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Microclimate Conditions of the Developed Peatland in Central Kalimantan

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Abstract: This study describes temperature and soil moisture profile of peatland for four land uses condition: Agricultural area, forest, regrowing forest and destroyed forest. The study area covers the former Mega Rice Project (1996-1999) with an area of 1.5 million ha in central Kalimantan, Indonesia. Daily and hourly temperatures and soil moisture content were observed during dry (July-August) and rainy (March) seasons for two years. Results of this study reveal that the developed peatland increases peat surface and air temperatures ranging from 1.09 to 2.97°C. Daily and diurnal temperature fluctuations ranging from 2.25 to 5.55°C affected significantly the decreasing of 11.65% soil moisture content within the top peat layer of 20 cm. This findings offer possible restoration options in order to control hydrogeological change within the study area.

Key words: Forest, land use, peatlayers, soil moisture, temperature, vegetation cover

INTRODUCTION

Peatlands are wetland ecosystems characterised by accumulation of organic matter that is produced and deposited at a faster rate than it can be decomposed (Gore, 1983; Kurnain *et al*., 2002). Peat formation in the tropics commences under conditions of constant waterlogging or in wet coastal areas where organic matter is produced in abundance by an adapted vegetation of mangroves, grasses or swamp forest trees (Driessen, 1977; Radjagukguk, 2000). Approximately 12% of the global peatland area occurs in humid tropical zones, mainly in mainland East Asia, Southeast Asia, the Caribbean and Central America, South and southern Africa (Rieley *et al*., 1996). Peatland in Indonesia covers about 16 to 27 Mha (Radjagukguk, 1992; Rieley *et al*., 1996). These ecosystems are vitally linked to conservation issues such as carbon sequestration affecting global climate change and provision of key habitat for a diverse range of the world's flora and fauna. They also are the source of a significant portion of the freshwater and many economic resources vital to human survival. In addition, peatland ecosystems are important for water resources conservation since their ability to store water is very high and can be up to 8 times of the peat volume (Boelter, 1972; Inoue *et al*., 2004; Widjaja-Adhi, 1997).

Tropical peatlands, however are also the subject to land use pressures including forestry development and agriculture on them as well as extraction for energy and horticulture (MacDicken, 2002). In 1996, 1.5 Mha of Peatland in Central Kalimantan was developed for rice production-the so called Mega Rice Project (MRP). This project failed and was closed down in 1999 but left on legacy of habitat destruction and fire occurrence. Conservation of vast peatland area for the carbon stored in them as well as for water protection seems to be one solution for the future. It seems, however, that even if conservation shows a great and significant success, the loss of forest still occurs at an alarming rate. The involvement of local communities therefore is important to the success of conservation of tropical peatland. Therefore the purpose of this study is to describe the microclimate conditions of the developed peatland area in the former MRP especially on air and peatland temperatures as well as soil moisture content. This description will enable the forestry decision makers to draw management priority in using and protecting the land as well as maintaining nutrient balance (Sulistiyanto, 2003) and water resources within the developed peatland (Takahashi *et al*., 2002).

MATERIALS AND METHODS

Site descriptions: Research was carried out within the area of the former Mega Rice Project (MRP) in Central Kalimantan, Indonesia, that was launched through

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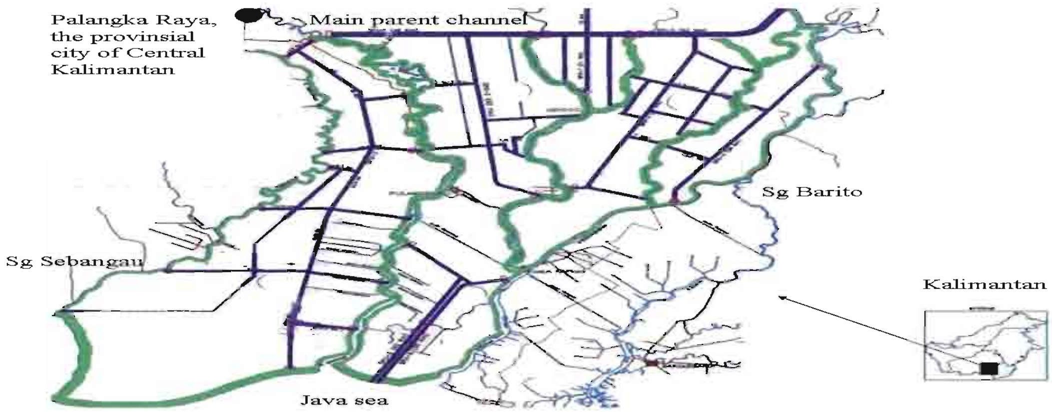

Fig. 1: Study area

Presidential Decree No. 82/1995 on 26th December 1995, to develop approximately one million hectares of wetland (mostly peatland) for food crop production, especially rice. The MRP covers an area of 1,457,100 ha bounded by Sg. Sebangau in the west, Java Sea in the south, Sg. Barito in the east and the Main Parent Channel in the north (Fig. 1).

Hydrometeorology: Soil moisture was measured for different depth of peat layers, i.e., 10, 20, 30 and 40 cm. Standard laboratory practice was applied using gravimetric method. Fluctuations of peat surface temperatures were obtained from monitoring instruments placed in the field. Thermometers for measuring air and peat soil temperatures were established at the same location where includes a forest area, regrowing forest, as well as an agriculture area.

Daily and hourly temperatures and soil moisture content were observed during dry (July-August) and rainy (March) seasons for two years. Examination of soil moisture content in peatland was carried out at the depth of 10, 20, 30 and 40 cm. Statistical analysis was used to evaluate the significant level at $p = 0.01$.

RESULTS AND DISCUSSION

Daily air temperature: Table 1 shows the average daily temperature and its frequency analysis. The average daily temperature and its fluctuation in the agriculture area and destroyed forest were higher than in the forest and regrowing forest. In the agriculture area, the average temperature ranged from 23.79 to 31.49°C with an average of 27.62±1.38°C. From the examination of the entire data, most temperatures (82.34%) within the agriculture area were between 26 to 30°C. In the destroyed forest, the range of temperature was between 23.41 and 29.74°C and the average of 27.20±1.12°C. Most of the temperatures (87.99%) in the destroyed forest lay between 26 to 30°C. In contrast, in those areas with denser vegetation cover, temperature ranges from 23.32 to 27.76 (averages of 25.72±0.72) in the forest and from 23.27 to 27.93 (averages of 26.04±0.81) in the regrowing forest. Most of temperature values in the forest (99.08%) and regrowing forest (98.54%) lie between 24 and 28°C.

Table 1: Average daily air temperatures within several land-uses

Land use	Means (°C)	Std. Dev. (°C)	Min (°C)	Max (°C)
Agriculture	27.62	1.38	23.79	31.49
Destroyed forest	27.20	1.12	23.41	29.74
Forest	25.72	0.72	23.32	27.76
Regrowing	26.04	0.81	23.27	27.93

Table 2: Paired samples test on the daily air temperature between locations

	Paired differences					
Land use	Mean	Std. dev.	Std. error mean	t-value	df	Sig. (2-tailed)
AGR-DEST	-0.0616	0.47634	0.02792	-2.204	290	0.028
AGR-FOR	1.9327	1.16152	0.06200	31.175	350	0.000
AGR-REGR	1.8882	1.48551	0.09284	20.337	255	0.000
DEST-FOR	1.3519	0.59877	0.03165	42.720	357	0.000
DEST-REGR	1.2280	0.84746	0.05148	23.853	270	0.000
FOR-REGR	-0.0989	0.62918	0.03298	-2.998	363	0.003

The paired sample t-tests, presented in Table 2, show that there were significant differences in the means of daily temperature between each location, except between agriculture area and destroyed forest.

Hourly temperature: Similar data for hourly air temperatures were obtained within agriculture area, destroyed forest, forest and regrowing forest (Table 3). The highest average hourly temperature and its fluctuation were in the agriculture area (27.62±4.17°C), following by destroyed forest (27.22±5.55°C), regrowing forest (26.12±3.02°C) and forest area (25.73±2.25°C).

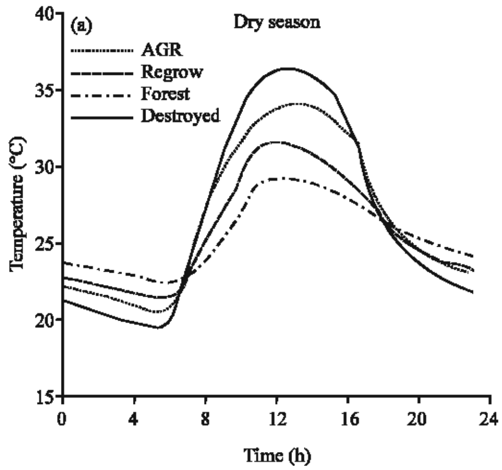

Fig. 2: An average daily period of air temperature fluctuation, taken from dry season and rainy season

Table 3: Hourly air temperature within several land-uses

Land use	Means (°C)	Std. dev. (°C)	Min (°C)	Max (°C)
Agriculture	27.62	4.17	16.38	40.13
Destroyed	27.22	5.55	15.23	42.94
Forest	25.73	2.25	20.19	38.32
Regrowing	26.12	3.02	19.90	36.57

The pattern of diurnal temperature fluctuation in all four land cover types was similar. Figure 2 shows the average fluctuation of air temperature for July and August (dry season) and March (rainy season). The temperature was almost stable until 6 or 7 am and increased slightly reaching a maximum at 12 am to 2 pm with a temperature of 36.26°C (destroyed forest), 34.09°C (agriculture area), 31.71°C (regrowing forest) and 29.21°C (forest) in the dry season. In the rainy season, however, the maximum temperature was slightly lower at 33.94°C (destroyed forest), 32.76°C (agriculture), 28.98°C (regrowing forest) and 28.43°C (forest). Temperatures decrease until around 6 pm and remain relatively constant until 7 am Both the data on daily and diurnal temperature fluctuations confirmed the significance of forest or vegetation cover to reduce the temperature.

Peat surface temperature: The data for peat surface temperature at the top layer (0-20 cm) and air temperatures are summarized in descriptive statistics as presented in Table 4. Peat surface temperature was higher than air temperature in the agriculture area and regrowing forest while, in the forest, peat surface temperature was lower than air temperature. The highest average surface peat temperature of 30.22°C occurs in the agriculture area followed by regrowing forest (26.71°C) and forest (22.88°C).

The analysis of means by using paired samples test between air and peat temperature in agriculture area, forest and re-growing forest and also peat surface temperature between the three locations is presented in Table 5. This shows a highly significant difference between the average air and peat surface temperatures within each location and between all locations.

Table 4: Descriptive statistics of air and peat surface temperature within three land uses

Land use	N	Min (°C)	Max (°C)	Mean (°C)	Std. dev. (°C)
AGR-Air	27	25.13	29.66	27.25	1.03
AGR-Peat	27	28.22	32.08	30.22	0.86
FOR-Air	137	23.27	29.35	25.84	0.85
FOR-Peat	137	21.18	23.78	22.88	0.57
REG-Air	136	23.28	27.26	25.62	0.83
REG-Peat	136	25.98	27.09	26.71	0.21

Table 5: Paired samples test between air and peat temperature

	Paired differences					
Land use	Mean	Std. dev.	Std. error mean	t-value	df	Sig. (2-tailed)
AGRA-AGRP	-2.961	0.46179	0.08887	-33.32	26	0.000
FOR A-FORP	2.968	0.63409	0.05417	54.79	136	0.000
REGA-REGP	-1.091	0.73323	0.06287	-17.35	135	0.000
AGRP-FORP	6.952	0.67002	0.12895	53.91	26	0.000
AGRP-REGP	3.481	0.82089	0.15798	22.04	26	0.000
FORP-REGP	-3.838	0.45364	0.03890	-98.67	135	0.000

The pattern of diurnal peat surface temperature fluctuations in the three land cover types differs. The average data of hourly measurement within a month was used to show this pattern. Compared to the pattern of air temperature, in general, the pattern of peat temperature showed increases that are about 1 to 2 h behind. The peat surface in the agriculture area during the rainy season (March) had a relatively stable temperature between 27.5 and 28.8°C until 7 am and then increases slightly reaching a maximum of 33.67°C, between 2.00 and 3.00 pm, after which it decreased slowly to 29.15°C at 11.00 pm. The peat surface temperature at forest area was stable at a range of temperature between 22.98 and 23.41°C over 24 h periods, while the same pattern was also found at the regrowing forest area with a range between 26.72 and 26.75°C.

Vegetation cover on tropical peatland has a significant influence on the average daily air and peat surface temperature in the study area. Open peatland areas, such the agriculture area with an average of 27.62±1.38°C and destroyed forest with an average of 27.20±1.12°C have much higher temperatures and variation than those with a vegetation cover (Rieley *et al*., 1996; Takahashi and Yonetani, 1997) such as regrowing forest (26.04±0.81°C) and forest site (25.72±0.72°C). Similar ranges of temperature were also found by Hirano *et al*. (2003) who obtained an air temperature of 26.5°C in a forested area at a height of 41.7 m above the peat surface.

Within the forested area, the average peat surface temperature was 2.96°C lower than the average air temperature while, for the developed peatland area (e.g., the agriculture and re-growing forest areas), the average peat surface temperature was between 1.09-2.97°C higher than the average air temperature in the same locations. From these data, it is clear that the loss or changes of vegetation cover in peatlands is strongly influencing the peat surface temperature. The existence of plants that grow on the peat swamp alters the heat and water balance of the soil on which they grow. It has been found, for example, that peat swamp forest reduces the ground albedo significantly contributing to the frequency of rainfall that decreases when forest is cleared. With reference to radiation exchanges, there are marked differences between forested and deforested areas with respect to their solar radiation exchange (Silvius and Giesen, 1992).

Variations also occurred in both air and peat surface temperature under different land conditions. The highest variation was in the agriculture area, followed by destroyed forest, re-growing forest and the forested area. This again supports the importance of vegetation cover in controlling temperature fluctuation. Compared to air temperature, however, peat surface temperature is higher than air temperature but shows a smaller variation for all sites.

The higher temperatures will have an effect to the increase of oxidation process and, furthermore, will lead to higher gas efflux rates, especially CO_2 and methane. In sub arctic/boreal fen, Moore and Knowles (1989) and Moore *et al*. (1990) as well as Fiedler and Sommer (2000) reported that soil temperature has a positive correlation with methane flux, while Otter and Scholes (2000) found a similar relationship between methane flux and temperature for the wetlands of South Africa. In tropical peatland of Central Kalimantan, Indonesia, Hatano *et al*. (2004) reported that soil temperature has a moderate significant correlation with CO_2 flux and N_2O as well as a positive correlation with methane flux.

Soil moisture: Data for hourly soil moisture are presented in Table 6. Average soil moisture was significantly different in each layer depth. Data analysis using paired t-tests (Table 7) showed that the thickness of the peat layer was affected significantly on soil moisture.

The volumetric soil moisture at 10 cm depth varies from 24.16 to 68.79%, with an average of 44.31%. The soil moisture in this layer has the highest fluctuation as shown by the highest standard deviation (11.65%). At 20 cm depth soil moisture ranges from 37.84 to 68.64% with an average of 58.70%, showing a higher difference of 14.39% of soil water content compared to 10 cm depth. These soil moisture profiles would be correlated to air temperature (Table 8). The volumetric soil moisture at peat depth of 10 and 20 cm had significantly correlated, which were not applicable for the deeper peat layers. This explained that highest fluctuation of soil moisture content at the top peat layer was due to fluctuation of air temperature.

The peat in the agriculture area, based on continuous measurement, has a wide range of soil moisture from 0.2416 $m^3\ m^{-3}$ at a depth of 10 cm to 0.7107 $m^3\ m^{-3}$ at 30 cm. In comparison, the measurement at a depth of 10 cm, it showed that soil moisture in the agriculture area

Table 6: The range of volumetric soil moisture in different peat layers

Depth of peat layer (cm)	Range of soil moisture (% vol)	Average of soil moisture (% vol) at p = 0.01
10	24.16-68.79	44.31±11.65
20	37.84-68.64	58.70±8.81
30	44.76-71.07	65.69±7.71
40	59.57-70.55	69.21±2.35

Table 7: Paired t-tests of volumetric soil moisture in different peat layer

Depth of peat layer (cm)	Paired differences Mean	Std. deviation	Std. error Mean	99% confidence interval Lower	Upper	t-value	df	Sig. (2-tailed)
40-30	0.0531	0.0549	0.0009	0.0507	0.0555	56.837	3459	0.000
40-20	0.1299	0.0578	0.0010	0.1274	0.1324	132.235	3459	0.000
40-10	0.2985	0.0671	0.0011	0.2956	0.3015	261.820	3459	0.000
30-20	0.0768	0.0270	0.0005	0.0756	0.0780	167.356	3459	0.000
30-10	0.2455	0.0450	0.0008	0.2435	0.2474	321.061	3459	0.000
20-10	0.1686	0.0312	0.0005	0.1673	0.1700	318.184	3459	0.000

Table 8: Summary of correlation between volumetric soil moisture and air temperature

Depth of peat layer (cm)	Statistical parameters	Air temperature at p = 0.01
40	Pearson correlation	-0.003
	Sig. (2-tailed)	-0.864
	N	3460.000
30	Pearson correlation	-0.015
	Sig. (2-tailed)	0.376
	N	3460.000
20	Pearson correlation	-0.081**
	Sig. (2-tailed)	0.000
	N	3460.000
10	Pearson correlation	-0.078**
	Sig. (2-tailed)	0.000
	N	3460.000

**Highly significant

ranged from 0.326 to 0.367 $m^3 m^{-3}$, which was higher than the natural forest (0.175 $m^3 m^{-3}$) and regrowing forest (0.216 $m^3 m^{-3}$) (Hatano *et al*., 2004). It was stated that land use clearly influences the gravimetric field water content of peat because in pristine forest of Central Kalimantan, Indonesia, it was 574% and significantly higher compared to clear cut peat forest (203%), cultivated peatlands (438%) and burnt peat forest (305%). Temperature only affects soil moisture to a depth of 20 cm below the surface.

The moisture condition of peat soil has an important role in soil management since most physical characteristics are related to the moisture conditions. Soil moisture in peat soil directly influences the degree of subsidence, pore geometry, buffer capacity and soil thermal characteristics (Bouman and Driessen, 1985). Soil moisture has a significant role in carbon balance. The emission rate of CO_2, for example, depends on the moisture condition (Jauhiainen *et al*., 2002; Toyota and Okazaki, 2004). For the tropical peatland of Central Kalimantan, Indonesia, it was found that the largest CO_2 emission occurs at water content of 65% in both natural and re-growing forest while, in the burnt area, it takes place with a water content of 85%. In addition, based on the work of Hatano *et al*. (2004) and Morishita *et al.* (2004) in the same region, in addition to soil moisture positively affects methane flux, but has only a moderately significant correlation with NO_2 flux.

CONCLUSIONS

Result of this study reveals that daily and diurnal temperature fluctuations have confirmed the significance of forest or vegetation cover to reduce the temperature. The loss or changes of vegetation cover in peatland was strongly shown to influence the peat surface temperature. In turns, these affected soil moisture content within the peat where the top layer was significantly correlated to temperature fluctuation.

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