

Delineating suitable site for settlement in potential earthquake vulnerable areas using spatial multi-criteria decision analysis in the Sukabumi regency, Indonesia

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Abstract: Land suitability assessment is an important stage in land use planning that guides the direction of optimal land use. The objective of this study was to select a suitable location for settlements in earthquake-prone areas using the integration of the Analytical Hierarchy Process (AHP) and Geographical Information System (GIS). In total, six maps were considered to determine a suitable location for settlements, namely topography, soil, geology, land cover/land use, a regional spatial planning pattern map, and an earthquake vulnerability map. The results showed that in medium earthquake-prone areas, the suitable land area which are available for settlement was 90.25 km² (46.36% of the total land area available – 194.68 km²). Whereas in highly earthquake-prone areas, the suitable and available land area was 528.11 km² (70.25% of the total land area in the high vulnerability zone – 751.81 km²). The research proved that AHP and GIS integration is very effective and robust for mapping land suitability in earthquake-prone areas. The results of the analysis can be used by planners to prioritize settlement development in the Sukabumi regency. The methodology developed is recommended to be applied in selecting locations for settlements in other parts of Indonesia.

Keywords: Analytical Hierarchy Process (AHP), earthquake vulnerable areas, Geographical Information System (GIS), land availability, regional planning

INTRODUCTION

Indonesia is the fourth most populous country in the world and is also a country prone to natural disasters. USGS [2015] stated that Indonesia experiences earthquakes more frequently than any other country in the world. In Indonesia, an average 14 earthquakes and five volcanic disasters occur each year, resulting in death and damage to infrastructures [World Bank 2019]. It has been estimated that 60 cities in Indonesia and around 42% of Indonesia's population (110 mln) had been exposed to natural disasters [GUNAWAN *et al.* 2015]. Its position, which is at the confluence of three tectonic plates, namely Eurasia, Indo-Australian, and the Pacific plates, makes Indonesia prone to earthquakes. The meeting of the three plates forms a highly active

zone, with the presence of a fault that stretches from Sumatra to Papua with volcanoes along it [VERSTAPPEN 2010]. PUTRA *et al.* [2012] reported that during the period from 1799 to 2010 in Indonesia there were more than 48,000 earthquake disasters with a magnitude of $M \geq 4$ on the Richter scale. The largest earthquake in the last 15 years with a magnitude of 9.3 on the Richter scale occurred in Aceh on 26 December 2004 and caused a tsunami that affected 15 countries and left 130,000 people dead, alongside destroying 250,000 houses in Aceh [World Bank 2011].

The Indonesian government has made various efforts to reduce the risk of earthquake disasters, including the creation of a national earthquake hazard map and establishing the InaSAFE [InaSAFE 2015] which is a software used for analysing the impact of natural disasters. This software was established by the National

while flat areas (29%) are predominantly distributed around the city of Sukabumi and in its southern part. There are two volcanoes located in this district: Mount Salak and Mount Gede. Geologically, according to SUPARTOYO [2006], Sukabumi is dominated by sedimentary deposits in the form of alluvial plains, coastal sediments, volcanic sediments, and tertiary sediments which are unconsolidated rocks that are very susceptible to earthquake shocks.

DATASET

Six datasets were used in this study, namely topographic maps at a scale of 1:25,000 [BIG 2014], soil maps at a scale of 1:50,000 [BBPPSDLP – Badan Litbang Pertanian 2017], geological maps at a scale of 1:100,000 [KUSNAMA, HERMANTO 1998], Land Use/Land Cover (LULC) maps at a scale of 1:50,000, regional spatial planning pattern (RSPP) maps [Peraturan ... Nomor 22], and earthquake vulnerability maps [PVMBG 2014]. From these datasets, 13 thematic maps were produced which were used for further analysis.

ANALYSIS

The study was divided into four stages, namely: (i) determining the weight using the AHP, (ii) applying weights to evaluate land suitability for settlements, (iii) evaluating land availability for settlements, and (iv) selecting settlement locations on available land in earthquake-prone areas. The process is illustrated in Figure 2.

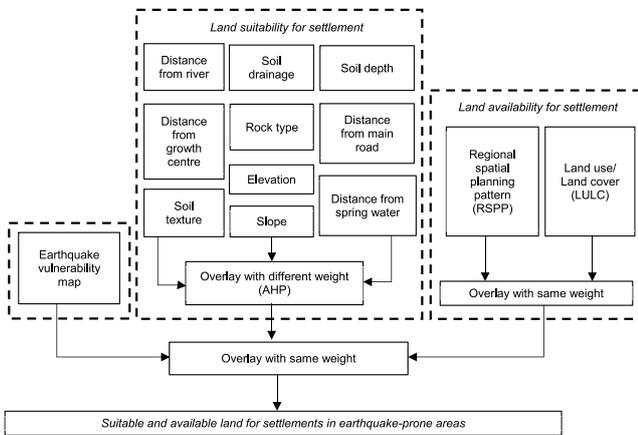


Fig. 2. Research flow diagram; source own elaboration

Assigning the weights of criteria using AHP methods

The success of this research was largely determined by the success of the identification of the criteria, the quality of the data, and the conditions of the area. In this study, ten criteria were used to determine the location of settlements in earthquake-prone areas, which were slope, elevation, rock type, distance from main roads, distance from rivers, distance from springs, distance from growth centers, soil texture, soil depth, and soil drainage. The earthquake criteria itself did not become a factor in the calculation of land suitability maps, because all study areas were located in areas prone to earthquakes. The earthquake criteria were used in the determination of the area being considered for settlement in each class of earthquake vulnerability.

An important step after specifying the criteria was to determine the weights of the criteria and the sub-criteria scores. Both weights and scores were classified based on their contribution to the selection of suitable sites for settlements, judged by experts. Weights were assigned to each of the main criteria using the AHP approach. Comparisons were made by assessing the relative importance of the two criteria involved in determining suitability [SAATY 1980]. The AHP structure for site suitability analysis for settlements is shown in Figure 3. Five experts were involved in determining the weights in this study to compare the criteria in the pairwise comparison matrix. A scale of 1–9 was used for land suitability parameters. If the criteria were equally important, they were given a weight of 1, while a weight of 9 indicated that one criterion was much more important than another [SAATY 1980]. Each pair of criteria was assessed for importance. The verification of the consistency of expert opinions was carried out by setting the value of consistency ratio (CR) as described by BOZDAĞ *et al.* [2016].

The scoring value was assigned based on a literature review and an assessment of the expert team. The score for each sub-criterion was given by giving a value of 0 to 10, where 0 indicated the influence of the lowest sub-criteria and 10 represented the most important sub-criteria [WIDIATMAKA *et al.* 2016].

Preparing data input for analysis of land suitability for settlements

In this study, a land suitability map for settlement was developed based on ten criteria which are slope, elevation, distance from main road, distance from water spring, distance from river, distance from growth center, rock type, soil depth, soil drainage, and soil texture. The land suitability map is obtained by multiplying the weight of the criteria and the sub-criteria scores

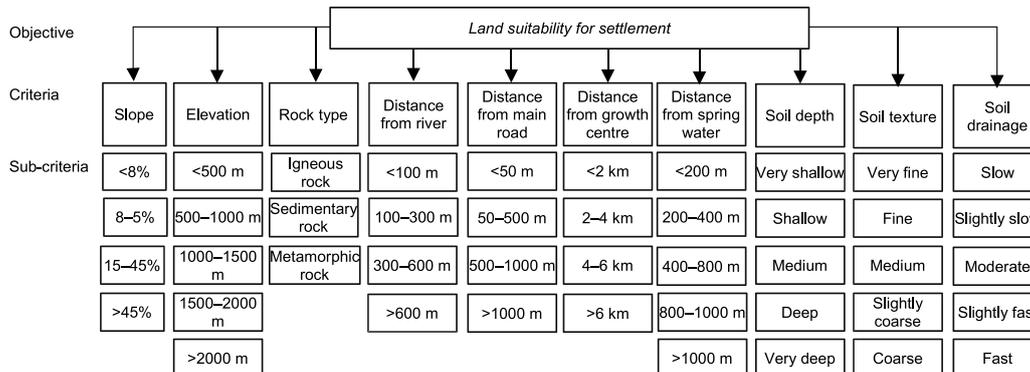


Fig. 3. Structure of land suitability decision making for settlements; source own elaboration

according to Equation (1) [WIDIATMAKA *et al.* 2016]. The level of suitability of the settlements was divided into four classes: highly suitable (S1), suitable (S2), marginally suitable (S3), and unsuitable (N).

$$S = \sum_{i=1}^n w_i x_i \quad (1)$$

where: S = land suitability; w_i = weight of land suitability criteria; x_i = score of sub-criteria i ; n = number of land suitability criteria.

Slope is one of the main criteria that affects the direction of development planning in an area related to topography [OMAR, RAHEEM 2016]. The slope was created from the contour layers on the topographic map. Generally, settlements are recommended in flat areas (<8%) since construction costs are cheaper, and constructions are more stable. The slopes (in %) were classified into four classes which are: (i) <8, (ii) (8; 15), (iii) (15; 45), and (iv) ≥ 45 .

Elevation is related to soil stability, accessibility, construction costs, and disaster risk. The elevation was created from the topographic map contour layer. The elevation (in m a.s.l.) was divided into five classes which are: (i) <500, (ii) (500; 1000), (iii) (1000; 1500), (iv) (1500; 2000), and (v) ≥ 2000 .

Distance from rivers was modelled from the river layers on the topographic map. Buffer zones were created from the river bed boundaries from both sides and were classified into four classes, namely: (i) <50, (ii) (50; 500), (iii) (500; 1000), and (iv) ≥ 1000 m.

Distance from main roads were established from the road layers on the topographic map. The buffer zone was established around the main road, and it was classified into four classes, namely: (i) <50, (ii) (50; 500), (iii) (500; 1000), and (iv) ≥ 1000 m.

Distance from growth center was created from the building layer of topographical map. The centroid of the regency and sub-district government was selected as a growth center point. The buffer zone was created around the centroids and was classified into four classes which are: (i) <2, (ii) (2; 4), (iii) (4; 6), and (iv) ≥ 6 m.

Distance from water spring was considered as an important criterion for the location of settlements and was established from the lake layers of the topographic map. Buffer zones were created around springs and lakes and were divided into five classes, which are: (i) <200, (ii) (200; 400), (iii) (400; 800), (iv) (800; 1000), and (v) ≥ 1000 m.

Rock type was derived from the geological map at a scale of 1:100.000. It consisted of three classes: (i) igneous, (ii) sedimentary, and (iii) metamorphic rocks.

Soil texture is an important criterion for determining an area's suitability for the construction of houses. Soil texture was split into five classes: (i) very fine, (ii) fine, (iii) medium, (iv) slightly coarse, and (v) coarse.

Soil drainage was classified into five classes. They are: (i) slow, (ii) slightly slow, (iii) moderate, (iv) slightly fast, and (v) fast.

Soil depth was classified into five classes (in m). They are: (i) very shallow (<25), (ii) shallow (25–50), (iii) medium (51–75), (iv) deep (76–100), and (v) very deep (>100).

Preparing land availability maps for settlement

The land availability map was analysed using the RSPP and LULC maps. The result was a delineation of available land and unavailable land for settlement. The first map used was the RSPP map of the Sukabumi regency [PEMKAB Sukabumi 2012] which contained information on land allocation for various formal sectors. The RSPP map of the Sukabumi regency consisted of

13 space allocations, which were Protected Forest Area (PFA), Conservation Forest Area (CFA), Production Forest Area (DFA), Limited Production Forest Area (LPFA), Reserve Forest Area (RFA), Plantation Allocation Area (PAA), Wetland Agriculture Area (WAA), Upland Agriculture Area (UAA), Enclave Area (EA), Rural Settlement Area (RSA), Urban Settlement Area (USA), Coastline Boundary Area (CBA), and River Boundary Area (RBA). Among these 13 available space allocations, only the allocation of urban settlement areas and rural settlements could be used for settlement development. The second map used was the LULC Map which described the existing LULC conditions. The LULC map was created using SPOT 7 imagery [DHARMA 2020]. The satellite image was georeferenced to the UTM 48S zone projection system. The image's visual interpretation for LULC was carried out. The LULC, which reflected vegetation cover, was classified into 11 categories as follows: (i) forest, (ii) dry land, (iii) building area, (iv) barren area, (v) plantation, (vi) irrigated rice field, (vii) rainfed rice fields, (viii) shrubs, (ix) lakes, (x) rivers, and (xi) ponds. Among these 11 LULC categories, the LULCs that were not available for settlement were built-up areas, lakes, rivers, and ponds. The remaining eight LULC were deemed available for settlements.

Establishing land suitability maps for settlements on available land in earthquake-prone areas

This step involved three input maps, which included a land suitability map for settlements, land availability map for settlements, and map of earthquake vulnerability. The overlay process was carried out with equal weight for the three input maps using the ArcGIS software. Subsequently, the final map was reclassified into four classes, which were highly suitable (S1) and available, suitable (S2) and available, marginally suitable (S3) and available, and unsuitable (N) for settlement. The final map was presented in two output maps: (i) a land suitability map for settlements on available land in medium earthquake-prone areas, which were then given symbols (S1, S2, S3, and N) and (ii) the land suitability map for settlements in highly earthquake-prone areas, which were named as S1, S2, S3, and N.

The earthquake vulnerability map of the Sukabumi regency (Fig. 4M) was used in this research to identify areas that are prone to earthquakes. The map was taken from the earthquake vulnerability map of Banten and West Java at a scale of 1:50,000 [PVMBG 2014]. Based on this map, the entire Sukabumi regency is located in an area that has the potential to be affected by high and moderate earthquake shocks. Areas that are potentially affected by high earthquakes with an intensity scale greater than VIII Modified Mercally Intensity (MMI) covered 77% of the study area, while areas with moderate earthquake intensity scales between VII–VIII MMI accounted for the remaining 23%.

RESULTS

WEIGHTING CRITERIA AND SCORING SUB-CRITERIA WITH ANALYTICAL HIERARCHY PROCESS

This study considered ten criteria for determining suitable locations for a settlement, which were slope, elevation, rock type, distance from the road, distance from the river, distance from

springs, distance from the growth center, soil texture, soil depth, and soil drainage. Several researchers have previously used criteria such as slopes, flooding, drainage, gravel, texture, and effective depth for the study of selecting locations for settlements [HARDJOWIGENO, WIDIATMAKA 2007]. SANTOSO *et al.* [2019] studied land suitability for settlements in Palu, Indonesia using criteria such as slope, distance to the road network, distance to education facilities, distance to health facilities, distance to trade facilities, and disaster vulnerability. Likewise, research conducted by DEĞERLIYURT [2014] used lithology criteria, distance from the fault line, shear speed, groundwater, distance to the sea, and slope as determining factors. RUSDI *et al.* [2015] conducted land suitability assessments for settlements based on soil permeability, topography, and geology parameters at the same location, namely Banda Aceh. These researchers showed that the land suitability criteria for settlements varied widely and were highly dependent on regional conditions, the availability of spatial data, research focus, and the researchers involved. It has been shown that a very important stage in the evaluation of land suitability is the determination of the criteria [AL-SHALABI *et al.* 2006]. The selection of criteria in land evaluation must pay attention to the number of decision makers, the number of objectives, the number of alternatives, the existence of constraints, and risk tolerance [RIKALOVIC *et al.* 2014]. So far, there are no standard criteria for settlements. Several researchers have stated that the general criteria for settlements consisted of geomorphological, socio-economic, and environmental factors [AKINCI *et al.* 2013]. There was one parameter, slope, which was used by all researchers, including in this study.

The results of expert judgment in determining the land suitability weight for settlements are shown in Table 1. Such results showed that the slopes had a highest weight (29%), meaning that slopes played an important role in determining land suitability for settlements, followed by the distance from the road (21%). The distance from the water spring and the distance from the river had the lowest weight, which were 1.9% each. Similar results were obtained in research conducted by DEĞERLIYURT

[2014] in Turkey and ZHAO *et al.* [2014] in China which indicates that slopes affect the spatial distribution of settlements. AL-SHALABI *et al.* [2006] stated that areas with a slope of more than 10% were not suitable for settlement development. Proximity to roads was one of the important criteria that should be considered in terms of accessibility, economy, and social aspects, as well as evacuation in the event of a natural disaster. According to OMAR and RAHEEM [2016] road accessibility is one of the important parameters for urban development because it provides connectivity between settlements; besides that, the presence of roads represents human activity. YEH and LI [1998] stated that the location of the settlements should be close to the road. In areas with a low population density, a distance of one to five km from the main and secondary roads is recommended.

Judging from the consistency of the experts involved in determining the weight using AHP, the ratio of consistency was 0.05 which was calculated using Equations (1)–(4). In the details of the assessment, the maximum eigenvalue (γ_{max}) was obtained = 10.73453477, $n = 5$; $CI = 0.081614974$; $RI = 1.49$ and $CR = 0.054775151$. SAATY [1988] reported that the acceptable consistency ratio (CR) should be ≤ 0.1 . Thus, the experts involved in this study were quite consistent in making assessments.

THEMATIC INPUTS MAP AND SETTLEMENT SUITABILITY MAP

The land suitability map for settlement was established by considering ten criteria and 45 sub-criteria resulting from the AHP and GIS approaches are presented in Table 2 and Figure 4. The result found that the study area was dominated by a slope of over 15 to 45% (43.4%) and flat areas which had a slope of 0–8% (29%) (Fig. 4A). A higher score was assigned to lower slope values (Tab. 2). Considering elevation, the study area was dominated by an elevation <500 m a.s.l. (57%) which was generally found in the southern and western parts of the study area. Meanwhile, elevations between 500 and 1000 m a.s.l. (36%) were generally found in the eastern part of the study area (Fig. 4B). The highest

Table 1. A pairwise comparison matrix for calculating the weight (relative importance) of criteria for settlement suitability.

Criterion	Criterion										Weight
	S	DMR	RT	DGC	E	ST	SD	SDr	DWS	DR	
S	1	2	3	4	5	6	7	8	9	9	0.2905
DMR	1/2	1	2	3	4	5	6	7	8	8	0.2103
RT	1/3	1/2	1	2	3	4	5	6	7	7	0.1517
DGC	1/4	1/3	1/2	1	2	3	4	5	6	6	0.1093
E	1/5	1/4	1/3	1/2	1	2	3	4	5	5	0.0784
ST	1/6	1/5	1/4	1/3	1/2	1	2	3	4	4	0.0558
SD	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	3	0.0392
SDr	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	2	0.0272
DWS	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	1	0.0188
DR	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	1	0.0188

Explanations: S = slope, DMR = distance from main road, RT = rock type, DGC = distance from growth centre, E = elevation, ST = soil texture, SSD = soil depth, SD = soil drainage, DWS = distance from water spring, DS = distance from river.

Source: own study.

score was assigned to low altitude areas (<500 m) and the lowest scoring occurred in the highland areas (1500–2000 m a.s.l.) – Table 2. Areas with an elevation >2000 m a.s.l. were a constraint and were not included in the analysis, because based on the statutory regulations on spatial planning [Keputusan ... Nomor 32; Undang-Undang ... Nomor 26], settlements cannot be installed at these heights.

Based on Table 2 and Figure 4C, the study area was dominated by locations that had a distance from the river greater than 600 m (87%). The most ideal areas for settlement were those that were situated between 100 and 300 m from the river, but in this study, this range of distances covered only 4% of the area. The highest score referred to the areas at distances ranging from 100 to 300 m from the river. Areas <100 m from a river were defined as a constraint that could not be used for settlement, according to regulations [Keputusan ... Nomor 32]. According to the distance from main roads (Fig. 4D), the research site was dominated by areas with a distance from the main road of >1000 m (77%). While areas which were <50 m away from the main roads comprised only 1% of the entire Sukabumi regency. The most suitable sites for settlement were at distances from roads ranging from 50 to 500 m and were assigned the highest score (Tab. 2).

Referring to the criteria of distance from growth center, the research area was dominated by areas that were far from the center of growth (>2 km); these comprised about 86% of the study area, while those <2 km away only covered 14%. The highest score referred to the nearest class (<2 km) from the growth center. Based on the criteria for distance from springs, 98% of the study area was located >1000 m from water springs and only 2% were located <1000 m away. The highest value referred to the class of areas located between 200 and 400 m from water spring, while areas <200 m away were defined as a constraint, as stipulated in statutory regulations [Keputusan ... Nomor 32].

Rock type of the study area was dominated by sedimentary rocks (53%) which were mainly distributed in the southern and middle parts of the study area (Fig. 4G). Igneous rocks (45%) are one of the most stable lithologies and are therefore very suitable for settlement, resulting in its high score value (Tab. 2). Soil texture is an important criterion for determining an area's suitability for the construction of houses. The study area was dominated by soils with a fine texture (73%) and slightly fine texture (21%). Meanwhile, coarse and slightly coarse soils were only found in the northern part of the study area (Fig. 4H). The highest score referred to the medium (slightly fine) texture, while the lowest score was assigned to the very fine and fine texture classes. Soil drainage of the study area was dominated by moderately drained soils (94.91%) (Fig. 4I). The study area was dominated by deep soil (86%). Meanwhile, very deep soil (>100 cm) covered 12% of the area and was generally found in the north-western part of the research area (Fig. 4J). The highest score was given to very shallow soils, followed by shallow soils; both soils were found only in the northern part and around Mount Gede (2%).

LAND SUITABILITY FOR SETTLEMENT

Land suitability maps for settlements were made by considering the ten criteria and 45 sub-criteria produced at the stage of determining the criteria weight using AHP. The land suitability

Table 2. The selected criteria and sub-criteria involved in the suitability evaluation for settlements

Criterion	Sub-criterion	Scoring	Area	
			km ²	%
Slope (%)	<8	10	1,212.25	29.35
	(8; 15)	8	622.16	15.06
	(15; 45)	6	1,794.05	43.44
	≥45	0	501.48	12.14
Elevation (m a.s.l.)	<500	10	2,362.77	57.21
	(500; 1000)	8	1,489.17	36.06
	(1000; 1500)	6	232.39	5.63
	(1500; 2000)	4	25.41	0.62
	≥2000	0	20.20	0.49
Distance from main road (m)	<50	10	58.14	1.41
	(50; 500)	8	449.44	10.88
	(500; 1000)	4	424.35	10.27
	≥1000	2	3,198.01	77.43
Distance from water spring (m)	<200	0	9.66	0.23
	(200; 400)	10	12.81	0.31
	(400; 800)	8	40.67	0.98
	(800; 1000)	6	27.36	0.66
	≥1000	4	4,039.44	97.81
Distance from river (m)	<100	0	116.67	2.83
	(100; 300)	10	181.56	4.40
	(300; 600)	8	251.21	6.08
	≥600	6	3,580.49	86.70
Rock type	igneous rock	10	1,881.39	45.55
	sedimentary rock	8	2,226.86	53.92
	metamorphic rock	6	21.69	0.53
Soil depth (cm)	very shallow (<25)	10	6.81	0.16
	shallow (25–50)	8	86.59	2.10
	medium (51–75)	6	-	-
	deep (76–100)	4	3,559.92	86.18
	very deep (>100)	2	477.39	11.56
Soil drainage	slow	6	78.64	1.90
	slightly slow	6	-	-
	moderate	10	3,919.82	94.91
	slightly fast	8	21.78	0.53
	fast	8	109.70	2.66
Soil texture	very fine	6	9.50	0.23
	fine	6	3,034.82	73.48
	medium	10	860.75	20.84
	slightly coarse	8	93.40	2.26
	coarse	8	131.48	3.18
Distance from growth center (km)	<2	10	566.15	13.71
	(2; 4)	8	1,252.62	30.33
	(4; 6)	4	1,086.23	26.30
	≥6	2	1,224.95	29.66

Source: own study.

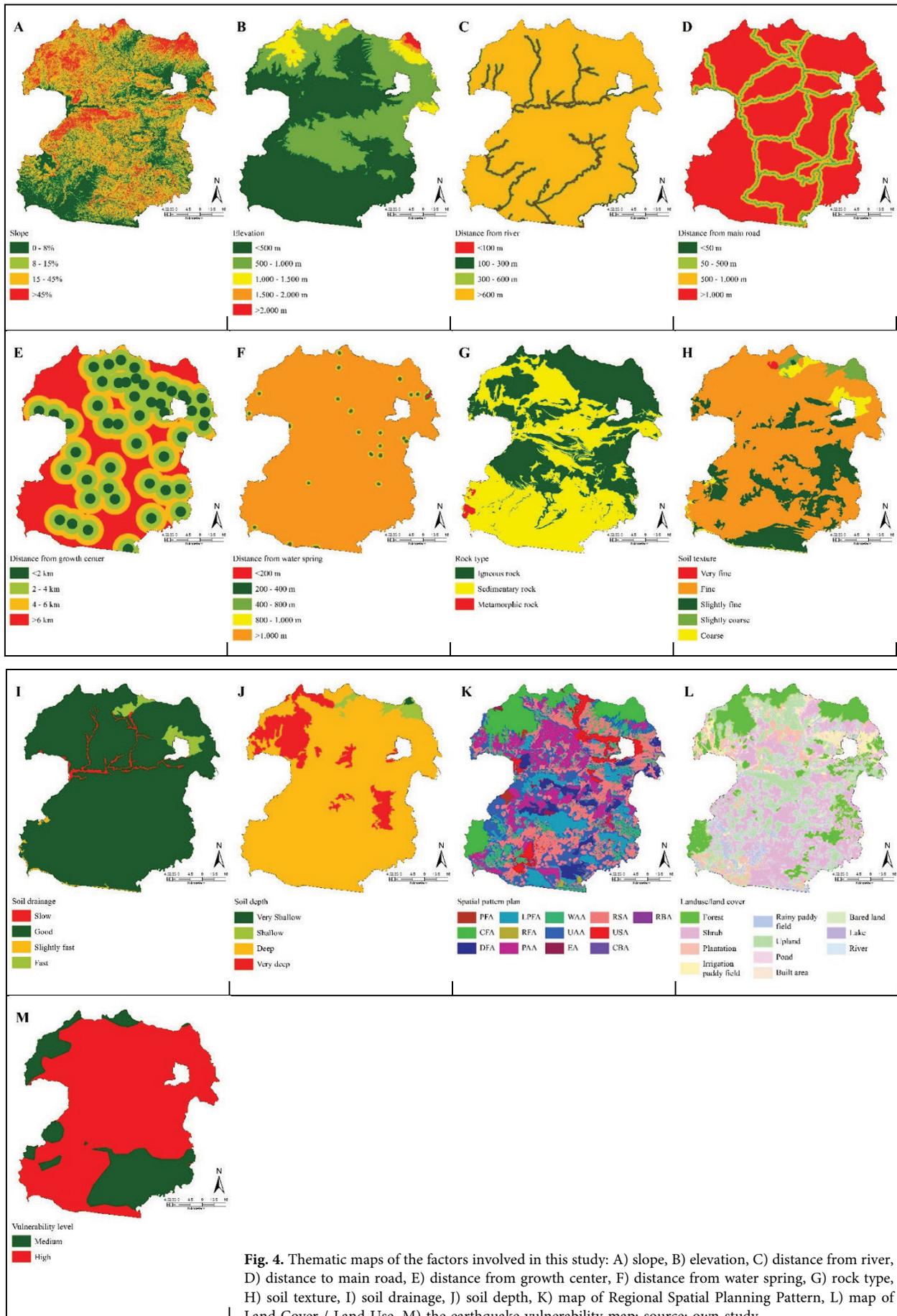


Fig. 4. Thematic maps of the factors involved in this study: A) slope, B) elevation, C) distance from river, D) distance to main road, E) distance from growth center, F) distance from water spring, G) rock type, H) soil texture, I) soil drainage, J) soil depth, K) map of Regional Spatial Planning Pattern, L) map of Land Cover / Land Use, M) the earthquake vulnerability map; source: own study

map was classified into four categories for further analysis: highly suitable (S1), suitable (S2), marginally suitable (S3), and unsuitable (N). The spatial distribution of land suitability for the settlements is shown in Figure 5 and a summary of the results is presented in Table 3.

The results found that from the total study area (4,129.94 km²), 2,313.49 km² (56%) was classified as land suitable for settlements. The land suitability varied from highly suitable (S1), suitable (S2), and marginally suitable (S3) classes, which were 9.43, 27.48, and 19.11%, respectively. However, the study area was dominated by the suitable class (S2). The highly suitable class (S1) could only be found in the northern part of the study area, more precisely around the city of Sukabumi. Meanwhile, locations that were unsuitable for settlement covered an area of 1,143.74 km² (27.69%) of the total study area and it was the dominant class. Locations which were unsuitable for settlement were scattered in almost the entire study area. The high proportion of areas of class of N and S3 were due to the fact that the study area was dominated by areas with slopes exceeding 15%, a distance from the highway of more than 1000 m, a distance from a river >600 m, and a distance from a growth center >2 km. In this study, about 16% of the area was a constrained area, generally found in the northern part, more precisely around Mount Gede and around the Cimandiri Fault. Based on the expert's assessment, the constraint area is an area that is not recommended for residential locations due to its physical characteristics. In this study the constraint areas were located on a slope >45%, at an elevation >2000 m, at a distance from the water spring <200 m, and a distance from the river <100 m. Those obstacles were implemented by the laws and regulations which are in effect in Indonesia [Keputusan ... Nomor 32].

LAND AVAILABILITY FOR SETTLEMENT

Land availability for settlement considers RSPP and LUCC (Fig. 5B). This figure provides information that the available land for settlement was 946.49 km² (23% of the total area) which was sporadically spread throughout the study area. Meanwhile, 77% of the land was not available for settlement and was widespread in all study area. When we considered only RSPP, suitable lands for

settlement were urban settlement areas and rural settlement areas, which covered 299.03 km² (7.20%) of the total study area. Whereas land that was unsuitable based on the considerations of the RSPP were Protected Forest Areas, Conservation Forest Areas, Production Forest Areas, Limited Production Forest Areas, Reserved Forest Areas, Plantation Allocated Areas, Wetland Agricultural Areas, Dry Land Agricultural Areas, Enclave Areas, Coastal Border Areas, and River Border Areas, which were found on around 3,863.38 km² (92.80%) of the study area. Most of the areas which were not available coincided with the areas allocated as Protected Forest Areas. This protected area must be obeyed because this area is the upstream part of a large watershed which includes the Cimandiri River and the Cikaso River. Analysis of land availability by considering only LULC showed that the land which was suitable for settlement included almost all the LULC classes, namely forest, fields/moor, open land, plantations/gardens, rice fields, rainfed rice fields, and shrubs with a total area of 3,888.68 km² (93.42% of the study area). Meanwhile, areas which were not available for settlements were ponds, rivers, lakes, and built-up land, which covered an area of 273.81 km² (6.58% of the total study area). Although theoretically available, lands such as rice fields should prudently be considered as available, considering that converting rice fields into settlements will affect

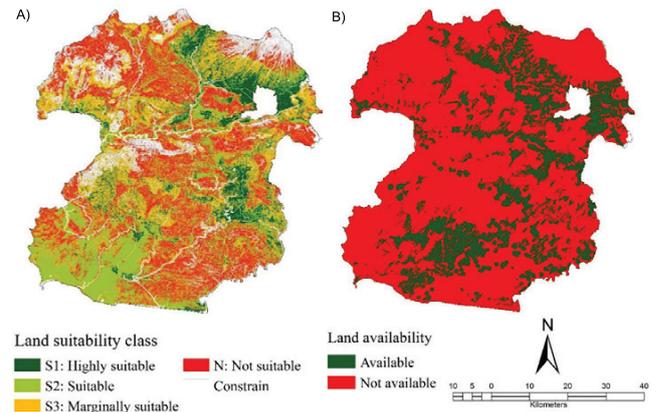


Fig. 5. The spatial distribution of land suitability for the settlements: A) settlement suitability map, B) map of land availability for settlement of the Sukabumi regency; source: own study

Table 3. Suitable and available lands for settlement in earthquake-prone areas in the Sukabumi regency

Suitability/ availability	Suitability		Suitable and available considering RSPP and LULC		Suitable and available considering RSPP, LULC and earthquake hazard level			
					medium (VI–VIII MMI)		high (>VIII MMI)	
	km ²	%	km ²	%	km ²	%	km ²	%
S1	389.36	9.43	128.42	13.57	7.51	3.86	120.92	16.08
S2	1,135.06	27.48	301.33	31.84	50.09	25.73	251.24	33.42
S3	789.06	19.11	188.61	19.93	32.65	16.77	155.96	20.74
N	1,143.74	27.69	246.03	25.99	78.57	40.36	167.46	22.27
Constrain	672.72	16.29	82.09	8.67	25.86	13.28	56.23	7.48
Total	4,129.94	100	946.49	100	194.68	100	751.85	100

Explanations: RSPP = Regional Spatial Planning Pattern, LULC = Land Cover / Land Use, MMI = Modified Mercally Intensity, S1, S2, S3 and N as in Fig. 5. Source: own study.

the supply of rice which is a staple food [Undang-Undang ... Nomor 41]. This can be a separate topic of discussion in the context of regional food security, but in this study, it was still considered as available land that could be used for settlements. Meanwhile, land availability by considering the RSPP and LULC maps can be seen in Table 3. The results of the analysis showed that the suitable and available area for settlement was quite wide, covering an area of 618.36 km² (65.33% of the total available area – 946.49 km²). Most of the area (301.33 km² or 31.84% of the available area) was suitable (S2). Meanwhile, there were 246.03 km² of unsuitable lands for settlements (25.99% of the available area).

SUITABLE LAND WHICH IS AVAILABLE FOR SETTLEMENT IN POTENTIAL EARTHQUAKE-PRONE AREAS OF SUKABUMI REGENCY

The land which was suitable and available for settlements in earthquake-prone areas was obtained from overlaying three maps, which were land suitability maps for settlements, land availability maps for settlements, and earthquake vulnerability maps. The results of the analysis are shown in Figure 6 (medium level earthquake), Figure 7 (high level earthquake) and Table 3 (suitable and available considering RSPP, LULC & earthquake hazard level).

According to the earthquake vulnerability map, entire Sukabumi regency is situated in an earthquake-prone area; namely the high potential for earthquakes covers an area of 3,195.89 km² (77%) and medium earthquake area of 934.05 km² (23%). Meanwhile, lands that were suitable for settlements on available land (946.49 km²) covered 618.36 km² or 65.33% of the study area. The results of the overlay of three maps are presented in Table 3, showing that the suitable and available lands for settlements in moderately earthquake-prone areas (S1, S2, and S3) covered 90.25 km² or 46.36% of the total land area in moderate

earthquake-prone areas (194.68 km²) and is displayed in Figure 6. The land suitability varied from being highly suitable (S1), suitable (S2), to marginally suitable (S3). Meanwhile, the unsuitable (N) areas were dominant (40.36%).

Figure 6 shows the distribution of the suitable lands which were available for settlements in areas with a moderate potential for earthquakes. The dark green area symbolising S1 was only found in a small part in the northern part of the study area (see box A). Settlement development in earthquake-prone areas was being prioritised in this S1 class area. Meanwhile, S2 class was scattered near S1 class in the north (see box A) and the south (see box C). S3 class was mostly found in the western part (see box B) and in the north (see box A). The area with a high earthquake vulnerability area is displayed in Figure 7 and Table 3. The suitable and available lands for settlements (S1, S2, and S3) covered 528.11 km² or 70.25% of the total land area in the high earthquake hazard zone (751.81 km²). The suitable class (S2) was dominant in areas prone to a high frequency of earthquakes. Figure 7 illustrates the land distribution of suitable lands on available lands for settlements in areas with a high potential for earthquakes. S1 class was a dark green area, generally found around the city of Sukabumi (see box A) and in the northern part of the study area, and to a lesser extent in the south (see box B). S1 class was a highly suitable location for settlements and development in high earthquake-prone areas. Especially all the existing criteria in this area made it the most suitable location for settlements because the location was on a flat slope, close to the center of growth, close to the main road, at an elevation of < 500 m, and close to water springs and river networks providing an environment which is convenient and accessible. Meanwhile, S2 class was generally found sporadically in almost all regions and mostly in the southern part (box B), while S3 class was found sporadically in the middle of the study area and in the western part of Sukabumi city (see boxes A and B).

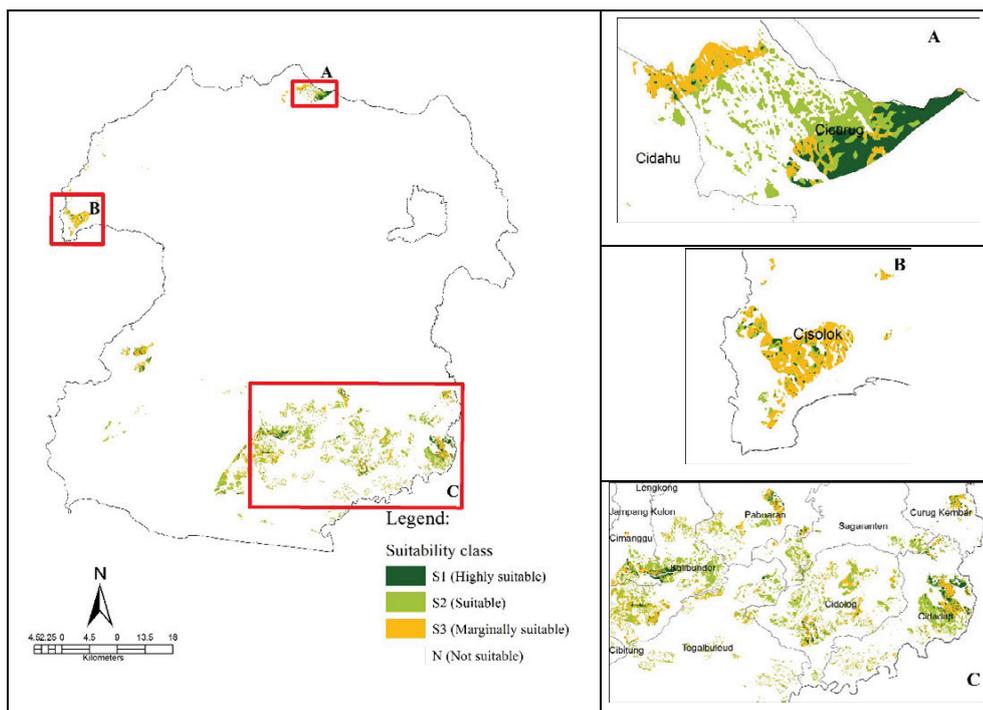


Fig. 6. Map of suitability and availability of land for settlements in medium potential earthquake areas of the Sukabumi regency; source: own study

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