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Peat soil quality index and its determinants as influenced by land use changes in Kubu Raya District, West Kalimantan, Indonesia

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Abstract. *Nusantara RW, Aspan A, Alhaddad AM, Suryadi UE, Makhrawie, Fitria I, Fakhrudin J, Rezekikasari. 2018. Peat soil quality index and its determinants as influenced by land use changes in Kubu Raya District, West Kalimantan, Indonesia. Biodiversitas 19: 535-540.* Tropical peatland is continuously damaged in large area in Indonesia, caused by deep and wide drains which change the ecosystem. This research was conducted to evaluate the soil quality index (SQI) based on peatland use. The research was conducted in Kubu Raya District, West Kalimantan Province, in secondary peat forest, shrubland, oil palm plantation and corn field. The variables observed in this research were subsidence, water-table level, depth of peat, bulk density, water content, porosity, organic carbon, total nitrogen, total potassium, cation exchange capacity, base saturation, ash content, available phosphorus, and exchangeable calcium, magnesium, sodium, C/N ratio and soil acidity. The results showed that SQI in secondary peat forest, shrubland, corn field and palm oil plantation were 0.40, 0.37, 0.37 and 0.37 respectively. The stepwise regression analyses showed that the variables influencing SQI were the depth of peat, water-table level, and ash content. Secondary forest had the highest level (0.74) for the depth of peat with 509 cm depth while the other sites had average level (0.41-0.43) with 108.4 cm-115.5 cm mean depth. SQI of peatland increased with the increasing depth of peat and ash content. The differences showed that land use change of peatland, from forest to plantation area would decrease its SQI.

Keywords: Determinant indicators, land condition, peatland-use change, physical and chemical characteristics, soil quality index

INTRODUCTION

There is 38 million hectares of peat land in the world, most of which (14.9 million) is located in Indonesia (BBPPSDLP 2011). Peat forest is one of the endangered wetlands caused by human activities. The change of forest into agricultural land can threaten the existence of natural peat swamp forests. The land clearing of peatland includes deforestation, shrubs cutting and vegetation burning, drainage-making, soil compaction during land preparation and the making of raised beds and sunken beds (Andriesse 1988).

All the phenomena shown on the peat as the impact of land-use change influence the peat soil quality. The information related to soil quality can help the manager in evaluating the positive or negative impacts and integrating information from each indicator in land management. Soil quality is the soil capacity to interact positively with its external environment in the same ecosystem (Larson and Pierce 1994). Soil quality integrates the physical, chemical and biological components. Soil quality becomes the specific capacity of the soil to naturally function as a foundation of animal and plant productivities, maintaining or improving water and air quality and supporting human residency. In short, soil quality is the capacity of soil to function (Karlen et al. 1997).

Soil quality index (SQI) is a tool to score the impact of land use and land management activities which can show the physical, chemical and biological characteristics and interaction process in each soil source (Karlen et al. 2001). Bhaduri and Purakayasthe (2014) mentioned that SQI could help the manager in evaluating the positive and negatives impact of continuous activities and integrating information from each soil indicator in land management (Mohanty et al. 2007). The soil quality can be determined by collecting indicator data which have been chosen (MDS). SQI can be used to observe and calculate the impact of agricultural system and management of the soil quality by analyzing each indicator that has been used (Seybold et al. 1996).

The environment quality can always be seen from the quality aspect of water and air. People appreciate clean water and fresh air. On the contrary, the appreciation of people to soil is low (James 1995). There are laws and regulations related to water and air quality, but until now, there are no laws that rule the soil quality, especially peat land quality based on the land-use continuously practiced by citizens as agriculture land. That is why the study of soil quality index of peat land which has been converted from natural ecosystem land to agriculture land is absolutely necessary. The purpose of this research was to discover the soil quality index of peat land based on peat land use in secondary forest, shrubland, corn field and oil palm plantation in Kubu Raya, West Kalimantan, Indonesia.

MATERIALS AND METHODS

Study area

The research was located in Rasau Jaya, Kubu Raya district, West Kalimantan Province. The types of lands studied were secondary peat forest (SPF), shrubland (SB), oil palm plantation (OPP) and corn field (CF), each having different land tillage(Figure 1).

Procedures

The procedures in this study consisted observation and measurement of the land, namely water-table depth (WTD), subsidence, peat depth and soil sampling for physical analyses (bulk density, water content, porosity) and chemical analyses (pH, total N, available P, total K, and exchangeable Ca, Mg, Na, organic C, ash content, cation exchange capacity and base saturation).

Observation and measurement subsidence, water-table depth and peat depth.

In each sampling point, water-table depth was measured based on the range of ground water level and ground level. Peat depth was measured based on the stakes permanently fixed in the soil. Peat subsidence was measured in cm for each month (the observation was done in four months).

Soil sampling

In each study site, there were five sampling points distributed in center the research location. There were 20 samples from four types of land. The peat soil sample was taken from 0-20 cm depth point. Every sample in tubes was let-dried for approximately one to two days. Then, each sample was separated from roots, pebbles, and dirt. Samples were then weighed, ground to prepare them for the analyses. Sample for soil bulk density was intact soil.

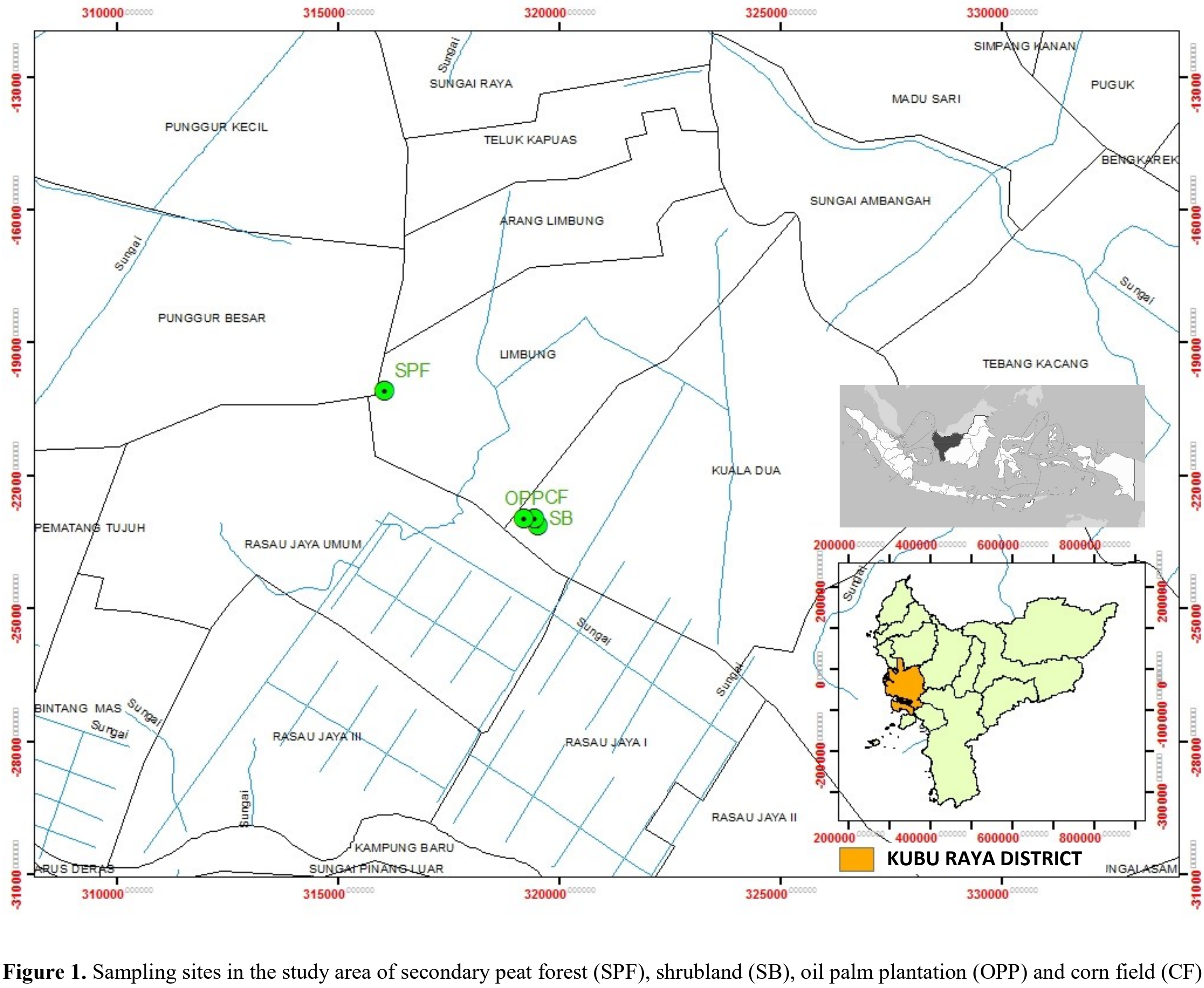


Figure 1. Sampling sites in the study area of secondary peat forest (SPF), shrubland (SB), oil palm plantation (OPP) and corn field (CF)

Soil sample analyses

Soil was analyzed to know the chemical properties, namely soil pH, total N, available P and exchangeable Ca, Mg, K, total K, organic C, ash content, cation exchange capacity and base saturation. Bulk density was determined using tube-measuring method and moisture content was determined from the difference between wet and dry weight of soil (Permenlh 2006). Ash content and organic C were determined using the loss of ignition (Lol) method.

Soil quality index analysis

All the data were analyzed with Principal Component Analysis (PCA) method using SPSS application. PCA was used to choose the minimum data set (MDS) from chemical soil indicators representing the soil function. Scoring of MDS indicators was done based on the performances in soil functions using the following two equations.

$$y = (x\text{-}s)/(1.1t\text{-}s) \text{ to "More is better"} \quad (1)$$

$$y = 1\text{-}\{(x\text{-}s)/(1.1t\text{-}s)\} \text{ to "Less is better"} \quad (2)$$

y is the score of soil data; x is chemical soil score converted to the scale of 0 to 1; s is the lowest score that possibly occurs based on soil characteristic (s=0), and t is the highest score of soil characteristic.

Equation [1], “more is better” was used for the following variables: bulk density, porosity, moisture content, peat depth, available P, total K, organic C, total N, exchangeable Ca, Mg, Na, CEC and base saturation. Equation [2] “less is better” was used for the following variables: soil pH, C/N ratio, subsidence and water-table depth. The scores of all indicators were combined into soil quality index using the formulas shown by Andrews et al. (2002):

$$SQI = \sum_{i=1}^{n} Wi\ Si$$

Where,

SQI = Principal Component Analysis as SQI base

Wi = Weight of PCA factors, equal to ratio of each factor for total coefficient of cumulative variant in equation.

Si = Score of each SQ indicator (modified from PPT 1983)

The result of SQI has scores ranging from 0 to 1. The closer the score of SQI to 1, the better it is (Partoyo 2005) (Table 1).

Table 1. The soil quality index (SQI) score (after Partoyo 2005)

Value	SQI
0.80 - 0.99	Very Good
0.60 - 0.79	Good
0.40- 0.59	Medium
0.20 - 0.39	Low
0.00 - 0.19	Very Low

Stepwise regression analyses were done to determine which variables influenced the soil quality and correlation analyses were used to determine the correlation between variables.

RESULTS AND DISCUSSION

Physical and chemical characteristics of soil

Land-use change from natural peatland into agricultural land caused changes in water-table depth, peat depth, moisture content, nutrient content, peat soil C and bulk density, soil pH, ash content and peat soil C/N ratio(Table 2). The decrease of nutrient in cultivation land was caused by the high amount of nutrient leaching in the soil solution and drainage in corn field and oil palm plantation. Other causes were the high amount of nutrient absorbed by the plantation in early-growing stage (vegetative) and cultivation process which might take the nutrient out of the land. Soil tillage and drainage might also caused high leaching of nutrient which was then adsorbeb by soi colloids. This condition is marked with the high ash content but the ash was easily lost into the drainage or water ground.

Soil quality index

Soil quality index can be measured by summing up the multiplication score of Si and Wi. SQI in SPF was higher (0.40-average) than those in SB (0.37-low), CF (0.37-low) and OPP (0.37-low), but the difference among SQI scores of the four lands were not high. SPF land had higher exchangeable K (0.51), exch. Na (0.39) and peat depth (0.74), while SB, CF, and OPP had higher exchangable Ca, Mg, Na and ash content (Figure 2 and Table 3).

The SQI scores showed that the secondary forest ecosystem did not change much, unlike the shrubland, and especially corn field and oil palm plantation. The secondary forest ecosystem was still natural as indicated by its species composition which included *Pandanus helicopus* (rasau), *Shorea albida* (balau), *Alastonia scholaria* (pulai), *Dyera lowi* (jelutung rawa), *Flickingeria aureiloba* (Anggrek hutan), *Nephentes ampularia* (Kantung semar) and *Garcinia bancana* (manggis hutan) (Nusantara et al. 2015). The ecosystem of corn field and palm oil had changed a lot. Those lands are monoculture with drainage, intensive land cultivation and the addition of organic and inorganic fertilizer and ash from the plantation burn. In the oil palm plantation there were drains on the left block, about 2.5m and 12m deep. On the corn field, there were drains, approximately 0.5 m and 0.5 m deep (Nusantara et al. 2014).

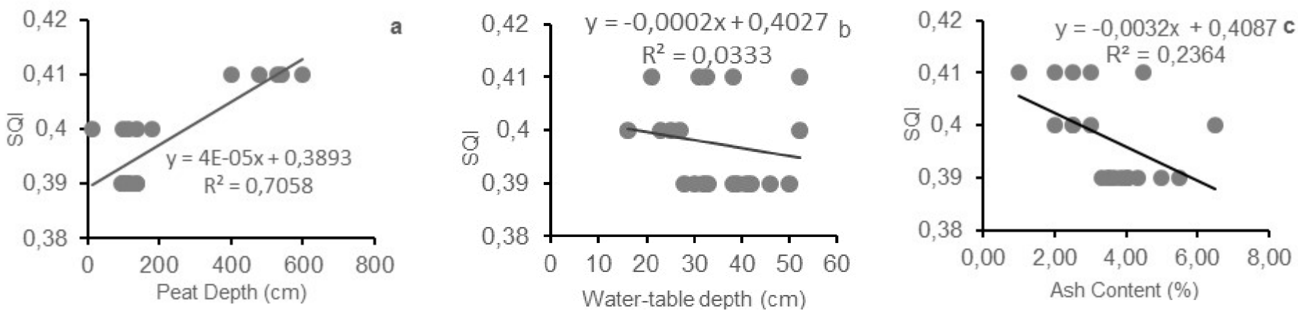
We agree with Armenise et al. (2013) that SQI can be considered good if it is sensitive to soil tillage, and land use change and easy to measure. Land use change from natural ecosystem has decreased soil nutrient. This condition is mainly caused by the change of water-table depth which influences aerobic - anaerobic condition, decomposition process of organic input from vegetations on the ground, climate (temperature and soil moisture), land-burning, liming and fertilization (Yule 2010).

Table 2. Physical paramaters of peatland, physical and chemistry of peat soil at secondary peat forest (SPF), shrubland (SB), corn field (CF), oil palm plantation (OPP)

Type of land	Water content (%)	Bulk density (g cm^{-1})	Porosity (%)	Total N (%)	Available P (ppm)	Exch K ($cmolkg^{-1}$)	CEC ($cmolkg^{-1}$)	Exch Ca ($cmolkg^{-1}$)	Exch Mg ($cmolkg^{-1}$)	Exch Na ($cmolkg^{-1}$)	Carbon (%)	Ash (%)	C/N	pH	BS (%)	Subsidence (cm)	Peat depth (cm)	WTD (cm)
SPF 1	65.41	0.17	95.04	2.03	194.76	0.23	121.69	3.31	2.12	0.50	56.55	2.50	27.86	3.20	5.06	0.30	401	21
SPF 2	82.65	0.15	95.56	2.26	276.61	0.19	121.25	3.36	2.16	0.46	56.26	3.00	24.89	3.54	5.08	0.20	541	38
SPF 3	76.73	0.10	97.00	2.03	218.93	0.23	122.53	1.97	1.26	0.61	56.84	2.00	28.00	3.61	3.32	0.15	527	32.5
SPF 4	69.68	0.16	95.26	2.42	146.62	0.04	119.67	1.13	0.73	0.29	55.39	4.50	22.89	3.91	1.83	0.18	598	52
SPF 5	73.05	0.14	96.02	2.77	184.21	0.27	123.70	1.14	0.73	0.59	57.42	1.00	20.73	3.46	2.20	0.18	478	31
SB 1	56.80	0.13	98.05	2.10	34.74	0.21	120.53	2.27	1.45	0.27	55.97	3.50	26.65	3.46	3.49	0.59	97	42
SB 2	73.16	0.18	94.74	1.95	78.64	0.13	118.24	1.21	0.77	0.48	54.81	5.50	28.11	3.41	2.19	0.46	136	33
SB 3	81.77	0.16	91.84	1.95	70.21	0.10	119.97	3.01	1.93	0.38	55.97	3.50	28.70	3.45	4.52	0.50	100	32
SB 4	70,66	0.15	95.62	2.18	80.46	0.26	119.54	1.48	0.95	0.67	55.68	4.00	25.54	3.25	2.81	0.44	109	50
SB 5	73.36	0.19	94.26	2.09	77.92	0.03	118.43	1.75	1.12	0.20	55.10	5.00	26.36	3.38	2.62	0.51	100	28
CF 1	68.90	0.18	94.74	1.53	73.32	0.20	121.34	2.13	1.37	0.57	56.26	3.00	36.77	3.76	3.52	0.72	100	25
CF 2	70.88	0.15	95.53	1.91	127.54	0.05	121.75	2.91	1.87	0.22	55.84	2.50	29.61	3.52	4.15	0.55	113	23
CF 3	74.95	0.12	96.38	1.90	55.18	0.05	121.41	2.60	1.66	0.27	56.55	2.50	29,76	4.48	3.77	0.66	115	27
CF 4	69.78	0.17	94.97	1.94	60.76	0.09	122.13	4.90	3.14	0.33	56.84	2.00	29.30	4.41	6.93	0.54	180	52
CF 5	75.34	0.16	95.36	1.84	45.19	0.09	116.54	5.45	3.49	0.32	54.23	6.50	29.47	3.53	8.02	0.53	138	16
OPP 1	58.91	0.28	91,71	2.15	52.48	0.07	120.13	4.67	3.00	0.25	55.49	4.33	25.81	3.49	6.65	1.20	113	30
OPP 2	68.41	0.21	93.66	1.83	53.16	0.05	123.66	3.07	1.68	0.21	55.65	3.33	30.41	4.59	3.68	0.78	137	46
OPP 3	57.52	0.23	93.47	1.99	46.89	0.03	121.87	3.03	2.03	0.21	55.84	3.87	28.06	4.23	2.92	0.63	123	38
OPP 4	82.15	0.18	94.67	1.99	79.91	0.18	122.31	9.32	5.97	0.21	55.87	4.05	28.08	3.63	10.78	1.10	94.5	39
OPP 5	77.56	0.18	97.55	1.91	77.19	0.07	121.52	3.65	1.70	0.25	55.45	3.67	29.03	3.95	3.84	0.80	110	41

Table 3. Peat soil quality index (SQI) at Secondary peat forest (SPF), Shrubland (SB), Oil palm plantation (OPP) and Cornfield (CF)

Indicator of soil	Index (wi)	Scoring				Soil Quality Index (SQI)							
		SPF (si)	SB (si)	CF (si)	OPP (si)	SPF	Criteria	SB	Criteria	CF	Criteria	OPP	Criteria
Water content (%)	0.472	0.33	0.33	0.33	0.33	0.16	VL	0.16	VL	0,16	VL	0,16	VL
Bulk density (g cm^{-3})	0.613	0.2	0.2	0.2	0.2	0.13	VL	0.13	VL	0,13	VL	0.13	VL
Porosity (%)	0.462	0.33	0.33	0.33	0.33	0.15	VL	0.15	VL	0,15	VL	0.15	VL
Total N (%)	0.646	1.0	1.0	1.0	1.0	0.65	G	0.65	G	0.65	G	0.65	G
Available P (ppm)	0.554	1.0	0.96	1.0	1.0	0.55	M	0.53	M	0.55	M	0.55	M
Total K (cmol kg^{-1})	0.612	0.84	0.76	0.56	0.56	0.51	M	0.47	M	0.34	L	0.34	L
KTK (cmol kg^{-1})	0.752	1.0	1.0	1.0	1.0	0.75	G	0.75	G	0.75	G	0.75	G
Saturation base (%)	0.594	0.2	0.2	0.2	0.2	0.12	VL	0.12	VL	0.12	VL	0.12	VL
Exch. Ca (cmol kg^{-1})	0.661	0.28	0.28	0.40	0.48	0.18	VL	0.18	VL	0.26	L	0.32	L
Exch. Mg (cmol kg^{-1})	0.641	0.6	0.52	0.68	0.6	0.38	L	0.33	L	0.44	M	0.38	L
Exch. Na (cmol kg^{-1})	0.701	0.56	0.48	0.44	0.40	0.39	L	0.34	L	0.31	L	0.28	L
Organic C (%)	0.679	1.0	1.0	1.0	1.0	0.68	G	0.68	G	0.68	G	0.68	G
Ash content (%)	0.651	0.59	0.73	0.66	0.66	0.38	L	0.48	M	0.43	M	0.43	M
CN ratio	0.528	0.36	0.20	0.20	0.20	0.19	VL	0.11	VL	0.11	VL	0.11	VL
Soil pH	0.729	0.25	0.25	0.30	0.30	0.18	VL	0.18	VL	0.22	L	0.22	L
WTD (cm)	0.513	0.59	0.59	0.39	0.59	0.30	L	0.30	L	0.20	L	0.30	L
Peat depth (cm)	0.741	1.0	0.56	0.56	0.58	0.74	G	0.41	M	0.41	M	0.43	M
Subsidence (mm)	0.829	1.0	1.0	1.0	1.0	0.83	VG	0.83	VG	0.83	VG	0.83	VG
Total						7.43		7.06		7.15		7.10	
SQI						0.40	M	0.37	L	0.37	L	0.37	L



A B C

Figure 2. Linear correlation of peat depth (a), water-table depth (b) ash content (c) soil quality index (SQI)

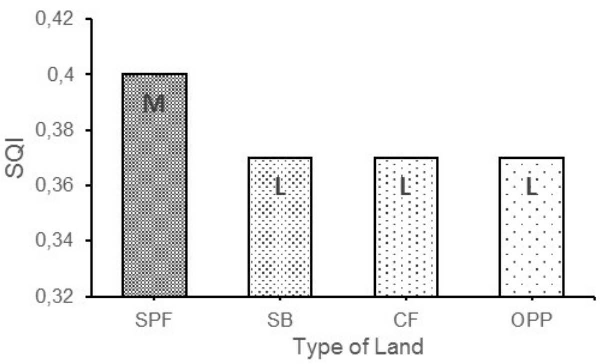


Figure 2. Soil quality index (SQI) in Secondary Peat Forest (SF), Shrubland (SB), Cornfield (CF) and Oil palm plantation (OPP). The M shows SQI medium value while L is low.

Meanwhile, Obade and Lal (2016) had different research result because they found that SQI on conventional tillage land (CT) had higher soil quality level than the natural vegetation (NV) and no-tillage land (NT). This might be caused by the higher sun light exposure that not only increased the evapo-transpiration but also created a suitable microclimate for the soil organisms.

Stepwise regression analyses showed that the variables affecting SQI the most were peat depth, water-table depth and ash content which had the strongest correlation (r=0.924). Figure 2a shows that peat soil's SQI tends to increase with the increase of the peat depth which shows a strong correlation (r= 0.84). This matches with SPF condition that had 509 cm peat depth and good SQI score (0.74-good) while the other lands had average scores of SQI, namely 0.41 (SB) and 0.44 (CF and OPP) with mean peat depth of 108.4 cm, 136.2 cm, 115.5 cm respectively.

Water-table depth was the second variable influencing SQI (Figure 2b). Both had a weak negative correlation (r= -0.182) with which SQI decreased slightly as WTD increased. The difference in WTD was caused by the different width and depth of drains; OPP had deep and wide drains encircling the area, causing more drainage of water (Nusantara et al. 2014). Fluctuation of WTD can influence aerobic-anaerobic conditions of peat soil which can trigger peat mineralization and nutrient-loss from the land. Decomposition occurrs more rapidly in the drained peat land, decreasing the quality of peat.

The ash content is one of peat decomposition indicator. Mature peat has higher ash content than young peat. The relation between ash content and SQI is shown in 2c. SQI decreases with the increasing ash content (r= -0.486). The ash content is related to physical land condition like the peat depth and water-ground level because both conditions influence organic decomposition process within the peat. This result is in accordance with the theory that the decrease of water-table depth causes the changes of anaerobic condition in the dried soil, resulting faster decomposition within peat materials. This means that as the water-table depth decreases, the anaerobic condition of soil changes to the aerobic one, then the peat decomposition increases as marked with the rise of ash content in the peat.

The changes which occurred because of the activities on the peatland should trigger us to search for information to support the proactive decision about their impact, such as discovering SQI of land use. Based on this information, appropriate measures must be taken to maintain the peat quality. Stepwise Regression analyses showed that the peat depth, WTD and ash content are influencing factors in land use change of peat. That is why water-table depth control is the key in utilizing peatland as agriculture land and in protecting the environment (Handayani 2009; Las et al. 2012). This is in agreement with the statement of Las et al. (2012) and Sabiham (2007) that macro and micro-water system strongly influence the peat soil characteristics. In conclusion, soil quality index (SQI) of the peat in secondary forest was 0.40 higher than that in shrubland (0.37-low), in CF (0.37-low) and in OPP (037-low). The Stepwise Regression analyses showed that the variables affecting SQI the most were peat depth, water-table depth and ash content (r=0.924). Those three variables will affect the physical condition of the peatland through their effects on the physical and chemical characteristics of the soil.

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