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ARTICLE

Conceptual Design of a Flood-Adjusted Land Value Index (FALVI) Methodology for Urban Areas: A Study Case at Bandung City, Indonesia

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ABSTRACT

Addressing these water management challenges requires a comprehensive and integrated approach. Floods and other water-related challenges in urban areas can have an impact on land values. However, the lack of studies has developed a comprehensive index methodology related to examining floods and land value relationships for urban areas. Therefore, the main purpose of this study is to develop a comprehensive index methodology related to examining floods and land value relationships for urban areas that is called a Flood-Adjusted Land Value Index (FALVI) Methodology. This paper illustrates the importance of the proposed FALVI methodology to determine the relationship between flood events and land value. Important variables within three main aspects—environmental, socio, and historical flood variables—would be elaborated and measured by GIS-based analysis. It provides a more accurate and thorough assessment of property values by taking flood risk variables into account throughout the valuation process. This methodology is also regarded as an essential methodology for examining floods and land value links in metropolitan areas. FALVI can help guide government strategies on flood management, land use planning, and catastrophe risk reduction. By identifying high-risk locations, governments can prioritize flood mitigation measures and enact restrictions that prevent development in susceptible areas. Urban areas in certain watershed systems can be kept viable for the long term by carefully reviewing this methodology and implementing suitable land management strategies.

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1. Introduction

Some developing countries like Indonesia are often facing various water-related issues [1]. The issues are getting more complex and more widespread due to several factors within. Some countries have made several efforts to handle the water-issues by connecting to the main sources [2–4]. In fact, there are still water problems such as water scarcity, pollution, and mismanagement due to rapid urbanization, land-use changes and climate change that cannot be solved completely [5, 6]. Water scarcity is very common in certain areas like arid or semi-arid areas, and naturally have limited water resources [7]. Meanwhile, water pollution is the worst human-caused water problem with common sources of water pollution such as industrial wastewater (chemicals, heavy metals, and other pollutants released by factories and industries can contaminate water sources), agricultural runoff (fertilizer, pesticides, and animal waste from farms can seep into nearby waterways), municipal wastewater (untreated or improperly treated sewage can release bacteria, viruses, and other harmful substances), and others [8]. Urban areas are particularly susceptible to water pollution due to high population density, industrial activity, and often inadequate infrastructure [9]. Water pollution can have severe consequences for both human health and the environment [10]. The major impacts include health risks and environmental degradation [11]. Pollutants can harm aquatic ecosystems, reduce biodiversity, and impair the water quality of rivers, lakes, and oceans. Moreover, water pollution brings impacts on social factors as well as economic factors that rely on clean water. Water pollution can also disproportionately affect marginalized communities and exacerbate existing environmental inequalities [12].

Addressing these water management challenges requires a comprehensive and integrated approach. The biggest challenges for water resources managers or stakeholders are creating sustainability in water management in the watershed [13–15]. Development in urban areas often ignores the negative impacts it causes, especially on the environmental aspects within a watershed [16, 17]. The complexity of physical and non-physical processes on land-use changes is increasing over time along with anthropogenic activities that have led to water management issues [18, 19]. Water issues are further exacerbated by economic factors that often have a direct negative impact on communities' lives, especially in urban areas. Various water issues that occur in urban areas such as floods often have an impact on land values [20, 21]. In Indonesia, there are several water issues that affect land values [22]. Previous studies have shown that land values are closely linked to flood events [23–27]. However, a lack of studies has developed into a comprehensive index methodology related to examining floods and land value relationships for urban areas. Therefore, the main purpose of this study is to develop an comprehensive index methodology related to examining floods and land value relationships for urban areas, called the Flood-Adjusted Land Value Index (FALVI) Methodology.

2. Materials and Methods

2.1. Study Area

This study is located in Bandung City, often referred to as the "Paris of Indonesia", a vibrant city nestled in the foothills of Mount Tangkuban Perahu, West Java Province, Indonesia. Known for its pleasant climate, stunning natural beauty, rich cultural heritage and economic growth. Compared to coastal cities in Indonesia, Bandung City's temperatures are generally cooler due to its higher elevation. The average temperature ranges from around 19 °C (66 °F) to 24 °C (75 °F) throughout the year. Climate condition of Bandung City is moderate rainfall throughout the year, with no distinct dry or wet seasons. However, there may be occasional showers or brief periods of heavier rainfall. Geographically, Bandung City is located at the south latitude of 6°44′–6°56′ and east latitude of 107°27′–107°, is the capital of West Java Province with an area of 167.52 km2 and consists of 30 sub-districts and 151 villages (**Figure 1**). As the capital city of West Java, this city plays an important role in economic activities in West Java, based on the BPS report on the Gross Regional Domestic Product (GRDP) of Bandung City in 2023 at current prices reached 351,284.45

billion rupiah which is the second largest GRDP in West Java with the Economic Growth Rate (LPE) of Bandung City in 2023 is 5.07%. The GDP per capita of Bandung City in 2023 is 140,143.63 thousand rupiah with a growth rate of 4.13%.

As one of the economic centers and centers of government in West Java, the city continues to grow in population, recorded until 2023 the population density of the city of Bandung is in second place as the most populous city in Indonesia (16,133 person km^{-2}) and is linearly growing every year by 0.12% (2021–2022), but population growth is not in line with the expansion of the city area, causing land prices in the city of Bandung to increase every year. Besides that, the population density in the city of Bandung invites several potential natural disasters such as flooding. Based on data from the West Java Regional Disaster Management Agency, it was recorded that floods were the most frequent natural disaster with 52 incidents throughout 2024 for the city of Bandung and its surroundings.

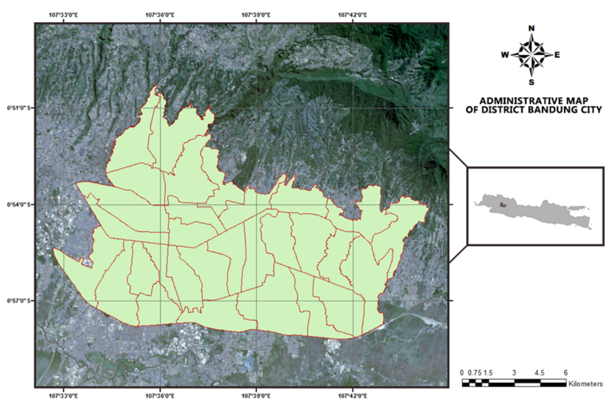

Figure 1. Location of study area.

2.2. Methodology

In this study, a Flood-Adjusted Land Value Index (FALVI) was developed by combining three main groups of variables that were selected based on an in-depth literature review and expert input (**Figure 2**). Environmental variables, consisting of elevation, slope, and land use, reflect the physical conditions of an area that can affect flood vulnerability. Social variables, represented by population density, indicate social vulnerability due to the high concentration of people in flood-prone areas. Meanwhile, historical variables, in the form of previous flood records, provide information on the frequency and intensity of floods that have occurred. Therefore, the FALVI, as described in this study, is a valuable tool for assessing the impact of flooding on land values. By combining environmental, social, and historical variables, it provides a comprehensive understanding of flood vulnerability.

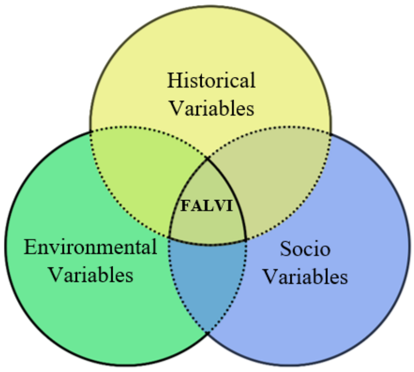

Figure 2. The combination process of a Flood-Adjusted Land Value Index (FALVI).

The relationship between a Flood-Adjusted Land Value Index (FALVI) and each quantitative variable was statistically tested using the correlation coefficient (r) that can be seen on Equation (1). This correlation coefficient shows how strong the linear relationship between two variables is. The results of the correlation test are then used to determine the relative weight of each variable in the index, so that variables that have a stronger correlation will contribute more to the index value.

$$r = \frac{n\sum_{i=1}^{n} X_i Y_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{\sqrt{\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2}\sqrt{\sum_{i=1}^{n} Y_i^2 - \left(\sum_{i=1}^{n} Y_i\right)^2}} \quad (1)$$

The first step in this methodology is to calculate the flood potential index, the index then used to classify the level of flood vulnerability of an area on a continuous scale from 0 (not vulnerable) to 1 (highly vulnerable). This classification allows the identification of areas that have a high risk of flooding so that it can be the basis for flood disaster mitigation planning.

- Elevation
  The elevation of an area can affect the direction of water flow and capacity. Higher elevations are generally less prone to flooding due to their position relative to water bodies and floodplains. In general, areas with low elevation have greater flood potential due to the natural concentration of runoff towards lower areas. In this study we took elevation data from the Global Multi-resolution

Terrain Elevation Data 2010 (GMTED2010) in Digital Elevation Model (DEM) format with a resolution level of 7.5 arc-seconds or 250 m × 250 m and then the data was analyzed using ArcGIS 10.8. Based on GMTED2010 data, the Bandung area has an elevation range of 629 m–1087 m, so with this data, researchers can make a local elevation classification (**Table 1**).

- Slope

Variable slope is an important geographical factor in causing flood disasters. Steeper slopes can facilitate rapid runoff, reducing the risk of flooding in certain areas. However, steep slopes can also contribute to landslides, which can indirectly impact land values. Areas with a high slope can accelerate the flow of water, making the area quickly (time of concentration) move excessive water which can cause flooding. In this research, slope data is derived from the results of elevation analysis using ArcGIS 10.8, the elevation results are then raster classification to get the average slope. In addition, the classification of slope is reviewed through the regulation of the Minister of Forestry of the Republic of Indonesia (P.60/Menhut-II/2014), which notes that the classification for slope resistance to flood vulnerability is divided into 5 classes with a range of 2% to <30% (**Table 1**).

- Land Use/Land Cover

Land use and land cover (LULC) is a reflection of how an area is utilized by humans. In addition, LULC can also be an indicator of population growth and environmental change. Impermeable land cover, such as road surfaces and buildings, reduces the infiltration capacity of water into the soil and increases the volume of surface runoff. As a result, the potential for flooding becomes higher. In this study, the data source is Landsat 8–9 Operational Land Imager and Thermal Infrared Sensor Collection 2 Level-1 Data with a resolution of 30 m × 30 m, this data is then processed using the interactive supervised classification method in order to be separated between land cover types (Urban, Road, Open space, forest and river) then the results will be calculated with the runoff water coefficient, which this coefficient becomes a parameter for determining the hierarchy of land cover influence (**Table 1**).

- Population Density

Population density is closely related to land use changes that contribute to the infiltration ability of land and runoff water in an area so that urban areas with high population density have a higher vulnerability to flooding than areas with low population density. Data for population density in this study was taken from the National Statistics Agency, while the density classification was taken from the comparison of population density levels of each provincial capital city on the island of Java so that the classification can be seen in **Table 1**.

- Flood Record

Flood record is a variable that describes the level of vulnerability of an area to the disaster itself. While specific flood records may vary over time, historical data can provide insights into the frequency and severity of flooding events in Bandung. Local authorities and disaster management agencies can access historical records to assess flood risk and develop mitigation strategies. By analyzing historical flood records, authorities can identify flood-prone areas, assess the potential impacts of flooding, and implement measures to reduce vulnerability and mitigate the effects of future flood events. Flood record data in this study was taken through the West Java Regional Disaster Management Agency and interviews with local residents, while the flood record classification was taken through the regulation of the Minister of Forestry of the Republic of Indonesia (P.60/Menhut-II/2014) concerning flooding in river basins (**Table 1**).

- Land Value

Land value is a key variable in determining the market value of an area in this study. Value of land data was obtained from two main sources, namely the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency (ATR/BPN) and a public opinion survey of local communities and property agents. Land value data from ATR/BPN (**Figure 3**) was processed using the interactive supervised classification method through ArcGIS 10.8 software. This method allows the separation of land values based on color groups that have been assigned to the ATR/BPN data, then re-classification is carried out to obtain the average value of land prices per region. The formation of land value classes was done by dividing the price ranges identified in the data into five locally relevant classes.

Table 1. A proposed Flood-Adjusted Land Value Index (FALVI) classification.

Definition	Environmental			Social	Historical
	Elevation	**Slope**	**Land Use**	**Population Density**	**Flood Record**
	m	**%**	**%**	**Person km^{-2}**	
Very low	629–673.5	<2%	<20%	0–5763	Never
Low	≥673.5–718	2%–8%	20%–40%	5763–11527	1 per 5 years
Medium	≥718–762.5	8%–15%	40%–60%	11527–17290	1 per 2 years
High	≥765.5–807	15%–30%	60%–80%	17290–23054	1 per year
Very high	>807	>30%	80%–100%	>23054	More than 1 per year

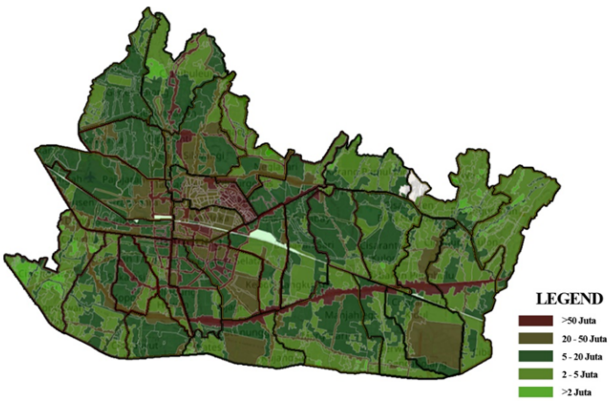

Figure 3. The land value map from the Ministry of Agrarian Affairs and Spatial Planning.

In this study, Geographic Information System (GIS) served as a powerful analytical tool to explore the relationships between various parameters, including the Flood Adjusted Index and land values. One of the key components in this analysis is the utilization of a Digital Elevation Model (DEM) to map the slope and elevation of an area. Using ArcGIS, a popular GIS software, the DEM data was further processed through raster classification based on administrative boundaries. This classification makes it possible to identify zones with different slopes and elevations, which significantly affect vulnerability to flooding. To analyze land use and land values, a supervised image classification method was chosen. This method allows the grouping of objects in an image based on their spectral characteristics, such as color. In the context of this research, supervised classification is very useful for identifying land value classes that have been determined by the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency. In addition, this method also makes it possible to classify different types of land use, such as settlements, agriculture and green areas. By combining the results of the slope, elevation, land use and land value analyses, this study aims to identify areas with high flood risk and analyze their effect on property values. A better understanding of the relationship between these physical and social factors can provide valuable information for spatial planning, disaster management and property investment decision-making.

3. Result and Discussion

The index developed in this study aims to measure the feasibility of land value or prices by considering the level of vulnerability to flood disasters. Economic losses from flooding, both direct (e.g., infrastructure damage) and indirect (e.g., decreased purchasing power), can have a significant impact on property values. Therefore, the FALVI index integrates the flood-adjusted index with land price data and creates its classes (**Figure 4** and **Table 2**).

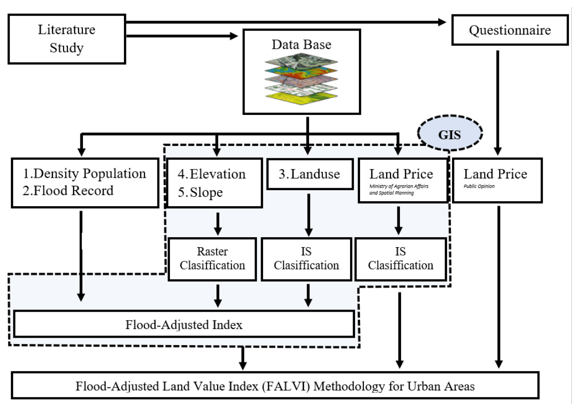

Figure 4. The Flood-Adjusted Land Value Index (FALVI) Methodology for urban areas.

A FALVI value close to 1 indicates that an area has a relatively high land price compared to the level of flood risk, so it can be categorized as an overprice area. Conversely, a FALVI value close to 0 indicates that land prices in the area are more in line with the existing flood risk. This means that areas with low FALVI values tend to have more realistic land prices that take into account potential losses due to flooding (**Table 2**). The FALVI methodology can be a useful tool in decision-making regarding property investment, spatial planning, and flood mitigation. By understanding the relationship between land prices and flood risk, policymakers and investors can make more informed and sustainable decisions.

Table 2. A proposed Flood-Adjusted Land Value Index (FALVI) classes.

FALVI	Classes
<0.2	Underprice
0.2–0.4	Under market value
0.4–0.6	Market value
0.6–0.8	Upper market value
0.8–1	Overprice

In this study, there are some strengths of the FALVI that are easy-to-use, comprehensive, relevant, and flexible. This study offered an easy-to-use methodology related to flood events and land value. The FALVI incorporates a wide range of factors that influence flood vulnerability, including environmental conditions, social factors, and historical data. The variables selected for the FALVI are directly relevant to flood risk assessment, providing a practical and informative tool for policymakers and land use planners. The FALVI can also be adapted to different geographic contexts and can be used to assess flood risk in various urban and rural areas. On the other hand, there are some limitations and potential improvements such as data collection or data availability, weighting of variables and the dynamic nature of flood risk. The availability of high-quality data for all the variables used in the FALVI may be a challenge in some regions. Determining the appropriate weights for each variable in the FALVI can be subjective and may require expert judgment. In determining the weight for each variable in the development of FALVI, it is also necessary to consider the opinions of related experts so that their opinions can be used as input in determining the weight with a certain method such as the AHP method. Analytic Hierarchy Process (AHP) is a decision-making technique that organizes complex decisions into a hierarchy of objectives and criteria. It is a multi-criteria decision analysis (MCDA) approach that compares and prioritizes alternatives based on their relative value. The step sequence of AHP is to clearly describe the decision problem and objectives, construct the hierarchy of AHP, and conduct pairwise comparisons. The prepared questionnaire to be answered by the experts should examine the land value related to flood events. The limitations of the AHP method are in subjectivity, complexity and consistency issues. The method relies on subjective judgments, and the results can be influenced by the biases of the decision-makers. For complex problems with many criteria and alternatives, the pairwise comparison process can become time-consuming and tedious. Ensuring consistency in pairwise comparisons can be challenging, especially for large matrices. Concerning the dynamic nature of flood risk, flood risk is a dynamic process influenced by factors such as climate change, land use changes, and infrastructure development. The FALVI may need to be updated regularly to reflect these changes.

The other issue to be considered is that the parameters to define land price or property do not only depend on one factor. Land prices in Bandung City vary widely and are influenced by several factors, such as location, land size, land condition, accessibility, and other factors. Downtown areas, business districts, or areas close to public facilities such as schools, hospitals, and shopping centers tend to have higher land prices compared to peripheral areas. Land with a larger area generally has a lower price per square meter compared to land with a smaller area. Land that is flat, dry, and free from problems such as flooding or landslides will have a higher price. Land that is easily accessible by public transportation or major highways tends to have a higher price. Land that has the potential to be developed into commercial or residential buildings will have a higher price. Other factors that can also affect land prices in Bandung include government regulations, economic conditions, market demand and conditions. Government policies related to spatial planning, licensing, and property taxes can affect land prices. Economic growth, inflation rates, and interest rates can affect people's purchasing power and land prices. High demand for land in a particular area can push up prices.

Concerning the collection of data for the latest land prices in Bandung, this study searched for information on the internet and from government institutions. Many property websites provide information on land prices in various locations in Bandung City. The provided data includes location, land size, and price range. Another method that can be done from this study is by visiting a property agent in Bandung City. Property agents can provide more detailed information on land prices in a particular area. The property agents can also help you find land that suits your needs. Contacting the landowner directly. The main issues are land prices can change at any time; therefore, it is important to validate the land price with several stakeholders such as the marketplaces, property agents, government institutions, banks, and other stakeholders that are related to the land price.

However, there are potential implementations of the FALVI in many sectors. In land use planning, the FALVI can be used to identify flood-prone areas and guide land use planning decisions to minimize the impact of flooding. The FALVI can also be used to assess the risk of flooding for individual properties and neighborhoods. Moreover, insurance companies can use the FALVI to determine flood insurance premiums based on the risk of flooding. Regarding disaster mitigation and prevention, the FALVI can be used to inform disaster management plans and identify vulnerable populations. The resulting flood potential index map visually represents the spatial distribution of flood risk across the study area (**Figure 5**).

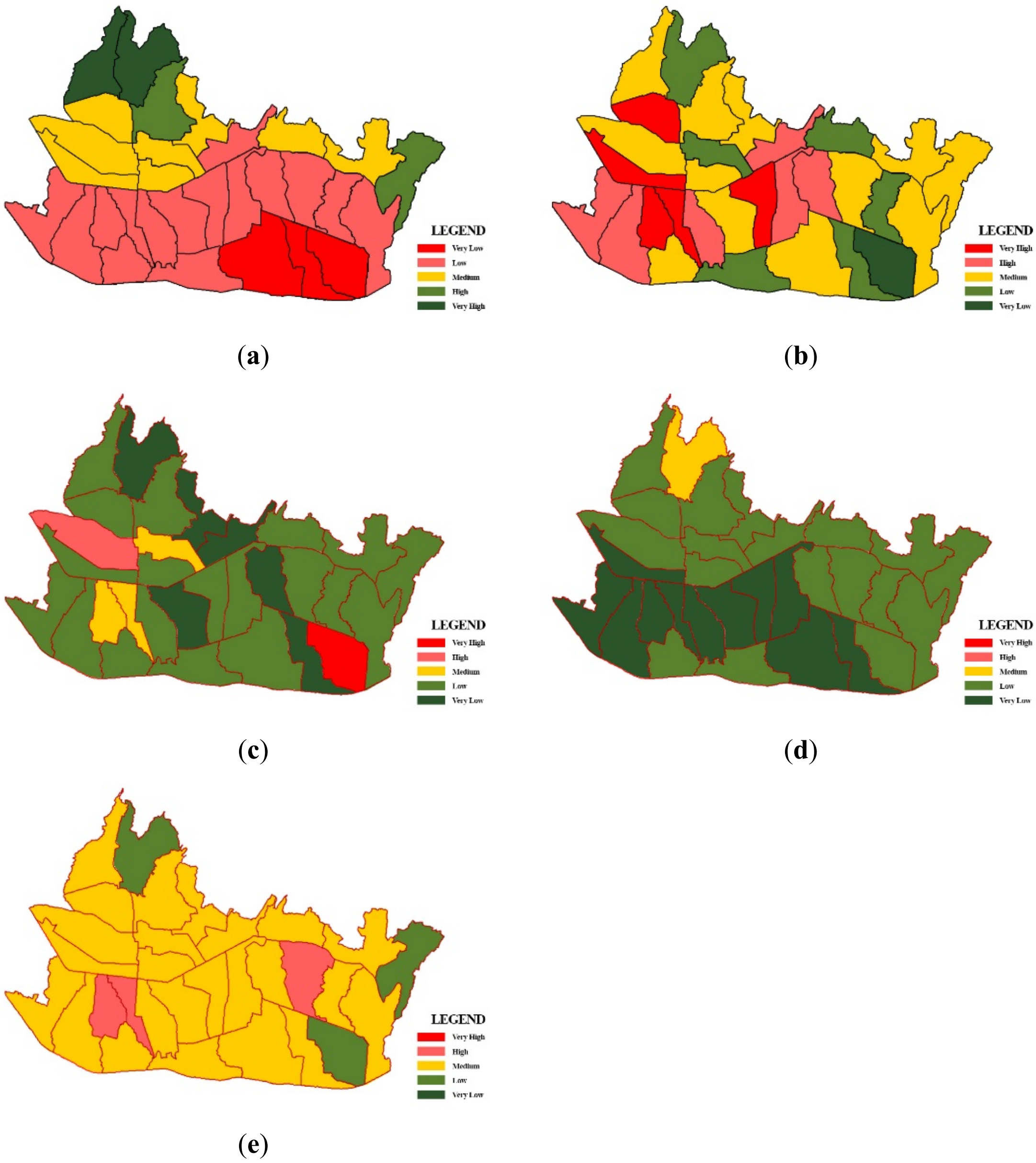

Figure 5. The spatial distribution of flood risk in the study area: (**a**) elevation, (**b**) population density, (**c**) flood record, (**d**) slope, and (**e**) land use.

Following the spatialization of each flood potential variable in Bandung City, a correlation analysis was performed to determine the relative weight of each variable. Pearson's correlation coefficient (r) was employed for this purpose, and the results are summarized in **Figure 6**.

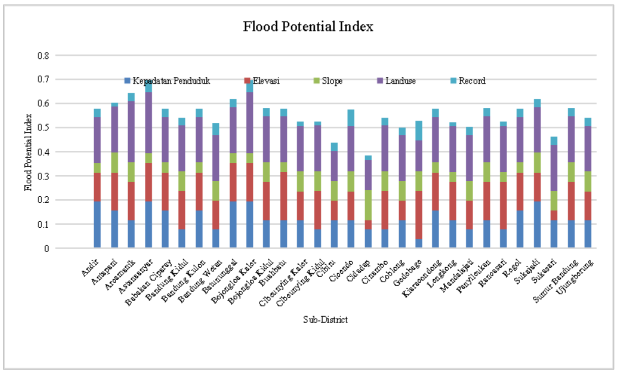

Figure 6. Flood potential index.

As shown in the table, the FALVI index directly compares flood variables with land prices in a comprehensive manner, unlike other methods that merely treat disaster indices as minor sub-variables. FALVI is specifically designed to assess land value based on its vulnerability to flooding, thus providing a more direct and accurate valuation.

4. Conclusions

The relationship between land value and water issues is complex and multifaceted. Water is a critical resource that influences land use, property values, and economic development. There are several factors affecting the relationship between land value and water issues such as water quality, water quantity, land-use types and regulations. Zoning laws and other land use regulations can impact the relationship between land value and water issues. For example, restrictions on development in flood-prone areas or near sensitive water bodies can affect land values as well as infrastructure development. This paper illustrates the importance of a proposed FALVI methodology to determine the relationship between flood events and land value. Important variables within 3 main aspects—environmental, socio, and historical flood variables—would be elaborated and measured by GIS-based analysis. It provides a more accurate and thorough assessment of property values by taking flood risk variables into account throughout the valuation process. This methodology is also considered an indispensable approach related to examining floods and land value relationships for urban areas. FALVI can inform government policies related to flood management, land use planning, and disaster risk reduction. By identifying high-risk areas, policymakers can prioritize flood mitigation measures and implement regulations to discourage development in vulnerable zones. Urban areas in certain watershed systems can be kept viable for the long run by carefully examining this methodology and applying appropriate land management measures. Furthermore, this methodology can help decision-makers and policymakers create effective laws and regulations that preserve and sustain watershed systems while simultaneously supporting economic growth and social development. Public education and awareness campaigns are essential for the successful implementation of FALVI. By addressing these considerations, FALVI can contribute to more sustainable and resilient urban areas such as in Bandung City and other urban areas.

Author Contributions

M.M., R.Y.T. and O.C.P. conceived of the presented idea. R.Y.T. developed the theory and supervised the findings of this work. G.G.M. checked the results of the GIS analysis and interpretation in the study. All authors discussed the results and contributed to the final manuscript.

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Institutional Review Board Statement

The study did not require ethical approval.

Informed Consent Statement

Not applicable.

Data Availability Statement

The authors agree to share their research data upon request.

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Conflicts of Interest

The authors declares no conflict of interest.

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