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Research articles

Spatial distribution of land susceptibility to degradation and recommendation for its improvement: a case study in the upper Solo Sub-Watershed

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Abstract: Spatial distribution of land properties and its susceptibility to degradation is essential for watershed management planning. Therefore, a study was carried out to assess spatial distribution of land susceptibity to degradation and provide some recommendations for its improvement. The location of the study was in the upper Solo sub-watershed which majority located in Central Java Province. To classify degree of land susceptibility, a watershed typhology was applied. The typhology of watershed was based on land system and land cover type. Data of land cover and slope steepness were derived from sattelite images. Land system was obtained from Regional Physical Planning Programme for Transmigration (RePPProT). The results show that 36% of the study area is covered by highly susceptible and 55% moderate susceptible to degradation. The rest are classified as very high, low, and very low suceptible to degradation. Improvement of the degraded land can be achieved by applying land use planning which is suitable with its capability, in fact agricultural areas are found at land use capability classes VI and VII which have to use for production forest and limited production forest. In addition, conservation practices need to be applied, especially for agricultural land at Vst of land capability class.

***Keywords**: land capability, land degradation, watershed typhology*

Introduction

Spatial distribution of land properties is necessary for many application, e.g. for watershed management planning. Characterization of land properties provide information on its potential and its susceptibilty to degradation. Based on the information of land potential, a manager have to maintain or improve its productivity of a watershed/sub-watershed Kar et al., 2009).

Besides the potential of land, information of the degree of land susceptibility to degradation is also important in watershed management. Soil erosion and nutrient depletion are generally the major causes of land degradation ((Tesfa and Mekuriaw, 2014). Land degradation is not just a local problem, but it is a global environment and development issue (Bai and Dent, 2008). Land degradation causes economic loss associated with decreasing land productivity and has negative impacts on environment (Gao and Liu, 2010). Therefore, implementation of rehabilitation and improvement of degraded land is important because to meet the need of food, biomass energy, fiber, and timber for growing human population; to regulate greenhouse gas fluxes and global energy balance; to recover biodiversity; and to improve economic output in developing countries (Daily, 2007).

Commonly, measurements of land degradation are conducted at plot bases which may not be applied for drawing conclusions at a farm or policy level, therefore assessment should be within a watershed scale (Scherr and Yadav, 1996). Method to assess land susceptibilty to degradation for a watershed or a sub-watershed is based on a watershed thyphology (Paimin et al., 2012). Criteria for a watershed thyphology consist of land system and land cover. The use of watershed thyphology for evaluating the potential and susceptibility of land within a watershed is essential since the concept of watershed management is based on the interrelationships between land use, soil and water resources and the linkage between uplands and downstream areas (Makhamreh, 2011)..

Land system reflects natural properties, it can be derived from Regional Physical Planning Programme for Transmigration (RePPProT). The RePPProT provides information of land system, landform, slope steepness, soil, and climate condition. In addition to the natural properties mentioned above, watershed typhology is based on existing land cover which is effected by management. Land cover or land use is a key variable controlling hydrological process in a watershed/sub-watershed (Bormann and Elfert, 2010). Detriment of land cover will accelerate soil erosion and water loss and it leads to land degradation in a watershed.

Based on the background mentioned above, a study was undertaken to assess spatial distribution of land susceptibity to degradation (especially erosion) and provide some recommendations for its improvement. The location of the study was in the upper Solo sub-watershed which is categorized as one of the priority sub-watersheds wich have to be recovered .

Materials and Methods

Description of the study area

The study was undertaken in the Upper Solo sub-Watershed. Adminitratively, the dominant area is located in Central Java Province and the rest is belongs to East Java Province. It covers several districts and some of the largest are Boyolali, Klaten, Sukoharjo, Wonogiri, Karanganyar, Sragen, Surakarta and Ngawi (Central Java Province). Geographically, the study area is located between 7°14' and 8°06' South latitude and 110°26' and 111°27' East longitude (Figure 1). Rainfall pattern is characterized by a single rainy season with the highest is between November to April. Average annual rainfall is around 2100 mm. Due to heterogeneity of land use, geological formation, topography and climate, consequently various soil types are found, including Ultisols, Inceptisols, Alfisols, Vertisols, Entisols, and small areas are covered by Mollisols. Slope varies from 0 to more than 60%.

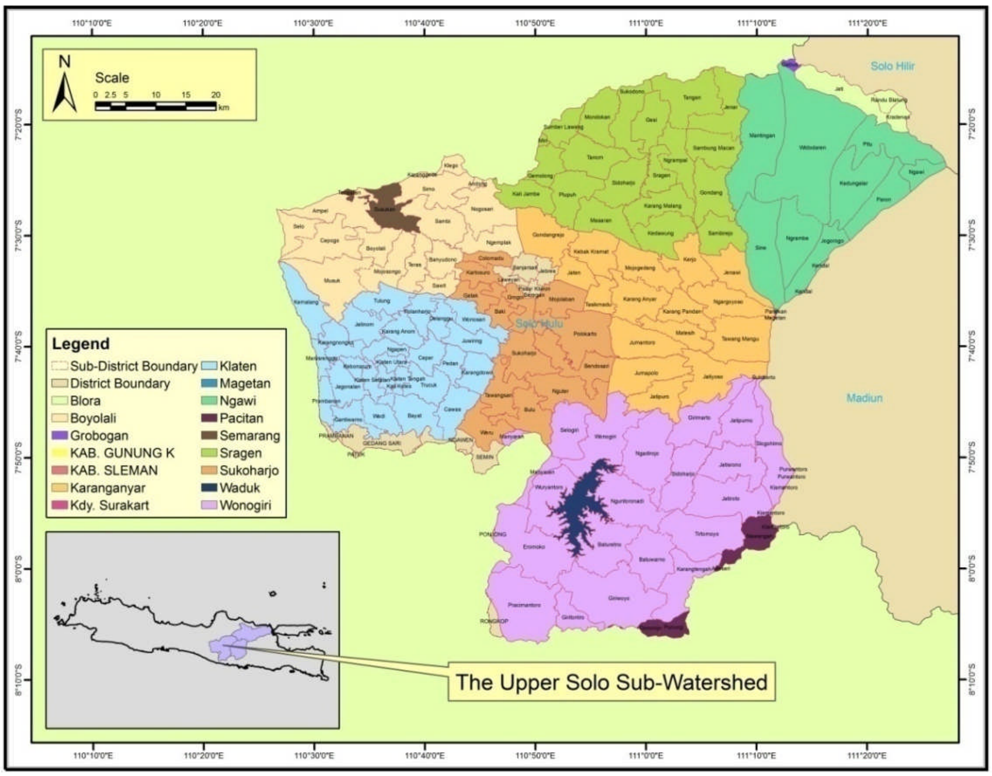

Figure 1. Location of the study area

Materials

Materials used in this study are land cover maps derived from Landsat-7 ETM+ obtained from Balai Pengukuhan Kawasan Hutan (BPKH), Jogyakarta, imagery from Google Earth, Digital Elevation Model (DEM) derived from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer). The DEM ASTER was used to derived slope steepness. Data of land system, land form, soil type, geomorpholgy, and lithology are obtained from RePPProT Rainfall data were collected from Balai Besar Wilayah Sungai Bengawan Solo.

Field campaign and data analysis

Prior fieldwork, land cover and slope analysis were carried out to produce preliminary maps. In addition, integration of land system and land cover was conducted to obtain map showing land susceptibility to degradation. The degree of land susceptibilty was based on watershed typhology introduced by Paimin et al. (2012) as provided in Table 1. The resulting maps were used to collect the necessary data such as soil properties, soil erosion, ground check of land cover, slope, landform, the degree of land susceptibility, etc.

Table 1. Degree of land sensitivity to degradation (erosion)

Land system/land form*	**Land cover***					
	Brackish water,Fresh water, Building (1)	**Protected forest, conservation forest (1)**	**Production forest/ Estate plantation (2)**	**Paddy field, Grass, Bush/ Shrub (3)**	**Settlement (4)**	**Dry land, Stoniness land (5)**
Marshes, Beach (1)	1	1	1	1	1	1
Alluvial plains, Alluvial valley (2)	1	1.5	1.5	2	2	2.5
Dataran (3)	1	2	2.5	3	3.5	4
Fans and lava, Terraces (4)	1	2.5	3	3.5	4	4.5
Mountains & hillies (5)	1	3	3.5	4	4.5	5

Remarks: *The number in brackets are value/score of its parameter. Source: Paimin et al. (2012)

Further analysis was undertaken to integrate the preliminary maps and the data from field campaign. The resulting data were evaluated and classified based on Table 2.

Table 2. Classification of land susceptibility to degradation (erosion)

Category	**value**	**Degree of sensitivity**
Very high	> 4.3	Very high degraded
High	3.5 – 4.3	High degraded
Moderate	2.6 – 3.4	Moderate degraded
Low	1.7 - 2.5	Low degraded
Very low	< 1.7	Very low degraded

Biophysical characteristics collected from the field was used to classify land use capability (LUC). The resulting classification provides information whether the existing land uses or land covers are suitable with their land capability. The data and classification of LUC were presented in Appendix 1.

Results and Discussion

Land covers

To analyze land covers, we not only used Landsat-7 ETM+, but also imagery from Google Earth. The image from Google Earth was used when there were difficulties to differentiate between two land cover types or to get more detail information. The use of remote sensing to assess spatial distribution of land cover is a proper choice, because land degradation is a dynamic process and remote sensing can capture and monitor the visual aspects of this dynamic through the analysis of land cover (Yiran et al., 2012). The land covers classification is presented in Table 3.

Based on that table, it can be seen that the dominant land cover is dryland agriculture areas (38% of the sub-watershed), followed by paddy field (33% of the study area). Dryland agriculture areas in the low altitude are usually used for cultivation of cassava, maize, peanuts, chili, sweet potato, etc. In high altitude, the dry lands are for growing vegetable.

Based on Google Earth analysis and ground check, there are different characteristics of settlements in village and urban areas, as consequent these two settlements are seperated. Settlements in the villages are characterized by large home garden, and these are often planted by annual crops or used as mixed garden. On the other hand, settlements in urban areas are commonly covered by concrete buildings without or with limited yard. Differentiation of these land covers is essential since runoff and sediment yield depend on ratio of impervious surface, soil, and land cover (Biggs et al., 2010). The spatial distribution of the land cover is provided in Figure 2.

Table 3. Land covers at various slope classes

Land covers	**Area (ha)**					
	0-8%	**8-15%**	**15-25%**	**25-45%**	**> 45%**	**Total**
Production forest	18428	13636.3	8298.5	13215.5	12176.4	65754.7
Estate plantation	1542.1	1617.3	1036.1	717.7	66.3	4979.4
Village settlement	57782.3	15224.4	2981.9	895.3	43.8	76927.7
Urban settlement	10456.8	1048.7	41.3			11546.9
Paddy field	157778.6	32370.9	5776.3	1446.4	22.9	197395.2
Bush and shrub	1055.1	543.1	290.3	98.3	168.2	2155.0
Bareland	220.4	122.7	50.9	24.3	359.9	778.2
Dryland cultivation	78413.7	55301.3	35223.6	45845.2	12180.6	226964.4
Water body						7366.4
Total	332622.8	120158.2	53776.57	62291.99	25018.15	593867.8

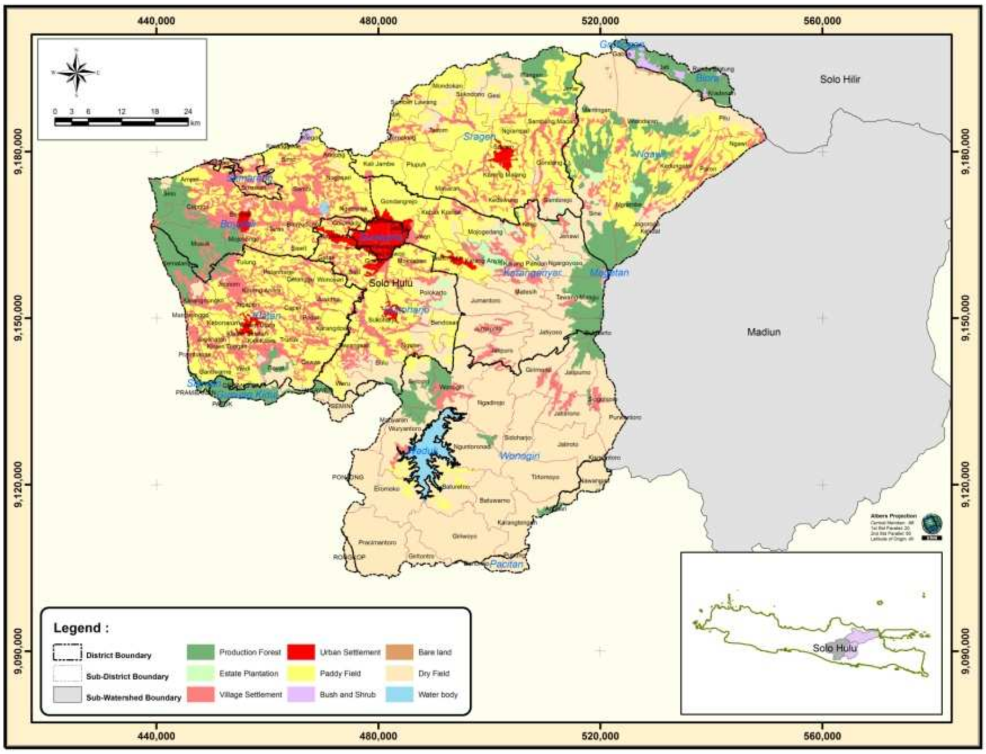

Figure 2. Land covers of the upper Solo sub-watershed

Land susceptibility

Degree of land susceptibilty was obtained by integration of land systems and land covers, the spatial distribution is shown in Figure 3. The result shows that the study area is dominated by moderate susceptible (55.1%), followed by highly susceptible (35.7%), and the rest are low susceptible (7.7%), very low susceptible (1.4%), and the least is 0.2%. Figure 3 shows that the areas with high susceptible are located in mountain areas, such as in Jatiyoso, some part of Ngargoyoso, Tawangmangu, Jenawi, Sine, Bulukerto, Jatipiro, Ngrambe, and Jogorogo sub-Districts which are at the foot of Lawu mountain. High susceptible is also found at some places at the South border of the upper Solo sub-watershed, commonly the areas consist of karst hillies and mountains. Some regions at the fan alluvial of Merapi mountain can be categorized as high and moderate susceptible such as in Kemalang, Kemusuk, Boyolali, Cepogo, Selo, and Ampel sub-District.

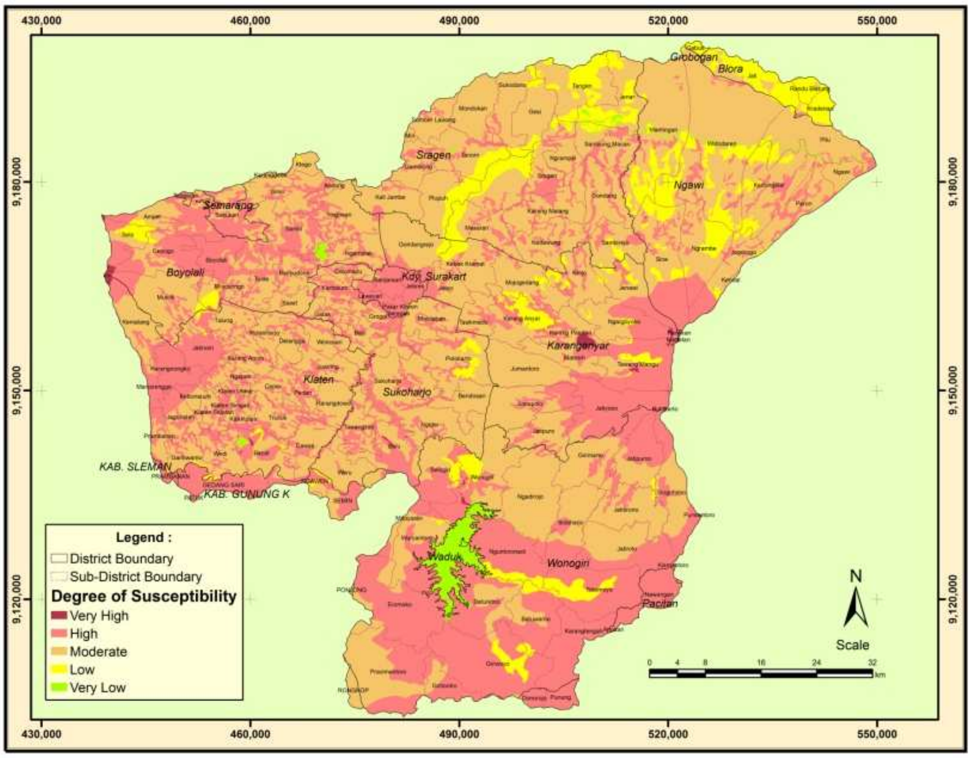

Figure 3. Spatial distribution of the degree of land susceptibility to degradation in the upper Solo sub-watershed

Recommendations to recover and improve of the degraded land in the study area

Utilization of land exceeded its capability is one of the causes land degradation. In the moist to wet regions, it leads water erosion and depletion of soil nutrients, furthermore reduction in land productivity. Due to those conditions, land management have to consider land use capability (LUC). The basic concepts of LUC is land management according to its biophysical properties. Due to high variation in land properties, therefore LUC should be classified base on its similarity. The LUC classes can be used for land use planning as well as recovering or improving degraded land. Afterwards, selection of soil conservation according to the local characteristics should be applied. Results of land use capability analysis suggest that the study area can be devided into LUC class III into VII as presented in Table 4. The ristriction for those classes are soil water erosion and soil conservation practices (e), wetness (permeability), gradient, and climate. From Table 4, it can be seen that dry land cultivation areas are not only found in the LUC class VI, but also in class VII which should be used for limited production forest (Priyono and Savitri, 1999).

Table 4. Land use capability classification of the study area

Land covers	**Areas**	**of**	**each**	**land**	**use**	**capa**	**bilit**	**y c**	**lass**	**es**	**(ha)**				
	IIIe	**IIIec**	**IIIg**	**III w**	**Iii wc**	**III wcg**	**III wg**	**IV c**	**IV cg**	**IV g**	**IV w**	**IV wc**	**VI c**	**VIg**	**VII**
Protection forest				621			881	1731	615	575	243	851	31	1568	
Estate plantation									384			155		77	
Village settlement				449		709	412	3467	246	239		7	16	133	
Urban settlement				68		23	69	322	8	4					
Paddy field				871	1013	986	860	8367	510	429	1	5	18	225	
Bush and shrub		5	9					140	6	32					
Bareland			1					41	7		23				
Dryland cultivation	223	738	1441					11756	4510	725	881		198	5436	1716
Total	223	743	1451	2009	1013	1718	2222	25824	6286	2004	1148	1018	263	7439	1716

Remarks: e = *erosion*, w =*wetness*, s = *soil*, c = *climate*, g = *gradient*

t

The other condition of some of the study area is provided in Figure 4. This area consists of rock outcrops with very shallow soil. With this condition, land rehabilitation by planting pioneer species is a proper choice. The root of pioneer species may accelarate weathering process of its parent materials. Besides that, decomposed litterfall may increase soil organic matter. Seasonal crop cultivation as shown in that figure must be avoided to prevent further nutrient depletation. Building terraces using available rocks that are easily found in that area is recommended to reduce soil erosion.

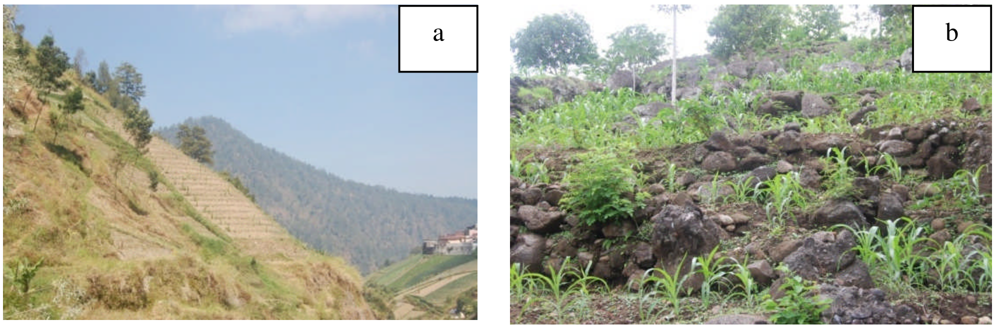

Figure 4. Dryland cultivation in steep slope area (a) and area covered by rock outcrops (b)

Bench terraces have generally been applied for paddy field as illustrated in Figure 5. However, when soil tillage is carried out for planting preparation, grasses for raiser strengthener are cleared. Cleaning all of the strengthener terraces induces soil erosion.

Figure 5. Bench terraces at paddy field.

Besides biophysical properties, the social, economy and institutional aspects must be considered to recover and improve land degradation. In general, (Scherr and Yadav, 1996) suggests that policy recommendation to improve land degradation can be achieved through 1). Improvement of information systems for land management, 2). Increase research and technology, 3). Promote investment, 4). Modify property rights to encourage longterm land investments, 5). Develop more flexible and participatory planning systems for sustainable use, 6). Support local organizations to manage local resources.

Conclusion

The spatial distribution of the study area shows various degree of land susceptibility to degradation. The dominant is moderate susceptible (55,1%) followed by highly susceptible (35,7%). In summary, recovery and improvement of land degradation in the study area have to consider land use capability. Furthermore, soil conservation practices must be consider biophysical properties as well as social, economic, and institutional aspects.

Acknowledgements

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Annex 1. Land Use Capability Criteria

No	Restriction	Class	I	II	III	IV	V	VI	VII	VIII
1	Soil conservation practices	e	100	100	60-80	60-80	20-60	10-40	1-20	1-20
2	Tingkat Erosi	e	Ignored	Ringan	Moderate	High	-	-	-	-
3	Drainage	w	Slow	Slightly slow	Moderate	Fast	Very fast	-	-	-
4	Soil texture	s	L, SiL	SL, SCL, CL, SiCL	LS, Si, SC, C, SiC	S	-	-	-	-
5	Struktur tanah	s	Coarse granular	Smooth granular	Blocky-platy	Blocky	-	-	-	-
6.	Soil depth (cm)	s	> 90	60-90	30-60	15-30	0-15			
7	Depth of regolith (cm)	s	> 200	100-200	80-100	60-80	40-60	20-40	10-20	<10
8	Percentage of gravel (%)	s	-	-	-	-	1-10	10-20	20-60	>60
9	Percentage of rock outcrop (%)	s	-	-	-	1-10	10-20	20-40	40-80	>80
10.	Iklim	c								
	• Wet month > 200 mm		7-12	7-9 or 5-6	5-6 or 3-4	3-4	3-4 or 0-3	0-2	0-2	0-1
	• Dry month < 100 mm	c	0-1	2-3 or 0-1	2-6 or 0-1	2-6	7-8 or 0-1	2-6	7-9	-
11	Slope (%)	g	0-8	-	8-15	15-25	-	25-45	>45	-

Remarks: e = *erosion*, w =*wetness*, s = *soil*, c = *climate*, g = *gradient*, L = *loam*, SiL = *Silty loam*, SL = *Sandy loam*, SCl = *Silty clay loam*, Cl = *Clay loam*, SiCl = *Silty clay loam*, LS = *Loamy sand*, Si = *Silt* , SC = *Sandy clay*, C = *Clay*, SiC = *Silty clay*