THE EFFECTS OF CLIMATIC VARIATIONS ON PEAT SWAMP FOREST CONDITION AND PEAT COMBUSTIBILITY[1)]

(*Pengaruh Variasi Iklim Terhadap Kondisi Hutan Rawa Gambut Dan Kemampuan Terbakar Gambut*)

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ABSTRAK

Studi tentang pengaruh variasi iklim terhadap kondisi hutan rawa gambut dan kemampuan terbakar gambut ini dilaksanakan di Hutan Simpan Sungai karang, Tanjong Karang, Selangor, Malaysia. Tujuan dari studi ini adalah untuk menentukan: 1) Variasi iklim di daerah penelitian , 2) Pengaruh variasi iklim terhadap kondisi hutan rawa gambut; 3) Kemampuan terbakar gambut dan faktor-faktor yang mempengaruhinya; dan 4) Pengaruh kebakaran hutan terhadap kondisi hutan rawa gambut. Studi ini dilakukan di kompartemen 127 selama dua periode, yaitu: Oktober 1999 sampai Januari 2000 dan Mei 2000 sampai Oktober 2000, sementara, studi tentang pengaruh kebakaran dilakukan di kompartemen 132 dari Oktober 1999 sampai dengan Januari 2000.

Studi ini mengklasifikasikan musim kemarau dan musim penghujan sebagai periode dengan curah hujan bulanan berturut-turut kurang dari atau sama dengan 125 mm dan lebih besar dari 125 mm. Daerah penelitian memiliki dua periode kering, yaitu: Januari, Februari, dan Maret sebagai periode pertama dan Mei sampai Agustus sebagai periode kedua. Secara statistik, musim berpengaruh pada kadar air, bulk density, potassium, magnesium, sodium dan tinggi muka air. Dengan menggunakan prediksi curah hujan mingguan, kadar air kritis dari lahan gambut terhadap kebakaran adalah 355 %.

Tingkat Keetch Byram Drought Index (KBDI) yang tinggi terjadi pada tahun 1999/2000 sebanyak dua kali, yaitu pada tanggal 25 dan 26 April 2000. KBDI dapat digunakan untuk memprediksi kadar air dan tinggi muka air di areal penelitian. Berdasarkan luas areal yang terbakar, kedalaman gambut yang terbakar dan warna abu, kebakaran hutan yang terjadi pada tanggal 9 Agustus 1999 merupakan kebakaran dengan intensitas yang rendah. Walaupun demikian, kebakaran hutan tersebut memberikan dampak penurunan Konduktivitas hidrolik (hydraulic conductivity) dan kandungan magnesium serta meningkatkan potassium dan sodium.

Keywords: climatic variations, peat swamp forest, forest fire, peat combustibility

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INTRODUCTION

Organic and peat soil in Malaysia covered about 7 % (2.4 million ha) of the land area of which about 0.8 million ha in Peninsular Malaysia, 0.2 million ha in Sabah and 1.4 million ha in Sarawak (Paramanathan *et al*., 1984). However, peat area in Malaysia, as in many other countries, has declined due to forest clearance and other developments. It is estimated that the rate of loss of the land was about 23,000 ha per year in the last two decades (Appanah, 1997). According to National Forest Inventory 3 (NFI 3) carried out by the Forestry Department of Peninsular Malaysia, peat swamp forests in Peninsular Malaysia covers an area of 444,680 ha (Mohd. Jinis *et al*., 2002).

Peat swamp forest plays a very important role in maintaining environmental balance. It prevents flooding during wet season and releases moisture back to the air during dry season. However, peat swamp forest is also a fragile ecosystem. When the forest is cleared, the exposed peat will dry out quickly and catch fire easily. Once this happens, the fire smoulders deep in the earth for a long period. It is nearly impossible to extinguish. Therefore, among forest fire types, peat fire is the most dangerous type.

In South East Asia, forest fire has become more common and has destroyed large forest areas since the last few decades. The forest fire mainly occurred in Indonesia and Malaysia. Fire episode in 1997/1998, has destroyed more than 10 million ha of forest and land in Indonesia (Saharjo, 1999), whereas, about 3,225 ha of forest area burned in Peninsular Malaysia during that period (Samsudin *et al*., 1999).

Undoubtedly, the 1997/1998-fire episode was worsened by the occurrence of peat fires. The transboundary haze pollution was mainly contributed by some clusters of peat fires in Indonesia particularly in Sumatra and Kalimantan. In 1998, about 99.1 percent of the forest fire in Malaysia occurred in peat forest areas while less than one percent occurred in ordinary forest areas with alluvial and laterite soils including oil palm plantations (Ainuddin and Saidy, 1998).

On the other hand, climatic factors have strong influence on forest fire occurrences and behaviour, particularly the occurrences of drought which are coincided with the ENSO (El Nino Southern Oscillation) phenomenon (Anonymous, 1998, Lee *et al*., 2000). Moreover, several studies (Buckley, 1992, Weise and Biging, 1996, Mori *et al*., 1999, Saharjo, 1999, Gomez-Tejedor *et al*., 2000) found that climatic factors influence fire behaviour strongly in terms of ignition, flame development, fire spread and smoke. In addition, fuel characteristics including fuel type, material content, intrinsic character, compactness and fuel moisture content are also influenced by climatic factors (Rice and Martin, 1985, Johansen, 1985, van Wagtendonk and Sydoriak, 1985, Saharjo, 1999).

In contrast to the importance of the peat swamp forest and the dangerous threats on the forest, there were few studies on peat fire conducted in tropical areas. Therefore, an integrated study on peat fire characteristics, behaviour and management is necessary to provide fundamental knowledge on controlling peat fire.

The study aims to determine: climatic variations in the study area, effects of climatic variations on peat swamp forest condition, peat combustibility and effects of fire on peat swamp forest condition.

METHODS

Study area

The study area located in the Sungai Karang Forest Reserve, Tanjong Karang, Selangor, between 3^o 25' N and 3^o 35' N and longitudes 101^o 10' E to 101^o 25' E, is approximately 36,655 ha (Figure 1). Together with Raja Musa Forest Reserve, Sungai Karang Forest Reserve was constituted on 18th January 1990 under Section 7 of the National Forestry Act (Adoption) Enactment 1985 by the Selangor State Government (Razani and Jalil, 1997). Before, they were state lands and have been logged selectively over 50 years ago. They are managed by the Pantai Klang District Forest Office.

Twelve sample plots were established in the burned (compartment 132) and unburned (compartment 127 and 132) areas. Forest fire in August 1999 destroyed about 2 hectares of the peat swamp area in compartment 132.

The study was conducted during two periods, namely: October 1999 to January 2000 (first period) and May 2000 to October 2000 (second period).

Methods

Climatic variations included classification of dry season and wet season in the study area, water balance and drought index. Multivariate cluster analyses, Climatic water balance of Thornthwaite and Mather (1955) and Keetch Byram Drought Index (KBDI) (Keetch and Byram 1988) were applied to determine the climatic variations. A-thirty years climatic data on rainfall and temperature was used in the analyses of season and water balance. Whereas, daily rainfall and maximum temperature for 1999-2000 were used for KBDI.

To observe the dynamic of peat swamp forest condition during the study period, several peat swamp forest condition including, moisture content, pH, bulk density, heat capacity, ash and organic matter contents, inorganic content, hydraulic conductivity and water level were measured.

Sample plots or stations were determined purposively based on the technical accessibility and the representation of condition of the sites. Twenty meters in distance of four stations as core and piezometer sites were established systematically based on the transect line which perpendicular to the small canal on burned (BA) and unburned areas (UA I and UA II).

Samples were taken at five different layers, 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm and were analysed for moisture content, pH, organic content, ash content and inorganic content. Sample for bulk density and hydraulic conductivity were taken at 5 cm and 30 cm depth. Each segment or various depth samples were then sealed in labelled polyvinyl bags for transport to the laboratory. The soil samples were taken fortnightly and analysed by using standard laboratory methods.

Storage of water in the soil was monitored by the measurement of the elevation of the water table. Four dip well of 3 m in depth and 20 m in distance were dug along the established transect in burned as well as in unburned areas. The 5 cm in diameter PVC tubes with small holes every 5 cm were placed in the dip wells as piezometers of which 30 cm of the PVC upper part emerged above the ground. The water levels were then measured fortnightly by using small torchlight fastened to the measurement tape.

Univariate data analyses were applied to determine the effects of climatic variations in term of season and the effects of forest fire on peat swamp forest condition.

Peat combustibility was approached by measurement of heat content and combustion rate of the peat. Bomb Calorimeter (IKA-calorimeter system C 5000 control) was used to measure heat content of the peat soil samples. Combustion rate of the peat was measured by using methodology applied by Frandsen (1997). A combustion test box sized 10x10x5 cm for inside dimensions was used to simulate lateral smouldering spread of peat samples. The source of ignition is an electrically powered ignition coil located inside the box, midway between the top and bottom of the sample.

The soil samples were prepared in various moisture content by drying them in the oven in various period of drying. The moisture content and weight variability of the samples were measured. In term of sample volume dimension, sample weight was used to obtain combustion rate as the difficulties in preparing cubical sample. To observe the influence of inorganic content to fire behaviour, the addition of Silica (SiO_2) was applied in various levels of 2.5, 5, 7.5, 10, 15, 17.5, 20 and 22.5 %. In total, there were about 150 samples analysed for this test.

The relationship among various peat characteristics (moisture and inorganic matter contents) and variation in combustion rate were obtained using regression analyses.

RESULTS AND DISCUSSIONS

Climatic variations

Climatic variability, in consequence, leads to the concept of climatic "normal" that is an average of climatic elements over at least 30 years (Robinson and Henderson-Sellers 1999). Moreover, it was explained that this long period was sufficient to smooth out the small-scale, year-to-year fluctuations and thus provide a time measurement of the climate. Therefore, climatic variability is the departure from supposedly "normal" conditions that often provide great insight into climatic processes, as well as having the greatest human impacts. Today, to most people, the climate is described by the monthly normals of average temperature and total rainfall.

The climatic normal had been established in this study and may be used for analysing any climatic departures (abnormality). Table 1. presents the climatic normals for rainfall, temperature and relative humidity.

Table 1. Climatic normals for Tanjong Karang, Selangor

Climatic factors	Number of observation day	Mini mum	Maxi mum	Mean	Standard Deviation
Rainfall (mm)	372	7	505	148.9	88.3
Maximum temperature (^{o}C)	372	28.3	33.9	31.1	0.8
Minimum temperature (^{o}C)	372	20.8	25.2	23.1	0.6
Relative humidity (%)	372	58	96	77.4	6.6

To analyse the effects of climatic variations on peat swamp forest condition, the study defined season based on cluster analysis of the rainfall. Cluster analysis is defined as a group of multivariate techniques whose primary purposes is to group objects based on the characteristics they possess. It classifies objects so that each object is very similar to others in the cluster with respect to some predetermined selection criteria. The resulting clusters of objects should then exhibit high internal (within-cluster) homogeneity and high external (between-cluster) heterogeneity (Hair *et al*., 1998).

Results from cluster analysis shows that the rainfall distribution in the study area can be grouped into two classes, namely: dry and wet season. The cluster centres are 124.9 mm and 323.5 mm for dry and wet season respectively. Based on the cluster centres, the study defined dry season as a period when monthly rainfall is similar or less than 125 mm and wet season as a period when monthly rainfall is greater than 125 mm.

The departure of rainfall 'normal' sometimes occur within a year in an area. The lack of rainfall received by an area is associated with the term 'drought' in general. According to Pyne *et al*. (1996), drought period is an interval of time, generally of the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply.

In monthly basis, drought occurrence can be assessed by annual moisture budget of Thornthwaite and Mafter (1955) which is based on three variables, namely: monthly rainfall (P), potential evapotranspiration (PE) and actual evapotranspiration (AE). Table 2. presents climatic water balance for the study area. It indicates that the long-term (1968-1998) annual rainfall at Tanjong Karang was 1787 mm and 1700 mm were lost to the air (AE). This make a total water surplus of 207 mm in 2 months (November and December). The annual PE (Potential evapotranspiration) was 1866 mm, 166 mm greater than AE. The 166 mm water deficit occurs in seven dry months (January, February, March, May, June, July and August). The total water utilization was 164 mm in the same period. Rainfall exceeded PE from September to December. However, water surplus did not occur until the last few days of the year. The excess of rainfall was used to replenish the soil water utilized by AE.

Table 2. The long-term (1968-1998) climatic water balance (millimeters) for Tanjong Karang, Selangor

Month	P	PE	AE	Moisture deficit	Utilization	Recharge	Moisture surplus
January	127	146	139	7	45		
February	106	139	127	12	21		
March	137	161	152	9	15		
April	175	167	167			8	
May	121	175	149	26	18		
June	86	165	120	45	34		
July	99	160	120	40	21		
August	122	159	132	27	10		
September	155	150	150			5	
October	217	153	153			64	
November	243	144	144			88	155
December	199	147	147				52
Year	1787	1866	1700	166	164	164	207

Information on drought occurrences will be very useful in assessing forest fire risk in an area as a precaution in forest fire management. To simplify the utilization of drought information several type of drought index have been developed.

Drought Index is an important tool for fire potential assessment. Keetch-Byram Drought Index (KBDI) is one of the kind, which has been applied in many countries including Indonesia. It is a continuous reference scale for estimating the dryness of the soil and duff layers. It relates to the flammability of organic material in the ground (Pyne et al. 1996). The index is based on the calculation of several climatic factors, namely: annual and daily rainfall and maximum temperature that are available in every meteorological station.

Daily climatic data of Tanjong Karang in the period of January 1999 to October 2000 were analysed to build such KBDI for the area. KBDI of Tanjong Karang fluctuated with time (Figure 2). It ranged from 68 on 9 January 2000 to 1524 on 26 April 2000, from low to high stage. Based on the stage classification, the KBDI during the study period can be defined as: low (54.85 %), moderate (44.48 %) and high (0.67 %). The high stages were observed twice, namely on 25 and 26 April 2000 of that were the transition period towards dry season. The moderate stages were found from 2 to 9 February 2000, from 27 February to 24 April 2000, on 23 July 2000, and from 21 August to 18 September 2000.

As KBDI was constructed by climatic factors of daily rainfall and daily maximum temperature, the statistical analyses revealed that only rainfall has significant effect on KBDI. The model was established with moderate performance (R^2 = 0.50) when KBDI was related to weekly rainfall (RF). Hence, the following model is possibly used for prediction:

KBDI = 1169.13 – 8.143 RF (1)

Though KBDI was developed based on mineral soil moisture condition, it still can be a best tool when applied to peat soil condition.

The effects of climatic variations on peat swamp forest condition

Climatic variations play an important role in peatland formation, which is characterised by the accumulation of organic matter. The formation of peat as a result of the greater rate in producing and depositing of organic matter than in decomposing, is influenced by climatic variables such as rainfall and temperature. On the other hand, in their pristine state, peat swamp forests stabilize local climatic condition. Among the climatic factors, rainfall seems to play a major role in determining of peat characteristics in tropical condition. Therefore, this study merely focused on the effects of season (wet and dry) which reflects rainfall distribution and fluctuation on several peat characteristics and hydrological condition of peat swamp forest.

Climatic variations affected peat swamp forest conditions at various degrees. Statistically, season as a reflection of rainfall occurrence and distribution influenced several peat characteristics that of moisture content, bulk density, potassium, magnesium, sodium contents and water level. Moreover, rainfall was linearly related to moisture content. In summary, the descriptive of peat characteristics based on season are shown in Table 3.

Peat characteristics also varied with peat layers (Table 4) and distance towards the canal (Table 5). Statistically, peat layers influenced moisture content, pH, organic content, ash content, calcium and sodium contents significantly. On the other hand, plot or distance towards the canal affected moisture content, bulk density, pH, organic content, ash content, calcium and potassium contents. However, peat swamp forest condition are not influenced by single factor alone, the interaction among the independent factors of season, peat layers and distance towards the canal have significant effects to the peat swamp forest condition.

Table 3. Summary of mean peat swamp forest condition in different season in unburned area I (UA I) in Sungai Karang Forest Reserve, Tanjong Karang, Selangor

Peat swamp forest condition	Season		Effect
	Wet	Dry	
Moisture content (%)	363 ± 131	315 ± 95	Decreased
PH	3.46 ± 0.24	3.43 ± 0.22	No effect
Bulk density (g/cm^3)	0.18 ± 2.191E-02	0.20 ± 4.036E-02	Increased
Hydraulic conductivity (cm^3/s)	3.137E-02 ± 4.533E-02	2.673E-02 ± 1.352E-02	No effect
Organic content (%)	96.84 ± 1.38	97.09 ± 1.19	No effect
Ash content (%)	3.16 ± 1.38	2.91 ± 1.19	No effect
Calcium (ppm)	2018 ± 1691	2118 ± 1627	No effect
Potassium (ppm)	477 ± 334	309 ± 153	Decreased
Magnesium (ppm)	442 ± 152	544 ± 160	Increased
Sodium (ppm)	552 ± 240	490 ± 283	Decreased
Water level (cm)	-97 ± 26	-122 ± 23	Decreased

Table 4. Summary of mean peat characteristics at various peat layers in unburned area I (UA I) in Sungai Karang Forest Reserve, Tanjong Karang, Selangor

Peat characteristics	Peat layers				
	0-20 cm	20-40 cm	40-60 cm	60-80 cm	80-100 cm
Moisture content (%)	231 ± 49a	277 ± 60b	367 ± 84c	427 ± 113d	454 ±130d
pH	3.63 ± 0.29a	3.47 ± 0.20b	3.41 ± 0.19b	3.38 ± 0.19b	3.37 ± 0.20b
Bulk density (g/cm³)	0.18 ± 2.836E-02	0.19 ±2.949 E-02	not measured	not measured	not measured
Hydraulic conductivity (cm³/s)	3.256E-02 ± 2.709 E-02	5.231E-02 ± 1.152E-02	not measured	not measured	not measured
Organic content (%)	95.38± 1.47a	96.95 ± 1.0b	97.41 ± 1.07b	97.52± 0.83bc	97.27±0.97b
Ash content (%)	4.62 ±1.47a	3.05 ± 1.0b	2.59 ± 1.07b	2.48 ± 0.83bc	2.73 ± 0.97b
Calcium (ppm)	3779± 2305a	1987± 1467b	1526 ± 947b	1401 ± 819b	1522± 1054b
Potassium (ppm)	479 ± 412	443 ± 283	423 ± 252	441 ± 316	387 ± 244
Magnesium (ppm)	455 ± 159	477 ± 198	473 ± 147	470 ± 135	462 ± 158
Sodium (ppm)	304 ± 193a	453 ± 171b	590 ± 200c	653 ± 236c	686± 240c

* Mean are significantly different when standard deviations are followed by different letters ($p \leq 0.05$)

Table 5. Summary of mean peat swamp forest condition in various distances towards the canal in unburned area I (UA I) in Sungai Karang Forest Reserve, Tanjong Karang, Selangor

Peat swamp forest condition	Distance towards the canal			
	20 m	40 m	60 m	80 m
Moisture content (%)	299± 97a	333 ± 95b	393 ± 138c	379 ± 142c
pH	3.49 ± 0.22a	3.37 ± 0.20b	3.55± 0.28ac	3.39 ± 0.19b
Bulk density (g/cm³)	0.20 ± 2.383E-02a	0.19 ± 2.639E-02a	0.17 ± 2.913E-02ab	0.19 ± 3.08E-02a
Hydraulic conductivity (cm³/s)	2.752E-02 ± 1.269E-02	2.75E-02 ± 1.269E-02	2.77E-02 ± 1.309E-02	2.458E-02 ± 1.201E-02
Organic content (%)	96.91± 1.14a	97.29± 0.99a	96.24± 1.70b	97.19±1.17a
Ash content (%)	3.09 ± 1.14a	2.71 ± 0.99a	3.76 ± 1.70b	2.81 ± 1.17a
Calcium (ppm)	2616± 2064a	1766± 1194b	2248± 1922ab	1543± 1106bc
Potassium (ppm)	494 ± 403a	472 ± 255a	366 ± 264ab	408 ± 271a
Magnesium (ppm)	437 ± 171	473 ± 171	473 ± 127	489 ± 166
Sodium (ppm)	517 ± 237	585 ± 282	538 ± 272	507 ± 206
Water level (cm)	-109 ± 30	-109 ± 28	-96 ± 27	-99 ± 25

* Mean are significantly different when standard deviation are followed by different letters ($p \leq 0.05$)

By defining moisture content as dependent variable and climatic factors as independent variables or predictors, the statistical analysis suggested that only rainfall has a significant effect on moisture content. Therefore, peat moisture content (MC) can be predicted by weekly rainfall (RF) as presented by equation 2. The model has a moderate performance with $R^2 = 0.537$.

$$MC = 316 + 1.003\ RF \qquad (2)$$

Climatic variations may influence the inorganic content variations that are related to the water movement in the soil that affect the mobility of inorganic contents through the eluviations and illuviation processes. The eluviations process means the loss of material from the surface horizon, while the illuviation process means the gain of material by the subsoil horizon of which are influenced by the water movement. Besides, circulation of elements through plant growth and decomposition of organic matter (Barshad 1965) also contribute to the mobility of inorganic content.

Drought occurrence also influenced water level. Drought occurrence may cause lowering of water level due to the evaporation of the soil surface and transpiration of the vegetation cover, beside water up taking by the vegetation. Moreover, Gilman (1994) explained that during dry periods, the day-to-day decline in

Statistically, there was a relationship between water level (Y) and KBDI (X) with a moderate performance of the model (R^2 = 0.53). The following model suggested that KBDI can be used to predict water level of the peat swamp area significantly:

$$Y = -52.05 - 0.057\ X \qquad (3)$$

Furthermore, drought index is a useful tool in predicting forest fuel condition. This study observed that a best-fit for peat moisture content (Y) – KBDI (X) model is a non linear regression equation with R^2 = 0.55, as follows:

$$Y = 1555.99\ X^{-0.2289} \qquad (4)$$

Peat combustibility

Knowledge of variations in heat content of wildland fuel is important in predicting fire behaviour or assessing the combustibility of different fuel complexes. It explains how susceptible is the fuel to fire. Heat content also influences the fire's rate of spread. The higher the heat content of the fuel the more susceptible to fire the fuel will be. Furthermore, the forest fuel may produce high combustion heat to the environment. Hence, it may increase the flammability of the forest fuel.

Heat content is influenced by several factors in different manner. Among them are moisture content, bulk density or compactness of the fuel and chemical component of the fuels. The study revealed that heat content highly fluctuated with the moisture contents, it appeared to decrease with moisture content. The peat in the study area had high value of heat content, ranging from 7.133 KJ/g to 22.688 KJ/g (Table 5). This means that the peat soil is a good fuel and highly flammable. The minimum heat content was observed at the moisture content of 303 % and the maximum one was found at the moisture content of 11 %. Statistical analysis observed a direct relationship with relatively high correlation (79 %) between heat content and moisture content.

Regression analyses suggested that the model with heat content as a dependent variable and moisture content as a predictor observed a moderate performance (R^2 = 0.628). As such, the moisture content (X) may be used to estimate the heat content (Y) such as follows:

$$Y = 19.790 - 4.281E\text{-}02\ X \qquad (5)$$

The combustion test suggested that not only moisture content affect combustion rate of the peat when detail observation was conducted for different fuel texture. It was observed that the maximum combustion rate was found in the high moisture content.

Therefore, fuel texture may influence the combustion rate. The mean combustion rates in different textures are shown in Table 6.

Statistical analysis observed that fuel texture affected combustion rate significantly. The combustion rate of coarse fuel texture was significantly higher than those of mixed and fine fuel textures. However, there was no difference of combustion rates of mixed and fine fuel textures. The fine texture fuel which was found mostly in the high decomposed peat seemed to be more compacted and hold moisture content stronger than the coarse texture. Besides, the oxygen in the fine texture was less freely moving among the soil pores when compared with the coarse texture fuel. As such, the fire had more difficulty in consuming the fine texture fuel. In contrast, the coarse texture fuel which is commonly found in the surface peat layer (low decomposed) seemed to be looser that allow the oxygen supply more freely move and so the fire will be easily consume the fuel.

Table 6. Mean peat combustion rate at various textures in Sungai Karang Forest Reserve, Tanjong Karang, Selangor

Fuel textures	Combustion rate (g/min)	
	Mean	Standard deviation*
Mixed	1.04	0.57a
Coarse	2.31	0.81b
Fine	1.25	0.52ac

* Mean are significantly different when standard deviations are followed by different letters ($p \leq 0.05$)

Furthermore, the study observed no obvious trend of combustion rate when it was related to silica addition. Statistical analysis observed that the effect of SiO_2 addition on combustion rate can be modelled with Vapour Pressure Model (Figure 4.34). The model has a good performance ($R^2 = 0.74$). Therefore, the following model can be used to predict the effect of SiO_2 addition (X) on combustion rate (Y):

$$Y = \exp(2.32 - 4.21/X - 0.63 \, Ln(X)) \quad (6)$$

The effects of forest fire on peat swamp forest condition

Forest fires affect soil properties vary depending on many factors such as the type of soil, the moisture content of soil, the intensity and duration of fire, the timing and intensity of post-fire precipitation (Chandler *et al*., 1983), and the other properties of the fuel (Pyne *et al*., 1996). The consequences are physical, chemical and biological. The results seem to be different and vary from place to place. The effects of fire on peat soil is more serious than that of on other soil type, though, only a few studies have been performed on peat soil. The study on the effects of forest fire in Sungai Karang Forest Reserve is summarized in Table 7.

Peat swamp forests do dry during drought periods and when the water table recedes, and, as a consequence they become subject to fire occurrences. Fire can ignite the organic layers of these soils. Only rarely, however, will the soil body burn. The primary form of combustion in organic soils is smouldering. Fire typically burns in concentric patterns