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# Utilizing Semi-Variograms and Geostatistical Approach for Land Value Model in Urban Region

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The availability of land in Bandung City become a challenge for urban development. Bandung has long been an urbanization destination for Indonesians besides Jakarta, Surabaya, Medan, and Makassar. Currently there was still limited research that explores land values and spatial planning for urban areas. This study aims to develop spatial modeling for land values using a semi-variogram and geostatistical approach in urban areas. Our research was conducted in Bandung City, West Java (Indonesia). Data was selected based on purposive sampling involving 50 land price and 95 building price samples throughout the city. The collected data were then analyzed using 4 semi-variogram models and Ordinary Kriging to derive the spatial distribution of land values. Land value referred to spatial modeling from the geographic information system. The results of the analysis indicated that the semi-variogram stable type was the most suitable model, exhibiting the minimum error by root mean square, mean standardized, root mean square standardized, and average standard error. According to our model, the areas with the highest land values are located close to the city square "Alun-alun", which is closely associated with government offices, trading areas, defense and security facilities, service areas, education, cultural tourism, and high-density housing. These areas are well known since the Dutch East Indies era. Interestingly, despite the growth pole in Gedebage, the western part of Bandung has higher land values compared to the eastern part. This could be attributed to historical and actual aspects which have had a greater impact on land values than regional plans implemented by the government. Land values management is necessary to guarantee living space as well as to achieve a sustainable city.

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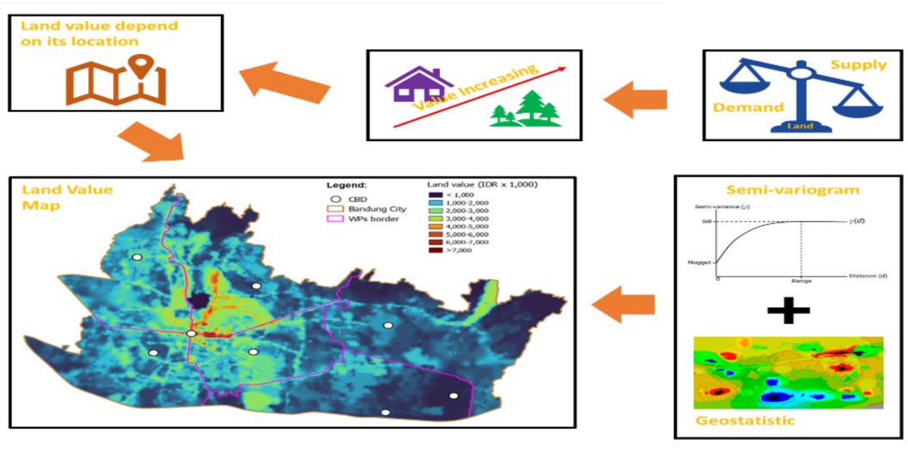
**Graphical Abstract**

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## 1. INTRODUCTION

Land serves as a natural resource for various purposes in development and human activities [1]. It is important to note that land encompasses not just soil or ground, but also includes all objects on the earth's surface, making it a vital component of the geosphere [2]. With the growth of the human population, the demand for land and its resources has increased, while its availability is relatively constant [3, 4]. This heightened competitive land use leads to scarcity and encourages landscape changes from vegetated areas to built-up areas [5].

The demand for land remains high in urban areas, driven by a growing population, even market equilibrium is not ideal when the development pace is difficult to stop [6]. The availability and allocation of land in urban areas are increasingly limited, particularly in meeting the needs of settlements, public infrastructure, and commercial areas [7]. This limited availability of land leads to the formation of urbanized landscapes and peri-urban areas, which in turn drives up land values that become uncontrollable [8]. Human dependence on land has caused it to become an invaluable object, and this is reflected in its price [9].

The value of land in urban areas is heavily influenced by spatial structure. Many countries have implemented spatial planning that integrates registration and valuation of land objects as important considerations [10]. Accessibility plays a crucial role in determining land value, with infrastructure and the built environment being key factors that contribute to high prices, as observed in Arizona (The United States) [11]. The spatial configuration and development pressure as seen in spatial configuration caused land values in Central Strip, Israel to always be dynamic, even though historical aspects influence the values to be a reference for settlement development [12]. In Australia, spatial zoning had increased land and house prices by up to 73% [13]. Moreover, rising land values have also been observed in emerging industrialized countries such as China [14], Pakistan [15], Turkey [16], Vietnam [17], and Indonesia [18].

Previous studies on land values primarily focused on non-spatial economic analyses. However, in some research, the geospatial approach has started to be used to reveal the complexity involved [19-21]. The geospatial approach for assessing land values should include geostatistical analyses, as the value of land shares the same concept with elevation, water depth, groundwater exploitation, and environmental pollution which are not constrained by formal boundaries [22-24]. Previous studies have also not been able to link land values with urban development patterns. In fact, urban planning and development is multidisciplinary and multi-aspect management that combines knowledge about engineering, economic, socio-cultural, environmental as well as human behavior [25-28]. Therefore, the objective of this study is to develop spatial modeling for land values using a geostatistical approach in Bandung City. Our findings can contribute to the integration of spatial planning activities with land registration, which are currently separate, especially in Indonesia. This research would reveal the phenomenon between land values, urban planning, and other aspects that rationalize price differences in Bandung City. This article presents land value modeling compared to Bandung City's spatial planning, starting from introduction, materials and methods, results and discussion as well as conclusion.

## 2. MATERIALS AND METHOD

Our study takes place in Bandung City, West Java (Indonesia). Bandung serves as the provincial capital and the center of Bandung Raya Metropolitan Area (Figure 1). The city is home to over 2.5 million people, including thousands of commuters from neighboring areas such as Cimahi City, West Bandung Regency, Bandung Regency, Sumedang Regency, Subang Regency, Cianjur Regency, and Garut Regency [29]. Administratively, Bandung City is divided into 30 districts and 153 urban villages. It has emerged as a significant metropolis alongside Jakarta, Surabaya, Medan and Makassar [30]. Bandung City has problems related to land availability and its high price. Provisioning public facilities and low-cost housing become a big challenge in the development, coupled with Bandung's natural landscape as a basin surrounded by mountains.

Bandung City features two primary centers, 1) the square also known as "Alun-alun" and 2) Gedebage. Additionally, the city has 6 secondary centers serving development areas or WP, namely Setrasari (WP Bojonagara), Sadang Serang (WP Cibeunying), Kopo Kencana (WP Tegallega), Turangga (WP Karees), Arcamanik (WP Ujungberung), and Margasari (WP Gedebage) [31]. These centers are designated as central business districts (CBD) which have a significant impact on land values. Urbanization has resulted in urban sprawl, particularly in the eastern and southern parts of the city, leading to the emergence of new built-up areas [32].

**2. 1. Data Preparation** The data of this study were obtained through purposive sampling, which involved collecting information on 50 land prices and 95 building prices across the city (Figure 2). The sampling process followed specific criteria that were chosen to align with the research objectives [33]. Two key criteria were used in this study: 1) representing property sales, and 2) containing property rental information. It is important to consider income capitalization rates when assessing land values, as they form the basis for property valuation [34-

36]. We determined the capitalization rates based on 5 categories: vacant land (0.5-2%), rental houses (3-5%), shop houses and office houses (6-9%), kiosks and shops (5-10%), and apartments and condominiums (7-2%).

The land data used in this study consisted of geospatial polygons with various attributes, such as price, property type, building area, and site area. To facilitate the analysis, the data were converted into centroids using the Universal Transverse Mercator (UTM) coordinate system with the World Geodetic System (WGS) 1984 as datum [33, 34]. In addition to land values, we also incorporated other relevant information related to development, such as the city-level regional spatial plans (RTRW). These plans were sourced from the Bandung City Government and were obtained from the respective Regional Work Unit (SKPD) as person in charge [39].

**2. 2. Data Analysis** Land values are determined by comparing market prices with income capitalization. To assess land values accurately, data on property sales and rentals (supply) must be converted into land prices per square meter according to Equations (1)-(3). The geostatistical analysis is used in this study as it provides a stochastic model that allows optimal estimation at random points within the study area [36, 37]. The geostatistical analysis involves measuring variograms or semi-variograms, which include methods such as Circular, Spherical, Tetraspherical, Pentaspherical, Exponential, Gaussian, Rational Quadratic, Hole Effect, K-Bessel, J-Bessel, and Stable [42]. In this study, we utilized 4 semi-variogram models, namely Stable, Gaussian, Spherical, and Exponential, as the basis for Kriging interpolation. Kriging is a spatial interpolation

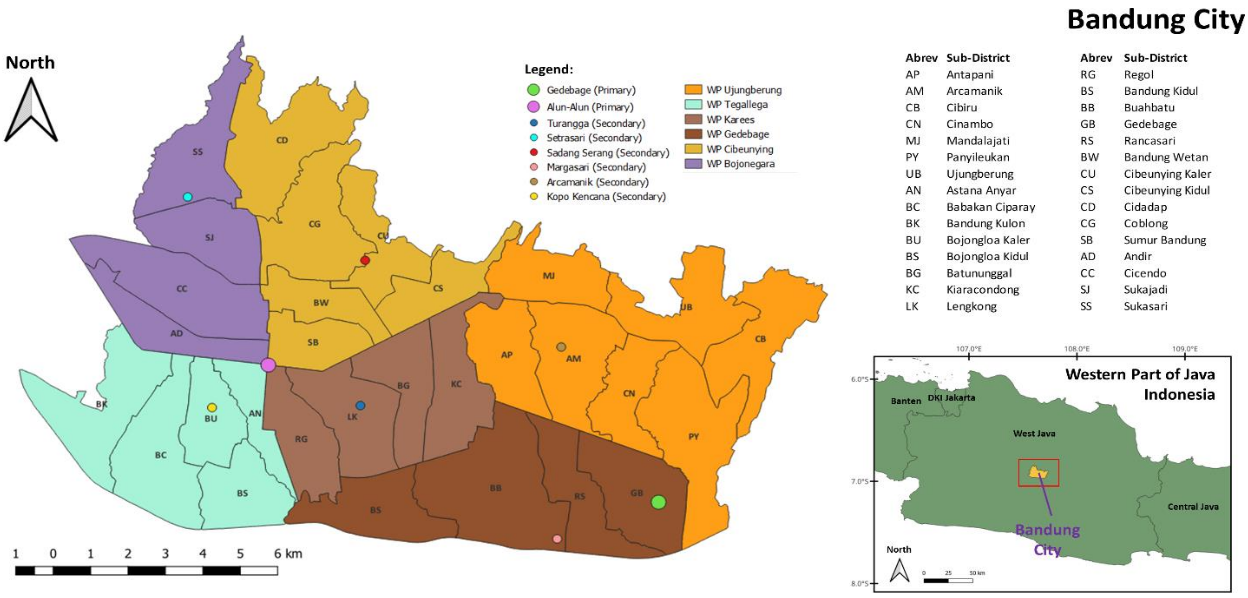


**Figure 1.** The research location in Bandung City, highlighting its 8 CBDs, 6 WPs, and 30 districts

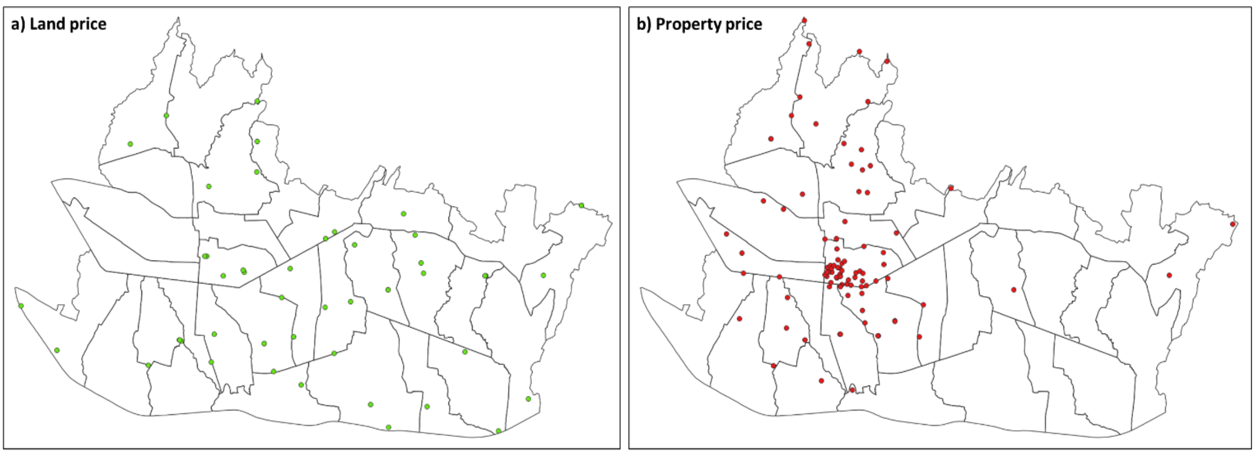


**Figure 2.** Sample distribution for measuring land values, a) land prices, and b) building prices

technique that provides accurate estimates with lower mean error (ME), root mean square error (RMSE), and R-square ($R^2$) as shown in Equation (4) [43]. Figure 3 presents the research process for a land value model in Bandung City.

$$LV = \frac{SP}{LA} \quad (1)$$

$$LV = \frac{PP - (BP \times BA)}{LA} \quad (2)$$

$$PP = \frac{ONI}{CL} \quad (3)$$

In the equations used, several variables are defined as follows: LV represents the land value, SP denotes the selling price, LA refers to the land area, PP represents the property price, BP denotes the building price, BA refers to the building area, ONI represents the annual net operating income, and CL represents the capitalization level. The value and price are expressed in units of local currency, while area refers to units per square meter.

$$Z(s) = \mu(s) + \varepsilon(s) \quad (4)$$

$$\gamma(h) = \frac{1}{2N(h)}[Zi - Zj]^2 \quad (5)$$

In the equations used, the variables are defined as follows: Z(s) represents the expected value of the variable, μ(s) denotes the deterministic trend, ε(s) represents the random error, s indicates the position in a particular space, $\gamma$(h) is the semi-variance that describes the expected value between sample values, Z represents the sample value at i and j locations, N(h) represents the number of samples, and H represents the distance between data points (lag).

The semi-variogram is a tool used to assess the correlation between two points in space, and it can be likened to a least squares regression [44]. It quantifies the expected value of the difference in sample values based on the distance (h) between pairs of sample points (Equation (5)). The semi-variogram is characterized by nuggets, sills, and ranges (spatial trend boundaries) [45]. The nugget represents the variability at zero distance and reflects both sampling and analytical errors, while the sill represents the variability at zero distance and reflects both sampling and analytical error, while still representing the variability of spatially independent samples and acts as the maximum limit of value [46]. To develop a reliable land value model, it is important to ensure that the estimation closely aligns with reality. This can be evaluated using metrics such as root mean square (RMS), mean standardized (MS), root mean square standardized (RMSS), and average standard error (ASE) [43, 44].

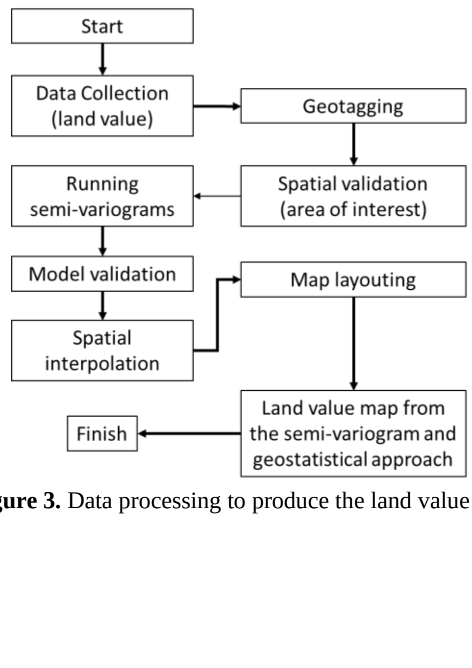


**Figure 3.** Data processing to produce the land value map

## 3. RESULTS AND DISCUSSION

Land values are attached to each centroid, with x and y coordinates, while the z coordinate serves as the main input for geostatistical analysis. Among the tested semi-variograms, the Stable model performed the best based on the testing of 4 semi-variograms. Figure 4 shows this model accurately estimates the actual land value conditions in Bandung City. The Stable model adjusts the distributions of land values, exhibiting exponential growth that gradually slows down after reaching the saturation phase. Regarding accuracy, the Stable model demonstrates the lowest value as summarized in Table 1. Its positive values for all four error parameters indicate a robust estimation reference for explaining the phenomenon [49-51]. The Stable semi-variogram as the best model has also been proven by researchers in agriculture and geophysics [52, 53].

The Stable semi-variogram and Ordinary Kriging were used to determine the distribution of land values and generate isoline-based classifications, as shown in Figure 5. Ordinary Kriging is an estimation method based on stationary data and BLUE - the best linear unbiased estimator [54]. The combination of precise semi-variogram and Ordinary Kriging would be the best option for numerical variables spatially [55]. In this case, the fit combination produced a land value model in Bandung City. High land values are concentrated around Alun-alun and its surroundings. Alun-alun has served as the primary growth center and has existed since the Dutch East Indies era [56-58]. In the western part of the city, which includes WP Bojonagara, WP Cibeunying, WP Tegallega, and WP Karees, the land values closely follow the pattern established by Alun-alun. In addition to its historical factors, Alun-alun attracts economic activities, such as office areas, businesses, star hotels, and tourism destinations [59, 60].

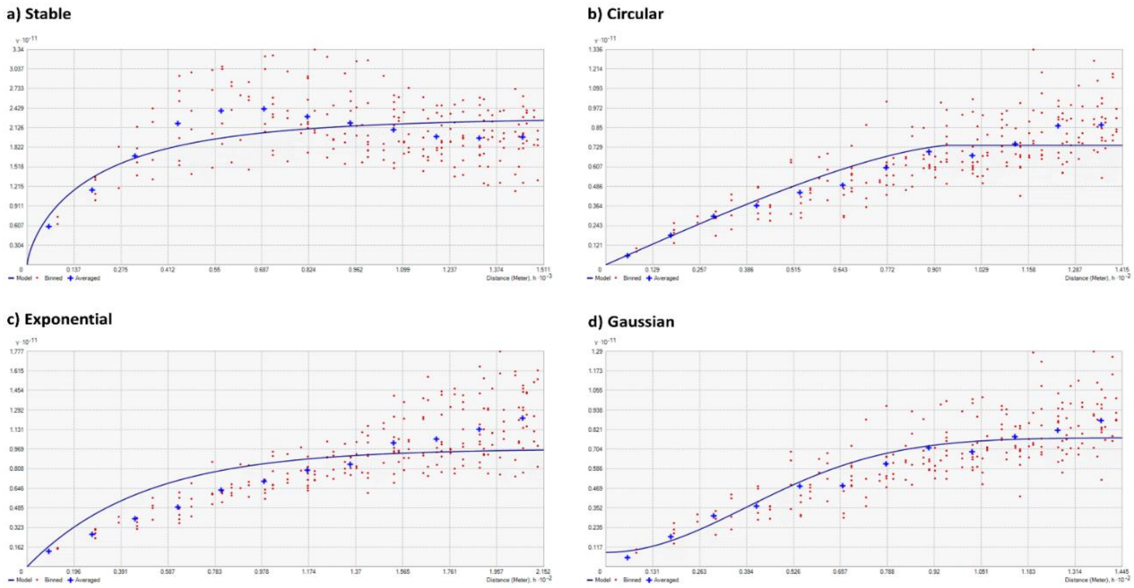


**Figure 4.** Land values' semi-variogram curves. Where "+" represents the actual values and the line represents an estimated model

**TABLE 1.** Error comparison for 4 types of semi-variogram in IDR currency unit

| Type | RMS | MS | RMSS | ASE |
|---|---|---|---|---|
| Stable | 106,201 | 0.001 | 0.790 | 105,662 |
| Circular | 104,958 | -0.002 | 0.694 | 113,883 |
| Exponential | 104,172 | -0.003 | 0.615 | 126,061 |
| Gaussian | 157,840 | 0.011 | 0.768 | 202,135 |

Different scenarios can be observed in Gedebage and its surroundings. Despite being the second primary center, Gedebage has not experienced an increase in land values. Currently, the area mainly consists of vegetated rice fields. Interestingly, the land value around Arcamanik is higher compared to Gedebage and Margasari. In the eastern part of the city, land values actually increase in the southeastern area, which directly borders Bandung Regency. This area is in close proximity to industrial centers such as Rancaekek and Majalaya, where large textile factories operate. Furthermore, new settlements for workers have emerged on formerly paddy fields, swamps, and brushes [61]. On the other hand, the Jatinangor Education Area, a new growth center, has not been able to significantly increase land values in the east due to its separation from the city by Cileunyi District (Bandung Regency) [62-64]. New

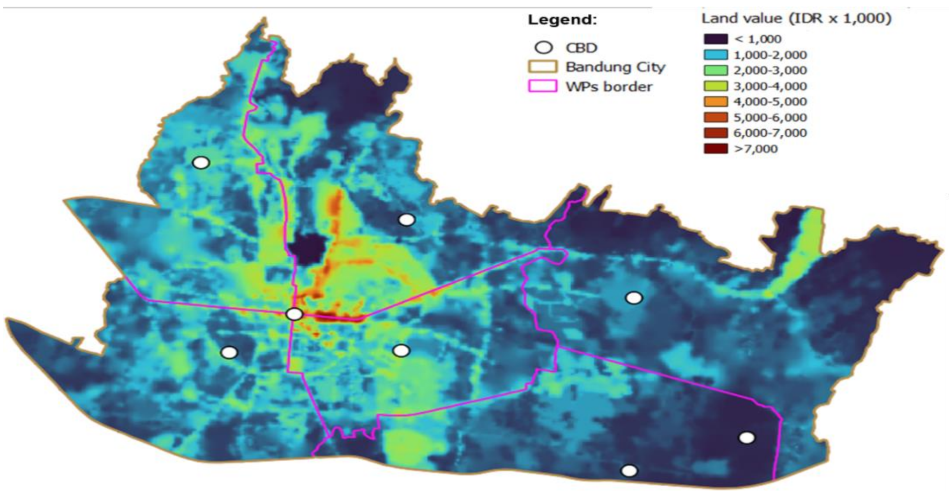


**Figure 5.** Land price model for Bandung City based on the Stable semi-variogram

growth centers that have not had a significant impact quickly on development often occur in Indonesia because there was still a lack of accessibility, promotion, and community stigma to these projects [65]. West Java itself, not only Gedebage, a similar phenomenon can be seen in Meikarta (Bekasi Regency) and Kertajati (Majalengka Regency) [66-68].

High land values in the city are closely associated with specific spatial patterns, such as government offices, trading areas, defense and security installations, service areas, education institutions, cultural tourism sites, and high-density housing, all forming a cohesive unit (Figure 6). This area serves as the core area as well as the administrative center for the West Java Provincial Government. Zhang et al. [69] revealed that the combination of adaptive expectations and the area's role as a cross-hierarchical government center can significantly impact land values, leading to continuous growth. Interestingly, if the money polarity is not fulfilled, for example only in high-density housing, the land value will not be high as in the southwestern (WP Tegallega). In other areas with lower land values, such as WP Gedebage, the government's effort to develop public infrastructures have not had a significant impact on land prices. Despite the establishment of an internationally renowned sports center (Gelora Bandung Lautan Api Stadium) and the introduction of elite housing projects by national developers [32]. However, these lands do not quickly change land values because of the political situation at the local to national level which could be changing spatial planning policies every 5-10 years [5, 70]. The influence of historical factors and the existing socioeconomic landscape appears to be more dominant in shaping land values, as they offer a sense of profit certainty [71].

Land values have been increasing in the northern regions of WP Ujung Berung and WP Cibeunying, which are located adjacent to the conservation area. Real-estate developers are tempted to construct housing near these green open spaces, as they provide various ecosystem services to its residents, including fresh air, beautiful scenery, adequate accessibility, and free traffic jam [72-77]. This phenomenon has led to a significant surge in land values, particularly in areas previously dominated by traditional-style housing [78]. Green areas offer cooler temperatures amid the urban heat island in big cities [79]. An imbalance between land value with environment and socio-economic situation and natural factors would threaten urban sustainability [80, 81]. The rise in land prices can be attributed to factors such as accessibility including the presence of arterial or collector roads, as well as the growth rate of land transactions [82-84]. To regulate land values and ensure planned development, the city has implemented a spatial planning document, Bandung City's Regional Regulation Number 18 of 2011, which includes maps outlining the city's development plans from 2011-2031.

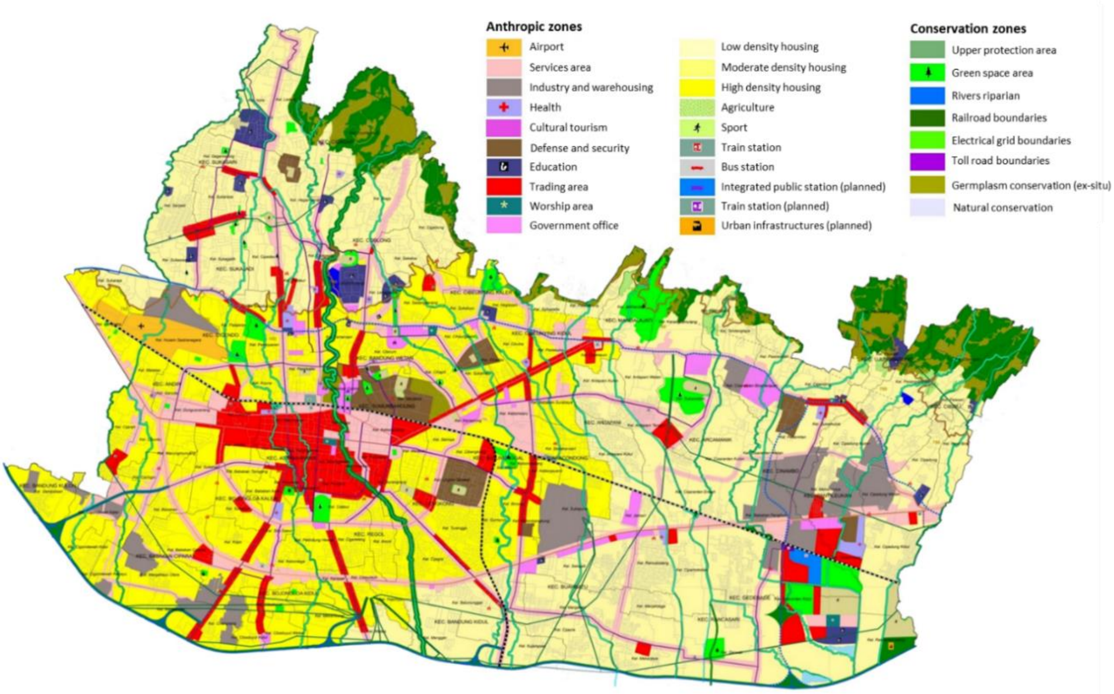


**Figure 6.** Spatial pattern of Bandung City in 2011-2031. The map is part of a spatial planning document based on Bandung City's Regional Regulation Number 18 of 2011

However, it is worth noting that this document has been revised with the introduction of Bandung City's Regional Regulation Number 05 of 2022. Although, the updated maps are not yet available. These regulatory measures play a vital role in shaping land values, promoting equitable development, and preventing unplanned growth [85-87]. Affordable land and housing for urban communities is a necessity, besides security, rule of law, transportation, communications and basic needs availabilities [88].

## 4. CONCLUSION

The spatial modeling used semi-variogram (Stable) and geostatistical (Ordinary Kriging) shows that the highest land values are concentrated in the western part of the city, particularly around Alun-Alun. Other growth centers in Bandung city do not affect the land value. Among the four WPs, namely Bojonegara, Cibeunying, Karees, and Tegallega, the highest land value is observed in the area between these areas. The high land values are associated with government offices, trading areas, defense and security installations, service areas, education institutions, cultural tourism sites, and high-density housing. The model also reveals the presence of land values ranging from IDR 3-4 million in proximity to conservation areas located in WP Cibeunying and WP Ujungberung. Densely populated areas have higher land values compared to sparsely populated areas that are dominated by agricultural lands. Despite the existence of spatial patterns and development plans for socio-economic purposes as stated in the document, it appears that new growth centers have no significant impact on the increase in land values. The new growth centers were unable to replicate the same impact as Alun-alun (circa 1810 AD). The high land values observed in Alun-alun highlight those historical aspects and ongoing socio-economic activities carry more impact than planning aspects. Efforts to maintain Alun-alun as a growth center can be seen from the improvement of this site by the government as a center for cultural tourism. This study has limitations because it has not included various other variables. To reveal land values due to new spatial patterns and detailed development plans in Bandung City, further studies are needed that incorporate various urban physical, environmental, social and cultural variables.

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## Persian Abstract

**چکیده**

در دسترس بودن زمین در شهر باندونگ به چالشی برای توسعه شهری تبدیل شده است .باندونگ علاوه بر جاکارتا، سورابایا، مدان و ماکاسار مدت‌هاست مقصد شهرنشینی اندونزیایی‌ها بوده است .در حال حاضر هنوز تحقیقات محدودی وجود دارد که ارزش زمین و برنامه ریزی فضایی را برای مناطق شهری بررسی می کند .این مطالعه با هدف توسعه مدل‌سازی فضایی برای ارزش‌های زمین با استفاده از رویکرد نیمه متغیری و زمین‌آماری در مناطق شهری انجام شده است .تحقیق ما در شهر باندونگ، جاوای غربی، اندونزی انجام شد .داده‌ها بر اساس نمونه‌گیری هدفمند شامل 50 نمونه قیمت زمین و 95 نمونه قیمت ساختمان در سراسر شهر انتخاب شدند .سپس داده‌های جمع‌آوری‌شده با استفاده از 4 مدل نیمه‌واریوگرام و کریجینگ معمولی برای استخراج توزیع فضایی ارزش‌های زمین مورد تجزیه و تحلیل قرار گرفت .ارزش زمین به مدل سازی فضایی از سیستم اطلاعات جغرافیایی اشاره دارد .نتایج تجزیه و تحلیل نشان داد که نوع پایدار نیمه متغیری مناسب ترین مدل است که کمترین خطا را بر اساس ریشه میانگین مربعات، میانگین استاندارد شده، ریشه میانگین مربع استاندارد شده و میانگین خطای استاندارد نشان می دهد .طبق مدل ما، مناطق با بالاترین ارزش زمین در نزدیکی میدان شهر-alun» «alunقرار دارند که ارتباط نزدیکی با ادارات دولتی، مناطق تجاری، تأسیسات دفاعی و امنیتی، مناطق خدماتی، آموزش، گردشگری فرهنگی و مسکن با تراکم بالا این مناطق از دوران هند شرقی هلند به خوبی شناخته شده است .جالب اینجاست که علیرغم قطب رشد در گدباج، قسمت غربی باندونگ در مقایسه با قسمت شرقی ارزش زمین بالاتری دارد .این را می توان به جنبه های تاریخی و واقعی نسبت داد که تأثیر بیشتری بر ارزش زمین نسبت به طرح های منطقه ای اجرا شده توسط دولت داشته است .مدیریت ارزش زمین برای تضمین فضای زندگی و همچنین دستیابی به یک شهر پایدار ضروری است.