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Soils in the Bulia micro watershed of Gorontalo province, Indonesia, and their quality assessment

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Abstract: Ten representative pedons from the Bulia micro watershed of Gorontalo Province, Indonesia, were characterized and classified to determine its land quality (LQ) class. Angular blocky, sticky, plastic consistencies and a hard consistency prevailed in the soil structure. In the alluvial plains the soil texture is dominated by the clay fraction, while in the hills and volcanic mountains the sand fraction is dominated. The soils in the Bulia micro watershed also have acid to neutral reaction, with the range of very low to high OC (organic carbon) levels, the reserve of exchangeable bases was dominated by Ca^{2+} in two series patterns, namely: Ca^{2+} > Mg^{+} > Na^{+} > K^{+} and Ca^{2+} > Na+ > Mg^{+} > K^{+}, cation exchange capacity (CEC) ranged from low to very high, and the base saturation varied from moderate to very high. The alluvial plain is represented by Inceptisol in P1 and Typic Humustepts (P7), also by Oxic Humustepts (P3), then Mollisol on P4 (Typic Argiudolls) and Typic Haplustolls (P6), Alfisol on P5 (Typic Paleustalfs). Entisol on P2 (Typic Ustipsamments) was found in volcanic mountains and P9 (Typic Paleustolls) P8 (Ultic Paleustalfs), P10 (Inceptic Haplustalfs) are typical of volcanic hills. On the alluvial plains the land was categorized as the LQ class II, III and IV, the volcanic mountains were the LQ class IV, while the land on the volcanic hills was categorized as the LQ class VI. River bank erosion on the land river terraces can be held by the manufacture of gabions, talud, cliff reinforcement plants and terraces. The soil temperatures and high clay content can be regulated by mulching and organic materials.

Keywords: Characterization, classification, soils of Indonesia, land quality, the Bulia watershed.

INTRODUCTION

Land is a crucial component of land resources which enables plants growth and food production. Land and plant productivity is primarily determined by soil and other land characteristics related to land quality (Subardja, Sudarsono, 2005). However, an intense tillage during agricultural cultivation and a pressure of the land use when its conservation and sustainability are ignored has resulted into a decrease of land quality. Agricultural production tends to level or even decrease (Nurdin, 2012). Corn is a traditional commercial crop in the province of Gorontalo, Indonesia, which has been intensively and massively cultivated since it was established as a prime commodity in the agropolitan program in 2001. Until 2019, hybrid corn yields in Gorontalo Province reached 1.7 million tons or increased by 9.3% compared to 2018, however, the productivity of maize was still low at only 5.0 tons/ha (BPS Gorontalo Province, 2020). In fact, the potential corn yield in Indonesia can reach 10-11 tons/ha (Yasin et al., 2015), while the achievement of the national productivity in 2018 was only 5.2 tons/ha (Indonesian Ministry of Agriculture, 2019).

The Bulia micro watershed area is a corn production centre that also supports the agricultural area below. The watershed has a vital role because it supplies irrigation water for agriculture and other activities (Mahapatra et al., 2019). The corn cultivation in this watershed has exceeded the carrying capacity indicated for the corn planting on the slope of >25%, so that the land degradation often occurs. Soil erosion, according to the corn agropolitan program of Gorontalo, reached 1,396 tons/ha/year (Husain et al., 2004). Meanwhile, the corn productivity in this area is only 5.0 tons/ha (BPS Gorontalo Regency, 2020), which could happen due to the fact that the crop was cultivated on a non-suitable land.

Soil characterization is essential because it provides some necessary information about the soil characteristics for growing plants (Devi et al., 2015). For sustainable management of soil resources in agroecological areas we need timely monitoring of significant physical, chemical and biological soil characteristics and responses to the changes in land management (Supriya et al., 2019). These soil characteristics then form the basis for land classification. Combining soil characterization with classification is a powerful tool to develop management strategies for food security and environmental sustainability (Satish et al., 2018). However, the efforts to link land characteristics and classification with a specific land quality are still relatively rare. Land quality is a land ability to perform a specific function before the land is degraded (Beinroth et al., 2001). Understanding soil types and their distribution, its limits and potential is essential for a proper management to increase productivity and yields (Niranjana et al., 2011).

The survey and mapping of soil resources in the Paguyaman watershed were carried out by the Soil and Agro-climate Research Centre of the Indonesian Ministry of Agriculture (Puslittanak Research Team, 1995), however, the mapping scale was 1 : 50,000. In 2010, some research was carried out on the development, classification and potential of the paddy soils on toposequence (Nurdin, 2010), however, it only focused on the rainfed paddy soils, while the dry land was only compared to the locations close to the soil pedon in the rice fields. Considering the high intensity of the land management and the massive corn cultivation in this sub-watershed, this research has become significant.

MATERIALS AND METHODS

Study location

The Bulia micro watershed is a part of the Paguyaman watershed located in the northern part, it covers Mootilango and Boliyohuto District of Gorontalo Regency of Gorontalo Province, Indonesia (Figure 1). Geographically, the research location is between 0°39′123″ and 0°51′321″ N, 122°35′21″ and 122°43′12″ S (Table 1), which is 67 km from Gorontalo City, Indonesia.

Table 1. Site characteristics of the pedons in the Bulia micro watershed

Pedon/ Villages	**Location**	**Elevation (m msl)**	**Landform**	**Slope (%)**	**Drainage**
P1, Tolite	0°39′44.80″ N 122°35′27.20″ S	24	Alluvial plain	0–3	Poorly drained
P2, Monggolito	0°40′01.20″ N 122°37′57.20″ S	159	Volcanic mountain	15–30	Well drained
P3, Huyula	0°42′59.9″ N 122°39′43.2″ S	63	Alluvial plain	0–3	Moderately drained
P4, Payu	0°44′04.4″ N 122°37′48.4″ S	53	Alluvial plain	0–3	Moderately drained
P5, Pilomonu	0°43′53.80″ N 122°35′22.60″ S	75	Alluvial plain	0–3	Moderately drained
P6, Karyamukti	0°42′20.50″ N 122°41′05.50″ S	109	Alluvial plain	3–8	Moderately drained
P7, Karyamukti	0°42′10.30″ N 122°41′19.40″ S	114	Alluvial plain	3–8	Moderately drained
P8, Sukamaju	0°44′05″ N 122°40′04″ S	253	Volcanic hill	8–15	Well drained
P9, Payu	0°45′12″ N 122°38′08″ S	285	Volcanic hill	8–15	Well drained
P10, Huyula	0°43′11.10″ N 122°40′31.20″ S	262	Volcanic hill	8–15	Well drained

Overall, the Bulia micro watershed has 21,456.58 ha and consists of upland amounted to 18,993.44 ha (32.59%), and paddy fields amounted to 2,991.15 ha (13.94%). Specifically, the upland agriculture covers the agricultural land areas amounted to 6,993.44 ha (37.87%), settlement areas – 461.59 ha (2.50%), and forest areas amounted to 11,010.40 ha (59.63%). The soils in this area are generally developed from volcanic material in the upper watershed and lacustrine deposits in the middle and the bottom of the watershed. The study area is located in tropical climate with rainy and dry seasons. The average annual rainfall was only 1,478 mm with 1 wet month only and 4 dry months, so it belongs to the E2 agro-climate zone (Oldeman, Darmiyati, 1977). The average annual air temperature reaches 28.19 °C with the maximum temperature of 28.73 °C and the minimum temperature of 27.63°C. Under these conditions, the soil moisture regime is determined ustic and the soil temperature regime – isohyperthermic (Soil Survey Staff, 2014).

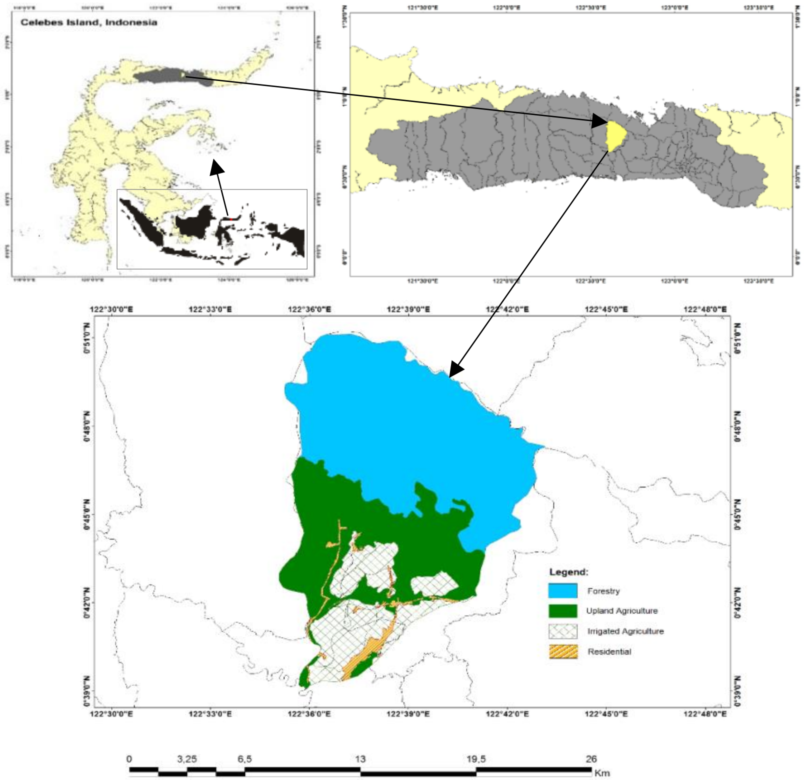

Fig 1. Location Map of the Bulia Micro watershed.

Soil surveying, characterization and classification

Ten representative pedons were selected to conduct the soil survey. The description of soil morphology refers to the Soil Survey Manual (Soil Science Manual, 2017; Sukarman et al., 2017). According to standard procedures, soil samples were taken at each horizon and their physical and chemical properties were analyzed (Jackson, 1973; Eviyati, Sulaeman, 2009). The morphological and the soil properties data obtained during the laboratory analysis are used for the soil characterization together with the climate and the terrain conditions data, according to Sukarman et al. (2017). The soil characteristics are used for soil classification according to the keys to soil taxonomy (Soil Survey Staff, 2014).

Land quality assessment

Land quality (LQ) class assessment follows the method according to Beinroth et al. (2001). This method has been modified based on availability of soil characteristics and classification data without including local population data. Soil pedons (P), which were classified in taxa according to the Soil Taxonomy System (Soil Survey Staff, 2014), were combined with a land unit (LU) basing on the similarity of the criteria in taxa. Soil and pedoclimate information was used to place each LU into I to IX land quality classes with class I having the most appropriate attributes and class IX having the least suitable ones for crop production. The results of the land quality analysis are widely presented and described with the help of Arc GIS.

RESULTS AND DISCUSSION

Morphology and soil physical properties

The results of field studies and the laboratory characterization of ten soil pedons were presented in Table 2, Figure 2. The soils in the study area have been developed as indicated by the horizon structuring (horizons A and B), with the depth of the soil solum varying from shallow to very deep. The soil colour is only of 7.5YR and 10YR hue, where 7.5YR is dominant. P1, P2, P3, P5, P8, P9 and P10 soil colour varies from dark brown, brown to strong brown with hue 7.5YR, ranging from 3 to 5, and chroma – from 1 to 6.

Table 2. Morphological characteristics and soil physical properties in the Bulia micro watershed

Pedon and Horizon	Depth (cm)	Colour Moisture	Struc-tures	Consistence			Sand	Silt	Clay	Texture Class
				w	m	D	%			
P1 (Alluvial Plain)										
Ap	0–23	7.5 YR 4/4	m, 3, abk	s, p	fi	H	9	40	51	Silty Clay
Bw1	23–43	7.5 YR 4/2	m, 3, abk	ss, sp	fi	H	3	46	51	Silty Clay
Bw2	43–75	7.5 YR 4/4	m, 3, abk	ss, sp	fi	H	3	54	43	Silty Clay
Bw3	75–100	7.5 YR 4/2	m, 1, abk	ss, sp	vfi	Vh	3	46	51	Silty Clay
P2 (Volcanic Mountains)										
Ap	0–5	7.5 YR 4/4	f, 1, cr	so, po	fr	L	85	10	5	Loamy sand
Bw1	5–37	7.5 YR 4/4	f, 2, sbk	so, po	fr	L	84	2	14	Loamy sand
Bw2	37–61	7.5 YR 4/4	m, 2, p	so, po	fr	L	75	10	15	Sandy Loam
C	61+	7.5 YR 4/2	m, 3, p	so, po	fr	L	66	15	19	Sandy Loam
P3 (Alluvial Plain)										
Ap	0–14	7.5 YR 3/3	f, 1, cr	ss, sp	fi	H	33	41	26	Loam
Bw1	14–43	7.5 YR 4/4	f, 2, abk	s, p	fi	H	31	37	32	Clay Loam
Bw2	43–68	7.5 YR 4/4	f, 1, abk	ss, sp	fi	H	23	54	23	Silty Loam
Bw3	68+	10 YR 3/6	f, 1, cr	s, p	fi	H	23	48	29	Clay Loam

Pedon and Horizon	Depth (cm)	Colour Moisture	Struc-tures	Consistence			Sand	Silt	Clay	Texture Class
				w	m	D				
P4 (Alluvial Plain)										
Ap	0–14	10 YR 3/3	m, 3, abk	s, p	fi	H	27	26	47	Clay
Bw	14–50	10 YR 4/3	f, 1, abk	s, p	fi	H	32	34	34	Clay Loam
Bt1	50–81	10 YR 3/2	f, 1, abk	ss, sp	fi	H	12	24	64	Clay
Bt2	81+	7.5 YR 4/1	f, 1, abk	s, p	fi	H	16	25	59	Clay
P5 (Alluvial Plain)										
Ap	0–21	7.5 YR 4/4	f, 2, sbk	ss, sp	fi	H	23	43	34	Clay Loam
Bw	21–46	7.5 YR 4/4	f, 2, sbk	ss, sp	fi	H	23	48	29	Clay Loam
Bt1	46–84	7.5 YR 4/3	f, 2, abk	s, p	fi	H	25	35	40	Clay
Bt2	84–117	7.5 YR 4/6	m, 2, p	s, p	fi	H	24	36	40	Clay
Btg	117+	7.5 YR 5/8	m, 1, sbk	ss, sp	fi	H	8	46	46	Silty Clay
P6 (Alluvial Plain)										
Ap	0–12	10 YR 3/3	f, 1, abk	s, p	fi	H	84	15	1	Loamy Sand
Bw1	12–34	10 YR 3/4	f, 1, abk	s, p	fi	H	61	10	29	Sandy Clay Loam
Bw2	34–71	10 YR 4/6	m, 3, abk	ss, sp	fi	H	61	24	15	Sandy Loam
C	71–90	7.5 YR 5/8	f, 1, cr	so, po	fr	L	84	5	11	Loamy Sand

Pedon and Horizon	**Depth (cm)**	**Colour Moisture**	**Struc-tures**	**Consistence**			**Sand**	**Silt**	**Clay**	**Texture Class**
				w	**m**	**D**				
P7 (Alluvial Plain)										
Ap	0–6	7.5 YR 4/6	m, 1, abk	s, p	fi	H	33	11	56	Clay
Bw1	6–17	10 YR 4/6	m, 3, sbk	s, p	fi	H	29	20	51	Clay
Bw2	17–33	10 YR 3/6	m, 1, abk	ss, sp	fi	H	21	20	59	Clay
Bt	33–49	10 YR 3/6	f, 1, p	ss, sp	fi	H	19	15	66	Clay
BC	49+	7.5 YR 4/6	f, 1, abk	ss, sp	fi	H	18	29	53	Clay
P8 (Volcanic Hills)										
Ap	0–7	7.5 YR 3/3	f, 1, abk	ss, sp	fi	H	64	10	26	Sandy Clay Loam
Bw	7–24	7.5 YR 3/3	m, 1, abk	s, p	fi	H	47	24	29	Sandy Clay Loam
Bt1	24–44	7.5 YR 4/6	f, 3, p	s, p	fi	H	45	15	40	Sandy Clay
Bt2	44–63	7.5 YR 5/6	m, 3, abk	s, p	fi	H	42	16	42	Clay
Bt3	63+	7.5 YR 5/6	m, 1, abk	s, p	fi	H	42	6	52	Clay

Pedon and Horizon	Depth (cm)	Colour Moisture	Struc-tures	Consistence			Sand	Silt	Clay	Texture Class
				w	m	D				
P9 (Volcanic Hills)										
Ap	0–16	7.5 YR 3/2	m, 3, abk	vs, vp	vfi	Vh	54	31	15	Sandy Loam
Bw	16–34	7.5 YR 3/3	m, 1, abk	s, p	fi	H	42	24	34	Clay Loam
Bt	34+	7.5 YR 4/4	m, 1, abk	ss. sp	fi	H	50	15	35	Sandy Clay
P10 (Volcanic Hills)										
Ap	0–20	7.5 YR 3/3	m, 3, abk	ss, sp	fi	H	48	26	26	Sandy Clay Loam
Bt1	20–44	7.5 YR 3/4	m, 3, abk	s, p	fi	H	41	15	44	Clay
Bt2	44–76	7.5 YR 4/6	c, 3, sbk	s, p	fi	H	42	14	44	Clay
BC	76+	5 YR 4/6	c, 3, p	vs, vp	vfi	Vh	31	2	67	Clay

Note. Structure: *size*: vf – very fine, f – fine, m – medium, c – coarse; *structureless grade*: l – weak, 2 – moderate, 3 – strong; *type*: cr – crumb, sg – single grain, abk – angular blocky, sbk – sub-angular blocky. Consistence: *dry* (d): s – soft, l – loose, sh – slightly hard, h – hard, vh – very hard, eh – extremely hard; *moist* (m): l – loose, fr – friable, fi – firm, vfi – very firm, efi – extremely firm, *wet* (w): so – non-sticky, ss – slightly sticky, s – sticky, vs – very sticky; po – non-plastic, ps – slightly plastic, p – plastic, vp – very plastic.

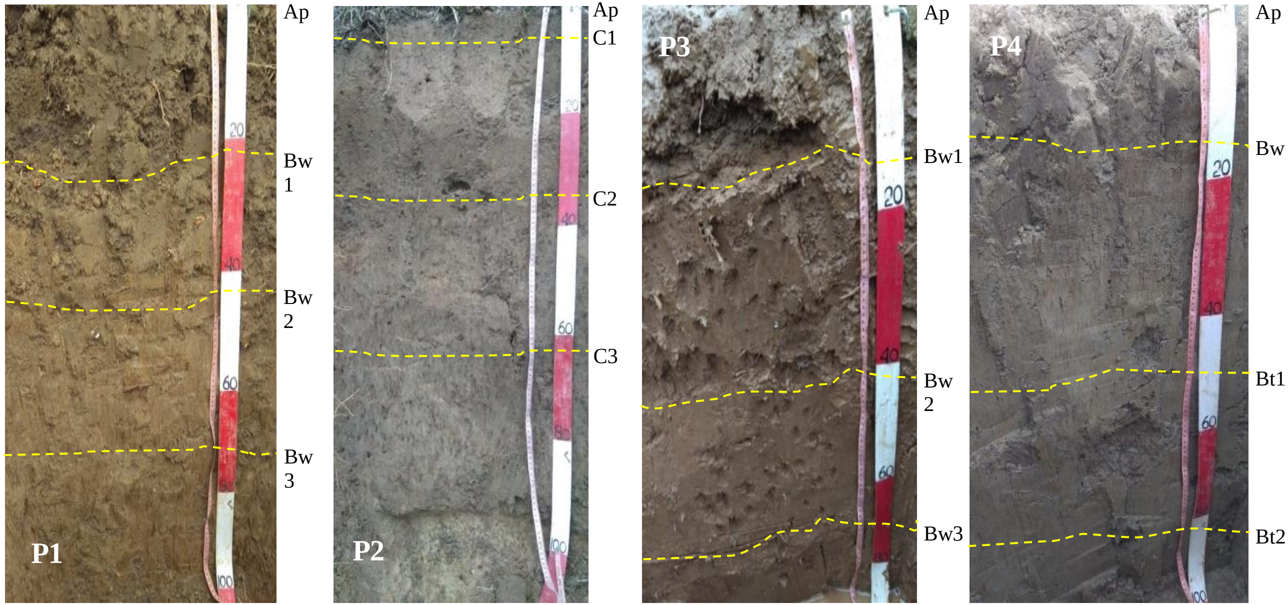

Fig. 2. Soil profile appearance of pedon 1 (P1), 2 (P2), 3 (P3) and pedon 4 (P4).

While in P4, P6 and P7, soil colour varies from very dark grayish brown, dark brown to dark yellowish-brown with hue 10YR, values ranging from 3 to 4, and chroma – from 2 to 6. The colour of soil horizon A is darker than of horizon B due to the fact that the organic matter content in horizon A is higher than in horizon B (Yatno et al., 2015). The higher the organic matter content, the darker the soil colour is (Suharta, 2007). Soil colour seems to be a function of chemical and mineralogical composition (Swarnam et al., 2004; Walia, Rao, 1997), and the soil texture is influenced by topographic position and humidity regimes (Walia, Rao, 1997).

The soil structure varies from crumbs, angular blocky, sub angular blocky to prismatic, with the dominant angular blocky. P1, P3, P4, P6, P7, P8, P9 and P10 were mostly of angular blocky structure with the sizes varying from fine, medium to coarse, with weak and strong structural development. While the soil structures of P2 and P5 varies between crumbs, angular blocky, sub angular blocky and prismatic with the sizes ranging from fine, medium to coarse and the level of the soil structure development varying from weak, moderate to strong. The angular blocky soil structures were strongly associated with higher clay fractions (Devi et al., 2015). Crumbly soil structure indicates newly developed soil (Manik et al., 2017). Intensive soil tillage results in soil structure disturbance (Jambak et al., 2017). The variation of soil structure will be consistently affecting the soil.

The soil consistency in wet conditions varies between non-sticky and non-plastic on Pedon 2, slightly sticky and slightly plastic, sticky and plastic in the horizon on P1, P3, P4, P5, P6, P7, P8, P9 and P10, very sticky and very plastic on the surface horizon (Ap) of P9 and the subsurface horizon (BC) of P10, however, slightly sticky and slightly plastic consistencies prevail. While in moist conditions the consistencies vary from loose, firm to very firm, the firm consistencies are still dominant. P1, P3, P4, P5, P6, P7, P8, P9 and P10 were dominated by hard consistencies, while P2 – by loose ones. There is a very hard consistency in P1 and P10 in the subsurface horizon (Bw and BC), while in the surface horizon (Ap) a very hard consistency can be only found in P9. The consistency in dry conditions varies from loose, hard to very hard, with a dominant hard consistency. P1, P3, P4, P5, P6, P7, P8, P9 and P10 were dominated by a hard consistency, however, in P1 and

P10 in the subsurface horizon (Bw3 and BC) one could notice a very hard consistency, while in P9 precisely a very hard consistency was found on the surface horizon (Ap). Sticky and plastic consistency might form due to a high clay content in the soil (Sarkar et al., 2001); (Kadao et al., 2003), while non-sticky and non-plastic consistency might form due to a very little clay content (Sireesha, Naidu, 2015; Devi et al., 2015).

The soil texture of all pedons varies greatly between sandy clay loam, sandy loam, loamy sand, sandy loam, silty loam, clay loam, silty clay and clay, except for P7 that was of clay texture in all horizons. Wide variations of soil texture may be caused by the variations in parent material, topography, in-situ weathering, translocation of clays by eluviation and soil age (Satish et al., 2018). Apparently, the pedons located in the alluvial group were more dominated by clay fractions, although the distribution patterns were irregular. The distribution of irregular clay fractions was typical for sediment materials (Nurdin, 2010). While a sand fraction dominated the volcanic group, the distribution of sand and clay fractions shows the opposite pattern. A decrease in the sand fraction is due to the clay illuviation and in-situ mineral destruction process, which was characterized by a decline in the absolute amount of sand in the middle of the solum (Rachim, 1994). The texture that is found in the subsurface horizon is caused by higher weathering in the subsurface layer (Dutta, 2009). The clay content in the solum middles (B-illuviation) was higher than in the upper horizon (A-eluviation) and in the lower layer horizon. This indicates the occurrence of a lessivage process with some clay skins seen, so that an argillic horizon was formed in P4, P5, P8, P9 and P10. Although the process of eluviation and illuviation occurred, the pedon remained, but the clay skins were not found, so the cambic and candic horizons were formed.

Soil chemical properties

Soil chemical properties are presented in Table 3. Soil pH varies from acid (pH 5.3) to neutral (pH 7.2). The pedons located on the upper watershed or in volcanic groups (P2, P8, P9 and P10) have a lower pH than the ones located on the lower watershed or in alluvial groups (P1, P3, P4, P5, P6, and P7).

Table 3. Soil chemical properties in the Bulia micro watershed

Pedon and Horizon	Depth (cm)	pH 1:1		OC (%)	Exchangeable cations				CEC	BS (%)
		H_2O	KCl 1N		K	Na	Ca	Mg		
					[cmol(+)kg^{-1}]					
P1 (Alluvial Plains)										
Ap	0–23	6.20	5.40	2.29	0.29	1.88	18.02	1.86	42.40	52.00
Bw1	23–43	6.00	5.20	0.90	0.18	2.01	15.47	2.97	39.19	52.62
Bw2	43–75	6.40	5.50	0.74	0.14	2.19	12.36	2.50	37.85	45.42
Bw3	75–100	6.50	5.60	0.65	0.14	2.23	15.22	3.26	37.58	55.49
P2 (Volcanic Mountains)										
Ap	0–5	6.50	5.60	1.19	0.10	0.34	3.77	0.30	11.13	40.55
Bw1	5–37	6.10	5.20	0.55	0.08	0.34	4.20	0.60	7.75	67.49
Bw2	37–61	6.20	5.30	0.63	0.08	0.35	3.91	0.15	8.87	50.52
C	61+	6.20	5.30	0.56	0.08	0.36	6.51	0.76	12.29	62.79
P3 (Alluvial Plain)										
Ap	0–14	5.60	4.60	0.80	0.05	1.46	4.84	0.61	16.15	43.00
Bw1	14–43	6.00	5.10	0.41	0.09	1.57	7.72	1.70	19.78	56.00
Bw2	43–68	5.80	4.90	0.32	0.05	1.55	8.95	0.91	21.58	53.00
Bw3	> 68	6.20	5.20	0.48	0.05	1.55	10.12	0.76	20.43	61.00
P4 (Alluvial Plains)										
Ap	0–14	6.50	6.10	0.41	0.06	1.49	11.87	0.62	25.55	55.00
Bw	14–50	6.70	6.30	0.96	0.19	1.43	9.71	2.12	21.60	62.00
Bt1	50–81	7.00	6.00	0.41	0.12	1.58	16.54	2.01	35.19	58.00
Bt2	81+	5.80	5.00	0.24	0.09	1.56	13.47	6.66	33.04	66.00

Pedon and Horizon	**Depth (cm)**	**pH 1:1**		**OC (%)**	**Exchangeable cations**				**CEC**	**BS (%)**
		H_2O	**KCl 1N**		**K**	**Na**	**Ca**	**Mg**		
					[cmol(+)kg^{-1}]					
P5 (Alluvial Plains)										
Ap	0–21	5.20	4.50	0.08	0.16	2.29	9.39	2.93	28.39	52.00
Bw	21–46	5.10	4.30	0.49	0.20	2.30	8.62	3.08	28.40	50.00
Bt1	46–84	5.70	4.90	0.57	0.12	0.26	7.69	2.00	21.56	47.00
Bt2	84–117	5.10	4.20	0.50	0.17	0.30	10.38	2.05	31.34	41.00
Btg	117+	5.10	4.10	0.42	0.25	0.34	15.37	1.90	38.58	46.00
P6 (Alluvial Plains)										
Ap	0–12	7.20	6.60	0.64	3.56	3.02	2.54	0.91	10.76	93.00
Bw1	12–34	7.10	6.60	0.32	0.28	1.72	6.03	0.30	11.79	71.00
Bw2	34–71	7.00	6.00	0.56	0.16	0.39	7.84	0.15	17.16	50.00
C	71–90	6.80	6.00	0.40	0.12	0.38	6.49	0.15	13.96	51.00
P7 (Alluvial Plains)										
Ap	0–6	6.30	5.40	0.76	0.10	0.42	5.31	2.41	18.31	45.00
Bw1	6–17	6.10	5.10	0.57	0.09	0.39	6.77	2.15	22.99	41.00
Bw2	17–33	5.90	5.00	0.57	0.07	0.44	8.55	4.04	25.45	51.00
Bt	33–49	5.60	4.80	0.33	0.08	0.45	13.64	3.72	29.79	60.00
BC	49+	5.90	5.00	0.41	0.12	2.04	13.16	0.31	33.06	47.00

Pedon and Horizon	Depth (cm)	pH 1:1		OC (%)	Exchangeable cations				CEC	BS (%)
		H_2O	KCl 1N		K	Na	Ca	Mg		
					[cmol(+)kg^{-1}]					
P8 (Volcanic Hills)										
Ap	0–7	6.00	5.20	0.96	0.24	2.09	10.15	0.45	19.40	67.00
Bw	7–24	6.40	5.50	0.80	0.17	2.05	10.30	0.61	21.55	61.00
Bt1	24–44	6.70	5.80	0.48	0.24	2.21	10.07	1.83	26.06	55.00
Bt2	44–63	6.60	5.60	0.49	0.33	2.21	9.47	0.78	26.52	48.00
Bt3	63+	6.60	5.60	0.50	0.49	2.35	13.84	1.27	32.83	55.00
P9 (Volcanic Hills)										
Ap	0–16	5.30	4.50	0.80	0.13	2.15	10.15	0.61	24.80	53.00
Bw	16–34	6.20	5.30	0.57	0.10	2.30	12.44	0.77	29.51	53.00
Bt	34+	6.20	5.20	0.48	0.06	2.25	13.49	0.46	30.54	53.00
P10 (Volcanic Hills)										
Ap	0–20	5.80	4.90	0.72	0.12	0.40	5.90	1.21	18.31	41.69
Bt1	20–44	6.10	5.20	0.64	0.05	0.40	8.23	0.46	18.44	49.59
Bt2	44–76	6.30	5.30	0.48	0.05	0.39	7.26	0.76	19.36	43.66
BC	76+	5.80	5.30	0.33	0.06	0.42	11.28	2.04	25.64	53.82

Note. CEC – cation exchange capacity, OC – organic carbon, BS – base saturation.

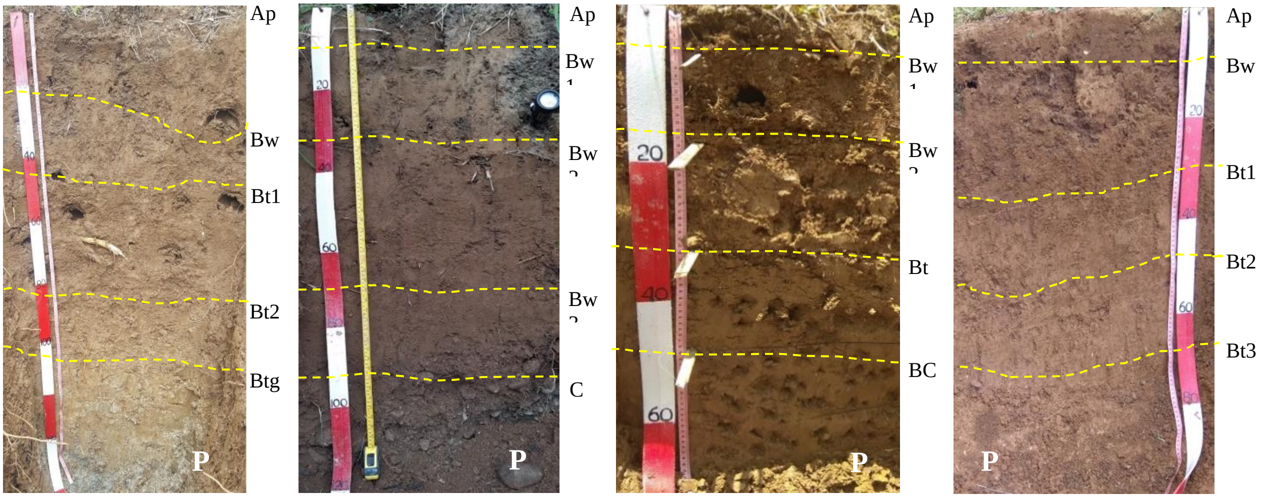

Fig. 3. Soil profile appearance of pedon 5 (P5), 6 (P6), 7 (P7) and pedon 8 (P8).

The pedon in the alluvial group represented a depressed area which is the accumulation of the bases carried by washing water from the hinterland section and the accumulation of more alkaline bases in soils with poorer drainage (Nurdin, 2010a). The pedons in the volcanic group experienced more intensive washing during the rain due to a better soil drainage. The trend of pH increasing with more depth may be explained by the release of organic acids during the decomposition of organic matter, these acids may have lowered the pH at the soil surface (Satish et al., 2018). The pH differences of KCl and the pH of H_2O of all pedons show negative values. This means that all pedons are dominated by negatively charged clay minerals (Suharta, 2007). The acid and slightly acid soil pH values in P1, P3, P5, P9 and P10 indicated that the soil had developed but the level of soil development was not yet advanced, while the neutral soil pH in P2, P4, P6, P7, and P8 shows that the soil is relatively new.

Organic carbon (OC) varies from very low to high (0.08–2.28%). The OC value was high in the surface horizon (Ap), except for P4 and P5. The OC value on the surface is higher due to the accumulation of organic materials, while its low values in P4 and P5 were due to the river flooding. The low OC value was also determined by a faster degradation of the organic material in the tropics and a low addition of farmyard manure (Vedadri, Naidu, 2018). A high OC distribution pattern on the surface and its dramatic decrease in horizon B in accordance with the depth is a general soil development pattern (Prasetyo, 2007).

The reserve (sum) of exchangeable bases vary between very low, low, medium, high and very high. Calcium cation is the dominating one in the exchangeable bases reserve, which ranges from 2.54–18.02 cmol(+)kg^{-1}, while magnesium (Mg^+) ranges from 0.15-6.66 cmol(+)kg^{-1}, sodium (Na^+) ranges from 0.26–3.02 cmol(+)kg^{-1}, potassium (K^+) ranges from 0.05–3.56 cmol(+)kg^{-1}. Based on a number of bases, the P1, P5, P7, and P10 patterns follow the sequence: $Ca^{2+} > Mg^+ > Na^+ > K^+$. This series pattern was the same as Nurdin (2011) and Satish et al. (2018) reported. At the same time P2, P3, P4, P6, P8 and P9 follow the sequence: $Ca^{2+} > Na^+ > Mg^+ > K^+$. A high rate of exchangeable bases in the surface horizon (Ap) results from the fertilization during corn cultivation, while in the lower layer rainfall washing together with good drainage conditions make it possible to wash in the soil solum.

The cation exchange capacity (CEC) varies from low (7.7 cmol(+)kg^{-1}) to very high (42.40 cmol(+)kg^{-1}). The CEC is influenced by the levels of organic carbon and soil minerals (Prasetyo et al., 2007; Suharta, 2007). It seems that CEC in P1, P3, P4, P5, P7, P8, and P9 were more influenced by OC content than by soil minerals. The higher the soil OC, the higher the soil CEC is (Suharta, 2007). While P2, P6 and P10 were thought to be more influenced by soil minerals, these bases can be exchanged and this CEC will eventually affect base saturation. Base saturation (BS) varies from moderate (40.55%) to very high (93%). All pedons generally have a medium and a high BS, except P6, which has a very high BS on the surface horizon (Ap). The variations in BS may be caused by the variations in nature and/or the content of soil colloids, and a relatively high base saturation in the surface layers can be attributed to the recycling of cation base through vegetation (Devi, Kumar, 2010). In addition, if soil has a number of bases which are smaller than CEC, BS tends to be lower, whereas when the soil has a number of bases close to or higher than CEC, BS tends to be higher (Nurdin, 2010b).

Soil classification

Based on morphological and soil characteristics, the pedons are classified according to their family level and the orders of the soils found, namely Entisol, Inceptiol, Mollisol and Alfisol (Table 4, Figure 4). P1 and P7, which are located on a slope of 3% and 5%, are based on the molic epipedon with a 23 cm thickness and a cambic horizon. These pedons did not experience aquatic conditions at the depth of 50 cm from the soil surface (humustept), the soil colour had a value of 4 with a chroma of 2 or less and the soil structure was sub angular blocky. In addition, it had more clay content than the horizons below or above it. Based on these properties, P1 was classified as Typic Humustepts, fine, isohyperthermic.

P2, located on a slope of 15%, is represented by the ochric epipedon with a 5 cm thickness and a candic horizon. In this pedon there was an increase in the percentage of clay in the fine soil fraction with a depth of 15 cm or less in the vertical distance.

Table 4. Soil classification in the Bulia micro watershed

Pedon	Soil Classification					Area	
	Order	Sub Order	Great Group	Sub Group	Family	ha	%
P1	Inceptisol	Ustept	Humustepts	Typic Humustepts	Fine, isohypertermic, Typic Humustepts	596.88	8.53
P2	Entisol	Psamment	Ustipsamme nts	Typic Ustipsamments	Sandy, isohypertermic, Typic Ustipsamments	472.68	6.76
P3	Inceptisol	Ustept	Humustepts	Oxic Humustepts	Fine loamy, isohypertermic, Oxic Humustepts	2,297.78	32.86
P4	Mollisol	Ustoll	Argiustolls	Typic Argiudolls	Fine, isohypertermic, Typic Argiustolls	107.35	1.54
P5	Alfisol	Ustalf	Paleustalfs	Typic Paleustalfs	Fine loamy, isohypertermic, Typic Paleustalfs	1,066.95	15.26
P6	Mollisol	Ustoll	Haplustolls	Typic Haplustolls	Coarse loamy, isohypertermic, Typic Haplustolls	1,026.23	14.67

Pedon	Soil Classification					Area	
	Order	Sub Order	Great Group	Sub Group	Family	ha	%
P7	Inceptisol	Ustept	Humustepts	Typic Humustepts	Fine, isohypertermic, Typic Humustepts	248.4	3.55
P8	Alfisol	Ustalf	Paleustalfs	Ultic Paleustalfs	Fine loamy, isohypertermic, Ultic Paleustalfs	61.87	0.88
P9	Mollisol	Ustoll	Paleustolls	Typic Paleustolls	Fine loamy, isohypertermic, Typic Paleustolls	48.35	0.69
P10	Alfisol	Ustalf	Haplustalfs	Inceptic Haplustalfs	Fine, isohypertermic, Inceptic Haplustalfs	1,066.95	15.26
Total						6,993.44	100.00

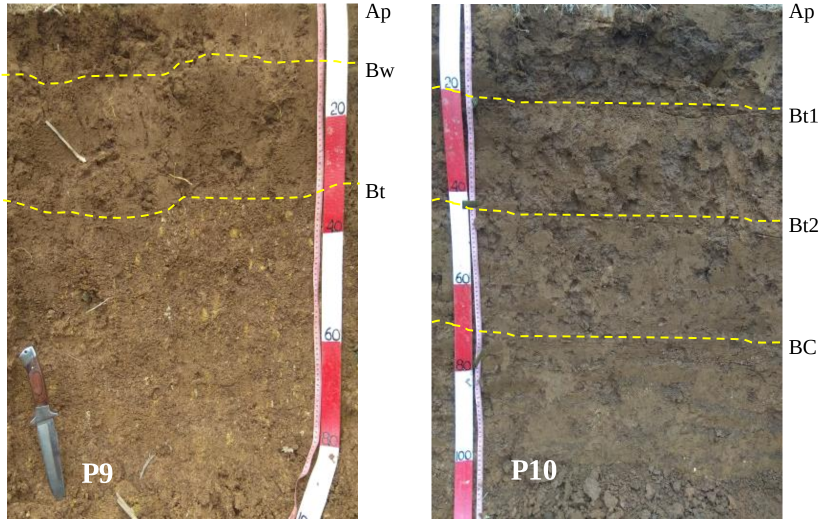

Fig. 4. Soil profile appearance of pedon 9 (P9), and pedon 10 (P10

The clay content was 4% or more (absolute value), which is more than that of the horizon above it, which has a total clay content in the soil fine fraction less than 20%. In addition, it had a loamy sand texture (psamments) and a CEC value (NH_4OAc, pH 7) > 16 cmol(p+)kg^{-1}. Based on these characteristics, P2 was classified as Typic Ustipsamments, sandy, isohyperthermic.

P3 is located on a slope of 1%, represented by the umbric epipedon with a 14 cm thickness and a cambic horizon. This pedon did not experience aquatic conditions at the depth of 50 cm from the soil surface (humustept), the soil colour had a value of 4 with a chroma of 2 or less and the soil structure is sub angular blocky. In addition, it had more clay content than the horizons below or above and its CEC (NH_4OAc 1N) value was 17.96 cmol(+)kg^{-1} only (oxic). Based on these properties, P3 was classified as Oxic Humustepts, fine loamy, isohyperthermic.

P4 is located on a slope of 15%, represented by the molic epipedon (BS 55%) with a 14 cm thickness and an argillic horizon. This pedon had a fine loamy class of particle size with a typical clay coating of the pore walls and the ped surface. In addition, there was 13% (> 8%) of clay on the eluvial horizon and 10YR hue with a chroma ≤ 3, and BS > 75%. Based on these properties, P4 was classified as Typic Argiustolls, fine loamy, isohyperthermic.

P5 is located on a slope of 3%, represented by the ochric epipedon with a 21 cm thickness and an argillic horizon. According to the particle-size classification, this pedon belongs to the fine loam and clay class with an argillic horizon thickness of 25 cm (> 7.5 cm), it also has a typical clay coating of the pore walls and the ped (aggregate) surface. In addition, the clay content in the argillic horizon is 64% or it contains 2.03 times more clay than the eluvial horizon, which was only 34%, and 7.5 YR was typical of all horizons (paleustalf). Based on these properties, P5 was classified as Typic Paleustalfs, fine loamy, isohyperthermic.

P6 is located on a slope of 3%, represented by the molic epipedon (BS 93%) with a 12 cm thickness and a cambic horizon. This pedon had a sandy clay texture and does not have the combination of aquic conditions within 50 cm of the soil surface or artificial drainage (ustoll). The colour value was with a chroma < 6 and it had a sub angular blocky soil structure. In addition, it had more clay content than the below horizons. Based on these properties, P6 was classified as Typic Haplustolls, coarse loamy, isohyperthermic.

P8 is located on a slope of 5%, represented by the molic epipedon with a 7 cm thickness and an argillic horizon. According to the particle-size classification, this pedon belongs to the fine loam and fine clay class with an argillic horizon thickness of 20 cm (> 7.5 cm), also it has a typical clay coating of the pore walls and the ped surface. In addition, the clay content in the argillic horizon is 69% or it contains 2.65 times more clay than the eluvial horizon, which was only 26%, and 7.5YR hue was typical in all horizons (paleustalf), with BS of 61% or > 75% only (ultic). Based on these properties, P8 was classified as Ultic Paleustalfs, fine loamy, isohyperthermic.

P9 is located on an 8% slope, represented by the molic epipedon (BS 53%) with a 7 cm thickness and an argillic horizon. According to the particle-size classification, this pedon belongs to the fine loam class with an argillic horizon thickness of 18 cm (> 7.5 cm), it also has a typical clay coating of the pore walls and the ped surface. In addition, the clay content in the argillic horizon is 69% or it contains 4.60 times more clay than the eluvial horizon, which was only 18%, and 7.5YR hue with a chroma of ≤ 4, and BS of < 75% of all horizons (paleustoll). Based on these properties, P9 was classified as Typic Paleustolls, fine loamy, isohyperthermic.

P10 is located on a slope of 15%, represented by the molic epipedon (BS 57%, 50%) with a 23 cm thickness and an argillic horizon. According to the particle-size classification, this pedon belongs to the fine loam and fine clay class with an argillic horizon thickness of 24 cm (> 7.5 cm), it also has a typical clay coating of the pore walls and the ped surface. In addition, the clay content in the argillic horizon is 88% or it contains 3.38 times more clay than the eluvial horizon, which was only 24%, and 10YR hue with a chroma of ≤ 3, and BS > 75%. Based on these properties, P10 was classified as Inceptic Haplustalfs, fine, isohyperthermic.

Land quality classes

The land quality (LQ) of the Bulia micro watershed was presented in Table 5 and Figure 5. The LQ of class II with the main factor determining the land stress was high temperature and low organic matter. The high temperature factor with an isohyperthermic soil temperature regime as an indicator was found on LU 3 (P3), while the low organic matter factor with an ochric epipedon indicator was only on LU 5 (P5). The LQ of class II is determined as good and this land has few problems for sustainable production, its productivity is generally very high and as a result, the response to management is high (Beinroth et al., 2001). Land management through the addition of organic matter, including green manure, may be adopted along with the recommended fertilizer doses (Sys et al., 1991; Singh et al., 2004; Mahaputra et al., 2019) and mulching to stabilize temperatures and maintain soil moisture (Odjugo, 2008; Eruola et al., 2012; Damaiyanti et al., 2013), which is of great importance. In addition, the use of rice straw mulch and sawdust mulch influences soil properties by decreasing the value of bulk density, increasing soil porosity and soil organic matter (Nasruddin, Hanum, 2015).

Table 5. Land quality classes in the Bulia micro watershed

Land Unit	Land Quality		Land Quality Class	Area	
	Major Land Stress Factor	Determinant of Land Stress		ha	%
3	High temperatures	Isohyperthermic of soil temperature regime	II	2,297.78	32.86
5	Low organic matter	Ochric epipedon	II	1,066.95	15.26
1, 6, 7	Seasonal water excess	Recent terraces	III	1,871.51	26.76
2	Low structural stability and/or crusting	Entisols	IV	472.68	6.76
4	Low structural stability and/or crusting	Clay soils	IV	107.35	1.54
8, 9, 10	Low water holding capacity	Sandy clay loam	VI	1177.17	16.83
Total				3,628.71	51.89

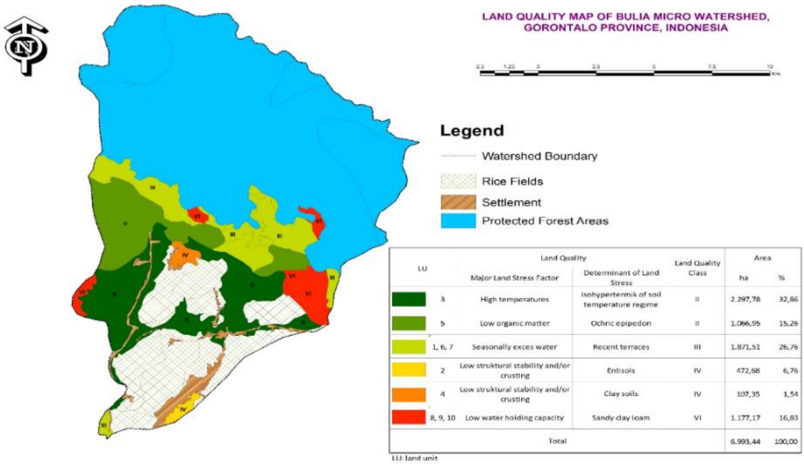

Fig. 5. Land quality map of the Bulia micro watershed.

The LQ of class III with the main factor determining the land stress was a seasonal excess of water. The indicators determining the land stress in class III were new terraces spread over LU 1 (P1), LU 6 (P6) and LU 7 (P7). These new terraces are generally located around the border or river meanders which were prone to erosion and river bank landslides. The LQ of land class III was still considered good and this land has few problems for sustainable production, but has the higher risk of low input of corn production specifically, which results in a response to high management (Beinroth et al., 2001). The land management through the manufacture of gabions and riverbanks (Rahman, 2013), planting river bank reinforcement plants and terraces (Suyana et al., 2017) was of great importance. Bioengineering methods for river bank erosion control commonly used include planting bamboo (Noor et al., 2011). Fine plant roots play a significant role in increasing the shear strength of the soil (Ludwig et al., 2007). The effectiveness of plants in reducing erosion rate is influenced by (1) the canopy or plant canopy, (2) the organic material produced, (3) the root system and the ability of plants to cover the soil (Rachman et al., 2004). Vetiver plants were useful for stabilizing river banks, irrigation canals, river erosion control and coastal embankments, excavation slopes and embankments on highways, sand dunes, erosion on sloped agricultural land (Noor et al., 2011). Vetiver grass, which has strong fibrous roots, holds the ground (Susilawati, Veronika, 2016). Soil nailing was one of the most economical techniques for slopes stabilization of retaining walls because the system works quickly and does not require large space (Sinarta, 2014; Noor et al., 2011).

The LQ of class IV with the main factors determining land stress was low structural stability and/or crusting. These main factors consist of two indicators, namely clay soil and Entisol. The indicator of heavy clay (> 50%) was scattered in LU 4 (P4). This indicator of clay soil was related to soil crusting which was shown by the average sub angular blocky soil structure, and the soil consistency under wet conditions was very sticky and very plastic, while it was very hard under dry conditions. Clay and organic matter are binding agents for aggregates (Rachim, 2007). Apparently, the influence of clay is more dominant than of organic matter as an aggregate binding agent because the OC content was very low. The Entisol indicators were spread on LU 2 (P2) only. Entisol is a soil that is still young and underdeveloped (Rachim, 2007). The results of the morphological analysis of the soil indicated that this Entisol has a granular structure (not solid), fine sized with a weak level of development, therefore the stability was relatively low. In addition, the texture of Entisol was classified as loamy sand with the sand of particle size which makes the soil structure stability relatively low. This class requires major inputs from conservation management; since a lack of plant nutrition is a major obstacle, therefore a plan to use good fertilizers should be adopted (Beinroth et al., 2001). Land management through the addition of organic matter can be applied together with recommended fertilizer doses (Sys et al., 1991; Singh et al., 2004; Mahaputra et al., 2019). Provision of organic matter in soils with clay texture can increase soil water content and available water capacity and reduce soil volume weight (Intara et al., 2011), increase soil porosity (Anastasia et al., 2014), increase N, P, and K uptake and crop yields in Entisol soils (Afandi et al., 2015). Addition of manure, compost and beneficial bacteria technology (custom bio) can reduce soil content weight, soil density, increase aggregate stability, soil porosity and moisture content in Entisol soil (Zulkarnain et al., 2013).

The LQ of class VI with the main factor determining the land stress was low water holding capacity. The indicators of the sandy clay loam texture were spread on LU 8 (P8), LU 9 (P9) and LU 10 (P10). The value of water available on the sandy clay loam texture was only around 20.42 mm (Haridjaja et al., 2013). The available water (pF) under conditions of field capacity (pF 2.0) on LU 8, 9 and LU 10 was indicated as 34 mm, 38 mm, and 37 mm respectively, and at permanent wilting conditions (pF 4.2) 24 mm, 17 mm and only 19 mm respectively, therefore, causing a low water holding capacity. This land should not be used for food production (i. e. corn) because this class requires major inputs from conservation management; since a lack of plant nutrition is a major obstacle, therefore a plan to use good fertilizers should be adopted or this land can be used as a biodiversity zone (Beinroth et al., 2001). However, if this land is used for agricultural cultivation, then the land management should consider the addition of organic matter along with the recommended fertilizer dosage (Sys et al., 1991; Singh et al., 2004; Mahaputra et al., 2019). Provision of organic material in soils with clay texture can increase soil water content and available water capacity and reduce soil volume weight (Intara et al., 2011), increase soil porosity (Anastasia et al., 2014).

CONCLUSIONS

Angular blocky, sticky, plastic consistencies, and hard consistencies prevailed in the soil structure of the Bulia micro watershed of Gorontalo Province, Indonesia. In the alluvial plain, a sand fraction prevailed in Volkan mountains. The soils in the Bulia micro watershed also react acid to neutral, with the range of very low to high OC levels, the reserve of exchangeable bases was dominated by Ca^{2+} in two series patterns, namely: $Ca^{2+} > Mg^{+} > Na^{+} > K^{+}$ and $Ca^{2+} > Na^{+} > Mg^{+} > K^{+}$, CEC ranged from low to very high, and the base saturation varied from moderate to very high. The primary soils found were Entisol on P2 (Typic Ustipsamments), Inceptisol on P1 and P7 (Typic Humustepts), and P3 (Oxic Humustepts), Mollisol on P4 (Typic Argiudolls), P6 (Typic Haplustolls), and P9 (Typic Paleustolls), and Alfisol on P5 (Typic Paleustalfs), P8 (Ultic Paleustalfs) and P10 (Inceptic Haplustalfs). On the alluvial plains the land was categorized as the LQ class II, III and IV, the volcanic mountains were the LQ class IV, while the land on the volcanic hills was categorized as the LQ class VI. River bank erosion on the land river terraces can be held by the manufacture of gabions, talud, cliff reinforcement plants and terraces. The soil temperatures and high clay content can be regulated by mulching and organic materials.

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