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The Influence of Land Use and Rainfall on Shallow Landslides in Tanralili Sub–watershed, Indonesia

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Land cover is an important factor affecting the occurrence of shallow landslides triggered by high intensity rainfall. The objectives of this study are the analyses of the influences of land use and rainfall on shallow landslides using the normalized difference vegetation index (NDVI) and antecedent rainfall threshold. This research was conducted in Tanralili sub–watershed, South Sulawesi Province, Indonesia. The analysis of NDVI using Landsat time series data of 2000, 2003, 2006, 2009, 2011 and 2013. The result indicated that in the course of 14 years high vegetation density land cover (81% to 100%) has lost around 24.21% or 6219 ha. The vegetation density decrease is caused mainly by land use change, especially the conversion of shrubs and forests into mixed dryland farming. 76.67% of shallow landslides occurred are concentrated in mixed dryland farming on the low vegetation density (0 to 40%). The analysis of the absolute and calibrated antecedent rainfall associated with each major shallow landslide event showed that shallow landslides occurred in short duration (1 day) with a high intensity 225 mm/day and longer duration (1 month) with a lower intensity 13 mm/day. The rainfall threshold for shallow landslides in the study area are ruled by the function $I = 25.5D^{-1.10}$, where I is the average rainfall intensity in mm/day and D is duration of rainfall in days.

Key words: Land use, Landslides, Rainfall, Indonesia

INTRODUCTION

Landslides are one of the most frequent disasters in Indonesia. National Disaster Management Agency (2015), reported that in the last 10 years, landslides become the third highest type of disaster after floods and whirlwind. Landslides including shallow landslides occurred on various types of land use and generally occur during the rainy season with high rainfall intensity (Hasnawir and Kubota, 2012).

The influence of land use change on landslide under different geomorphic conditions has been analyzed by researchers taking into account different methods (Pande *et al.*, 2002), including historical archives (Glade, 2003), aerial photographs interpretation (Su and Stohr, 2000), susceptible mapping, multivariate statistical analyses, laboratory and field investigations (Gerrard and Gardner, 2002), modeling (Abe and Ziemer, 1991; Montgomery *et al.*, 2000; Van Beek and Van Asch, 2004), geographical information systems (Temesgen *et al.*, 2001), remote sensing (De La Ville *et al.*, 2002), and diachronic analysis (Alcantara–Ayala *et al.*, 2006). Land use change is also recognized as an important factor influencing landslides (e.g. Cruden and Varnes, 1996; Fell *et al.*, 2008; Wasowski *et al.*, 2010; Gioia *et al.*, 2015).

The influence of rainfall on landslides differs substantially depending upon landslide dimensions, kinematics, material involved, etc. Shallow failures are usually triggered by short intense storms (Campbell, 1975; Wieczorek, 1987; Polloni *et al.*, 1992; Crosta, 1998; Paronuzzi *et al.*, 2002; Sanchez–Castillo *et al.*, 2015) while most deep–seated landslides are affected by long–term variation of annual rainfall which has to last several years (Bonnard and Noverraz, 2001). For landslides such as rockfalls, no precise correlation with rainfall can be surmised, as they appear more sensitive towards other factors such as chemical–mechanical weathering of the rockmass and temperature fluctuation across the freezing point (Sandersen *et al.*, 1996): only late spring and summer rockfalls can be related with rainfall (Aleotti, 2004). Rainfall thresholds are useful to establish an early warning system for landslide disaster prevention but a proper early warning system must have strong meteorological information, hydrogeological and geotechnical components (Ibsen and Casagli 2004, Guzzetti *et al.*, 2007; Hasnawir and Kubota, 2008, Baum *et al.*, 2010). Several investigators have attempted to determine rainfall amounts responsible for triggering sediment–related disasters establishing rainfall thresholds. Caine (1980) first established worldwide rainfall intensity–duration threshold values for landslides. Recently, Ma *et al.* (2015) studied rainfall thresholds for landslide activity in Zhejian Province, China and Nolasco–Javier *et al.* (2015) in Baguio, Philippines.

Therefore, the objectives of this study are the analy-

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ses of the influence of land use and rainfall on shallow landslides using analysis normalized difference vegetation index (NDVI) and antecedent rainfall threshold with data from 2000 to 2013 in Tanralili sub–watershed, Indonesia.

MATERIALS AND METHODS

Study area

Tanralili sub–watershed is located at 5° 0'– 5° 12' South latitude and 119° 34' – 119° 56' East longitude on South Sulawesi Province, Indonesia. The area of the sub–watershed is about 25684 ha (Fig. 1). The geology is composed of lava (8679 ha or 33.79%), Camba formation (23.42% or 6016 ha), volcanic rocks (17.96% or 4613 ha) and another geology is breccias, basalt dikes, sediment stoppers, and rocks of Tonasa formation (24.83%). Type of soil in Tanralili sub–watershed consists of dystropepts (92.40%), rendolls (5.51%) and trapaquepts (2.09%). Regarding land use in Tanralili sub–watershed, 60.93 % of the land use is mixed dryland farming, 22.65% is forest, 6.82% is paddy field, 6.05% is settlement, 2.61% is shrubs, 0.87 is savanna, and 0.07% is lake/river. The average annual rainfall is about 3215 mm/year (2000 to 2013) with high intensity rainfall occurring in December, January, February and March (Fig. 2).

Methods

The influence of land use and rainfall on shallow landslide in Tanralili sub–watershed using analyses of normalized difference vegetation index (NDVI) and antecedent rainfall threshold is conducted.

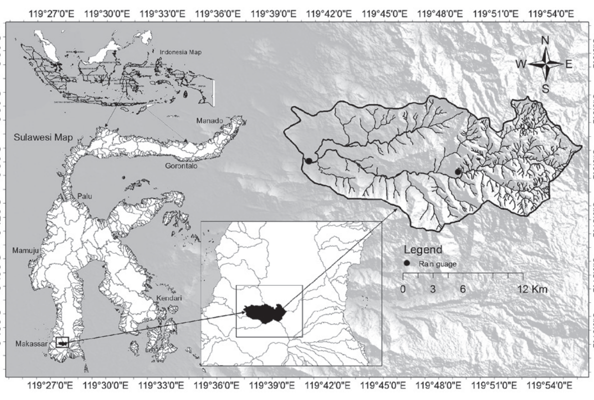

Fig. 1. Location map of study area in Tanralili sub–watershed, South Sulawesi, Indonesia.

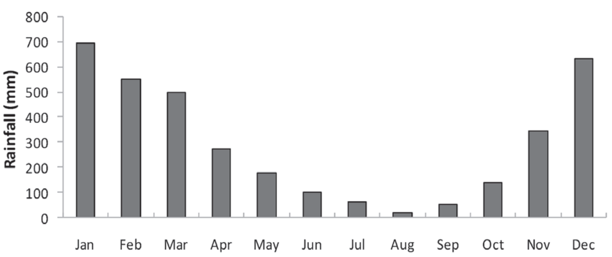

Fig. 2. The monthly rainfall of Tanralili sub–watershed, South Sulawesi, Indonesia (2000– 2013).

– Normalized difference vegetation index (NDVI) calculation

NDVI method is used for the interpretation of vegetation density to find the influence of land use on shallow landslides. Landsat data time series used is Landsat time series data of 2000, 2003, 2006, 2009, 2011 and 2013.

Vegetation indices derived from satellite images have been extensively utilized to monitor vegetation and land use changes, particularly NDVI. This index is a function of red and near–infrared spectral bands which depends on the type of sensor (Alcantara–Ayala *et al.*, 2006). The formula of NDVI as follows:

$$NDVI = \frac{NIR-R}{NIR+R} \quad (1)$$

where NIR is the near IR band, and R is the red band. The values for NDVI are obtained from SPOT image. Vegetation density classification using Arc GIS spatial analyst at 10.1.

– Rainfall thresholds and antecedent rainfall analysis

Rainfall thresholds

In this study empirical threshold was used. The empirical thresholds refer to relational values based on statistical analysis of the relationship between rainfall and landslide occurrences (Aleotti, 2004). The empirical threshold was studied by applying the intensity–duration (ID) threshold methodology developed by Caine (1980). The ID threshold assumes the general form of the following equation:

$$I = c + \alpha \times D^{-\beta} \quad (2)$$

where I is the rainfall intensity (in mm day^{-1}), D is the rainfall duration (in day), and c, α, and β are empirical parameters of the specific site conditions.

Antecedent rainfall

The shallow landslide events used in this study were collected from historical accounts, technical–scientific documents and regional reports. Based on field survey and information from the local people, the shallow landslides have occurred for more than ten years in the study area. Twenty major rainfall episodes that triggered shallow landslides were identified.

Hence the computation analysis of cumulative absolute rainfall for 1, 2, 3, 5, 10, 15 and 30 consecutive days before each shallow landslide events during 2000 to 2013 have been carried out by applying equation Marques *et al.* (2008).

$$Px = P1 + P2 + \cdots Pn \quad (3)$$

where Px is the absolute antecedent rainfall for day x; P1 is the daily rainfall for the day before x; Pn is the daily rainfall for the nth day before day x.

In order to account for this dampening effect in rainfall–shallow landslide analysis, the antecedent rainfall was calibrated applying the formula proposed by Crozier (1986).

$$CARX_n = KP1 + K^2 P2 + \cdots K^n Pn \qquad (4)$$

where CARXn is the calibrated antecedent rainfall for day x; P1 is daily rainfall for the day before x; Pn is the daily rainfall for nth day before x. The constant K is an empirical parameter (typical value range between 0.8 and 0.9) depending on the draining capacity and hydrological characteristics of the area (Capecchi and Focardi, 1988). After a few tentative trials we have decided to assume in this study that K= 0.9, making negligible precipitation occurred 30 days before a shallow landslide event. A good assumption of this K value can be 0.9 for a maximum of 30 antecedent days (Marques *et al.*, 2008; Khan *et al.*, 2012).

RESULTS AND DISCUSSION

Land use and shallow landslide

Thirty shallow landslides occurred in Tanralili sub–watershed from 2000 to 2013. Regarding to the land use, the shallow landslide occurrence was observed 23 times in mixed dryland farming, 4 in primary forest, 2 in secondary forest, and 1 time in savanna. The significant impact of land use change from 2000 to 2003 in Tanralili sub–watershed was an increase of land without vegetation cover around 21.30% (Table 1 and Fig. 3). Changes in land use that quite clearly can be attributed to the occurrence of shallow landslides in Tanralili sub–watershed in where the number of shallow landslides increased after 2003. Furthermore, in 2000 land cover with high vegetation density between 81% to 100% is around 8548 ha or about 33.28% from the total area of Tanralili sub–watershed. However, after 13 years, high vegetation density decreased to only 2329 ha or 9.07%. This shows that there has been a loss of high vegetation density around 24.21% or 6219 ha. The vegetation density decrease is caused mainly by the land use change, especially shrubs and forests into mixed dryland farming. It is also causes about 76.67% of shallow landslides concentrated in mixed dryland farming (Fig. 4). The decreased level of vegetation density is an important factor influencing the incidence of shallow landslides. It is seeming from the concentration of shallow landslides that generally they tend to occur on land with low vegetation density (0 to 40%) (Fig. 5). Glade (2003) indicates that the land use change is an important factor in the occurrence and movement of rainfall triggered landslides and the occurrence of landslides is directly related to variation in land use. In other study in the Sierra Norte, Mexico it is implied that landsliding is a consequence of the reduction in the density of vegetation, which in many instances resulted in bare surfaces (Alcantra–Ayala, *et al.*, 2006).

Rainfall and shallow landslide

Twenty rainfall events resulted in thirty shallow landslides in Tanralili sub–watershed in the period 2000 to 2013. There are not any reports or information about shallow landslide before 2000.

Table 1. Classification of vegetation density in Tanralili sub–watershed, Indonesia (2000–2013)

Vegetation Density (%)	2000		2003		2006		2009		2011		2013	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
0	170	0.66	5650	22.00	4257	16.57	4009	15.61	2223	8.66	514	2.00
1–20	1184	4.61	2306	8.89	2745	10.69	4251	16.55	4410	17.17	2074	8.08
21–40	5275	20.54	5597	21.79	5886	22.92	6218	24.21	6189	24.10	2584	10.06
41–60	3842	25.95	4947	19.26	5401	21.03	5216	20.31	6671	25.97	10168	39.59
61–80	6665	33.28	6329	24.64	6203	24.15	5239	20.40	4862	18.93	8015	31.21
81–100	8548	33.28	855	3.33	1192	4.64	751	2.92	1329	5.17	2329	9.07
Total	25684	100.00	25684	100.0	25684	100.0	25684	100.0	25684	100.0	25684	100.0

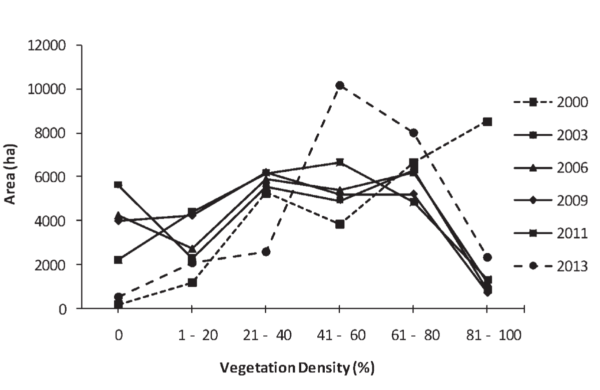

Fig. 3. The vegetation density (%) with area (ha) in Tanralili sub–watershed, Indonesia (2000–2013).

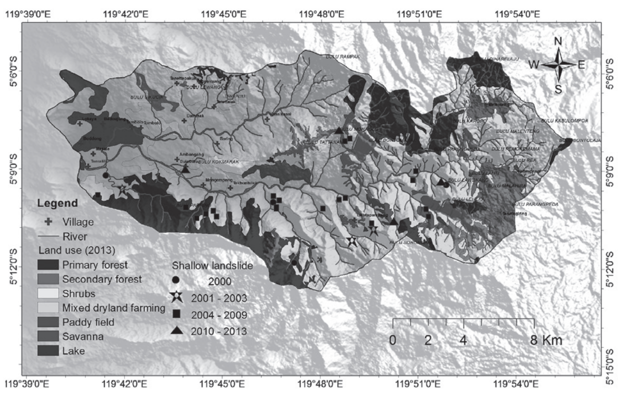

Fig. 4. Shallow landslides and land use in Tanralili sub–watershed, Indonesia (2000–2013).

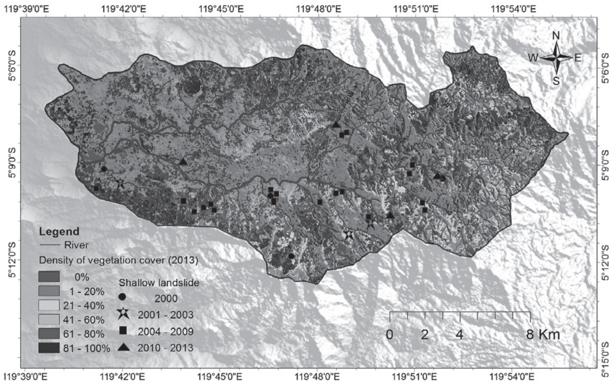

Fig. 5. Shallow landslides and vegetation density in Tanralili sub–watershed, Indonesia (2000 – 2013).

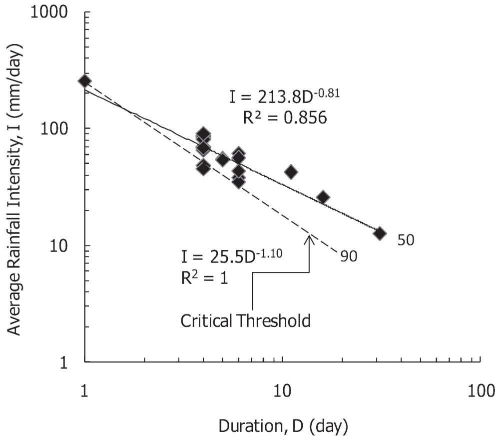

Fig. 6. Rainfall thresholds for shallow landslide in Tanralili sub watershed from 2000 to 2013. Line [90] represents the triggering threshold; the other limit [50] represents different percentage of points in the graph.

Table 2 summarizes absolute antecedent rainfall for shallow landslide events. The rainfall conditions are traced by shallow landslide activity triggered by short and long episodes of rainfall accumulation. Important shallow landslide took place on January 11, 2004, and this event had the highest rainfall intensity (250 mm/day). Few days before the shallow landslide occurrence there were high intensity of rainfall events. Five shallow landslides occurred in that day and resulted in many damages along the local roads. In the same time there was flood disaster in the Tanralili sub–watershed. Another important shallow landslide event in February 29, 2005, there is no rain recorded at least 2 days before the shallow landslide and the daily rainfall intensity was 225 mm/day. The shallow landslide on February 29, 2005 is the largest shallow landslide during 2000 to 2013 producing a volume of 2400 m^3 of sediment. Table 3 summarizes results of calibrated antecedent rainfall for shallow landslide events.

The regression value of rainfall thresholds for shallow landslide (line [90]) was $I = 25.5D^{-1.10}$, where I is the average rainfall intensity in mm/day and D is duration of

Table 2. Absolute antecedent rainfall from 1 to 30 days corresponding to shallow landslide events in Tanralili sub–watershed, Indonesia (2000–2013)

No	Date	1 day (mm)	2 days (mm)	3 days (mm)	5 days (mm)	10 days (mm)	15 days (mm)	30 days (mm)	Rainfall Intensity (mm/day)
1	Feb. 03, 2000	6	45	78	126	182	207	229	200
2	Mar. 03, 2000	37	48	67	107	204	224	278	122
3	Mar. 04, 2001	24	38	78	88	109	147	184	261
4	Dec. 28, 2002	6	36	58	79	121	163	193	200
5	Jan. 13, 2003	12	67	129	216	289	309	352	150
6	Jan. 11, 2004	12	28	52	72	98	197	358	140
7	Jan. 25, 2004	18	62	97	132	148	213	281	250
8	Feb. 04, 2004	43	84	102	153	206	283	329	218
9	Dec. 19, 2004	12	38	54	103	148	179	275	200
10	Jan. 10, 2005	7	13	18	74	100	154	230	163
11	Feb. 28, 2005	0	0	5	33	95	120	195	225
12	Mar. 12, 2005	36	67	125	145	163	220	295	135
13	Mar. 28, 2006	25	46	78	114	209	320	456	228
14	Feb. 21, 2007	11	58	102	173	217	314	520	160
15	Feb. 02, 2008	20	78	82	109	287	421	610	172
16	Jan. 31, 2009	56	128	204	259	325	524	689	158
17	Jan. 12, 2010	34	137	168	197	283	478	679	89
18	Feb. 28, 2011	8	12	35	38	43	67	315	125
19	Mar. 19, 2012	4	37	47	62	84	198	281	148
20	Jan. 14, 2013	2	25	31	63	117	146	198	195

Table 3. Calibrated antecedent rainfall (CAR) for shallow landslide events in Tanralili sub-watershed, Indonesia (2000–2013)

No	Datea	Daily rainfall (mm)	3 days (mm)	5 days (mm)	10 days (mm)	15 days (mm)	30 days (mm)
1	Feb. 03, 2000	200	42	99	181	289	399
2	Mar. 03, 2000	122	72	121	191	312	431
3	Mar. 04, 2001	261	52	109	167	231	309
4	Dec. 28, 2002	200	35	77	129	200	287
5	Jan. 13, 2003	150	65	159	301	471	636
6	Jan. 11, 2004	140	33	71	119	176	281
7	Jan. 25, 2004	250	66	137	224	311	424
8	Feb. 04, 2004	218	107	181	281	403	554
9	Dec. 19, 2004	200	42	81	149	236	331
10	Jan. 10, 2005	163	17	30	79	138	219
11	Feb. 28, 2005	225	0	4	25	81	145
12	Mar. 12, 2005	135	87	178	273	369	486
13	Mar. 28, 2006	228	60	117	191	315	485
14	Feb. 21, 2007	160	57	131	245	373	540
15	Feb. 02, 2008	172	81	141	212	382	606
16	Jan. 31, 2009	158	154	303	473	665	943
17	Jan. 12, 2010	89	142	264	393	560	814
18	Feb. 28, 2011	125	17	42	67	93	128
19	Mar. 19, 2012	148	34	68	109	158	263
20	Jan. 14, 2013	195	22	45	86	155	233

rainfall in days. This regression is considered as a reliable rainfall threshold for study area, above which, shallow landslide events may occur. In Tanralili sub–watershed shallow landslide occurred in short duration (1 day) with intensity 255 mm/day, and longer duration (1 month) with a lower intensity 13 mm/day (Fig. 6).

CONCLUSIONS

Recent observations and reports information showed that shallow landslides are frequent in Tanralili sub–watershed, Indonesia. During 14 years the land cover with high vegetation density (81% to 100%) had a loss of vegetation density of around 24.21% or 6219 ha. The vegetation density decrease is caused by land use change, especially of shrubs and forests into mixed dryland farming. 76.67% of shallow landslides that occurred is concentrated in mixed dryland farming on the low vegetation density (0 to 40%).

The rainfall conditions are traced by shallow landslide activity triggered by short and long episodes of rainfall accumulation in Tanralili sub–watershed. The shallow landslide occurred in short duration (1 day) with a high intensity 225 mm/day and longer duration (1 month) with a lower intensity 13 mm/day. The rainfall threshold for shallow landslides in the study area are rule by the function $I = 25.5D^{-1.10}$, where I is the average rainfall intensity in mm/day and D is duration of rainfall in days.

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