, this article focuses on allocation, where new land uses will be allocated within the existing land use. If the existing land use is fixed, the candidate will search for the most suitable location through the ongoing iterations.

2.2. Data Collection and Scenarios

The data were collected using Google Earth, which provides satellite imagery, combined with related datasets such as hospitals, schools, and other facilities. The primary reference, however, was data obtained from government websites that identify specific land use types, such as residential areas and similar categories (Figure 5).

In the optimization process, three scenarios were used: (1) Business-as-Usual (BAU), (2) Government Policy (GP), and (3) Sustainable Development (SD). Figure 6 shows the constraints for allocating new land uses. The Government Policy scenario is based on the 2015–2030 spatial plan, while the Sustainable Development scenario imposes stricter controls on open space and industrial areas. Meanwhile, the Business-as-Usual scenario allows allocation anywhere, as long as the location is allowable.

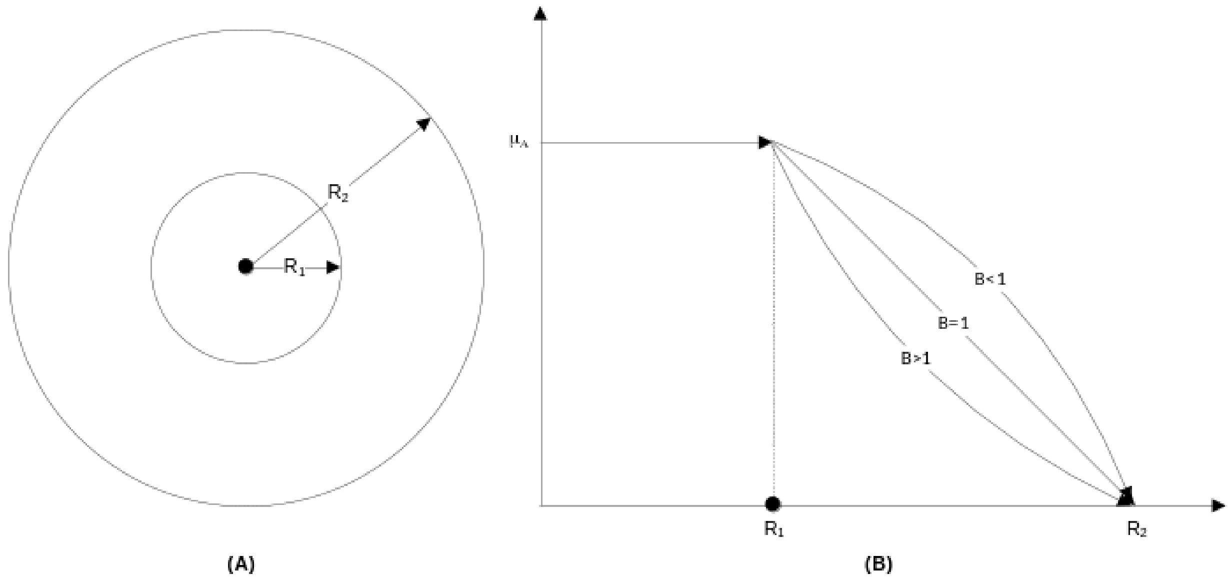

Figure 2: The spatial influence of a land use (LU) on surrounding land uses, consisting of (A) an effective core area and (B) a gradual transition (fuzzy) zone between R_1 and R_2.

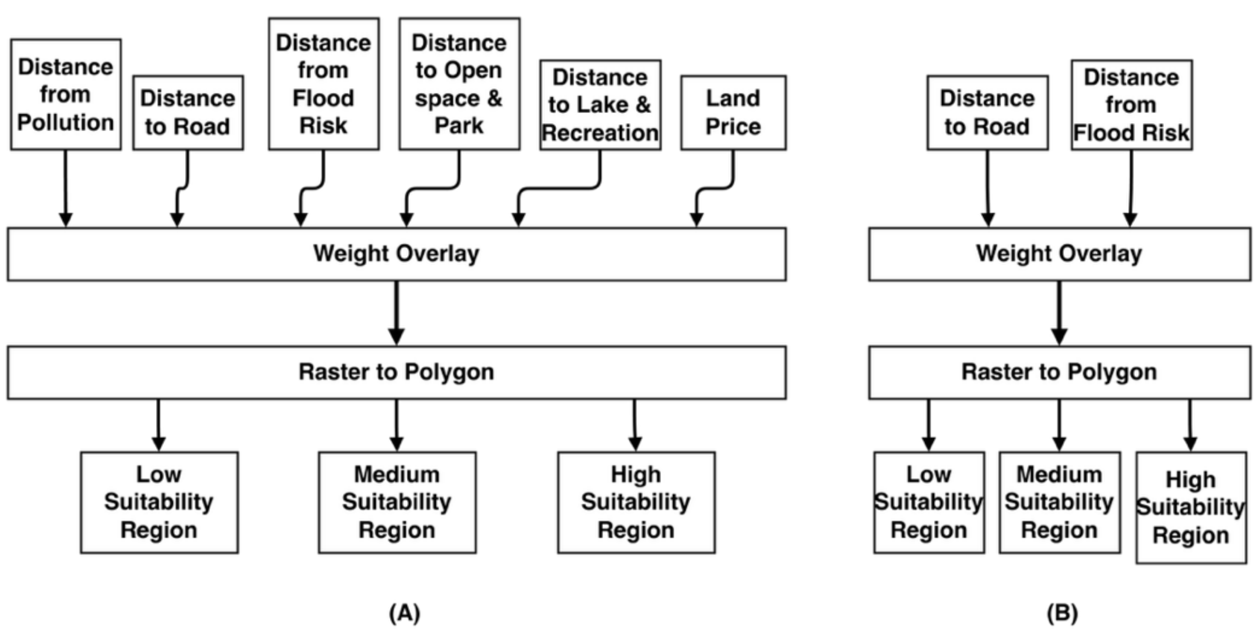

Figure 3: Spatial analysis using a weighted overlay for creating suitable regions for scoring: (A) residential areas; and (B) commercial, industrial, health, and educational areas.

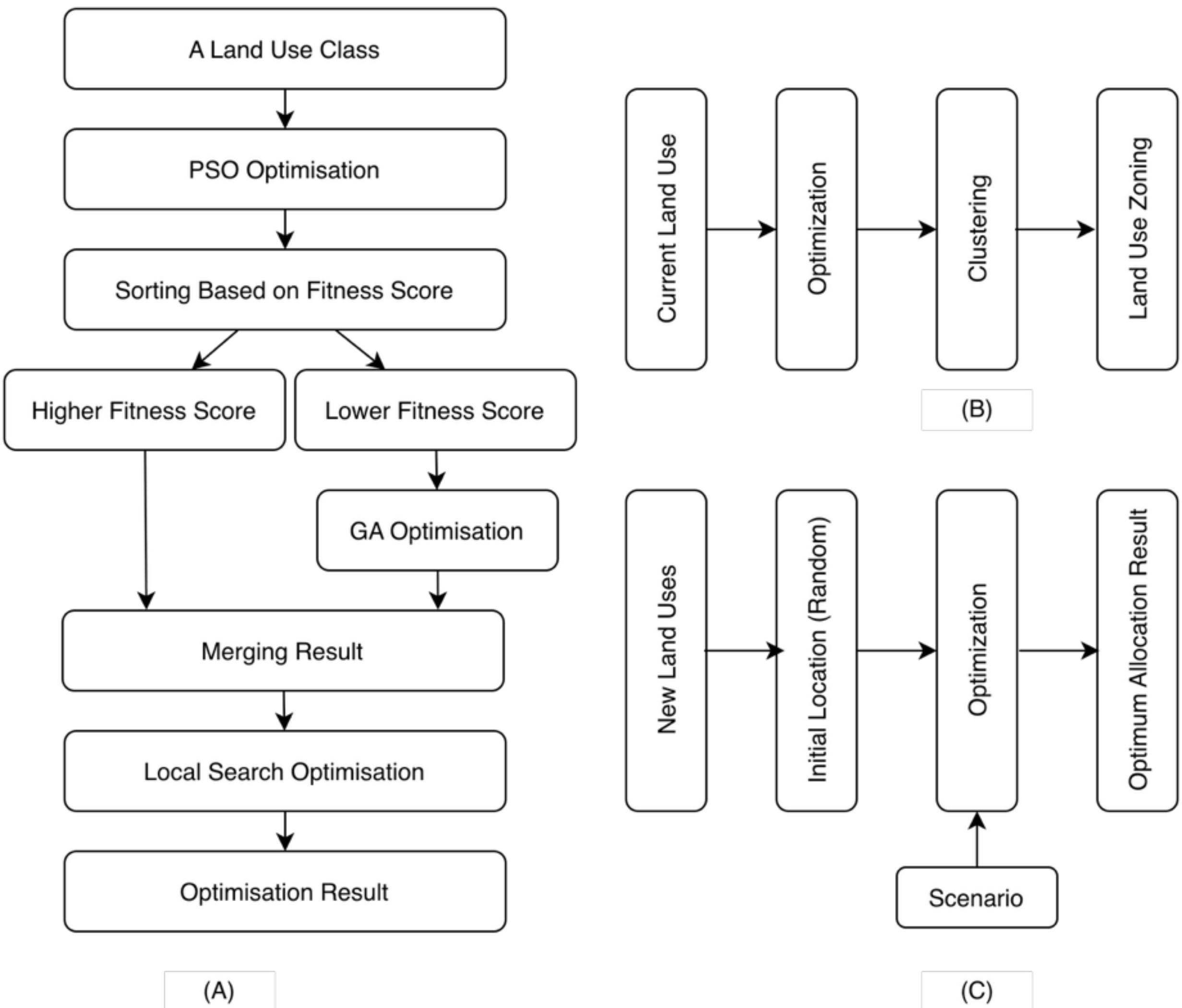

Figure 4: Diagram of the optimization module, consisting of (A) the main optimization module, (B) optimization of existing land use and clustering, and (C) optimization of new land use allocation.

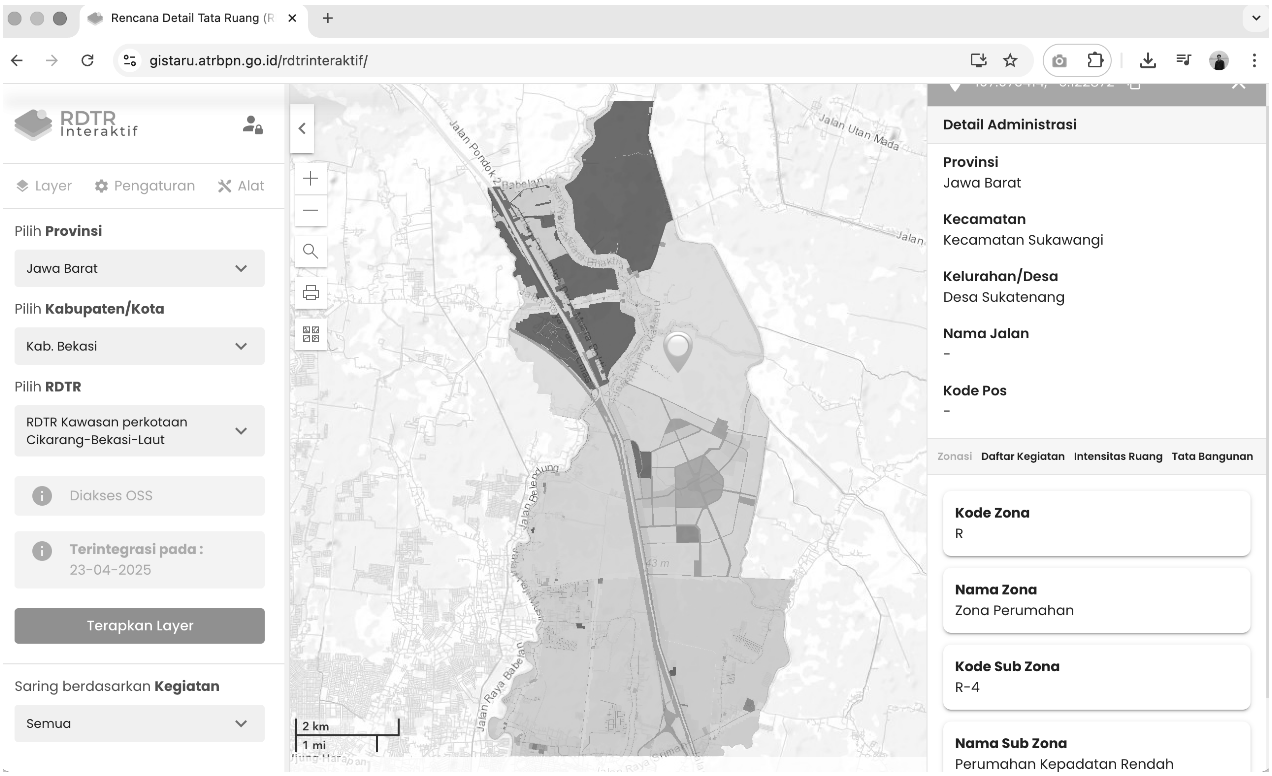

Figure 5: Information obtained from the government spatial planning website.

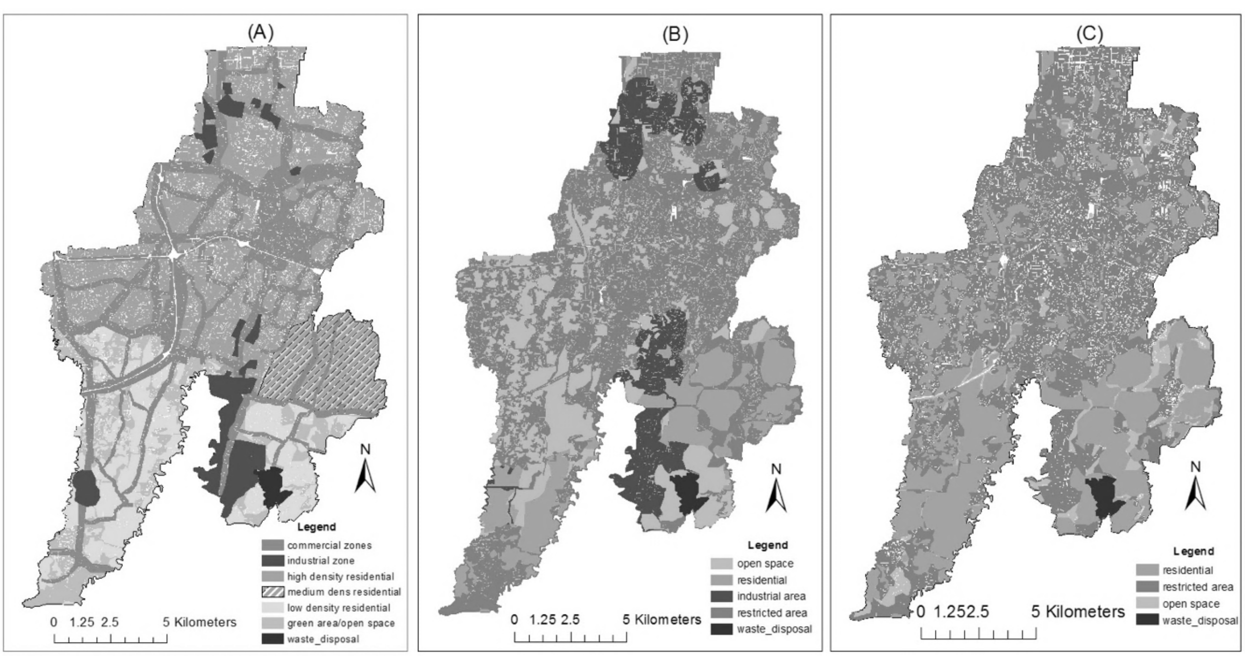

Figure 6: Constraint optimization process: (A) Bekasi City LU plan (2010–2030) as GP constraint; (B) open space and industrial zone as SD constraint; and (C) empty LUs as BAU constraint.

3. Result and Discussion

3.1. Optimization Result

Three scenarios were conducted, and their optimization score performance was then evaluated. The same objective function was applied; however, the placement of candidate locations differed. In the sustainable development scenario, candidate locations followed the predetermined designated sites based on suitability analysis. In the government policy scenario, candidate locations followed zones that had been adjusted through conventional feasibility studies, while in the business-as-usual scenario, locations were not restricted and could be allocated anywhere within allowable areas. Therefore, the suitability analysis objective was applied only in the sustainable development scenario and was not used in the government policy (GP) or business-as-usual (BAU) scenarios.

Figure 7 shows that the fitness score of the sustainable development scenario is higher than that of the GP and BAU scenarios. This indicates that government policy needs to be revised and, as much as possible, aligned with sustainable development guidelines. Figure 8 shows the actual locations resulting from the optimization based on the three scenarios.

3.2. Land Use Clustering

Clustering is the process of identifying similarities among data based on their attributes. In this study, three land use classes are the main focus, i.e., locations for settlement, business, and industry. By determining the centroid of each cluster, effective zoning can be established, thereby helping city governments formulate future spatial planning policies. A MATLAB module using Fuzzy C-Means was applied to these land uses. Figure 9 illustrates an example of using the FCM tool in MATLAB to determine the centroid of the residential cluster. Since the focus is on vertical housing, the main candidates are areas classified as high-density residential, which, according to the urban spatial plan, are located in the central and northern parts of Bekasi City.

Using a projection appropriate for the study area (UTM 48S), optimal locations were identified for residential centers and their supporting areas (commercial and industrial).

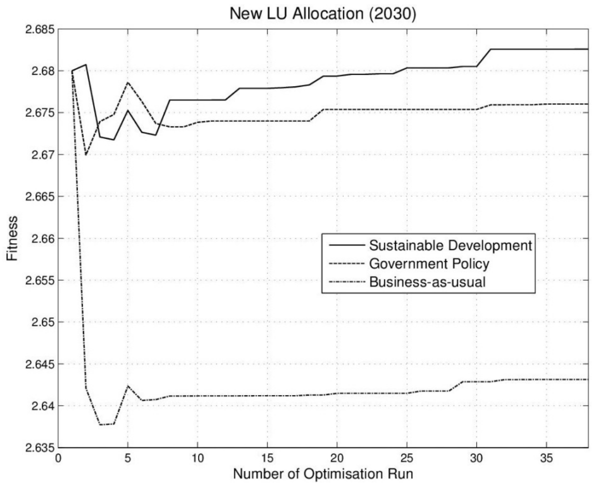

Figure 7: Results of new land-use allocation, illustrating the fitness scores of each scenario.

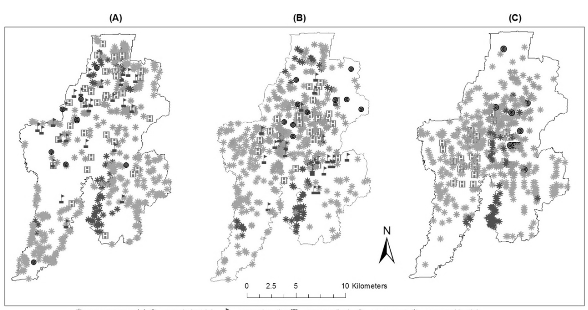

Figure 8: Result of future-LU optimization: (A) SD scenario; (B) GP scenario; and (C) BAU scenario.

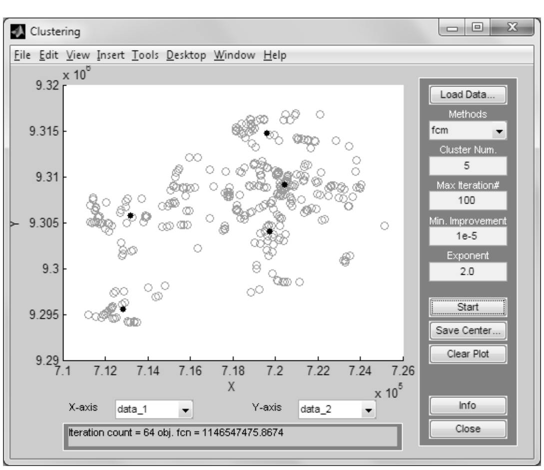

Figure 9: Tool for finding the center of a cluster.

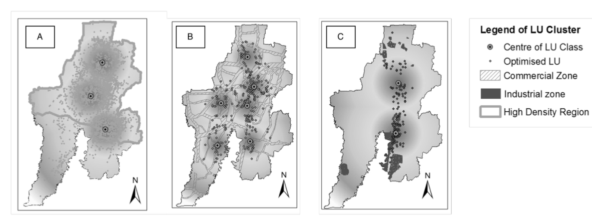

Figure 10: Results of land use clustering: (a) residential zones, (b) commercial zones, and (c) industrial zones.

4. Conclusions

Limited land availability requires city governments to allocate land for vertical housing developments. The choice of location is very important in shaping the quality of settlements and housing in order to support SDG 10: Reduced Inequalities, which aims to reduce inequality within and among countries, including improving housing affordability. Land use optimization can help urban planners assess the score of land use arrangements to determine whether they are good or poor. Objective functions can also be used to compare urban planning quality with that of other areas. Suitable locations can be identified through the centroid of each related land use type; for example, for vertical housing, the ideal location would be at the centroid of the residential cluster. In low-density areas, city governments need policies to control the number of buildings and encourage residents to occupy the provided vertical housing. The use of urban analytics can serve as an objective reference for policies made by city governments.

Credit authorship contribution statement

Rahmadya Trias Handayanto – Conceptualization, Methodology, Software, Analysis, Draft Writing. Teddy Mantoro – Supervision, Reviewing. Media Anugerah Ayu – Reviewing, Validation. Herlawati – Methodology, Data Curation. Nitin Kumar Tripathi – Supervision, Reviewing. Pramod Kumar – Reviewing, Editing.

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Conflicts of Interest: The authors declare no conflict of interest.

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