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GIS - MULTI CRITERIA EVALUATION AND ANALYTICAL NETWORK PROCESS FOR DETERMINATION OF LAND CAPABILITY CLASS AND SUITABILITY OF RESIDENTIAL LAND

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Abstract

In this study, a GIS-based multi-criteria evaluation for residential construction takes into some environmental factors by making effective criteria and sub-criteria. The final super-matrix of the weight values is achieved using an analytical network process in an outstanding decision-making software. Adjusting the weight of each criterion cluster with the spatial layer of EMC GIS, produces a land capability map (LC) and a land suitability evaluation map (LSE) for residential construction. The results showed that the value of good suitability is a suitable area for the development of residential areas because of the low potential for natural hazards and ecological damage. Results from the LSE map assessment with urban regionalization showed that natural disasters of floods and landslides originating from very critical land uses must be considered as a high priority, because Garut is an area with high flood and landslide hazards has an impact on high social, economic and spatial vulnerability. The increasing trend of high-rise building construction in poor residential areas is in stark contrast to the natural preservation of these areas.

Keywords: EMC, GIS, LSE.

1. Introduction

In recent years, world faces problems in the large urban areas, specifically on how to make a stability among urban growth, social economy, and consideration of environmental characteristics [1]. Urban relates to the growth of economy, creating problems if we cannot manage the condition [2].

There are extensive publications in the field of urban planning as well as regional science, considering to the urban land evaluation models [3]. The models are classified into two groups: (i) traditional procedure; and (ii) empirical procedures. In the traditional method (such as Feng-Shui theory), the procedure is one of the useful approaches for estimation of ecological landscapes [4]. In the empirical method, this is appropriate for assessment of land suitability or spatial planning [5].

Many reports have suggested empirical techniques for multi-criteria evaluation integrated spatial planning (known as MCE) for giving integrated urban land use evaluation [6], urban landfill site selection [7], an interactive indicator set model to design urban spatial and non-spatial indicators [8], and to determine different levels of urban vulnerability [9]. Also, other reports showed quantitative, integrated spatial planning to achieve dual natural resource management uses in areas such as environmental management [10, 11], forestry [12], agricultural resource management [1], sustainable hillside development [13], and urban natural disasters [14].

Urban construction is explained as a framework of spatial relationships among lands, different environmental parameters, as well as expressions of spatial configuration of functions. These are assessed based on analytical processes, land evaluation models, as well as geographic information system (GIS) analysis.

The integration of land evaluation and GIS are able to set a better basis for facing with land spatial suitability. Then, process and analysis as a multi-criteria decision-making tactic are to arrive at a preference scale among a set of alternatives [15].

One of the most crucial fundamental topics in the urban planning is paying consideration on the construction of high-rise buildings. In the construction of high-rise buildings, they can determine the degree of use of the urban environment. Building construction can carry considerable impacts on social, economic, and environmental benefits. This can make some facilitating interactions in densely packed areas, agglomerative economies of urban density, shopping, and health care facilities [3]. This also can make in preventing the use of mobile phones, increasing energy efficiency, as well as reducing carbon dioxide emissions. In addition, the negative impacts of high-rise building construction are high pressure on urban infrastructure, urban traffic congestion, environmental quality degradation such as blocked sunlight, trapping of air pollution near highways [16].

Therefore, there are several important factors in the construction of urban elevations and the development of their environment such as the vulnerability or capability of urban land. In addition, the urban elevation construction pattern is a very significant factor in relation to environmental sustainability [17]. To meet the challenges of urban sustainability, urban land needs to be evaluated spatially with an interdisciplinary approach that integrates ecological, economic, social, and design/planning sciences [18]. This is the key focus of the study of the urban future. Recently, the achievement of consistent and appropriate building construction in urban areas to provide a high quality of life and development improvement is one

of the requirements for this goal. The increases in population have made a limitation in the environmental resources in urban areas, where they need to get appropriate land use development. In general, the evaluation of land suitability mainly considers on environmental attributes, in which these refer to the ecological, spatial, economic, and social configuration of land use development in urban planning. Therefore, a multi-criteria evaluation method is utilized to determine the sustainable balance for the configuration to be assessed based on the land unit suitability index for sustainable urban development in an area.

On this point, the objective of this paper was to show an integrated procedure for analytical network data processes (ANP) and GIS to estimate land suitability for the construction of residential buildings in Garut District, West Java Province, Indonesia. Method that used in this study is quantitative and qualitative descriptive. The novelties of this study were (i) based on the carrying capacity of the environment to support buildings on it and (ii) mitigation efforts for floods and landslides.

2. Methodology

Methodology contains about data preparation, study area, multi criteria evaluation (MCE), ANP and parameter, rate and weight of input capability and land suitability. Data preparation is the work of preparing graphic data (satellite images and analogue maps) as well as statistical attribute data for Garut District. The study area describes the geographical boundaries, area and boundaries of neighbours around Garut Regency. Multi-criteria evaluation is used in this study because spatial analysis based on geographic information systems for housing and settlement areas is influenced by many parameters. The analytical network process is a method used to perform spatial analysis based on geographic information systems with several input parameters. Parameter, rate and weight of input capability and land suitability. Parameters, rates and weights for input capability and land suitability explain the input parameters, rates and weights used to produce land capability and suitability outputs.

2.1. Data preparation

Urban systems were established over temporal and spatial scales, in which these are based on dynamic interactions among social, economic, and biophysical processes. These result in different forms. In order to comprehend the main role in the urban systems in the construction process of residential buildings, it is necessary to study all the effective factors consisting of anthropogenic and ecological characteristics. The inputs used for the development of the land suitability class map model for residential built using satellite imagery and digital elevation model (DEM) are drainage conditions, effective soil depth, rainfall, flooding, erosion sensitivity, soil texture, rocks, and slopes. The evaluation of the ecological aspect is used to get and analyse the potential of land for the development of land suitability for residential in Garut Regency.

In order to comprehend the main role of urban systems in the construction process of residential building construction and land capability, it is necessary to study all the effective factors that comprise the ecological characteristics. Aspect condition ecological, including 8 criteria, were used as input points to get the output of land suitability class maps for residential from the points, specifically, in the results of the digital spatial analysis process using ArcGIS 10.2. All effective

parameters were compacted and summarized into 31 sub-criteria and then grouped into 8 main criteria (see Table 1). This table shows that all sub-criteria measurement scales are presented. This table also shows that all sub-criteria measurement scales are presented. In this table all criterion measurement scales are presented.

All data requirements are collected based on official documents from the Garut Regency Government. Then all the different criteria, classes and degrees are considered and sorted in the GIS to get the reclassified raster layer. The GIS procedure is utilized to create a land suitability layer for the building of residential buildings by combining the effective factors. All criteria, consisting of thematic maps: (1) drainage, (2) rainfall, (3) effective soil depth, (4) flooding, (5) soil texture, (6) erosion sensitivity, (7) rock, (8) slope, are presented in Figs. 1-8.

2.2. Study area

Garut Regency has a planning position in supplying the needs of Bandung City and Regency residents as well as playing a role in controlling environmental balance. Garut Regency is one of the places in West Java, specifically is placed in the southern part of West Java Province at coordinates 6º56'49" - 7 45'00" South Latitude and 107º25'8" - 108º7'30" East Longitude. Garut Regency has an administrative area of 306,519 Ha (3,065.19 km²) with the following boundaries: (i) In the North, it is with Bandung Regency and Sumedang Regency, (ii) in the East, it is with Tasikmalaya Regency, Indonesian South Ocean, (iii) In the West, , it is with Bandung Regency and Cianjur Regency. Garut Regency which is geographically close to Bandung City as the capital of West Java province, is a buffer zone for the development of the Greater Region of Bandung.

2.3. Multi Criteria Evaluation (MCE)

MCE is one of the analyses that can be defined as a decision support aspect. This analysis relates to the context of GIS-based decision making that has been focused as a beneficial strategy for solving problems in spatial management. This is also a powerful method to land suitability evaluation [19]. MCE simply combines criteria to build a single composite that is utilized for decision making for a specific purpose.

The main purpose of implementing the MCE aspect was to integrate assessment of the study area and to analyse land suitability comprehensively [20]. MCE uses a number of different qualitative or statistical methods, such as, analytical hierarchy process (AHP), logistic regression (LR), ANP, multivariate statistical approach (MSA), and weighted linear combination (WLC) [21]. In this study, MCE was valued as an ANP statistical method due to its reliability and combinability in GIS.

2.4. Analytical Network Processes (ANP)

ANP is an extension of the AHP. AHP is a well-known technique that can break down a decision-making problem into several stages and levels, in which the levels form a hierarchy with a unidirectional hierarchical relationship between components level [22]. ANP is a nonlinear structure with bilateral relationship [23]. Thus, the main innovation of ANP is in its network structure that allows interactions among elements locating in different clusters and dependencies among elements in the same cluster [24]. ANP has the ability to model the relationship and feedback between factors effectively in the decision-making process.

2.5. Parameter, rate and weight of input capability, and land suitability

The parameters used as points in the input data are soil drainage, rainfall, flooding, soil texture, erosion sensitivity, rocks, slope and effective soil depth [25, 26]. One of the important points is soil drainage [27]. Soil drainage has 4 classes, rainfall has a class, flooding has a class, soil texture has a class, erosion sensitivity has a class, rocks have a class, the slope of the slope has a class, and the effective depth of the soil has a class.

Results analyses are shown in Figs. 1-8. Soil drainage has 4 classes, namely: good, somewhat good, somewhat bad, bad. Soil drainage map of Garut district is presented in Fig. 1. Rainfall has 4 classes, namely: very high, high, medium and low. Rainfall map of Garut district is presented in Fig. 2. Floods have 2 classes, namely: non-flood and infrequent.

Floods map of Garut district is presented in Fig. 3. Soil texture has 3 classes, namely: fine, medium, and coarse. Soil texture map of Garut district is presented in Fig. 4.

Erosion sensitivity has 4 classes, namely: insensitive, slightly sensitive, sensitive, very sensitive. Erosion sensitivity is presented in Fig. 5. Rocks have 4 classes, namely: a little, moderate, a lot, very much. Rocks is presented in Fig. 6. The slope has 6 classes, namely: flat, sloping, wavy, slightly steep, steep, very steep. Slope is presented in Fig. 7. The effective depth of soil has 4 classes, namely: deep, medium, shallow, very shallow. The effective depth of soil is presented in Fig. 8.

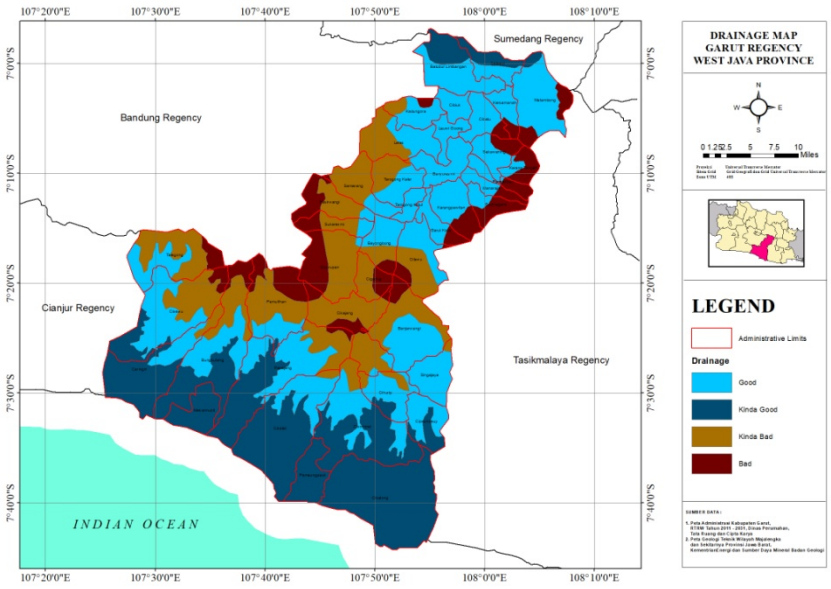

Fig. 1. Soil drainage map of Garut district.

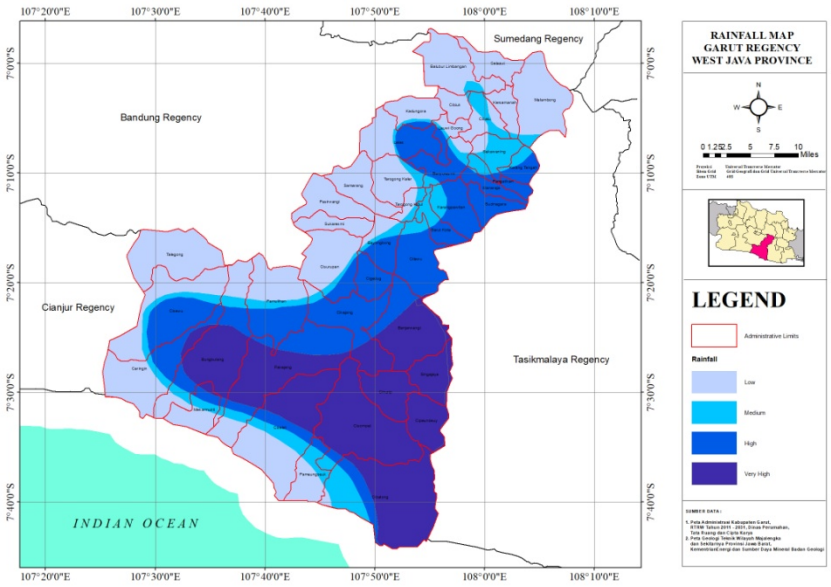

Fig. 2. Rainfall map of Garut district.

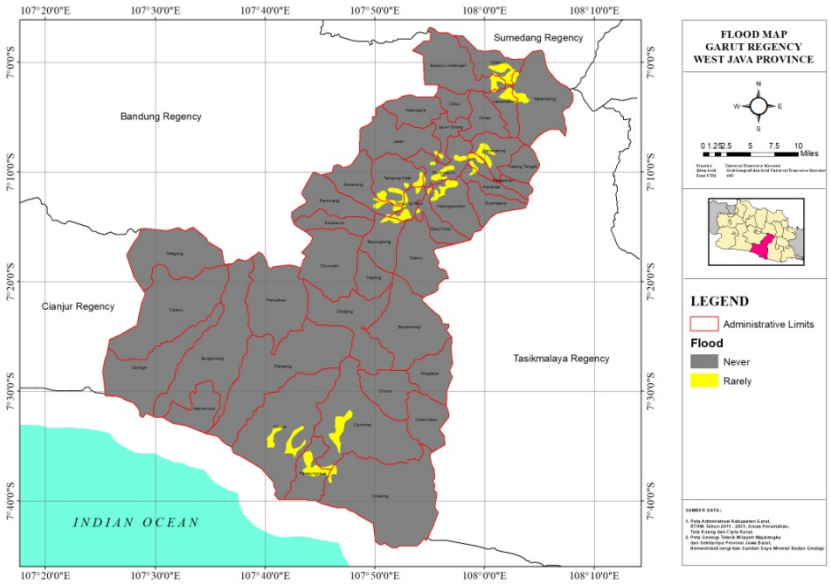

Fig. 3. Floods map of Garut district.

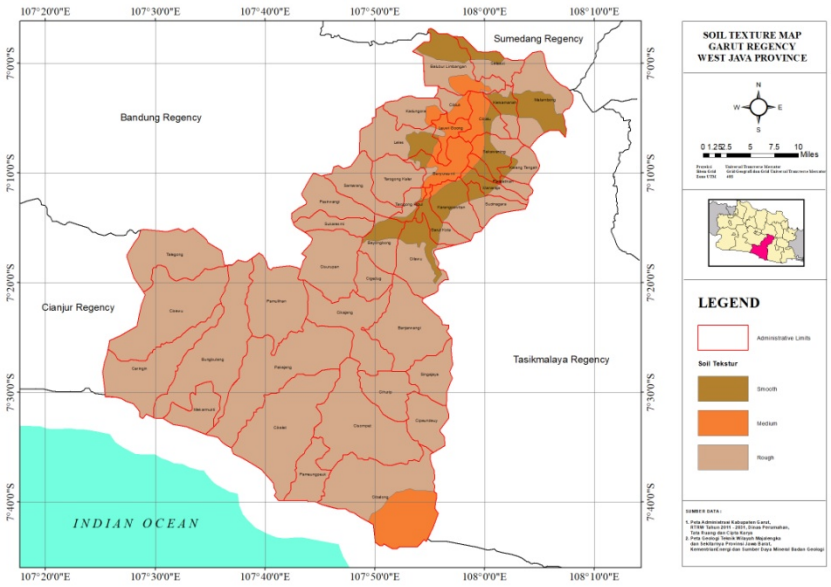

Fig. 4. Soil texture map of Garut district.

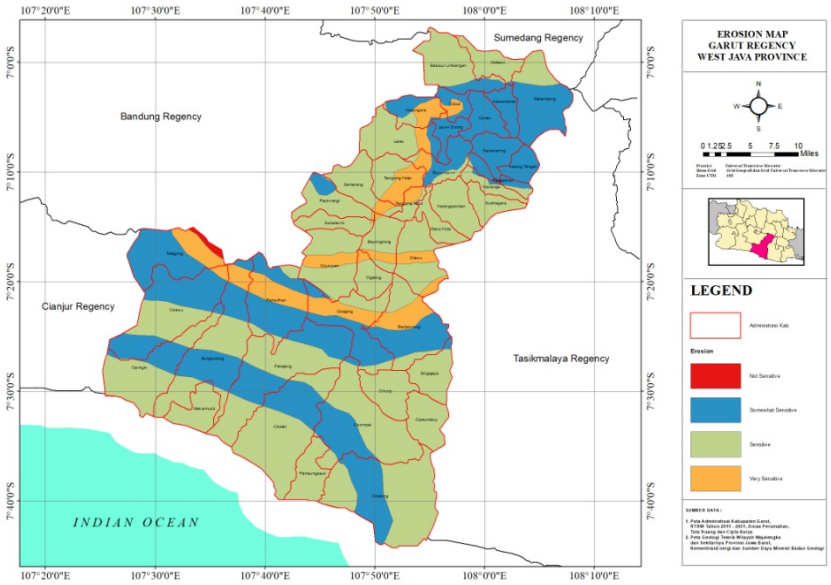

Fig. 5. Erosion sensitivity map of Garut district.

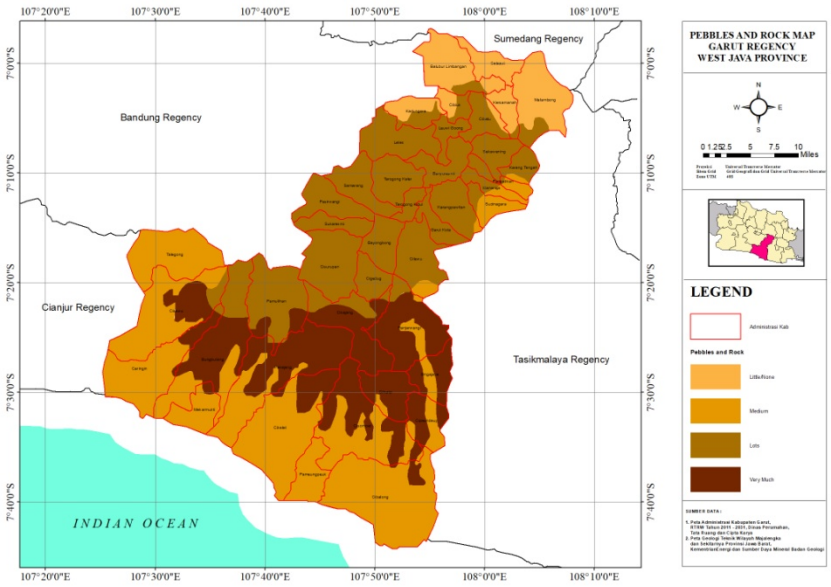

Fig. 6. Rocks map of Garut district.

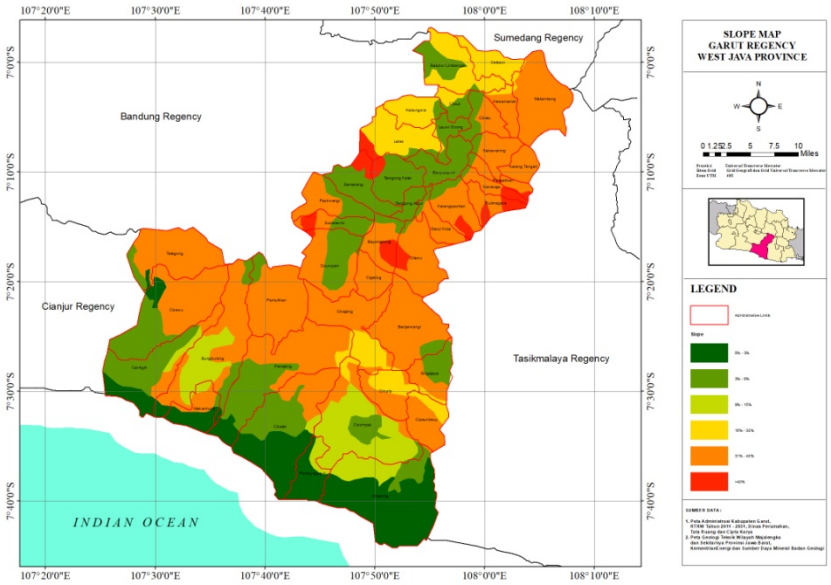

Fig. 7. Slope map of Garut district.

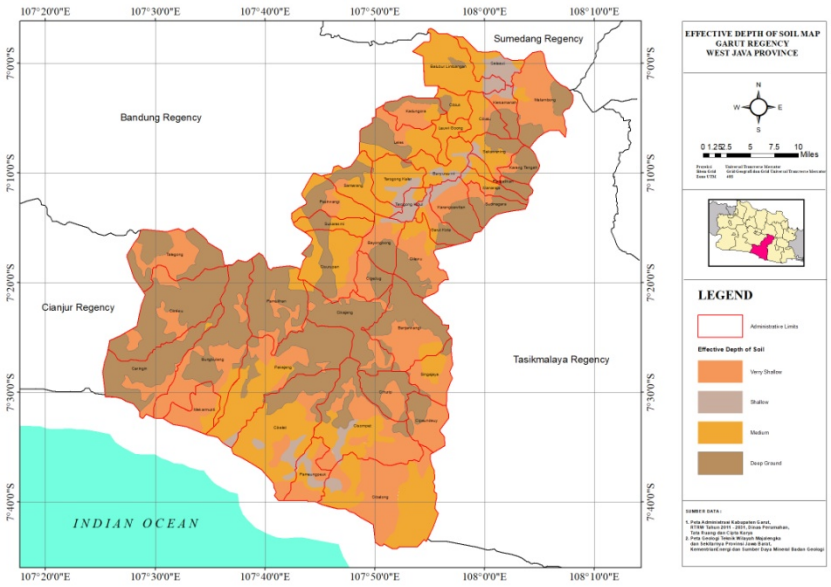

Fig. 8. The effective depth of soil of Garut district.

Summary of normalized weight values for criteria based on ANP presents input parameters with rates for each class as well as weights from expert judgement input results calculated by ANP for land capability and suitability. The stages describe the 8 stages that are passed in the study to get the capability and suitability of residential land in Garut district. Summary normalized wight values for criteria based on ANP is presented in Table 1.

3. Results and Discussion

3.1. Deployment of process analytics network (ANP)

In this study (see Table 1), pair wise comparison matrices with normalized weight values were set for 8 criteria for clusters with 31 sub-criteria. Pair wise comparison matrices and weight values were estimated using Super Decision software in the preference type and verbal mode. Then, the CR value obtained from the matrix for pair wise comparisons between the six clusters was found to be lower than 0.10, in which this shows an acceptable ratio.

As shown in Table 1, the natural characteristics of soil drainage and rainfall have the heaviest weights, corresponding to values of 0.22 and 0.19, respectively. The natural characteristics of the urban environment have a main role in evaluating land suitability and land capability. Considering urban regionalization in Indonesia, flood natural disasters originating from drainage and rainfall factors should be considered in high priority, because areas with poor soil drainage and high rainfall are areas with high vulnerability which will have social, economic, and spatial impacts. Residential buildings with multi-storey construction have a very high vulnerability to natural hazards and have a high sensitivity to natural characteristics. Flood natural disasters originating from drainage and rainfall factors must be considered in high priority, because areas with poor soil drainage

and high rainfall are areas with high vulnerability which will have social, economic, and spatial impacts. Residential buildings with multi-storey construction have a very high vulnerability to natural hazards and have a high sensitivity to natural characteristics. Flood natural disasters originating from drainage and rainfall factors must be considered in high priority, because areas with poor soil drainage and high rainfall are areas with high vulnerability which will have social, economic, and spatial impacts. Residential buildings with multi-storey construction have a very high vulnerability to natural hazards and have a high sensitivity to natural characteristics [28].

Table 1. Summary for normalized weight values for criteria based on the ANP analysis results.

Parameter	Rate	*Land Capability*	*Land Suitability*	Stages
Drainage (+)	40 30 20 10	0.125	0.22	
Effective depth of soil (+)	40 30 20 10	0.125	0.15	•Literature Review •Conceptual Model •Functional Model •Spatial Analysis SOP •Calculation of Criteria Weights With AHP •Geographic Information System (GIS) Spatial Analysis •Recommendation •Integration of research into regional development plans
Flood (-)	20 10	0.125	0.12	
soil texture (+)	30 20 10	0.125	0.11	
Erosion (-)	40 30 20 10	0.125	0.09	
Rock (-)	40 30 20 10	0.125	0.07	
Slope (-)	60 50 40 30 20 10	0.125	0.05	
Rainfall (-)	40 30 20 10	0.125	0.19	
Generated Thematic Map		Class I, II, III, IV, V, VI, VII, VIII	Land Suitability Good, Medium, Bad for Residential	

3.2. Generation of land capability evaluation (LC) and land suitability (LSE) for residential

This study used GIS software to generate criteria and sub-criteria maps that assist in the production of Land Capability (LC) and Land Suitability (LSE) evaluations for residential. Generation of LC and LSE for residential is the result of an analysis conducted in a raster data model using the weighted values of the eight cluster criteria calculated.

All weighted clusters were produced as models and raster data dimensions were 10 × 10 m after the derivation database of GIS operations. By assigning a weight value to each cluster, the specified weight value is multiplied by the sub criteria weight value to get a weighted super-matrix of the residential LC and LSE.

On this basis, residential LC and LSE maps were created for the study area (Figs. 9-10). Then the resulting map is adjusted to the pattern of land use in Garut Regency to show the number of percentages of land capability and land suitability for residential building construction [29].

The land capability has eight classes, namely: I, II, III, IV, V, VI, VII, and VIII. The land capability is presented in Fig. 9. The land suitability has 3 classes, namely: good, medium. The land suitability is presented in Fig. 10.

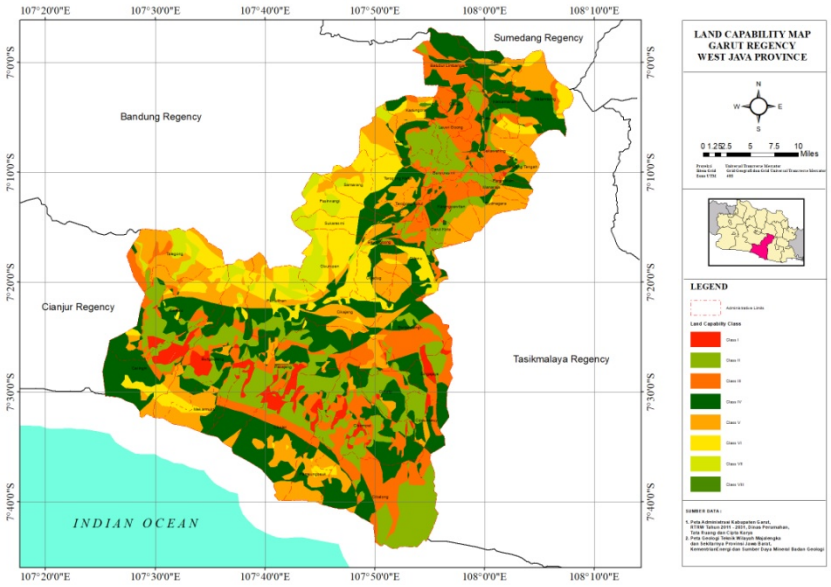

Fig. 9. Thematic map of land capability class in Garut district (Source of 2020 analysis results).

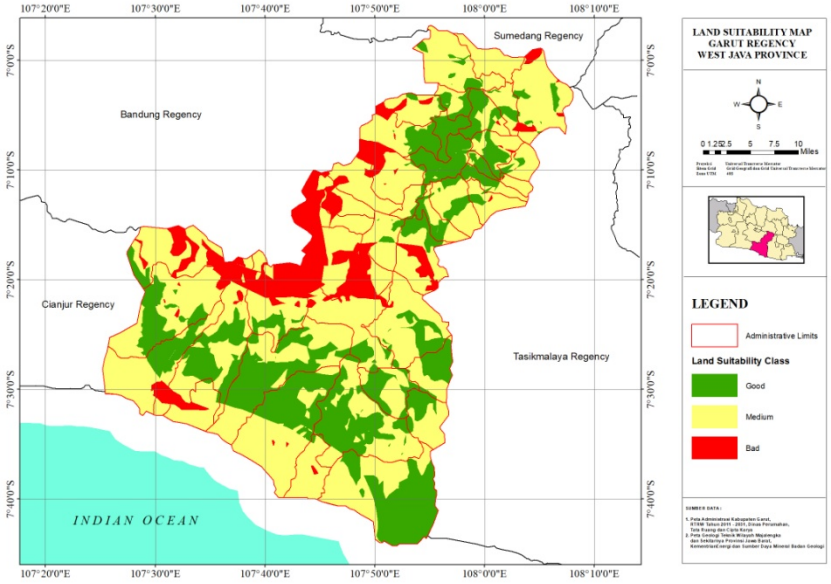

Fig. 10. Thematic map of land suitability of residential land in Garut district (Source of 2020 analysis results).

3.3. LC map assessment based on district land use patterns

Small village units Map based on Land Capability has 12 classes, namely: production forest, limited production forest, community forest, plantation, wetland farming, dryland farming, settlement, river border, middle ground movement prone area. high ground movement prone area, high tsunami prone area, sanctuary and nature conservation area. District Map based on Land Capability is presented in Fig. 11.

The results of the evaluation of the accuracy of the preparation of the district by referring to the land capability class being built show that:

- Production forest the largest area is in land classes 4.5 and 6 (28.08%) meaning that apart from having severe barriers that limit the choice of plants to be cultivated, it requires very careful management or both (creating terraces, alternating with cover crops/ forage/green manure for 3-5 years), create drainage canals, also have little or no erosion, but have other hard-to-remove barriers that limit land use. This soil is only suitable for permanent grass cultivation or forestry because it has very heavy barriers, so it is not suitable for agriculture.
- The largest limited production forest is on land class 3-4 (28.06%) which means that apart from having a rather severe barrier that reduces the choice of plant species cultivated or requires special soil preservation efforts or both (planting in strips, crop rotation with cover). soil, has severe barriers that limit the choice of crops to be cultivated, requires very careful management or both (creation of terraces, alternating with cover crops / fodder / green manure for between 3 and 5 years), constructing canals drainage.

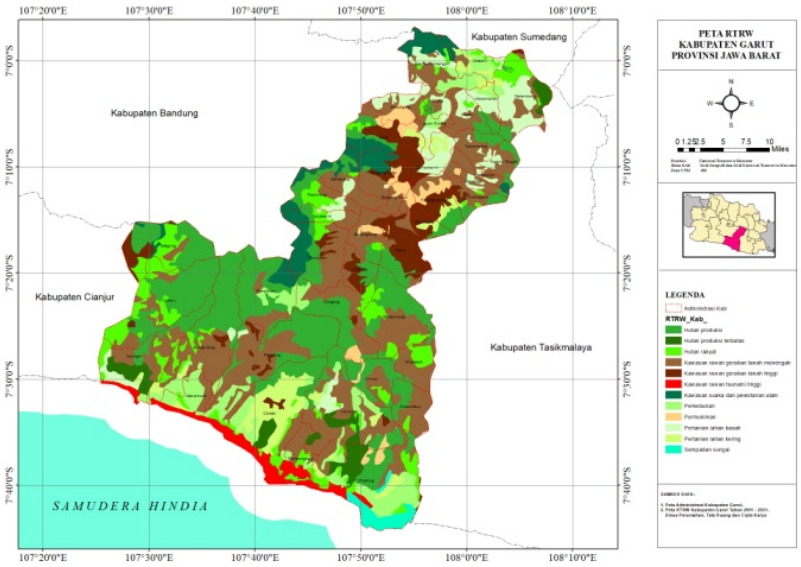

Fig. 11. District map based on land capability class in Garut district. (Source of 2020 analysis results)

- The largest community forests are in land class 4-5 (26.22%) meaning that apart from having severe barriers that limit the choice of plants to be cultivated, they require very careful management or both (creating terraces, alternating with cover crops/ forage/green manure for 3-5 years), create drainage canals, also have little or no erosion, but have other hard-to-remove barriers that limit land use. This land is only suitable for permanent pasture or forestry.
- The largest plantations are in class 4-5 (32.33%) which means that apart from having severe barriers that limit the choice of plants to be cultivated, they require very careful management or both (creating terraces, alternating with cover crops / food crops). livestock/green manure for between 3 and 5 years), create drainage canals, also have little or no erosion, but have other hard-to-remove barriers that limit land use. This land is only suitable for permanent pasture or forestry.
- The largest wetland agriculture is in class 3-4 (34.94%) which means that apart from having a rather severe barrier that reduces the choice of plant species cultivated or requires special soil preservation efforts or both (planting in strips, crop rotation with ground cover, have severe barriers that limit the choice of crops to be cultivated, require very careful management or both (creation of terraces, alternating with cover crops / fodder / green manure for between 3 and 5 years), create drainage canals.
- The largest dryland agriculture is in class 2 and 4 (26.44%) meaning that it has several barriers that can reduce the choice of plant species cultivated or require moderate soil preservation efforts (soil cultivation according to contours, crop rotation), have severe barriers that limiting the choice of crops cultivated, requiring very careful management or both (creation of terraces, alternating with cover crops/fodder/green manure for 3-5 years), constructing drainage canals.

- The largest settlements are in land class 3-4 (34.04%) which means that apart from having a rather severe barrier that reduces the choice of plant species cultivated or requires special soil preservation efforts or both (planting in strips, crop rotation with ground cover, it also has severe barriers that limit the choice of crops to be cultivated, require very careful management or both (creation of terraces, alternating with cover crops/forage/green manure for 3-5 years), constructing drainage canals,
- The largest river border is in class 2 land (74.09%) meaning that it has several barriers that can reduce the choice of plant species cultivated or require moderate soil preservation efforts (contour cultivation, crop rotation).
- The largest medium soil movement prone area is in class 4 land (29.64%) meaning that it has severe barriers that limit the choice of plants to be cultivated, requires very careful management or both (creating terraces, rotation with cover crops / fodder / green manure for 3-5 years), make drainage channels.
- The largest high soil movement-prone area is in class 2 land (25.51%) meaning that it has several barriers that can reduce the choice of plant species cultivated or require moderate soil preservation efforts (contour cultivation, crop rotation).
- The largest high tsunami hazard area is in land class 4-5 (51.15%) meaning that apart from having severe barriers that limit the choice of crops cultivated, it requires very careful management or both (creating terraces, alternating with cover crops/ fodder/green manure for between 3 and 5 years), create drainage canals, also have little or no erosion, but have other hard-to-remove barriers that limit land use. This land is only suitable for permanent pasture or forestry.

The main point from the above is the nature reserve and conservation [27]. This can change the number of reserved water and ecosystem, which can be used for daily life [30, 31]. The largest nature reserve and conservation area is in land class 6-7 (65.65%) meaning it has very severe obstacles, so it is not suitable for agriculture. Soil in grade 6 is only suitable for livestock grass crops which must be permanently maintained or reforested. Meanwhile, the land in class 7 land is not at all suitable for seasonal crop farming, only suitable for grazing or forestry [32].

3.4. Land suitability evaluation map assessment based on district land use patterns

The main idea is to predict how many areas for being used as a residential building [33]. LSE Map is the method for getting relative spatial probability of land suitability for the construction of residential buildings in the future. The area of land suitability for residential in Garut District, the results of the evaluation are shown in Table 2.

Table 2. Land suitability area for residential.

Residential Land Suitability Class	Area (km^2)
Good	1015.48 (33.13%)
Bad	337.24 (11.00%)
Medium	1712.45 (55.87%)
Total Area (km2)	3065,19

This study reveals that the constraint factor with a good suitability value is a suitable area for the development of residential building construction because of the large number of rock potentials, the slope between 135-40% and high rainfall. Therefore, even though the suitability value is good, it is still a prohibited area for

the development of residential building construction because of the high potential for natural hazards such as landslides and flood risk [34].

The results of the evaluation of the accuracy of the preparation of the district by referring to the suitability class of the residential land-built show that: To understand the LSE map (Fig. 12), we must consider the distribution trend of existing residential buildings in Garut district.

The existing condition of built-up land based on the land suitability class for residential has 3 classes, namely : good, medium bad. The existing condition of built-up land based on the land suitability class for residential in Garut District is presented in Fig. 12.

Existing condition of land suitability for residential based on land use in Garut district present the area of land suitability class to district land use patterns. Existing conditions of land suitability for residential based on land us in Garut district is presented in Table 3.

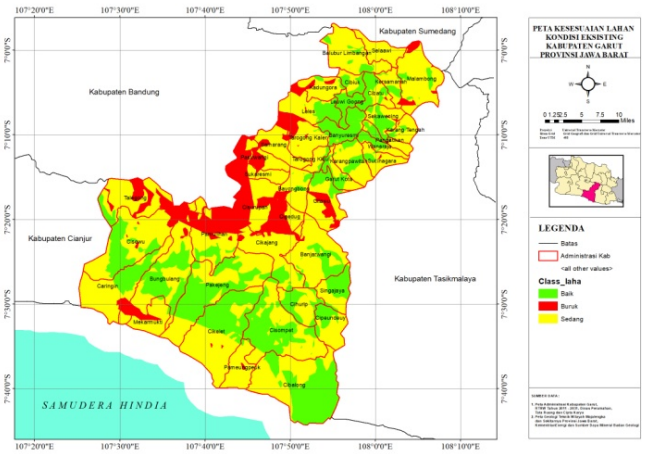

Fig. 12. Map of the existing condition of built-up land based on the land suitability class for residential in Garut district.

Table 3. Existing conditions of land suitability for residential based on land use in Garut district

District Land Use Patterns	**Land suitability class**		
Garut County	**Good**	**Medium**	**Bad**
Production forest	202.90	477.91	88.80
Limited production forest	17.47	65.54	3.15
Community forest	70,90	164.47	32.90
Plantation	75.61	125.42	12.94
Wetland farming	72.67	116.19	3.90
Dryland farming	61.48	63.83	2.69
Settlement	14.94	55.28	0.00
River border	25.09	5.39	0.00
Medium ground movement prone area	294.91	535.14	64.48
Areas prone to high ground movement	76.59	92.46	27.86
High tsunami prone area	1.59	66.28	0.00
Sanctuary and nature conservation area	3.06	62.13	81,20
Area (km^2)	**917.22**	**1830.05**	**317.92**

4. Conclusion

We conclude that environmental attitudes in evaluating land capability classes and land suitability for residential building construction can be carried out to achieve sustainable urban development, while environmental sustainability attitudes consider all ecological, social, and economic criteria with different weight values.

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