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Spatial Analysis of Land Susceptibility to Degradation and Alternative Plants for Its Rehabilitation

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Abstract. One of the drawbacks of developing plants for the rehabilitation of degraded land in Indonesia is the relative lack of information about species that are suited to the local conditions. Therefore, spatial information on land degradation and the plants suitable for rehabilitation is crucial. The objectives of this study were to map the susceptibility of land to degradation and to identify some alternative species for its rehabilitation. The research was conducted in Jang Watershed, Bintan Island, Kepulauan Riau Province, Indonesia. A quick assessment of land degradation was carried out to classify the degree of land susceptibility. The land suitability evaluation was conducted manually by matching the existing biophysical condition and plant growth requirements using a geographic information system. This analysis was applied for annual plants, such as *Acacia mangium, Durio zibethinus, Artocarpus champeden, Theobroma cacao* and *Hevea brassiliensis*. Furthermore, the maps of land susceptibility to degradation and species suitability were overlaid and the result was used to provide recommendations for rehabilitating the degraded land. This study showed that 22% of the Jang Watershed area can be categorised as highly susceptible to degradation. The suitability analysis illustrated that 59% of the degraded areas were suitable for *Acacia mangium*. The planting of fast-growing species such as *Acacia mangium* is expected to improve the physical, chemical and biological properties of the soil.

Keywords: degradation, land suitability, quick assessment.

Abstrak. Salah satu kelemahan dalam mengembangkan tanaman untuk rehabilitasi lahan terdegradasi di Indonesia adalah kurangnya informasi mengenai kesesuaian jenis dengan kondisi lahan setempat. Oleh karena itu, informasi spasial mengenai kerentanan degradasi lahan dan tanaman yang sesuai untuk rehabilitasinya sangat penting. Tujuan dari penelitian ini adalah untuk memetakan tingkat kerentanan lahan terhadap degradasi dan untuk menyediakan beberapa alternatif tanaman untuk kegiatan rehabilitasi. Penelitian ini dilakukan di Daerah Aliran Sungai (DAS) Jang, Pulau Bintan, Provinsi Kepulauan Riau, Indonesia. Sidik cepat degradasi lahan diterapkan untuk mengklasifikasikan tingkat kerentanan lahan. Evaluasi kesesuaian lahan dilakukan secara manual dengan mencocokkan kondisi biofisik yang ada dan persyaratan pertumbuhan tanaman menggunakan Sistem Informasi Geografis. Analisis ini diterapkan untuk tanaman tahunan, seperti *Acacia mangium, Durio zibethinus, Artocarpus champeden, Theobroma cacao*, dan *Hevea brassiliensis*. Selain itu, peta kerentanan lahan terhadap degradasi dan peta kesesuaian lahan ditumpangtindihkan untuk selanjutnya hasilnya digunakan sebagai rekomendasi untuk merehabilitasi lahan terdegradasi. Penelitian ini menunjukkan bahwa 22% dari DAS Jang memiliki tingkat kerentanan degradasi lahan yang tinggi. Analisis kesesuaian menggambarkan bahwa 59% daerah yang terdegradasi sesuai untuk *Acacia mangium*. Penanaman jenis pohon cepat tumbuh seperti *Acacia mangium* diharapkan dapat memperbaiki sifat fisik, kimia, dan biologi tanah.

Kata kunci: degradasi, kesesuaian lahan, sidik cepat.

1. Introduction

Land degradation is the decline in the natural quality of the soil component within an ecosystem (Eni, 2012). The level of degradation is indicated by a decrease in vegetation cover (Mawardi, 2010) and the capacity of a watershed to store water (Narulita *et al.*, 2008). In Indonesia, degraded lands result mainly from a mismatch or incompatibility between land use and its capability (Herrick *et al.*, 2019; Wahyuningrum & Basuki, 2014)Wonogiri District, Central Java. Mini catchment area of about 10.82 ha was used as unit analysis which was divided into land unit based on its biophysical characters. Dataused includeprecipitation, wetanddrymonthsof the year, soil type, soiltextureandstructure, effectivedepth, regolithdepth, slope, rock type, and thepercentage ofrockoutcropatthe surface, as well asdrainage. Universal Soil Lost Equation (USLE along with the over-use of land resources (Kubangun *et al.*, 2014). In addition, land becomes degraded through intensive agricultural activities carried out without soil and water conservation measures, combined with disturbance to the water regulation function in a watershed (Nugroho & Prayogo, 2008). As a result, degraded land must be rehabilitated, otherwise it will be a loss to the functionality of the ecosystem (Marchetti *et al.*, 2018) and consequently contribute to an increase in the frequency of floods, landslides and drought (Hasan *et al.*, 2016).

The recovery of degraded land through rehabilitation activities has been conducted for several decades; however, land degradation is still continuously taking place. This may be the result of a lack of integrated information on both land sustainability versus degradation and the species that are suitable for its rehabilitation. It is necessary to spatially classify the susceptibility of land to degradation in order to determine the priority in which to rehabilitate degraded land (Basuki & Wahyuningrum, 2014). This classification can be conducted by analysing the properties of land obtained using remote sensing data (Basuki & Wahyuningrum, 2016). These spatial data are essential in order to delineate degraded land (Tarigan, 2012).

In addition to spatial information related to degraded land, another important factor in terms of improving the success of land rehabilitation is the suitability of the species selected for planting on the land (Basuki & Wahyuningrum, 2016; Pratiwi *et al.*, 2014; Sudarmadji & Hartati, 2016). As such, it is necessary to match the growth requirement of plants with the properties of the land in question.

The use of remote sensing data to determine the degree of degraded land has been carried out in several areas (Basuki & Wahyuningrum, 2014; Basuki *et al.*, 2016; Tarigan, 2012), while analysis of the suitability of species to degraded land has been undertaken at other sites (Pratiwi *et al.*, 2014; Wahyuningrum *et al.*, 2003). As mentioned previously, in order to achieve the successful rehabilitation of degraded land, information on the degree of land susceptibility to degradation must be integrated with the proper selection of species. Therefore, this study is essential in order to bridge the gap between those previous studies.

The main objective of this study were to map the susceptibility of land to degradation and to identify alternative species for its rehabilitation. In this study, we used free access IKONOS satellite imagery from Google Earth to obtain our land cover map. This imagery has been widely used for land cover classification due to its high spatial resolution (Hu *et al.*, 2013). In this paper, the imagery was not only used for land cover classification but also for the analysis of land susceptibility to degradation. In addition to land cover mapping, a land suitability analysis of various species was undertaken aimed at their potential use in land rehabilitation.

2. Research Method

This study was conducted in 2016 in Jang Watershed, Bintan Island, Kepulauan Riau province, Indonesia. Jang Watershed covers an area of 7910 ha, extending from 104°26'14" to 104°35'0" East longitude and 0°50'38" to 0°56'50" North latitude (Figure 1). Based on Schmidt and Fergusson's classification, the climate type is A with a Q value of 0 % (Adi & Wijaya, 2016). Mean annual rainfall is 3243 mm and mean monthly rainfall exceeds 200 mm with no dry months (Adi & Wijaya, 2016). The elevation of the study area is 0–212 m above sea level and the land is characterised by flat to very steep slopes ranging from 0 to 52%.

The materials used in this study were land cover maps derived from IKONOS Google Earth 2014, and the slope steepness data were derived from DEM/SRTM (Digital Elevation Model/ Shuttle Radar Topographic Mission). Data on the land system, landform, soil type, geomorphology and lithology were obtained from The Regional Physical Planning Programme for Transmigration (RePPProT). Rainfall data were obtained from the Meteorological, Climatological and Geophysical Agency in Tanjung Pinang (BMKG Tanjung Pinang). In this paper, we focus only on biophysical factors. The research outline is given in Figure 2.

A quick assessment of land degradation was undertaken to classify the degree of land susceptibility to degradation. This ground check was conducted in 2016. The data were analysed spatially by overlaying the required maps. The degree of land susceptibility to degradation was classified into very low (1), low (2), medium (3), high (4) and very high (5). The formulation of the susceptibility of land to degradation is shown in Table 1.

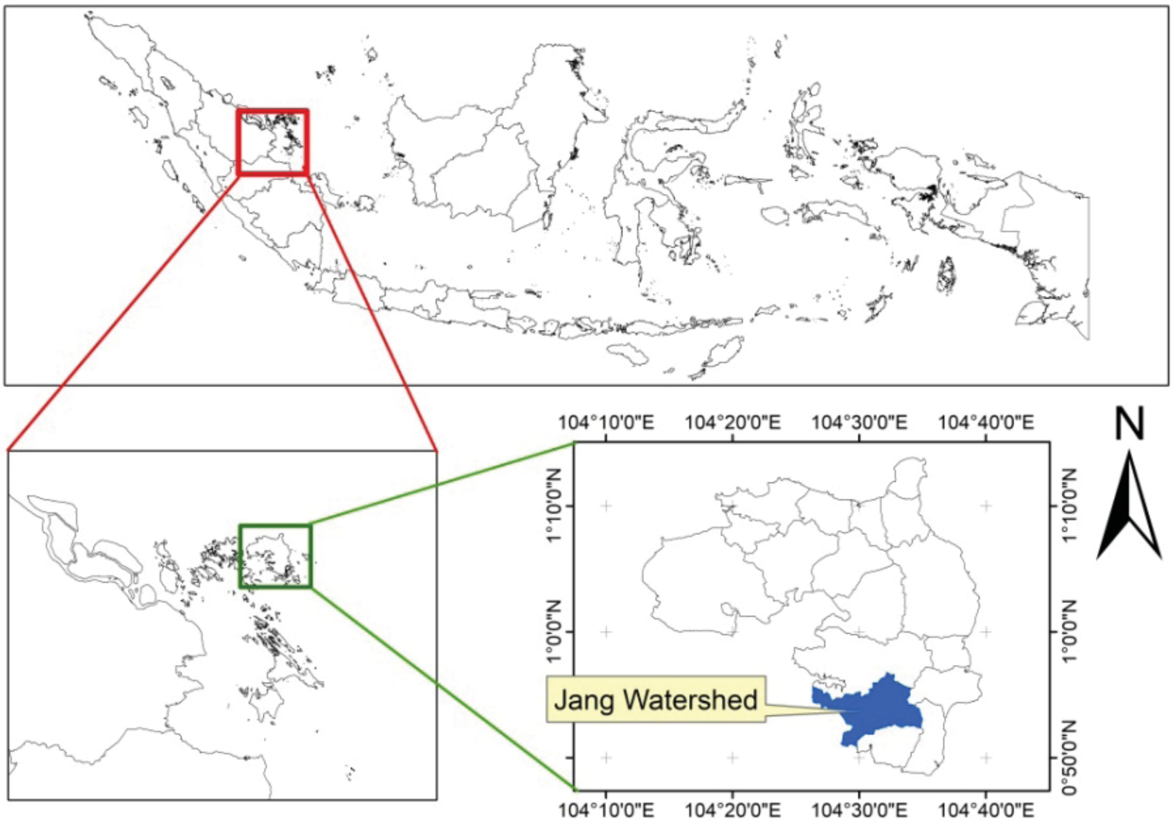

Figure 1. Location of the study area.

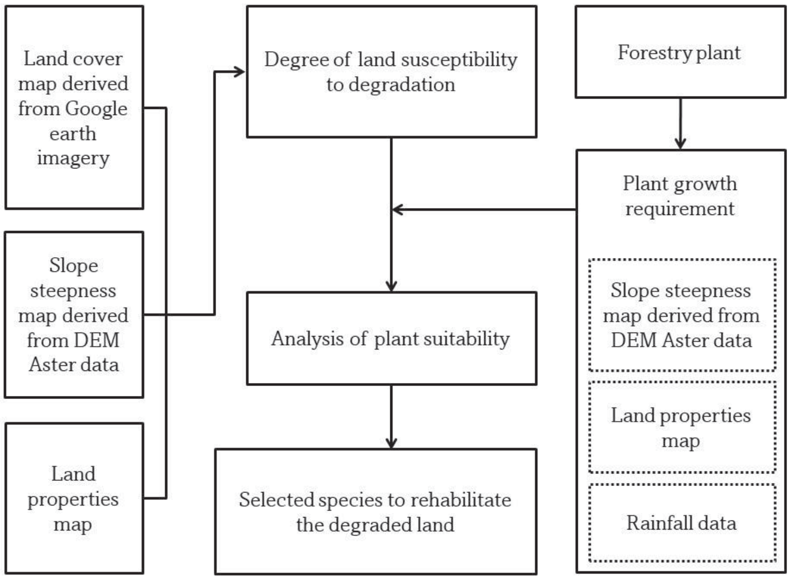

Figure 2. Research outline.

Table 1. Formulation of land susceptibility to degradation.

No	Parameters	Value	Scores
A	Nature (45 %)		
1	Solum (10 %)	> 90 cm	1
		60 - < 90 cm	2
		30 - < 60 cm	3
		15 - < 30 cm	4
		< 15 cm	5
2	Slope steepness (15 %)	0 - < 8 %	1
		8 - < 15 %	2
		15 - < 25 %	3
		25 - < 45 %	4
		> 45 %	5
3	Outcrop (5 %)	< 20 %	1
		20 - < 40 %	2
		40 - <60 %	3
		60 – 80 %	4
		> 80 %	5
4	Morfoerosion (10 %)	0 %	1
		1 - < 20 %	2
		20 - < 40 %	3
		40 - 60 %	4
		> 60 %	5
5	Soil texture (5 %)	Sand, loamy sand	1
		Silty clay, sandy loam, clay	2
		Clay loam, silty clay loam	3
		Loam, sandy clay loam, sandy clay	4
		Silt, silt loam	5

No	Parameters	Value	Scores
B	Management (55 %) *)		
1	Agricultural area (55 %)		
a	Vegetation cover (40 %)	50-80% forest/plantation + seasonal crop	1
		30-50% forest/plantation + densely seasonal crop	2
		30-50% forest/plantation + sparse seasonal crop	3
		10-30% forest/plantation + densely seasonal crop	3
		Densely seasonal crop	3
		10-30% forest/plantation + sparse seasonal crop	4
		Sparse seasonal crop	5
b	Soil conservation (15 %)	Level terrace	1
		Bench terrace	2
		Mixed terrace	3
		Contour terraces, hillside ditch, alley cropping	4
		No terrace	5
2	Forest / plantation area (55 %)		
a	Vegetation cover (45 %)	Forest, plantation + cover-crop litter plantation	1
		Main vegetation <50% + shrubs	2
		Shrubs	3
		Reed	4
		Bare land >50%	5
b	Soil conservation (10 %)	Contour terrace + crop	1
		Alley cropping	2
		Mulch contour	3
		Contour terrace	4
		No alley crop	5

Remarks: *) Management differentiated into “Agricultural area” and “Forest and plantation area”

Source: (Paimin *et al*., 2010)

Table 2. Classification of land susceptibility to degradation.

Value	Degree of susceptibility to degradation
>29.4	Very high
>23.8–29.4	High
>18.2–23.8	Moderate
>12.6–18.2	Low
≤12.6	Very low

Source : (Paimin *et al*., 2010)

Further analysis was undertaken to integrate the preliminary maps and the data from the field campaign. The resulting data were evaluated and classified based on Table 2. A number of previous studies have also applied this method in their efforts to identify the level of land degradation within the Tapan Micro Catchment in Karanganyar Regency (Basuki & Wahyuningrum, 2014), Upper Solo Sub Watershed in Wonogiri Regency (Basuki *et al*., 2016) and the Oyo Sub Watershed in Bantul Regency (Widya, 2015). The method was adopted here due to its ability to detect the potential of the degradation areas and also the occurrence of land degradation earlier. This is important because the dynamics in the watershed occur continuously due to both natural and human factors.

Table 3. Criteria used in land suitability analysis.

Parameter	Class of suitability	*Acacia mangium*	*Durio zibethinus*	*Artocarpus champeden*	*Theobroma cacao*	*Hevea brassiliensis*
Rainfall (mm)	S1	2500-3000	2000-3000	1000-2000	1500-2000	2500-3000
	S2	3000-4000, 2000-2500	1750-2000, 3000-3500	500-1000, 2000-3000	2500-3000	2000-2500, 3000-3500
	S3	-	1250-1750, 3000-4000	250-500, 3000-6000	1250-1500, 3000-4000	1500-2000, 3500-4000
	N	-	<1250, >4000	<250, >6000	<1250, >4000	<1250, >4000
Slope steepness (%)	S1	0-8	0-8	0-8	0-8	0-8
	S2	>8-15	>8-15	>8-15	>8-15	>8-15
	S3	>15-30	>15-30	>15-30	>15-30	>15-30
	N	>30	>30	>30	>30	>30
Drainage	S1	Well drained	Well drained, Moderately drained	Well drained, Moderately drained	Well drained, Moderately drained	Well drained
	S2	Moderately drained	Slightly poorly drained	Slightly poorly drained	Slightly poorly drained	Moderately drained
	S3	Slightly poorly drained	Poorly drained, slightly excessively drained	Poorly drained, slightly excessively drained	Poorly drained, slightly excessively drained	Poorly drained, slightly excessively drained
	N	Poorly drained, excessively drained	Very poorly drained, excessively drained	Very poorly drained, excessively drained	Very poorly drained, excessively drained	Very poorly drained, excessively drained
Solum (cm)	S1	>100	>100	>100	>100	>100
	S2	75-100	75-100	75-100	75-100	75-100
	S3	50-75	50-75	50-75	50-75	50-75
	N	<50	<50	<50	<50	<50
Morfo-erosion	S1	Very low	Very low	Very low	Very low	Very low
	S2	Low	Low–moderate	Low–moderate	Low–moderate	Low–moderate
	S3	Moderate	Severe	Severe	Severe	Severe
	N	Severe	Very severe	Very severe	Very severe	Very severe
Outcrop (%)	S1	<2	<5	<5	<5	
	S2	2-10	5-15	5-15	5-15	5-15
	S3	>10-25	15-25	15-25	15-25	15-25
	N	>25-40	>25	>25	>25	>25

Remarks: S1 (Highly suitable); S2 (Moderately suitable); S3 (Marginally suitable); N (Not suitable)

Source: (BBLSDLP, 2016)

The land suitability evaluation was conducted manually by matching the biophysical conditions, i.e. climate, soil and plant growth requirements (Wahyuningrum *et al.*, 2003) using a geographic information system. The land suitability classes were divided into highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). The land suitability analysis was applied to forestry plants such as *Acacia mangium*, *Durio zibethinus*, *Artocarpus champeden*, *Theobroma cacao* and *Hevea brassiliensis*. The land suitability classification was conducted by sorting the land characteristics data based on the land suitability criteria for each plant species. The land suitability criteria used to analyse the suitability of each plant species is provided in Table 3.

3. Results and Discussion

3.1. Land cover

The land cover was classified using satellite imagery from Google Earth 2014 and ground checks in 2016. Based on Table 4, it can be seen that the dominant land cover was shrubs (25% of the watershed), followed by built areas (24% of the watershed), which contain settlements, an airport and port, while bare land covers 21% of the watershed. Most of the three dominant types of land cover were in flat areas. The spatial distributions of the various types of land cover are given in Figure 3.

Table 4. Land cover type at various slope classes.

No	Land cover	Slope steepness (Ha)					Total
		0-8%	>8-15%	>15-25%	>25-45%	>45%	
1	Dryland Forest	168	67	45	43	2	325
2	Mangrove	709	38	9	0	0	757
3	Swamp Forest	146	30	13	2	0	191
4	Plantation	72	58	32	2	0	164
5	Shrubs	1327	527	150	11	0	2015
6	Dryland Agriculture	485	130	23	2	0	639
7	Built Areas	1380	415	68	2	0	1864
8	Bare Land	1161	422	82	2	0	1666
9	Fishponds	14	0	0	0	0	14
10	Swamp	73	1	0	0	0	75
11	Water Body	182	14	2	0	0	199
	Total	5718	1702	423	64	2	7910

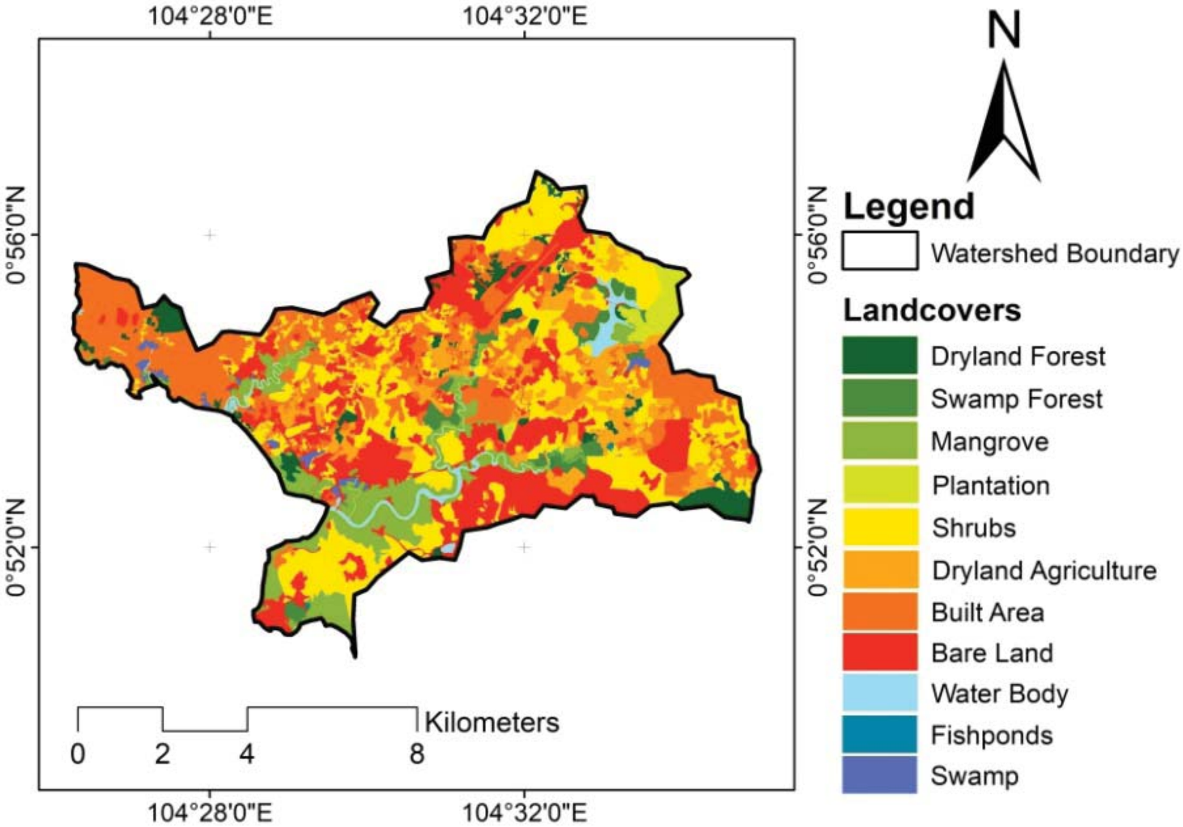

Figure 3. Land cover in Jang Watershed.

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3.2. Land susceptibility to degradation

The degree of land susceptibility was classified based on a quick assessment of land degradation. The study area is dominated by land that is moderately susceptible (49%), followed by highly susceptible (22%), with the susceptibility to degradation of the remaining land being very low (18%) and low (12%) (Figure 4). The spatial distribution of the susceptibility of land to degradation for each type of land cover is shown in Table 5. Most of the areas with high susceptibility to degradation were located in the bare land areas. Additionally, it is not only bare land that is susceptible to degradation, but also dryland forest.

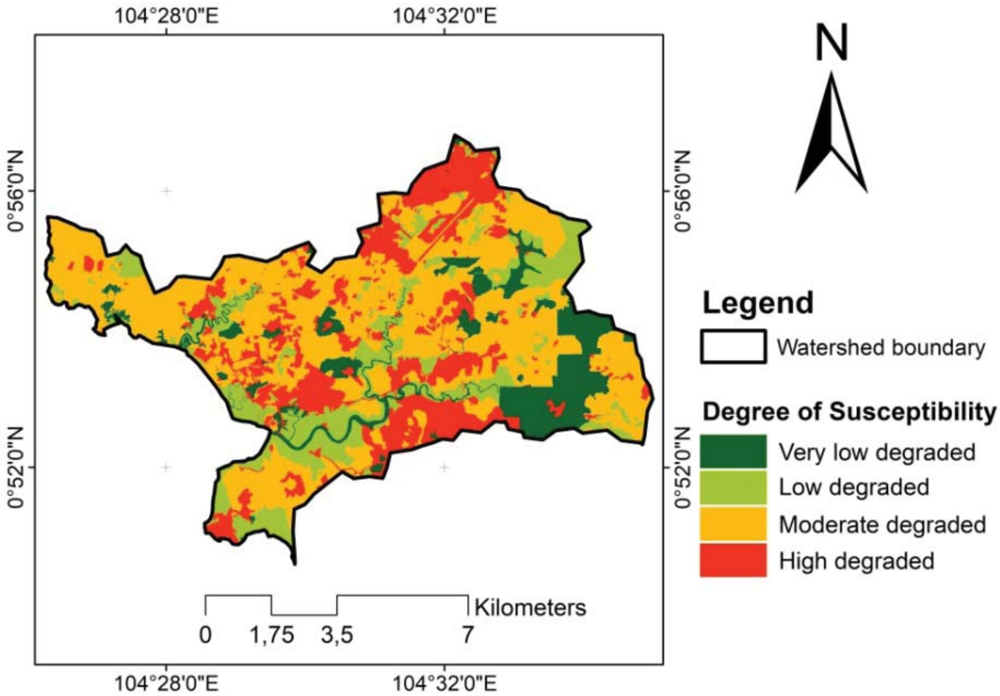

Figure 4. Spatial distribution of land degradation susceptibility.

Table 5. Distribution of land degradation susceptibility.

No	Land cover	Degree of land susceptibility to degradation (Ha)			
		Very low	Low	Moderate	High
1	Dryland Forest	278.4	2.8	44.2	0.03
2	Mangrove	756.6	0.1	0.1	-
3	Swamp Forest	191.2	0.2	0.1	0.02
4	Plantation	164.6	0.002	0.2	0.04
5	Shrubs	0.8	348.7	1475.3	192.1
6	Dryland Agriculture	0.2	0.02	634.0	6.1
7	Built Areas	0.2	177.6	1687.9	0.1
8	Bare Land	0.1	162.3	0.6	1504.4
9	Fishponds	-	-	-	-
10	Swamp	-	-	-	-
11	Water Body	-	-	-	-

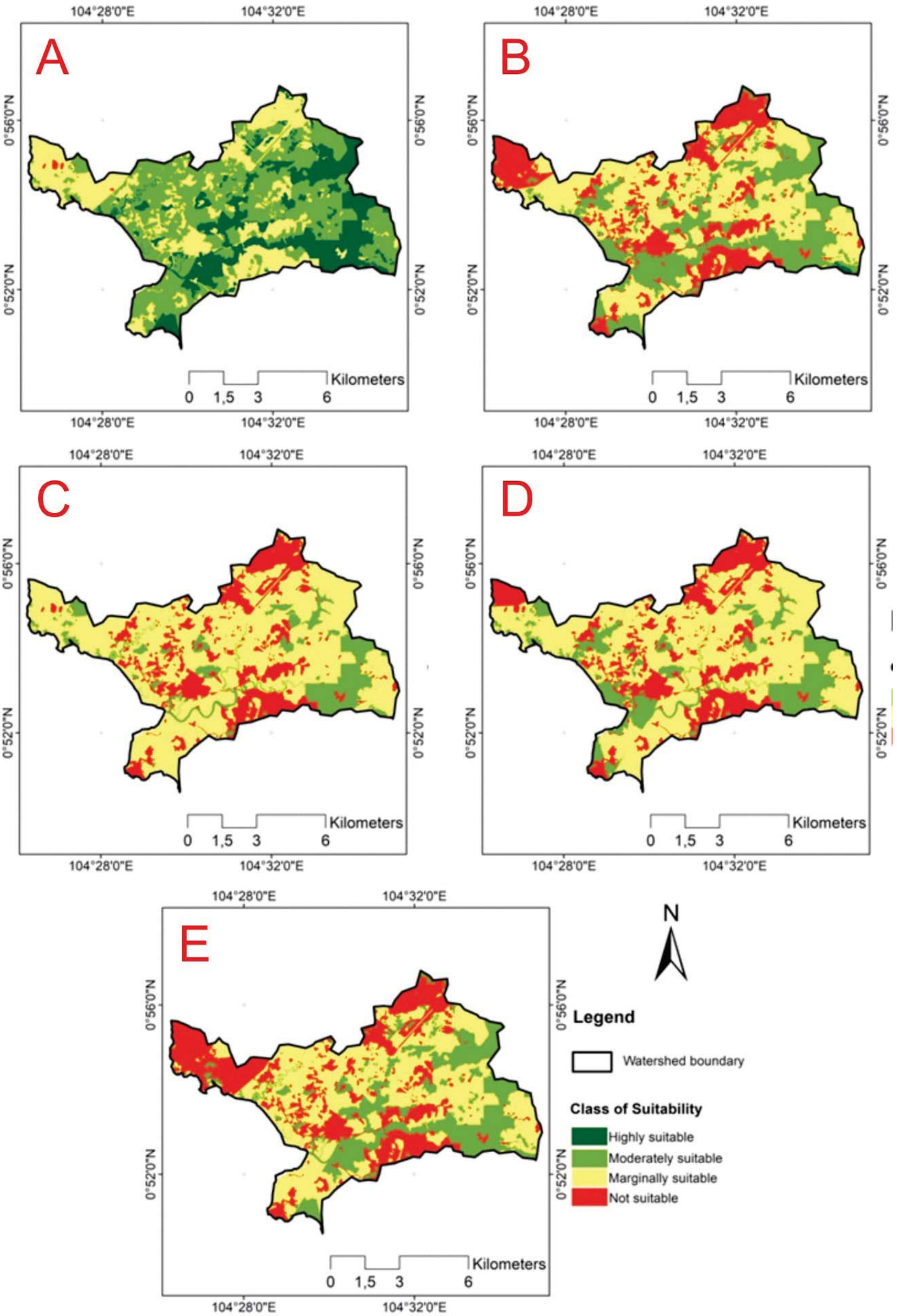

Figure 5. Spatial distribution of Acacia mangium suitability (A), Durio zibethinus suitability (B), Artocarpus champeden suitability (C), Theobroma cacao suitability (D), Hevea brassiliensis suitability (E).

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About 21% of the research sites consist of bare land. Based on the field observation, a majority of these are ex-mining lands. According to Ekyastuti *et al.* (2016), ex-mining areas have limitations in terms of planting. Clearly, the solum on these lands is very thin, which means that the selection of species for rehabilitation is based not only on their suitability but also their ability to improve the soil properties. This would pose quite a challenge to the rehabilitation of ex-mining areas.

3.3. Recommendations for rehabilitating degraded land

Land suitability analysis is a process for matching the characteristics of land resources to certain uses by employing a scientifically standardised technique (Wahyuningrum *et al.*, 2003). The results of land suitability analysis can be used as a guide to finding solutions to the fragmentation and degradation of entire landscapes. Spatial distributions of the suitability of the various species based on the degraded land of Jang Watershed are shown in Figure 5.

The result of the land suitability analysis indicates that the majority of the land in the study area is moderately suitable for *Acacia mangium* (47%), while *Durio zibethinus* (45%), *Artocarpus champeden* (65%), *Theobroma cacao* (59%) and *Hevea brassiliensis* (47%) scored highest for the marginally suitable class. The classes of suitability are presented in detail in Table 6. Based on the ground check, only the B and C horizons remain in the bare land areas due to the loss of topsoil. Organic material or compost is therefore required to improve the physical properties of these soils. In addition, chemical fertilisers must be added to both stimulate plant growth and provide the right conditions for growth to occur.

Table 6. Spatial assessment of land suitability based on degraded land in Jang Watershed.

Species suitability Very low degraded		Susceptibility of land to degradation (Ha)			
		Very low degraded	Low degraded	Moderate degraded	High degraded
Acacia mangium	S1	949	942	7	4
	S2	35	443	3274	10
	S3	3	1	578	1689
	N	0	0	0	20
Durio zibethinus	S1	0	20	0	0
	S2	979	1288	29	4
	S3	4	76	3498	10
	N	3	1	332	1709
Artocarpus champeden	S1	0	0	0	0
	S2	978	96	4	3
	S3	5	1290	3844	11
	N	3	1	10	1709
Theobroma cacao	S1	0	0	0	0
	S2	978	464	5	3
	S3	5	921	3719	11
	N	3	1	135	1709
Hevea brassiliensis	S1	0	1	0	0
	S2	978	939	13	4
	S3	5	445	3269	10
	N	3	1	577	1709

The rehabilitation of degraded land is a governmental programme requiring specific knowledge of soil characteristics, appropriate rehabilitation techniques, the proper selection of plant species, planting techniques and vegetation maintenance (Sudarmadji & Hartati, 2016). In order to ensure suitable plants are used to rehabilitate degraded land, the selected species should have moderate to high suitability for the classes of moderate to high degradation. Table 6 shows that *Acacia mangium* is suitable for growing in the areas covering 3295 Ha that are characterised by a moderate to high degree of land degradation (59%), while *Durio zibethinus* can be planted on 33 Ha (0.6%). *Artocarpus champeden*, *Theobroma cacao* and *Hevea brassiliensis* can be utilised on 8 Ha (0.2%), 8 Ha (0.2%) and 17 Ha (0.3%), respectively. Thus, *Acacia mangium* is the species that is recommended for rehabilitating degraded land in the Jang Watershed.

Acacia mangium is a fast-growing tree (Krisnawati *et al*., 2011) and the species is a pioneer that will grow in degraded lands. Based on Widiatmaka et al. (2010)chemical and biological properties of soil as growth media, in order to support the rehabilitation plans. The objective of this study were: (i, the rehabilitation of former mining land requires improvement to the physical, chemical and biological properties of the soil. Therefore, the planting of *Acacia mangium* is expected to improve the soil properties of the degraded lands. The root system of *A. mangium* can penetrate the compacted soil and stimulate the weathering process of its parent material. In addition, decomposed litter fall may improve the organic matter of the soil and release greater amounts of nutrients below the stand, thereby improving the soil properties (Yamashita *et al*., 2008).

In addition to the technical problems described above, the plants selected should be from species that are the most acceptable to the society in question. In this case, the selected plants are not only able to improve the degraded land but can also support the well-being of the society.

4. Conclusion

About 22% of Jang Watershed was found to be highly susceptible to degradation, with the majority comprising bare land. Revegetation of the degraded land has to take into consideration a land suitability analysis. It is essential that pioneer trees are planted prior to introducing other species that have greater requirements for growth. A pioneer such as *Acacia mangium* is expected to improve the physical, chemical and biological properties of the soil. Further research should be conducted into the economic aspect of those species deemed suitable for rehabilitating the degraded land. This is essential since such species are also the materials for some industries.

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