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RESEARCH PAPER

Land evaluation suitability for settlement based on soil permeability, topography and geology ten years after tsunami in Banda Aceh, Indonesia

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Abstract Years after the tragedy of the tsunami in Banda Aceh researchers are still saddled with the problem of water permeability, slope and geology suitability for settlements. Social and ecological vulnerability to disasters and outcomes of Oceanic earthquakes causing tsunamis remain an indelible phobia to potential residents at the western coast of Sumatra upto the northern part of Indonesia. Ten years after the disaster, this study evaluates the topography of the area to determine the level of suitability of the area for human habitat. This article examines the concept of land suitability evaluation and its potential as a tool of determining appropriateness of a settlement. The focus of the study centered on the application of geographic information systems GIS in handling spatial data permeability, slope and geology of the land in accordance with the FAO land suitability standard. To ensure that the application works, it requires geospatial analysis compiled based on the permeability, slope and geology that can be observed and measured for the residential requirements. Results showed that almost all the cities within Banda Aceh are suitable for residency (Ordos).

1. Introduction

Overhaul of the area vulnerable to tragedy with the introduction of basic infrastructures is a means of forestalling the confidence of prospective inhabitants of possible reoccurrence of such tragedy in future. Land assessment with current environmental conditions is a very important factor that dictates the usability of the factor of production. This approach determines the potential of land resources (Hardjowigeno and Widiatmaka, 2007). For instance land for residential purposes should be able to meet the following requirements which include (a) strong and ecstatic foundation, (b) provision of safety, comfort and efficiency, (c) support of the erected structure (Chiara and Koppelman, 1997). The information obtained from land suitability will provide a clue on the suitability of the land to the end use.

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Moreover, soil test is also vital in land evaluation (Niekerk, 2010) during planning for continuous soil management, however, quality of land use is considered a tool for predicting the suitability or potential of the landed property (Rossiter, 1996). Soil is a mixture of naturally occurring minerals and organic materials with definite form, structure, and composition (Buckman and Brady, 1969; Hardjowigeno, 2003). Soil carrying capacity is defined as the natural ability to fully support the growth of people, physical development or human resource exploration without destroying the natural ecosystem (Kaiser et al., 1995; Setyaningrum, 2003). In classifying land use, land for residential purpose should go in line with conducive environment (Masri, 2012) because; increased human existence in an area can disrupt the entire environment (Naqvi et al., 2014).

Developing countries generally pay less attention to planning settlement gradients. Geomorphology and topography of the land are factors determining the use of the land (El Gammal et al., 2013). Land geology has basic physical multi various conditions which dictate the application of its use (Golany, 1976). Sloping terrains require better consideration than flat land. Prioritizing is necessary in residential estate planning (Anderson et al., 2007) this is because, housing development on steep land is relatively more difficult than on flat ground. This involves excavation and leveling before any construction is carried out.

2. Methodology

Soil samples were taken directly in the field using ring samples. Soil permeability in the saturated state was determined using De Boodt Stayle (De Boodt et al., 1973; Laboratorium-Fisika-Tanah, 2014). The method based on Darcy's law (Darcy, 1856; Freeze, 1994; Djarwanti, 2009; Laboratorium-Fisika-Tanah, 2014; UConn, 2014) is described as follows:

$$K = \frac{Q}{r} x \frac{L}{h} x \frac{1}{A}$$

K = soil permeability (cm/h) Q = a lot of water flowing with each measurement (ml)

t = time measurement (h) L = Thickness of soil samples (cm)

h = water level of surface soil samples (cm) A = the surface area of soil samples (cm^2)

The work was run on geoprocessing of permeability, slope, and geology values (Indarto and Faisal, 2012; ESRI, 2013a) and land suitability evaluation adopted for settlements according to the FAO (FAO, 1976, 1985, 1990, 2007). GIS which applies the concept of surface analysis, extraction clip, and overlay was used to manage spatial data analysis while the result of the virtual classification (Indarto, 2013) and positioning was presented using GPS receiver (Abidin, 2007).

3. Results and discussion

3.1. Soil permeability

Results of the analysis and calculation of soil permeability in the lab are shown in Table 1 while the spatial distribution is presented in Fig. 1. This can be made to predict the soil permeability (Gleeson et al., 2011). Permeability is the ability of the rock or soil to split or pass water (Hillel, 1998; Gromicko and Shepard, 2014). Ground water flows through small cavities. The smaller the cavity in the ground, the slower the water flow. If the cavity is very small, the water molecules permeability will remain low. Very rapid permeability can disturb the soil, by weathering, loosening and widening the spaces between soil particles. Permeability is very slow to give the effect of stagnant water on the soil surface in the settlement area. Material accumulation greatly affected the underground water flow and the amount of ground water. The amount of ground water that can be stored in bedrock, sediment and soil is very dependent on permeability.

Using the results of analysis of permeability as shown in Fig. 1 to predict the overall land surface, GIS is used with the geo-statistical interpolation concept known as kriging. Kriging is a geo-statistical interpolation method that utilizes the variogram which depends on the spatial distribution of the data rather than the actual value (Arun, 2013). Spatial classification based on field permeability value was used in evaluating this function (Johnston et al., 2001; Mitchell, 2005; Prahasta, 2009; ESRI, 2013b). Interpolation which includes-Inverse distance weighted, natural neighbor, spline, and kriging trend are parameters used in the process of changing the data points of the area. Furthermore Booth and Mitchell (2001), Gorr and Kurland (2008) and Pramono (2008) confirm that kriging rules have the advantages of unbiased properties, minimum variance, and it involves a linear combination rather than observation. Kriging interpolation results from data analysis of permeability in Banda Aceh, are hereby presented in Fig. 2.

Land properties come in different characteristics which include red, black, and gray while texturally we have sand, silt, clay and so on. These differences also lead to differing permeability values. These differences are classified based on the criteria of Uhland and O'Neal (1951) and Arsyad (2010) as shown in Table 2. Based on the modification of

Table 1 Results of analysis of soil permeability.

No.	Latitude	Longitude	Permeability (cm/h)
1	5.536756	95.325963	6.60
2	5.535681	95.353651	5.01
3	5.551229	95.336983	24.18
4	5.516754	95.319411	10.76
5	5.533410	95.288631	18.57
6	5.563808	95.302550	4.28
7	5.569193	95.315586	18.02
8	5.577568	95.326312	20.95
9	5.579066	95.330287	35.51
10	5.585079	95.342514	7.20
11	5.581427	95.361985	6.88
12	5.554942	95.329328	15.97
13	5.535935	95.310714	2.48
14	5.538497	95.294152	3.72
15	5.558044	95.356970	4.42
16	5.571227	95.354585	2.44
17	5.555569	95.283064	31.34
18	5.593100	95.331899	34.55
19	5.595757	95.339833	22.10
20	5.603460	95.352591	21.75
21	5.535492	95.281025	18.34

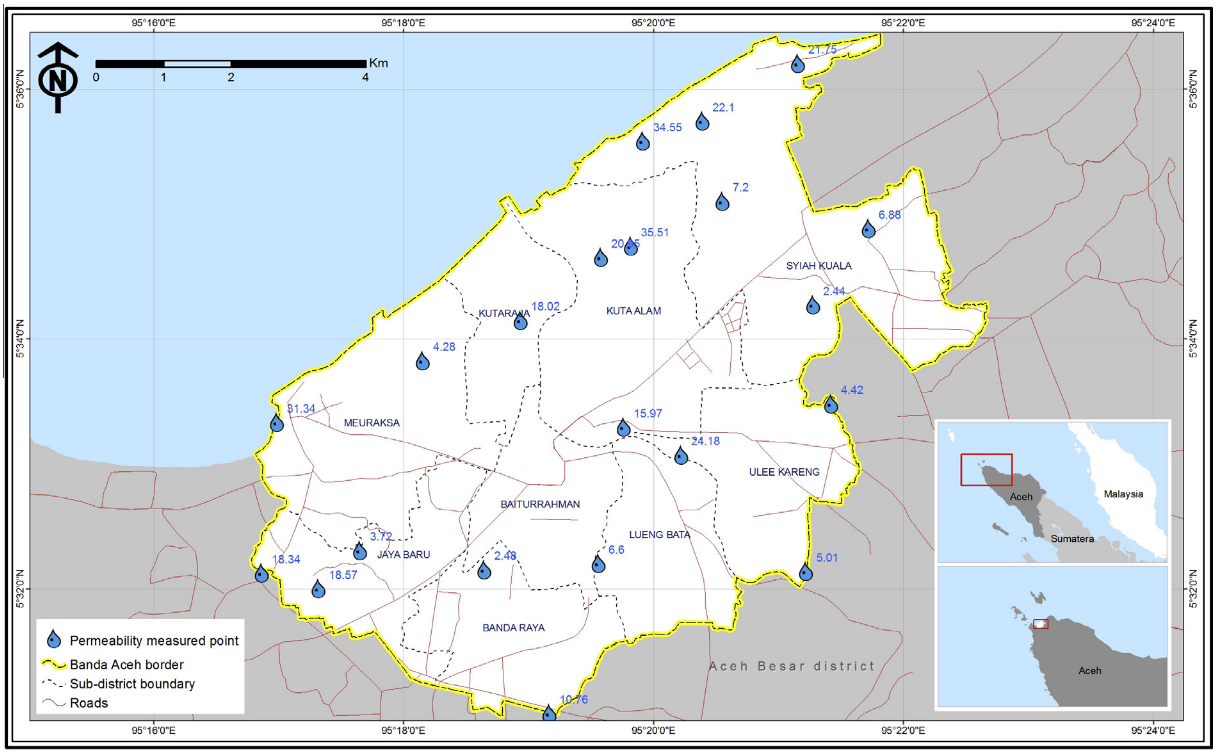

Figure 1 Spatial distribution from permeability analysis results.

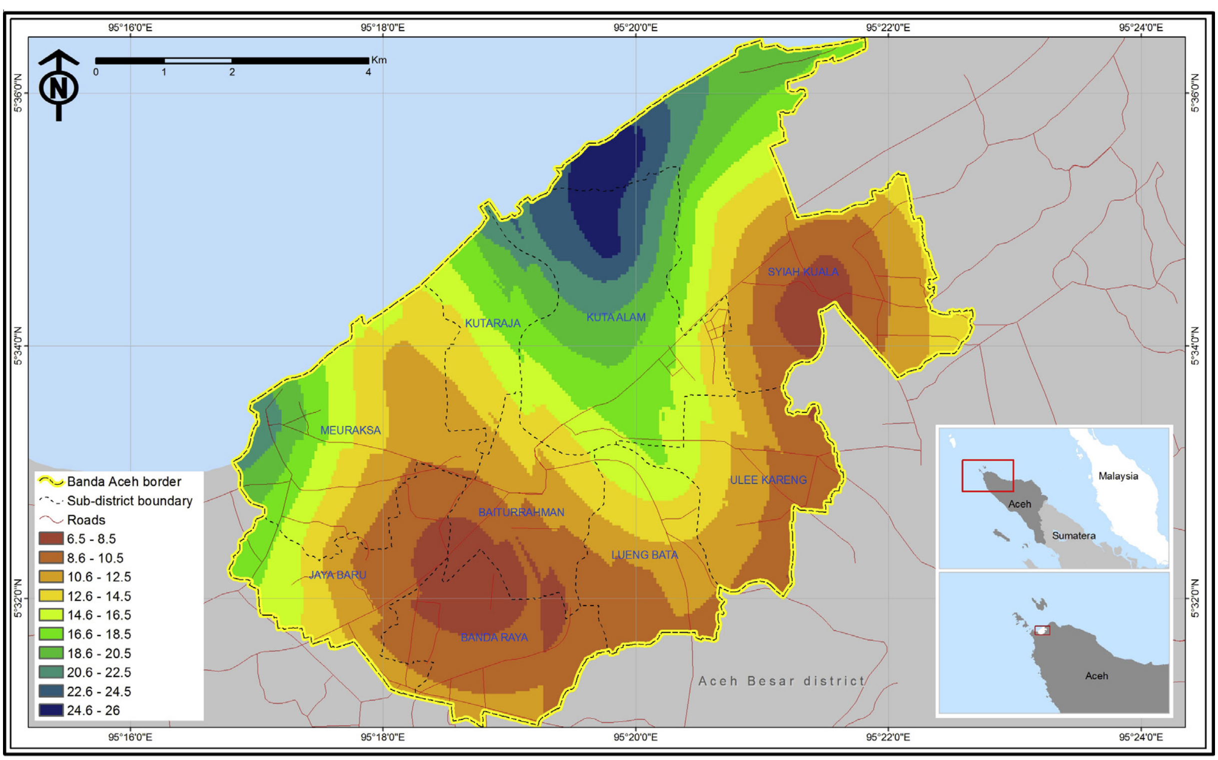

Figure 2 Map of kriging interpolation results from permeability.

Schollmeyer (2000), Hardjowigeno and Widiatmaka (2007) permeability classification can be modified into FAO land suitability, such as Table 2. Table 3 shows the principle of re-map interpolation and re-classes soil permeability (Fig. 2). This re-classification produces permeability suitability map for settlements as shown in Fig. 3.

Table 2 Permeability classification.

No.	Class	Permeability (cm/h)
1	Very slow	< 0.125
2	Slow	0.125–0.50
3	Rather slow	0.50–6.25
4	Medium	2.0–6.25
5	Rather fast	6.25–12.5
6	Fast	12.5–25
7	Very fast	> 25

Table 3 Permeability level class.

No	Suitability class	Permeability (cm/h)
1	S1	2.0–6.25
2	S2	6.25–12.5/0.5–2.0
3	S3	12.5–25/0.125–0.5
4	N1, N2	> 25/ < 0.125

Permeability to settlements in Banda Aceh is the order S (suitability). No matter the suitability, the classes are classified as either moderately suitable class (S2) or marginally suitable class (S3). In detail the results of this conformity are mentioned in Table 4. Fig. 3 also shows the distribution pattern of permeability, which in the area adjacent to the beach and the river shows higher permeability. This is made possible by the dominant land near the sea sand which is the shaft. Although the results of this study indicate that Banda Aceh has permeability values suitable for settlement, permeability still needs to be considered in urban planning. Setiabudi (2009) stated that an indication of permeability to water infiltration should be considered in residential areas to be as important as an attempt in anticipating the danger of flooding. In addition it may prevent a decline in ground water surface in order to realize the effect of the environment on housing.

Table 4 Land suitability based on soil permeability in Banda Aceh.

No	Suitability class	Hectare	Percent
1	S2 (moderately suitable)	3219	52.2
2	S3 (marginally suitable)	2944	47.8
Total		6163	100.0

Table 5 Classification slope of land in Indonesia.

No	Tilt (%)	Description
1	0–8	Flat
2	8–15	Sloping
3	15–25	Rather steep
4	25–45	Steep
5	> 45	Very steep

3.2. Topography

In general, the topography is a graphical representation of the landscape in the area and quantitatively expressed in units of slope (grade, length, and shape). Slopes are generally calculated in cent (%) or degrees (°). Classification of slope, in

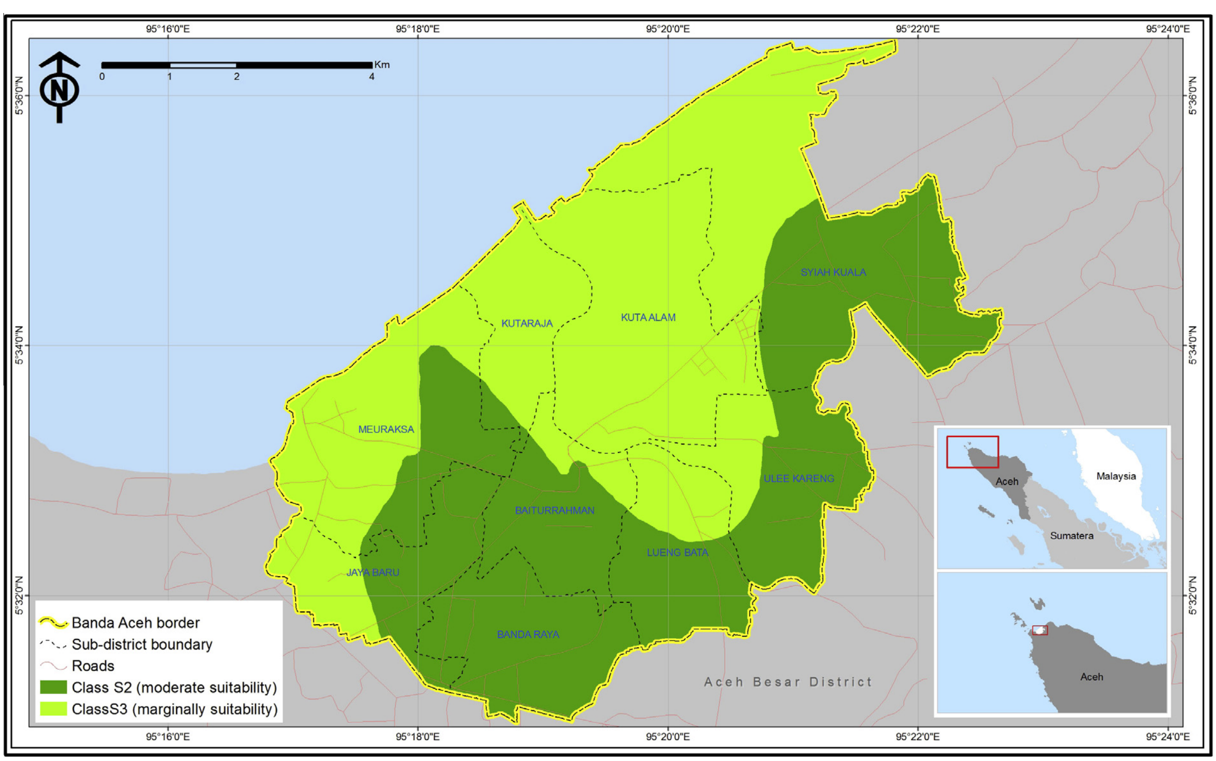

Figure 3 Permeability suitability maps for settlements.

Indonesia refers to Decision Letter (SK) Minister of Agriculture No. 837/KPTS/Um/11/1980 (Kementan, 1980) and Regulation of the Minister (Permen) Public Works No.41/PRT/M/2007 (PU, 2007) as given in Table 5. In the study area, contour interval of 0.5 m with the lowest value of 0 m and 5 m high, is presented in Fig. 4.

Based on the standard town planning construction of settlements in Indonesia housing development is allowed on

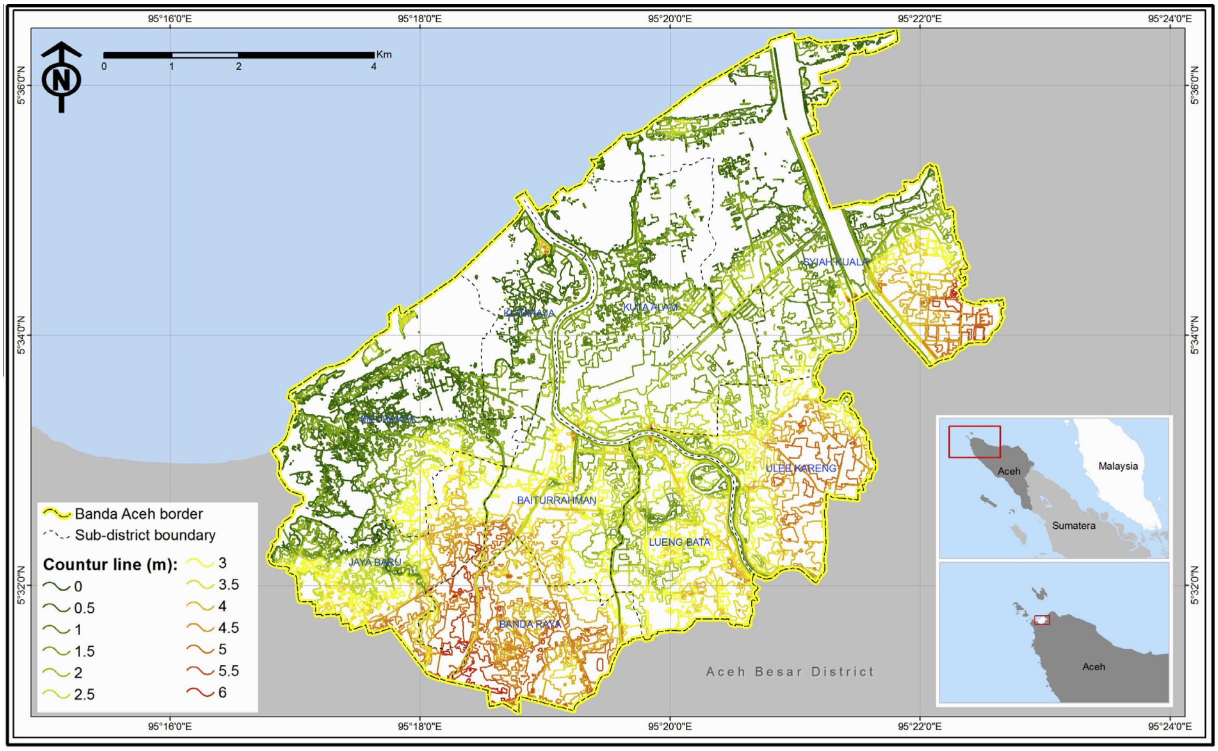

Figure 4 Contour interval in Banda Aceh.

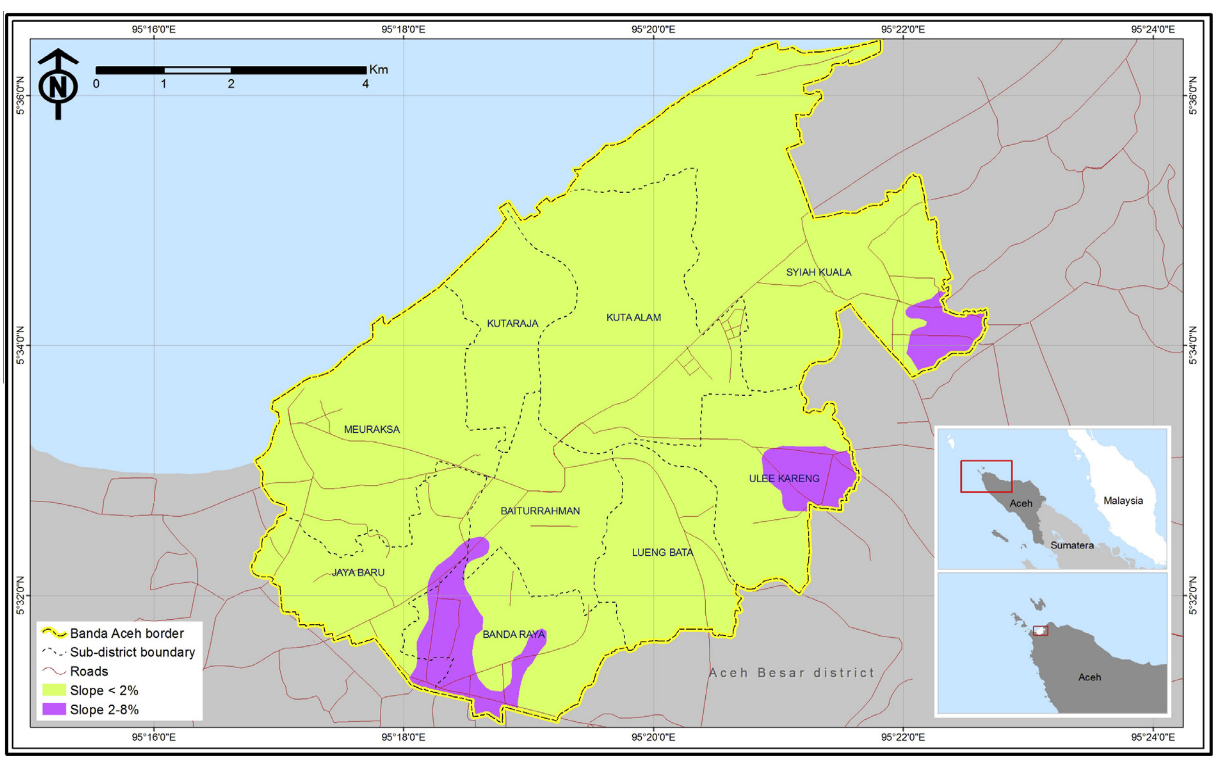

Figure 5 Slope suitability map for settlement.

Table 6 Class slope suitability for settlements.

No	Suitability	Slope (%)
1	S1	0–8
2	S2	8–15
3	S3	15–25
4	N1	25–40
5	N2	> 40

Table 7 Results of analysis of the slope of the settlements in Banda Aceh.

No	Slope class (%)	Suitability class	Hectare	Percent
1	< 2	S1	5735	93.1
2	2–8	S1	428	6.9
Total			6163	100

the slope of 0–25%, or from flat to rather steep (SNI, 2004; PU, 2007). It is also consistent with studies conducted by Saindane and Patil (2010), Değerliyurt (2014) and Zhao et al. (2014) which state that the slope affects the spatial distribution of settlements in various countries. Contour lines transformed for the entire land surface, are called the slope. It applies to the concept of surface analysis (Indarto and Faisal, 2012; ESRI, 2013a; Indarto, 2013), the results of this analysis are shown in Fig. 5. Slope criteria for residential areas according to Table 6, follow the modification from Setyowati (2007), Hartadi (2009), Purwaamijaya and Fikri (2009).

The slope analysis in Fig. 5 found that Banda Aceh is dominated by the slope of the class below 2%, it is an area of 93.1%. The remaining 6.9% is the slope class between two and eight per cent. View of the slope criteria for settlements (Table 6), into two slope classes in Banda Aceh still into the S1 class (highly suitable). So based on the slope of the settlements in Banda Aceh is the order of S (as appropriate) on the S1 class (highly suitable), in detail can be seen in Table 7.

3.3. Geology

Geological maps of Banda Aceh obtained from Aceh's geological map (Badan-Geologi, 1981) are shown in Fig. 6. Analysis of the geological maps found that Banda Aceh is located on Alluvial Deposition (Qh) and is not yet consolidated since the Holocene age and is still loose. Banda Aceh is surrounded by rocks of the Tertiary age-Holocene. South-west of Banda Aceh is dominated by carbonate rocks. East Banda Aceh is dominated by volcanic rocks. Both of these rocks are the bedrock for Banda Aceh.

Alluvial deposition covering Banda Aceh: This results in Banda Aceh not having geological tectonics such as faults and fractures, but Banda Aceh is quite influenced by geological structures flanking it. The Great Sumatran Fault runs constantly throughout the island of Sumatra from Semangko in Lampung to Pulau Weh and continues until the Andaman (Fig. 7). In the west of Aceh also are seen a Eurasian Plate and subduction zones Indo-Australian Plate. Movement of geological structures also affect Banda Aceh, but can be muted with lithological conditions in the form of unconsolidated sediment. So the conclusion is that geologically Banda Aceh has no barriers or in other words it is residentially suitable.

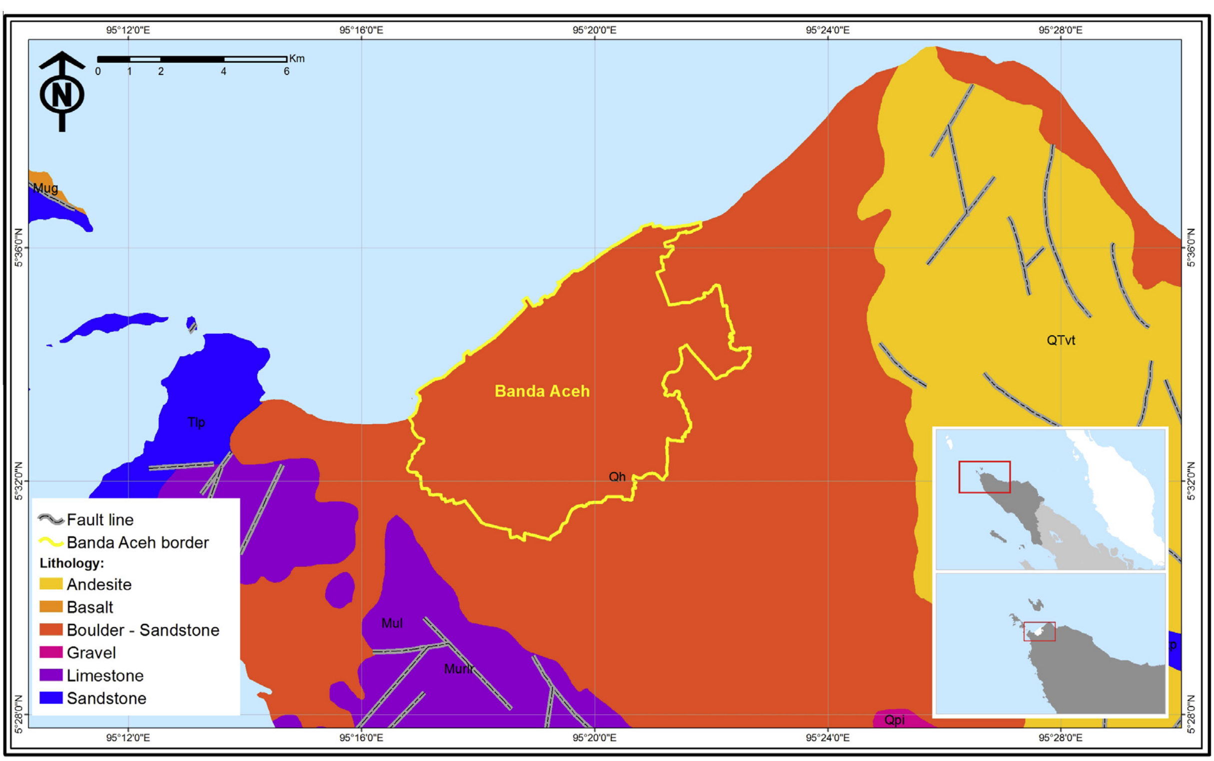

Figure 6 Banda Aceh's geological map.

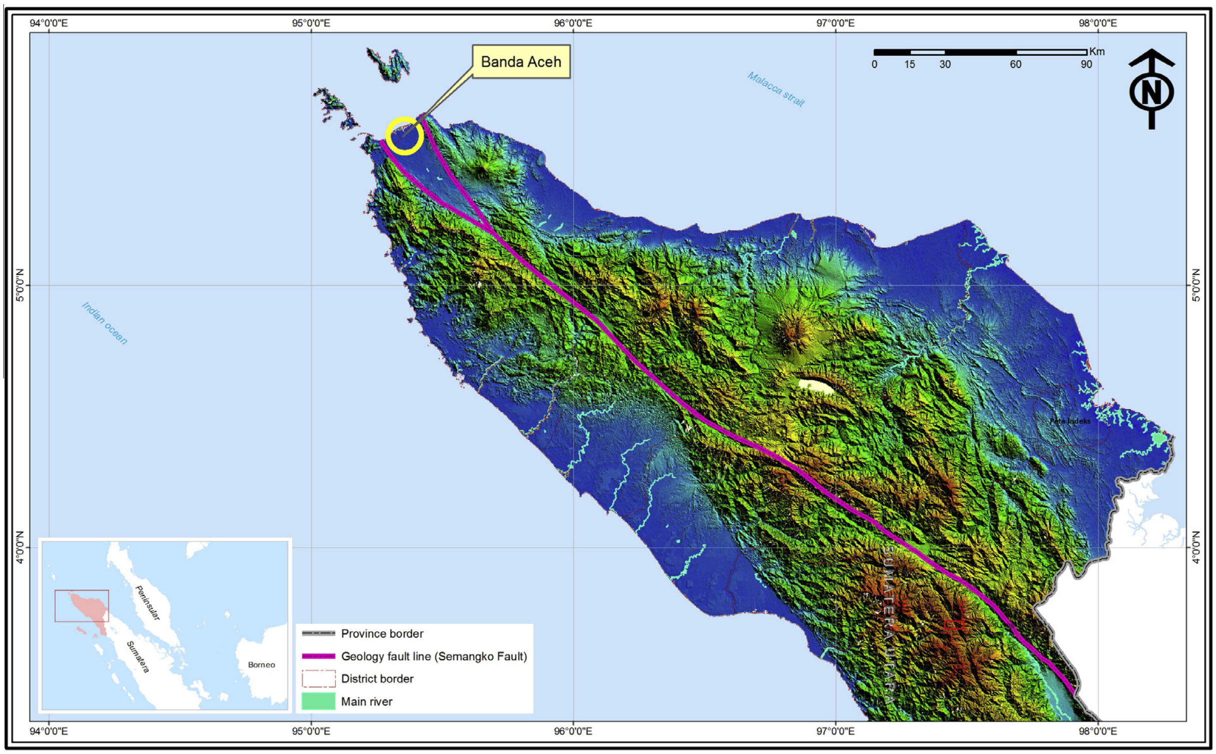

Figure 7 Semangko fault.

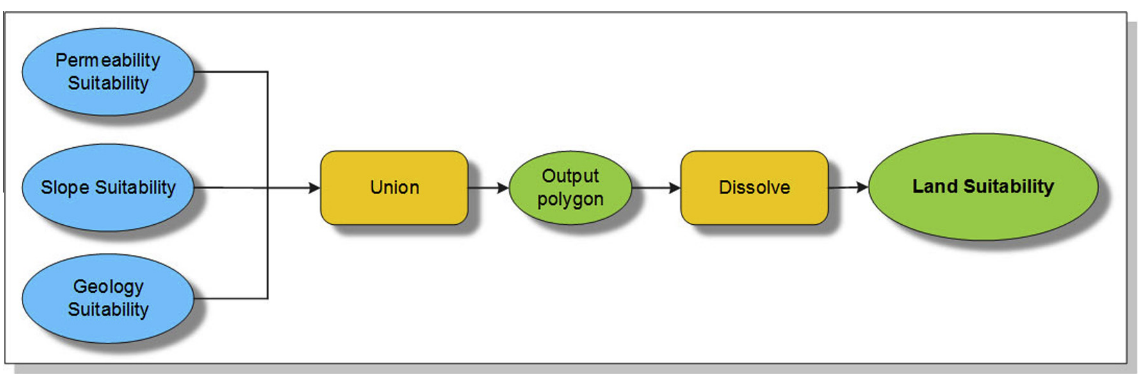

Figure 8 Flowchart on the overlay layer.

Table 8 Results of overlay analysis for settlements in Banda Aceh.

No	Permeability (*p*)	Slope (*s*)	Geology (g)	Sub class	Hectare	Percent
1	S2	S1	S	*S2p*	3219	52.2
2	S3	S1	S	S3*p*	2944	47.8
Total					6163	100

3.4. Evaluation of land suitability

Using order S correspondence by adopting the FAO standard can be categorized based on class suitability, land suitability evaluation could be carried out using class S1 as highly suitable, S2 as moderately suitable and S3 asmarginally suitable. Order N does not comply with Class S, hence N1 (currently not suitable) and N2 (permanently not suitable), while land suitability subclass is a kind of limitation in these classes. Each class may consist of one or more subclasses depending on the type of limitation that exists. This type of limitation is indicated by symbol lowercase letters placed after the symbol of class. E.g. S2 class that has restriction permeability (*p*) can be a subclass of S2p. Each subclass can have one, two, or at most three symbol restrictions, with the restriction that the

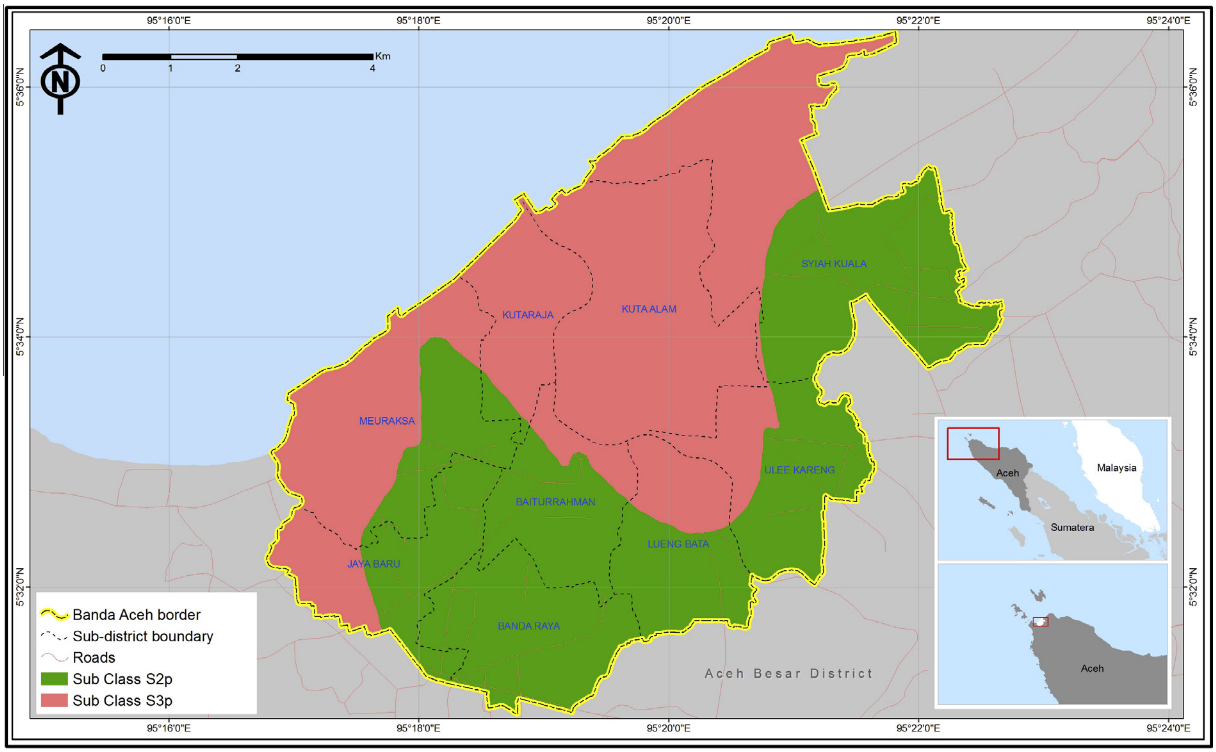

Figure 9 Suitability map settlement area in Banda Aceh.

dominant is written at the front. For example, in subclass S2*tp*, the restrictions topography (*t*) and permeability restriction (*s*). (*t*) is the restriction of the most dominant and (*p*) is the second restriction (FAO, 1976, 1985, 1990; Balittanah and ICRAF, 2007; FAO, 2007).

Model characteristics of layer parameters that are represented as a set of spatial processes continue for all layers. ESRI (2009) argued that the analysis layer (overlay) is a set of rules that apply in the selection of the optimum location or suitability model. Overlay for land suitability carried out according to the diagram is shown in Fig. 8.

The results of the analysis of the suitability of each single layer, are incorporated into the input layer overlay analysis. Each single layer or weights are given the same influence to make a decision. This process is used in the feasibility study of the site where there are a number of factors relating to the suitability of a site (Malczewski, 2004, 2006). Results of the assessment in the form of class and subclass suitability are determined by the heaviest limitation factor. Overlay analysis results can be seen in Table 8 while those of spatial analysis can be seen in Fig. 9.

4. Conclusion

In this study land for settlements in Banda Aceh as a whole conforms with order S (suitable). The limiting factor is permeability, which for the slope is very suitable while geology is not an obstacle. Details of the area with respect to percentage of suitability is sub-classed into; S2*p* (moderate suitability class) covering 3219 hectares or 52.2% and S3*p* (marginal suitability class) covering 2944 hectares or 47.8%. Land suitability is only limited to the soil permeability, slope and geology. Other factors may be added on further research.

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