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LAND USE PLANNING FOR SETTLEMENTS AREA IN CONSIDERATION OF FLOOD AND LANDSLIDE HAZARDS IN BAGELEN, PURWOREJO, INDONESIA

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ABSTRACT

The objective of this research is determining alternative land use for settlement development considering its hazards susceptibility. Data were obtained by interviews, participatory GIS, direct-observation, sampling of soil and secondary data analysis. The flood hazard map was produced using Kriging interpolation techniques; flood depth map for the largest flood in the year 2004 was created. The area with high landslide hazard is located on the hilly area in the eastern part of the area of study. The result from overlaying two hazard maps indicates that the area which considered as having less hazards is located on the colluvial plain. The result of suitability analysis including hazard and people perception-based criteria showed that the area suitable is mostly located in Bagelen and Krendetan Villages. The result of suitability analysis of the non-hazard criteria showed that the area suitable of which 338.1 Ha is an existing settlement.

Key words: suitability, settlement, land use planning, natural hazard

INTRODUCTION

The occurrences of natural disasters in Indonesia recently increasing have caused enormous destructions and human sufferings. The present use of land is

indicative of human activities and their relation to natural resources to fulfil their needs. The increasing number of population will be followed by the increasing needs of life, including the space for human to use the lands. The consideration of sustainable life has to be implemented with regard to the environmental and physical aspect integrated with the socio-economic aspects.

Located between the denudated hills in the east and floodplain in the west, the Centre of Bagelen Sub-district (Bagelen, Bugel, Bapangsari, Krendetan Villages) is prone to flood and landslide hazards [*PSBA,* 2004]. Since the present planning of local land use is lacking the aspects of natural hazards, it is important to initiate a local land use planning which integrates natural hazard susceptibility in order to establish a sustainable plan for human life and to generate general guidance to manage disasters. Land use planning can be used as an effective mitigation-tool to reduce the risks of natural hazards. Taking into account the multi hazards aspects into spatial planning becomes a main challenge. Land suitability for settlement development is brought as the focus in this study with a reason that settlement or development area is the most prone area against natural phenomena, such as flood or landslide. The impacts of natural hazards will have higher consequences toward settlement or development areas.

This study is an attempt to contribute to the better understanding of natural hazard susceptibility database collection and generating alternative natural-hazard-based land use plan for settlement development areas. As the present land use-settlement plan of Bagelen Sub-district has not yet been visualized in the map form (spatial data), it is important for the geographic information system to include natural hazard and non hazard criteria in the analysis to find a suitable settlement are to be developed. The main objective of this research is to focus on determining alternative land use planning for settlement development including its susceptibility toward natural hazards.

THE METHODS

Generally, the insufficiency of data is the major difficulty for this area in relation to disaster management. In this study area there are only few data of flood and/or landslide records, and statistical data are not even sufficient or disaster management purpose. The combination of resources and methodologies in this research is used in order to offer new approaches to small scale disaster management common for the lack in data.

Natural Hazards Mapping

Natural hazards mapping consist of two main mapping processes, namely flood mapping and the second landslide hazard mapping. A flood hazard map will be generated by means of GIS interpolation techniques, the flood depth map for the

2004 flood will be created (see Fig. 1). This will be done according to the largest flood in 2004, even larger than the large flood of 1965.

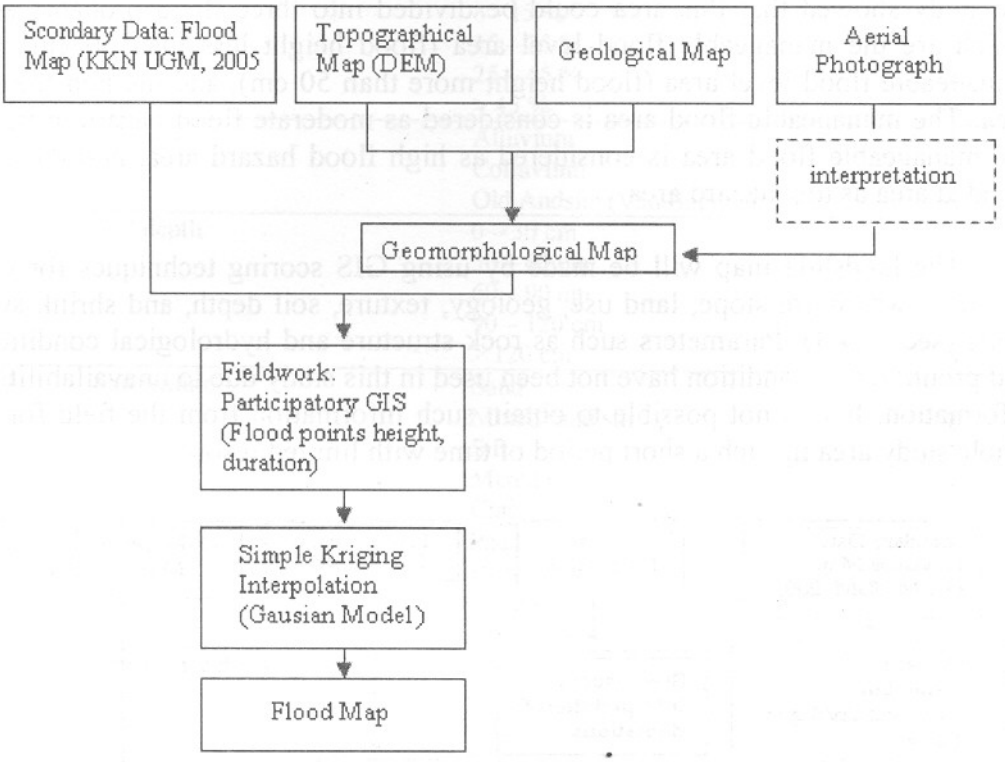

Figure 1. Flood Map Framework

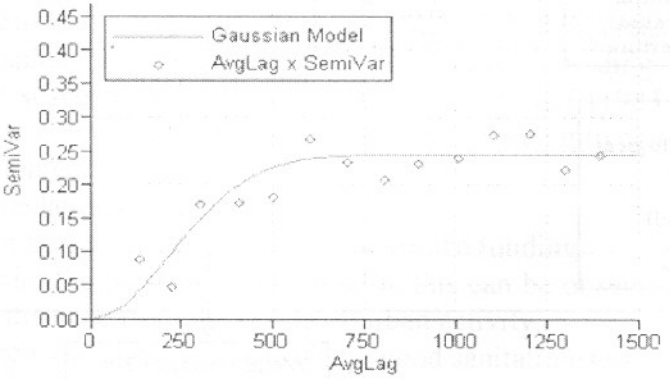

Figure 2 .Gaussian semi-variogrammodels for the data set of flood height (line), the points correspond to the variance of spatial correlation of the values (γ) with the distance (h)

The simple kriging is selected in this case with respect that in the simple kriging all input points are used to calculate each output pixel value. A nugget, sill and range are the input information for the kriging operation obtained from several

semi-variometer experiments to get the 'best' fit model. In this case, the *Gaussian model* shows the best result, with the nugget 0, sill 0.245 and range 315 (Fig. 2). Based on the people perception about the flood height and how they can manage, the study showed that this area could be divided into three flood probable zone which are the manageable flood level area (flood height less than 50 cm), not manageable flood level area (flood height more than 50 cm), and the non-flooded area. The manageable flood area is considered as moderate flood hazard area, the not manageable flood area is considered as high flood hazard area, and the non-flooded area as low hazard area.

The landslide map will be made by using GIS scoring techniques for each criterion, which are slope; land use, geology, texture, soil depth, and shrink-swell value (see Fig. 3). Parameters such as rock structure and hydrological conditions, and groundwater condition have not been used in this study due to unavailability of information. It was not possible to obtain such information from the field for the whole study area in such a short period of time with limited resources.

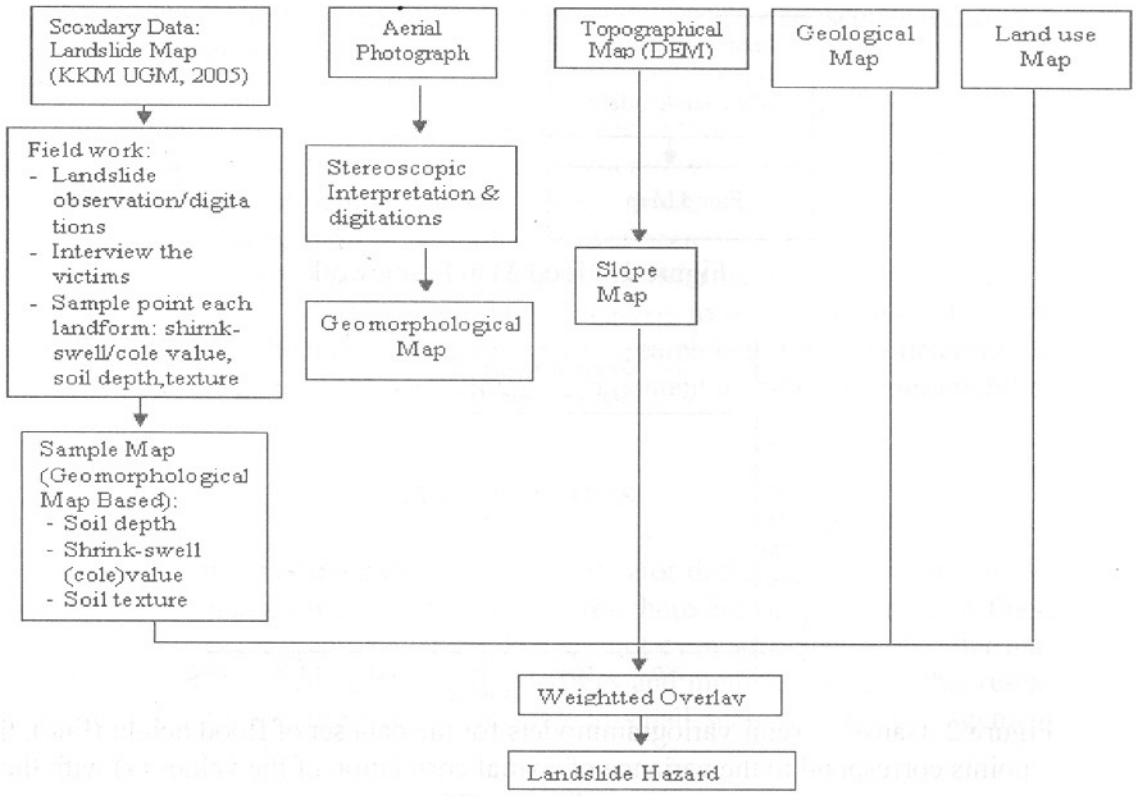

Figure 3. Landslide Framework

Table 1. Parameter of Landslide Hazard Mapping

No	Parameter	Paramter Class	Score
1	Slope	0 – 8 %	1
		8 - 15 %	2
		15 – 25 %	3
		25 – 45 %	4
		> 45 %	5
2	Geology	Alluvium	1
		Colluvium	3
		Old Andsite (Van Bemmelen)	5
3	Soil depth	0 – 30 cm	1
		30 – 60 cm	2
		60 – 90 cm	3
		90 – 120 cm	4
		> 120 cm	5
4	Soil texture	Sand	1
		Mixed sand silt	2
		Silt	3
		Mixed silt clay	4
		Clay	5
5	Land use	Paddyfiled/grass	1
		Homestead	3
		Shrubs	4
		Settement	5
6	Shirnk-sweel (cle value)	1.85	2
		5.66	3
		7.55	4
		8.51	5

Suitability Analysis

In this research, the suitability analysis refers to finding areas that meet ideal physical, geographic, and environmental conditions, including the flood and landslide hazard susceptibility areas. According to *Mirhad* [1983 in *Budihardjo*, 1984] there are several considerations that need to be taken into consideration when selecting for settlement areas:

- Free from inundation or flood hazard
- Stable soil for building construction to minimize funding.
- Reachable from the point of transportation, this can be observed from the road network and distance from the centre of urban activity.
- Sufficiency of fresh water and electricity, good sanitation/sewage system.
- Unfertile land areas
- The settlement area is supposed not to damage environmental functions
- Protect the ground water preservation area by not selecting it as settlement area.
- Near facility centre: schools, market, health care centre, and other social-economic activity centres.

The land suitability criteria proposed by USDA 1983 in [*Hardjowigeno et al*, 1984] will be used in this study with several modifications, based on the condition of Bagelen Sub-district located on the plain and hilly areas, considered as flood and landslide prone areas. According to USDA 1983 in [*Hardjowigeno et al.*, 1994] there are some land suitability criteria for settlement as described on Figure 4.

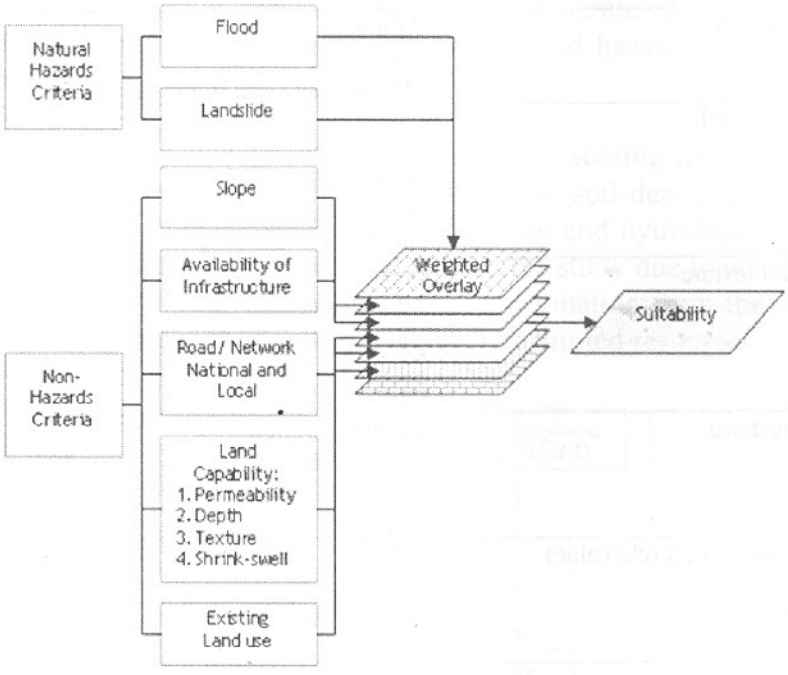

Figure 4. Suitability Analysis Framework

Table 2. Land Suitability Criteria for Settlement Purpose

No	Soil Characteristic	Land Suitable		
		Good	Moderate	Poor
1	Subsidence depth (cm)	-	Moderate	30
2	Flood Susceptibility	Without	Without	-
3	Water table height (cm)	> 75	45 - 75	< 45
4	Shrink-swell value (COLE)	(<0.03)	(0.03 – 0.09)	(> 0,09)
5	Soil texture according Unified System			OL,OH,PT
6	Slope (%)	< 8	8 - 15	> 15
7	Soil depth (cm)			
	Hard	>100	50 – 100	< 50
	Soft	> 50	< 50	-
8	Soil depth on hardened rock (cm)			
	Thick	>100	50 – 100	<50
	Thin	>50	< 50	-
9	Gravel-pebble contents (> 7,5 mm) (% weight)	> 25	25 - 50	> 50
10	Landslide	-	-	Present

Source: *USDA* [1983 in *Hardjowigeno et al.*, 1984]

Table 3. Suitability Criteria for Settlement Purpose

	Criteria	Class	Score
Slope	< 8 %	Suitable	1
	8 – 15 %	Moderrately suitable	2
	> 15 %	Less suitable	3
National Road	0 – 500 m	Suitable	1
	500 – 1000	Moderrately suitable	2
	>1000 m	Less suitable	3
Avialability of Infrastructure/ Facilities	0 – 1000 m	Suitable	1
	100 – 200 m	Moderrately suitable	2
	> 200 m	Less suitable	3
Soil Permeability	> 5.0 and < 15.0	Suitable	1
	0.15 – 15.0	Moderrately suitable	2
	<0.15 or > 15.0	Less suitable	3
Soil Depth	>100 cm	Suitable	1
	50 – 100 cm	Moderrately suitable	2
	< 50 cm	Less suitable	3
Soil Texture	Sand	Suitable	1
	Silt	Moderrately suitable	2
	Clay	Less suitable	3
Shrink and Swell Value	<0.03	Suitable	1
	0.03 – 0.09	Moderrately suitable	2
	>0.09	Less suitable	3
Existing Land Use	Setlement	Suitable	1
	Homestead and grass	Moderrately suitable	2
	Agricultural and Forest – shurubs	Less suitable	3
Flood Hazard	Non-flooded area	Suitable	1
	Manageable Flood (<=50 cm)	Moderrately suitable	2
	Non Manageable (> 50 cm)	Less suitable	3
Landslide Hazard	Low Hazard Zone	Suitable	1
	Moderete Hazand Zone	Moderately suitable	2
	High Hazard Zone	Less suitable	3

Source: *USDA* [1983 in *Hardjowigeno et al.*, 1984]

RESULTS AND DISCUSSION

Flood Hazard

As mentioned by *Kingma* [2002], the dangers of floodwaters are associated with a number of different characteristics of the flood, like depth of water, duration, velocity, sediment load, rate of rise, and frequency of occurrence. The presence of good quality data series related to flood hazard assessment in most of developing countries is inadequate or absent, causing the difficulty in applying high-quality hydrological approach for flood hazard. In this study area there is also a lack of flood data. However, although there is only small data regarding flood record documents, it was proposed on this research that some participatory mapping method could be used to get information of flood events in this area. One way to partly overcome the lack of data is to use a participatory flood mapping approach.

In order to get the input for settlement suitability, the result of the flood map was classified into three segments: manageable, not manageable and non flood area. This step was done based on the people's perception which was obtained from field work and adapted the flood hazard categories from *The Geological Society of Australia* [2005 in *Rahman,* 2006] (see Fig. 4).

Table 4. Flood Height Perception from field survey, 2007

No	Percent of respondents	Food Height Perception (meter)										
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	>1
1	16.67	Manageable Flood height						Not Manageable Flood height				
2	75											
3	8.33											

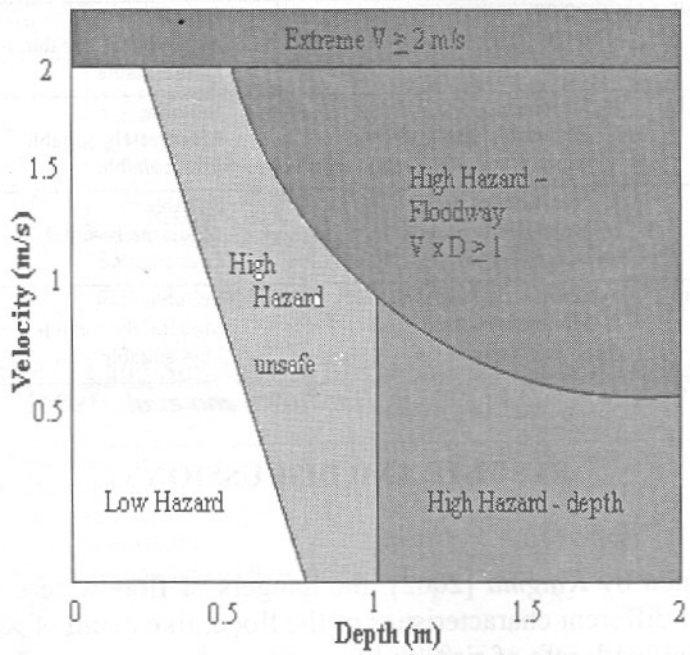

Figure 4. Flood Hazard Categories [*The Geological Society of Australia*, 2005 in *Rahman*, 2006]

The study showed that this area could be divided into three flood probable zones: manageable flood level area, not manageable flood level area and the non-flood area (Fig. 6). This result of flood map will be also be used as input for settlement suitability analysis. The flood map result showed that the area with manageable flood level is 0.85 km², most of them located in the Bagelen Village.

The area with not manageable flood level is 6.01 km², located almost all on the western part of the study area. And the non flood area is 4.57 km², located in the eastern part of the study area, which is geomorphologic ally as the colluvial plain and denudated hill.

Flood Mitigation Strategies

River flood might occur progressively or in a flash depending on the characteristics of the flood and watershed. Heavy prolonged rainfall could be a warning for river floods.

Structural Mitigation Strategies such as:

- Construction, maintenance or repair of levees
- Improvement of drainage and sewer channels
- Deeper dredging of river channels
- Construction of embankment and infiltration wells
- Construction of more flood resistant houses: raising the houses' foundation, build higher floors, using water-resistant materials, and using sturdier/stronger foundation
- Protection of important facilities (health facilities)

Non-Structural Mitigation Strategies such as:

- Land use planning: planning, zoning, building codes
- Emergency services: hazard recognition, warning systems
- Public information: environmental education, provision of hazard map information, informal workshop, dumping regulations
- Floodplain development regulations: watershed protection measures, waterway dumping regulations, soil erosion and sediment control
- Some other recommendations [*Montz,* 2002]: advance forecast and warning, risk assessment, linkage to the social science sustainable

Landslide Hazard

Landslides are common hazards which mostly happen on steep topography. In Bagelen Sub-district, landslide is another type of hazard which strikes the hilly areas, besides the flood which strikes the plain area. There were three big landslides occurrences in this study area, in Bapangsari Village (Pucungan and Kalimaro sub-villages) and in Krendetan Village (Sarangan sub-village). Approach for landslide hazard map in this study is using empirical approach with weighting scheme overlay method. The probability of the occurrence of landslide in this study is correlated with six parameters, which are slope, geology, soil depth, soil texture, land use and shrink-swell value. The landslide hazard map (Fig. 7) shows that this area of study is divided into three landslide hazard categories, the high, moderate and low hazard areas. This result of landslide hazard map will also be used as input for settlement suitability analysis in the next chapter. Based on the landslide hazard map the area with high hazard of landslide is 2.38 km² and located on the hilly area

in the eastern part of the area of study. The area with moderate landslide hazard is 6.42 km² and dispersedly located in the study area. The low landslide hazard is located in the plain area, with 2.62 km² area.

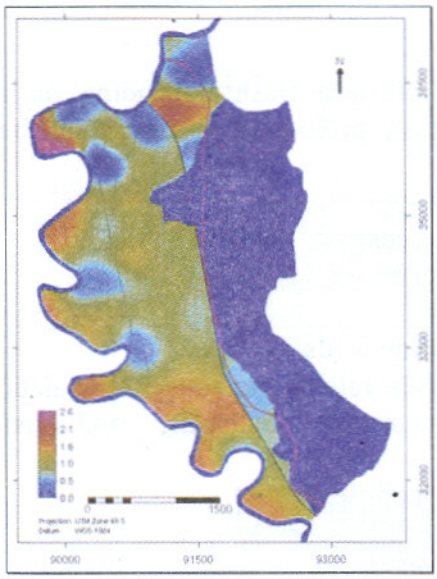

Figure 5. Flood Height Map

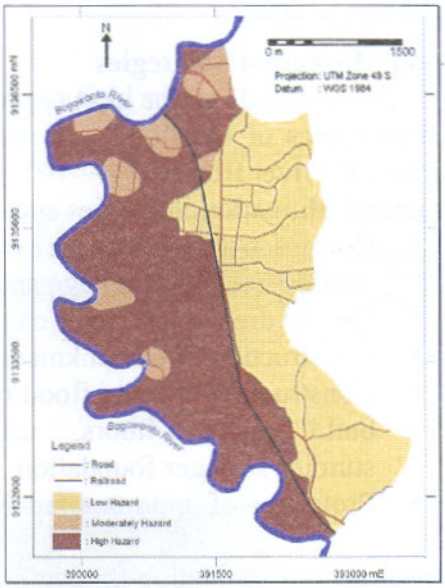

Figure 6. Flood Hazard Map

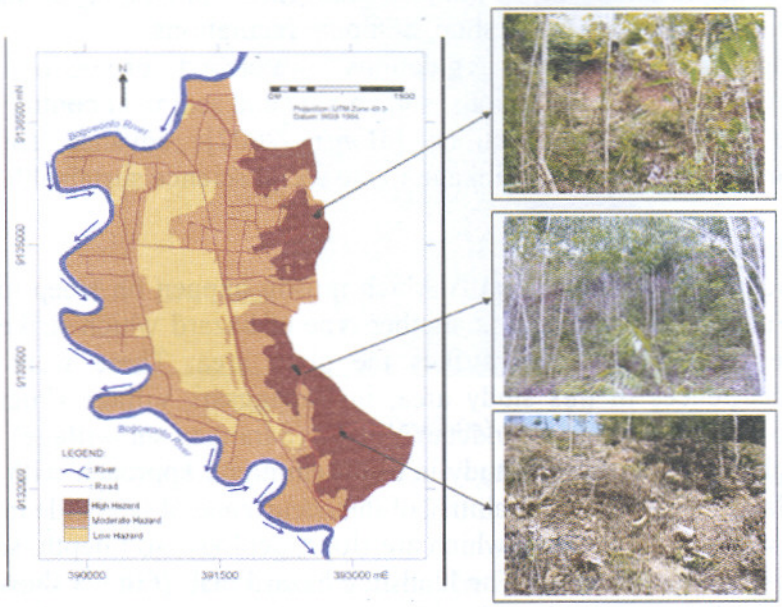

Figure 7. Landslide Hazard Map and pictures of landslide, (a) Landslide in Krendetan Village, (b) Landslide in Bapangsari Village (Pucungan Sub-village), (c) Landslide in Bapangsari Village (Kalimaro Sub-village)

Mitigation Strategy

The reasonable approach to prevent devastating landslide on the hilly area is to avoid building constructions on steep terrains that can be done through land use plan or regulations. The structural mitigation strategies can be prepared by engineering structures to withstand or accommodate potential ground movement, piled foundation to protect against liquefaction, flexible buried utilities, and relocation of existing settlement or infrastructures [*UNDP,* 1994].

Since floods and landslides usually happen in the rainy season, integrated mitigation strategy is needed, especially in the rainy season. Despite the socialization and warning strategy, during the prolonged rainy days in the rainy season, it is important to evacuate people in to safer areas. The flood and landslide maps from the previous analyses can be used to identify safer areas from flood and landslide hazard for evacuation purpose. Identification of safer areas was done by overlaying two hazard maps. The result of overlaying two hazard maps, flood and landslide, indicates that there are 7 unit of hazard combination area. The area considered as having low hazards both flood and landslide is located in Bagelen and Krendetan Villages in the colluvial plain (see Fig. 9).

Suitability Analysis based on the People's Perception

The settlement suitability map is a combination of slope availability of infrastructure per village, buffer road , land capability, existing land use, flood hazard, and landslide hazard maps. Weighting overlay method was performed in order to get the settlement suitability level. Criterion weighing is used to express the importance of each criterion relative to other criteria. The more important criterion had greater weight in the overall evaluation. The result of people's perception on first criterion is used to give weight on each criterion (Table 5).

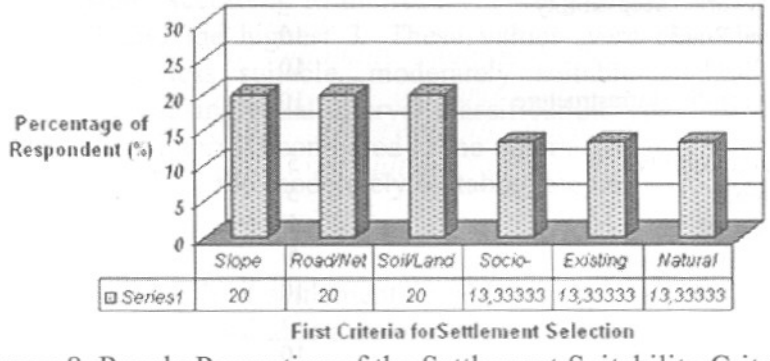

Figure 8. People Perception of the Settlement Suitability Criteria

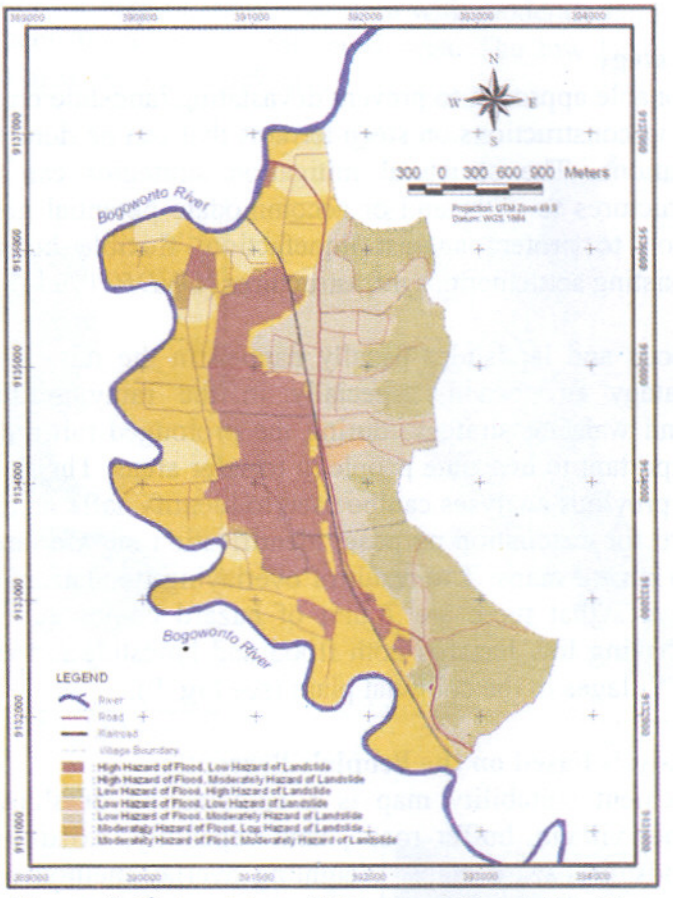

Figure 9. Union Map of Flood and Landslide Hazard

Table 6. Criterion Weighting

Criterion	Weight (%)	Total Weight (%)
Slope	20	20
Read Network / Accessibility		20
• National Road	10	
• Local Road	10	
Availibility of Facilities/Infrastructure	10	10
Land Capability		20
• Soil Permeability	5	
• Soil Depth	5	
• Soil Texture	5	
Shrink and swell / COLE value	5	
• Existing Land Use	10	10
Natural Hazard		20
• Flood	10	
• Lanslide	10	
Total	100	100

Level of suitability was defined from the scoring and weighting overlay analysis for the entire criterion, slope, availability of infrastructure per village, buffer road, land capability, existing land use, flood hazard, and landslide hazard maps. According to the result of weighting overlay analysis, the lowest value is 1.3 and the highest value is 3. These values were classified into three classes, which are less suitable, moderately suitable, and suitable. This classification was made using equal interval classification type, which means each class has the same interval as compared to the others. The less suitable class has the value of 1.300-1.867, the moderately suitable class has 1.868-2.433, and the suitable class has 2.434-3.

According to the results of the settlement suitability map (Fig. 8) suitable area is mostly located in Bagelen Village and Krendetan Villages with an area measuring 336.6 Ha (28% of the total area). In this suitable area, there is a 238.6 Ha area of existing settlement land use. The moderately suitable area measures 627.9 Ha (52% of the total area) dispersedly located in the study area of which 126.5 Ha consists of existing settlement land use. The less suitable area measures 234.1 Ha (20% of the total area) and is mostly located on the hilly area, with 6.0 Ha of the area consisting of existing settlement land use. The previous statements show that most of the existing settlement area or 65% of existing settlement is located in the suitable area. 34% of the existing settlement is located in the moderately suitable area; and, 1% of existing settlement is located in the less suitable area.

Suitability Analysis In Regard to Flood and Landslide Hazard

The Non-Hazard Criteria Analysis

The settlement suitability map (non-hazard criteria analysis) is generated from the combination of non hazard criteria, namely slope, availability of infrastructure per village , buffer road , land capability , and existing land use maps. Level of suitability was defined from the scoring and weighting overlay analysis for the entire criterion. According to the result of weighting overlay analysis, the lowest value is 1.1 and the highest 3. These values were classified into three categories, which are less suitable, moderately suitable, and suitable. This classification was made using equal interval classification type, which means that each class has the same intervals compared to the others. The less suitable category has a value of 1.100-1.733, the moderately suitable category 1.733-2.367, and the suitable class 2.367-3.

According to the result of settlement suitability map, based only on the non-hazard criteria (Fig. 10), the suitable area is mostly located in Bagelen Village and Krendetan Villages with an area measuring 435.84 Ha. In this suitable area, 338.1 Ha consists of existing settlement land use. The moderately suitable area measuring 557.9 Ha is dispersedly located in the study area. The moderately suitable area has 28.9 Ha of existing settlement land use. The less suitable area measures 215.36 Ha

and is mostly located on the hilly area, 5.1 Ha of which consists of existing settlement land use. The previous statements show that most of the existing settlement area or 91% of existing settlement is located in the suitable area. 8% in the moderately suitable area, and 1% in the less suitable area.

Table 7. Equal Weighting

Criterion	Weight (%)	Total Weight (%)
Slope	20	20
Read Network / Accessibility		20
• National Road	10	
• Local Road	10	
Availibility of Facilities/Infrastructure	10	10
Land Capability		20
• Soil Permeability	5	
• Soil Depth	5	
• Soil Texture	5	
Shrink and swell / COLE value	5	
Existing Land Use	20	20
Total	100	100

Hazard Criteria

Integrating the flood and landslide hazard criteria to the settlement suitability was done by overlaying the flood and landslide hazard map and the settlement suitability map of the non-hazard criteria (Fig. 11). The settlement suitability map of the non-hazard criteria has three categories: suitable, moderately suitable, and less suitable (Fig. 10). The flood and landslide hazard criteria used the results of flood and landslide combined map which has 7 units (Fig. 8).

1) A – I (High Landslide, Low Flood – Less Suitability. This 136.2 Ha area has less suitability level for settlement purposes and also possesses high landslide hazard. According to the land use map, there is no settlement in this area, except for a few houses. . The previous landslides in 2000 also happened in this unit. This area should not be used as settlement area.
2) A – II (High Landslide, Low Flood - Moderate Suitability). The A – II unit measures 105.1 Ha and has a moderate suitability level for settlement purposes, but there is high landslide hazard. There is 7.4 Ha of settlement area in this unit. Although it has a moderate suitability level for settlement purposes, this area should not be used as settlement area in order to minimize landslide risks.
3) A – III (High Landslide, Low Flood – Suitable). This 7.4 Ha area is suitable for settlement area from the non-hazard criteria perspective, but it has high landslide hazard. It indicates that this area should consider the natural hazard limitation. There is 5.7 Ha of existing settlement in this unit. The

settlement growth in this unit must be restricted with the purpose of minimizing landslide risks..

4) B – I (Low Landslide, High Flood – Less Suitable). Low Landslide, High Flood. This 24.7 Ha area has less suitability level for settlement purposes, and has high flood hazard. There is no settlement in this area. The B – I area should not be used as settlement area.
5) B – II (Low Landslide, High Flood - Moderate Suitability). The B – II unit which measures 177.2 Ha is moderately suitable for settlement purposes from the non hazard criteria, but there is a high flood hazard. It means that this area should be considered of its hazard criteria if people want to build settlement and inhabit this area. Mitigation strategy, such as building codes must be applied if people want to reside here. High foundation houses and or multi storey buildings can be imposed as one of the regulations if people want to build their houses in this area. Land use in this area is mostly paddy field and some homestead.
6) B – III (Low Landslide, High Flood – Suitable). This 34.6 Ha area is suitable for settlement, but there is high flood hazard here. It denotes that similar to the B – II unit, if people want to construct settlement in this place, building codes is a must here. High foundation houses and or multi storey buildings can be imposed as a rule for housing construction. The existing land use on this unit consists of paddy field (34.1 Ha), homestead (0.1 Ha) and settlement (0.5 Ha).
7) C – I (Low Landslide, Low Flood – Less Suitability)
8) The C – I unit is very small area measuring only 0.016 Ha and there is no settlement here, only homestead. Even though this area is considered as low flood hazard, this area should be preserved as homestead.
9) C – II (Low Landslide, Low Flood - Moderate Suitability). This 9.9 Ha area is moderately suitable for settlement and has low flood and low landslide hazard. This area consists of homestead and paddy field; there is no existing settlement in this area.
10) C – III (Low Landslide, Low Flood – Suitable). This C – III is suitable for settlement area and has low flood and landslide hazards. Although only 1.4 Ha in width this area is considered very suitable for settlement purposes because of its non-hazard criteria suitability and low hazard. This area is used as existing settlement and homestead.
11) D – I (Low Landslide, Moderate Flood – Less Suitability). With only 3.3 Ha, this D – I area has low suitability level for settlement. Under the natural hazard criteria, this area also has moderate flood hazard. The existing land use in this area is homestead and paddy field. This area is considered to be conserved as homestead and paddy field rather than for settlement area
12) D – II (Low Landslide, Moderate Flood - Moderate Suitability). This 4.1 Ha area is moderately suitable for settlement area, but has moderately flood hazard. The existing land use is paddy field and homestead. Similar to the D

– I area, this area is better to be preserved as paddy field and homestead rather than for settlement area.

13) D – III (Low Landslide, Moderate Flood – Suitable). This D – III unit measuring 5.4 Ha is suitable for settlement area, but has moderately flood hazard. The existing land use is mostly paddy field and some homesteads. Together with the D – I and D – II areas, this area is better to be preserved as paddy field and homestead rather than for settlement area.

14) E – I (Moderate Landslide, High Flood – Less Suitability). This E – I unit with 32.8 Ha in width is less suitable for settlement area, due to high flood hazard, and some of the areas, which is near the river, have moderate landslide hazard (riverbank erosion). The existing land use of this area is mostly homestead area. Because of the less suitability and high natural hazard, this area is better to be conserved as homestead rather than for settlement area

15) E – II (Moderate Landslide, High Flood- Moderate Suitability). The E – II unit which measures 154.2 Ha is moderately suitable for settlement, but there is high flood hazard limitation in this area. The existing land use in this area consists of homestead (132.95 Ha), 12.59 Ha of existing settlement and 8.69 Ha of paddy field. If people want to build settlement and inhabit in this area, they should put into consideration the hazard aspect. Mitigation strategy, such as building codes must be applied if people want to reside here. High foundation houses and or multi storey buildings can be imposed as one of the regulations if people want to build their houses in this area.

16) E – III (Moderate Landslide, High Flood – Suitable). The E – III unit with 178.8 Ha is suitable for settlement area, but from the natural hazard criteria, this area has high flood hazard. The existing settlement in this area is 165.9 Ha or 93 % of this area. This means that this area must be considered of its hazard by integrating mitigation strategy done for example by raising the foundation of the houses and or constructing multi storey building. Other mitigation strategy is by improving sewage or drainage system, especially along the railroad.

17) F – I (Moderate Landslide, Low Flood – Less Suitability). This F – I unit with 2.2 Ha in width is less suitable for settlement area. It has moderate landslide hazard. According to the existing land use map, there is no settlement in this area; there are only forest, shrubs, and homestead.

18) F – II (Moderate Landslide, Low Flood - Moderate Suitability). The F – II unit which measures 68.6 Ha is moderately suitable for settlement, but there is moderate landslide hazard in this area. The existing land use in this area consists of homestead (49.6 Ha), paddy field (10.1 Ha), forest and shrubs (2.1 Ha) and settlement (6.9 Ha). If people want to build settlement and inhabit in this area, they should avoid building constructions on steep terrains, structural mitigation by engineering of structures, and relocation of people especially in the rainy season.

19) F – III (Moderate Landslide, Low Flood – Suitable). The F – III unit with 138.8 Ha in width is suitable for settlement area, and from natural hazard criteria this area is located in the zone safe from flooding and moderate landslide, because most of this area is located on the colluvial plain. The existing settlement in this area is 109.3 Ha or 78 %. The rest of the area consists of homestead (28.8 Ha) and paddy field (0.7 Ha).
20) G – I (Moderate Landslide, Moderate Flood – Less Suitable). This E – I unit with 3.9 Ha in width is less suitable for settlement area. It has moderate flood hazard and some of the area, which is near to the river, has moderate landslide hazard (riverbank erosion). The existing land use of this area is mostly homestead area. Because of the less suitability and existence of natural hazard, this area is better to be conserved as homestead rather than for settlement area.
21) G – II (Moderate Landslide, Moderate Flood– Moderate Suitability). This G – II area with 11.8 Ha in width is moderately suitable for settlement area, but has moderate flood hazard. The existing land use is homestead (9.9 Ha), paddy field (0.1 Ha) and settlement (1.8 Ha). In line with the G – I area, this area is better to be preserved as paddy field and homestead rather than for settlement area.
22) G – III (Moderate Landslide, Moderate Flood – Suitable). The G – III unit with 57.1 Ha is suitable for settlement area, and from natural hazard criteria this area is located in the moderate flood hazard area. The existing settlement in this area is 56.3 Ha or 98 % of this area. The rest of the area consists of homestead (0.7 Ha) and paddy field (0.1 Ha). If people want to build settlement and inhabit in this area, they should put into consideration hazard aspects. Mitigation strategy, such as building codes must be applied if people want to reside here. High foundation houses and or multi storey buildings can be imposed as one of the regulations if people want to build their houses in this area.

According to the suitability levels, for the next settlement development, it is suggested to use the suitable areas rather than the moderate and less suitable zones. Considering the natural hazard limitation, the F – III unit area is decided as the most suitable area for settlement, because it has less flood and landslide hazards. Other suitable areas, which are A – III, B – III, C – III, D – III, E – III, and G – III, can be used as settlement areas, but the settlement development has to put into considerations natural hazard limitations along with their mitigation strategies.

Table 8. Comparison between Two Suitability Analyses

Characteristic	Suitability Analysis based on People Perception Towards Criteria	Suitability Analysis In Consideration of Flood and Landslide Hazard

Analysis	▪ Weighting Overlay Method for all criteria: slope, availability of infrastructure, road/network, land capability, existing land use, flood hazard, and, landslide hazards ▪ The weight of criteria in overlaying method based on people perception of each of the criteria ▪ Equal Interval Classification to decide the suitability categories	▪ Weighting Overlay Method for only the non-hazard criteria: availability of infrastructure, road/network, land capability, existing land use ▪ Equal weight of criteria in overlaying method ▪ Equal interval classification to decide the suitability categories ▪ Overlay the natural hazard criteria (flood and landslide hazard map) with the suitability map and analyse each of the units separately.
Results	▪ Classify the study area into three suitability categories: less suitability, moderately suitable , and suitable areas. ▪ The natural hazard criteria were included in overlaying process, difficult to give limitations in a certain area based on the natural hazard limitation.	▪ There are 21 unit areas with their suitability categories (less suitability, moderately suitable and less suitable , and flood and landslide hazard unit areas (7 units) ▪ Giving limitation in each units and also some mitigation related to the natural hazard criteria

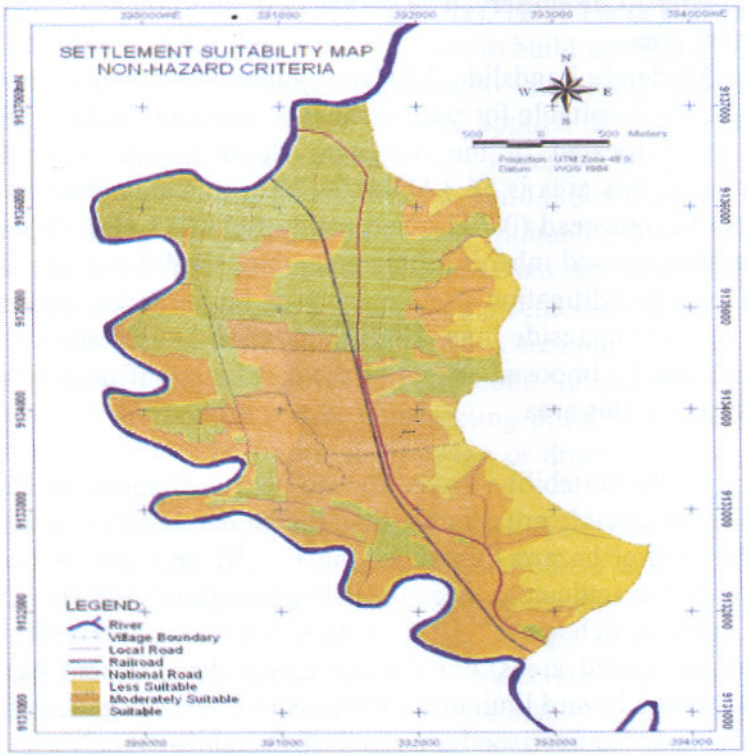

Figure 10. Settlement Suitability Map (Non Hazard and Hazard Criteria) Based on the People Perception Towards the Criteria (left)

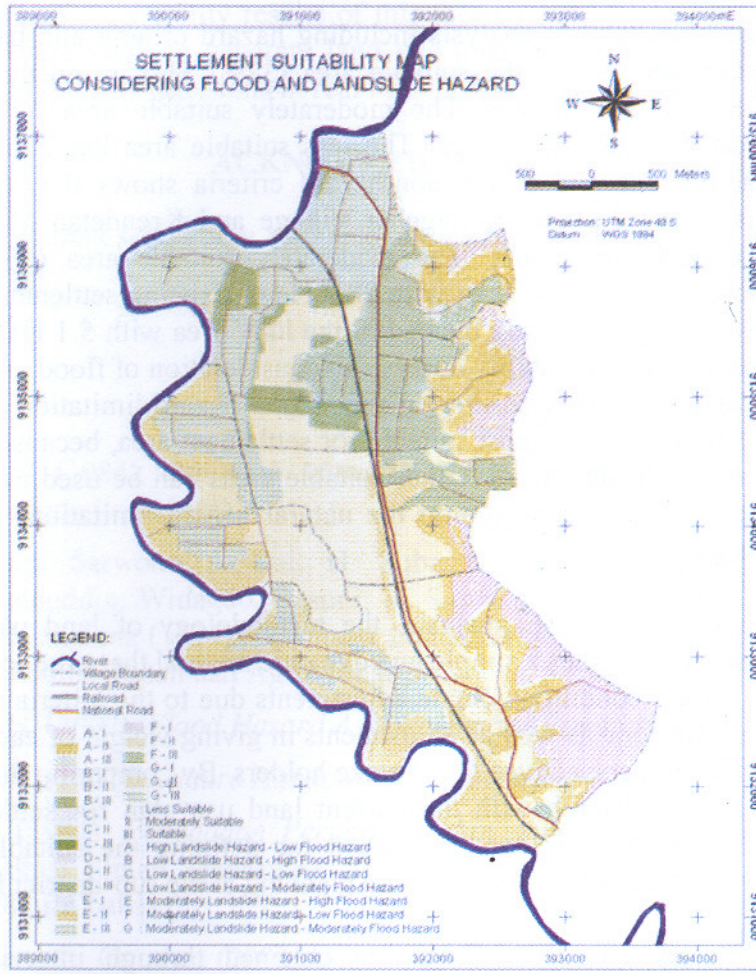

Figure 11. Settlement Suitability Map (Non Hazard Criteria) Equal Weighting of Criteria

CONCLUSION AND RECOMMENDATION

The study showed that the area with manageable flood level measures 0.85 km²; most of them located in the Bagelen Village. The area with not manageable flood level measures 6.01 km², located almost entirely on the western part of the study area. And the non flood area measures 4.57 km², located in the eastern part of the study area, which is geomorphologically as the colluvial plain and denudated hill. In this area of study, landslide hazard map is divided into three landslide hazard categories, the high, moderate and low hazard areas. Based on the landslide hazard map the area with high landslide hazard measures 2.38 km² and is located on the hilly area in the eastern part of the area of study. The area with moderate landslide hazard measures 6.42 km² and is dispersedly located in the study area. The low landslide hazard is located in the plain area, measuring 2.62 km² in width.

The result of suitability analysis including hazard criteria and based on the people perception shows that the suitable area (329.1 Ha) is mostly located in Bagelen and Krendetan Villages. The moderately suitable area (603.4 Ha) is dispersedly located in the study area. The less suitable area has 210.1 Ha. The result of suitability analysis of the non-hazard criteria shows the suitable area (215.36 Ha) is mostly located in Bagelen Village and Krendetan Villages with 338.1 Ha of existing settlement. The moderately suitable area (557.9 Ha) is dispersedly located in the study area with 28.9 Ha of existing settlement. The less suitable area (435.8 Ha) is mostly located in the hilly area with 5.1 Ha of existing settlement. The results of suitability analysis in consideration of flood and landslide hazards show 21 unit areas. Considering the natural hazard limitation, the F – III unit area is determined as the most suitable for settlement area, because it has less flood hazard and landslide hazard. Other suitable areas can be used as settlement area, but has to put into consideration the natural hazard limitations along with mitigation strategies.

By using GIS and MCE analysis, the methodology of land use plan for settlement suitability becomes a simple and dynamic method that produces land use plans to fulfil certain conditions. Some adjustments due to the criteria used in the methodology can be done as well as adjustments in giving weight of each criterion based on the different perspectives of the stake holders. By comparing the proposed methodology in this research with the current land use plan for settlement, the methodology in this research can be applied for defining the suitable area for settlement development purpose for land use planning at the sub-district level.

Taking into account the information obtained through interviews, field surveys and analysis results, some recommendations can be made within this study. The natural-hazard based land use plan for settlement development purposes presented in this study can be adopted by generating land use planning based on natural hazards. Below are the recommendations for better research:

- Detailed approach and or modelling can be used to generate e flood and landslide hazard map.
- Because this methodology is simple and dynamic, incorporating more criteria for settlement suitability analysis either physical criteria or socio-economic criteria would not be a problem.
- To produce better results which better reflect stakeholder and people interests in a given criterion weight, more interviews on stakeholders and villagers can be exercised. The weighting method in this research can be adjusted based on the different interests of the people and stake holders, which would also imply different results on suitability level.

- The settlement suitability results of this thesis must be taken very carefully as scientific approach to generate land use plan for settlement also needs the support of political decisions in real life condition.

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