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Particulate matter dispersion and haze occurrence potential studies at a local palm oil mill

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ABSTRACT: The emissions from palm oil industry through incineration and open burning are the major sources of air pollutions contribution in Malaysia. The consequence of increasing the particulate concentration, the particulate matter dissolves with vapour and grows into droplets when the humidity exceeds approximately 70% and causing opaque situation known as haze. This work focuses on the dispersion particulate matter from palm oil mill. Gaussian Plume Model from a point source, subject to various atmospheric conditions is used to calculate particulate matter concentration then display the distribution of plume dispersion using geographic information system. Atmospheric Stability, mixing height, wind direction, wind speed, natural and artificial features play an important role in dispersion process. Study on the dispersion of particulate matters and the haze potential are presented as a case study in this paper. The data obtained will be served as the purpose of modeling the transport of particulate matter for obtaining permits and prevention of significant deterioration to the environment.

Keywords: *Particulate matter, haze, gaussian plume model, stability, geographic information system*

INTRODUCTION

Malaysia has enjoyed one of the least polluted urban environments in Asia. The goal of achieving industrial country status by the year 2020 and the associated rapid economic growth have started to impose costs in terms of industrial pollution and the degradation of urban environment. Depletion of fisheries, air and water pollution, and contamination by industrial wastes become more serious in Malaysia in recent years. Among them, air pollution is the major issue that has been affecting human health, agricultural crops, forest species, and ecosystems. Only a few studies have been conducted on air pollution in Malaysia. Most of them are related to the 1997 haze episode. In most years, the Malaysian air quality was dominated by the occurrence of dense haze episodes. From July to October 1997, Malaysia was badly affected by smoke haze caused by land and forest fires. Previous incidents of severe haze in the country were reported in April 1983 (Chow and Lim, 1983), August 1990 (Cheang, 1991; Sham, 1991), June and October 1991 (Cheang, 1991), and August to October 1994 (Yap, 1995). The severity and extent of the 1997 smoke haze pollution were unprecedented, affecting some 300 million people across the region. From the record obtained from Headquarter of Department of the Environment (DOE), Malaysia, for the year 1993 to year 1998 in the whole Malaysia, it was found that emission of particulate from industrial processes source contribute the largest amount which took 76.1%, 85.5%, 64.7%, 59.5%, 35.2% and 54.2% respectively. During these six years, the highest amount of particulate emitted by industrial processes is in 1994, which derived from 85.54 percent of total particulates produced with value of 153,890 Metric tones. The second high emission of particulate comes from industrial fuel where palm oil mill grouped in. The percentages of total particulate emission recorded are 9.5%, 6.8%, 10.5%, 12.8%, 20.6% and 18.5% accordingly from year 1993 to year 1998 (DOE, 1999).

In Malaysia, at present more than 2.8 million hectares of land under oil palm cultivation. Table 1 shows the number of oil mills, refineries and palm kernel crushing factories in operation in 2001 in Malaysia. Palm oil industry is now the biggest biomass producer in Malaysia. Currently, most of these residues are disposed of through incineration and open burning. One of primary interest, the waste from the palm oil mills is utilized on-site to provide energy for the mills as well as electricity exports to the grid (Chuah, *et al*, 2006). Table 2 shows the typical chemical composition of oil palm

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residues. High carbon in these residual can be easily converted into particulate during the combustion process and caused air pollution. Previously, the particulates emission was obtaining serious attention by the local authorities as most of the palm oil refinery plants are established in the rural area, which is far distant around the country side. As time go on, the residential area developed gradually pass through the suburbs zone till its horizontal dimension (diameter of the urbanized area) vicinity to the industrial area. With the phenomenon of urban heat island, the emission of particulate matter from palm oil mill emission is only suspended within low-level turbulence thus far hinder the vertical motion for the pollutant dissipation. Under this blanket layer, the accumulated particulate matter will grow in size. Due to the moisture condition (normally over 70 percents relative humidity), the coagulated particles will start to scatter sun rays that subsequently impair visibility and causing opaque situation known as haze. Besides, particulate matter is damaging to the respiratory system of animals and human beings. From this point it is essential to study the daily particulate matter emission concentration from a single source and the area affected as it disperses. Also the ways meteorology conditions and physiographic influence its dispersion despite of identify area and under prevailing condition

Table 1: Number of oil mills, refineries and palm kernel crushing factories in operation

Region	Oil mills		Refineries		Crushing factories	
	No.	Capacity[a]	No.	Capacity[b]	No.	Capacity[c]
P. Malaysia	244	45,373,720	38	10,952,900	30	3,254,600
Sabah	89	18,750,600	9	4,596,500	8	1,057,500
Sarawak	19	3,620,400				
Total (Malaysia)	352	67,744,720	47	15,549,400	38	4,312,100

Source: Malaysian Palm Oil Board (www.mpob.gov.my)
[a] Tonnes FFB/year.
[b] Tonnes CPO/year.
[c] Tonnes Palm Kernel/year.

Table 2: Chemical composition of oil palm fiber and shell

Parameters	Fiber	Shell
Moisture %	36.40	16.40
Ash %	5.34	2.68
Carbon %	30.02	43.80
Hydrogen %	3.81	5.27
Nitrogen %	0.89	0.50
Sulfur %	0.19	0.17
Oxygen %	23.35	31.18
HHV (MJ/kg)	19.69	20.52

Source: Malaysian Palm Oil Board (www.mpob.gov.my)

where high concentration episode for example haze is likely to occur. Gaussian Plume Model is exclusively used to predict the concentration of particulate matter (Turner, 1994). Thus, in this study the model was used to determine particulate matter concentration and its effects to the surrounds of a palm oil mill in Dengkil Village, Selangor. In addition, Geographical Information System (GIS) was used in this study to model true characteristics of the actual geographical systems of Telok Datok area. Map overlay in GIS was used as a basic tool for spatial analysis. Overlay procedure is linking between different layer of thematic maps like topography, river etc to identify the downwind dispersion of particulate matter flow line and to forecast potential haze occurrence region. The data obtained will be served as the purpose of modeling the transport of particulate matter for obtaining permits and prevention of significant deterioration (PSD) to the environment.

MATERIALS AND METHODS

Source of emission

The site selected for investigation is a palm oil mill; located at 02°51' U latitude and longitude 101°39' E, which is 4 km from Kg. Dengkil of Telok Datok area in Selangor. This palm oil mill, situates 4 km from the Dengkil Village, is selected as the single emission source. The mill consists of a water tube boiler as main power source which generates 2.44 MW utilizing shell and fibre of palm oil as main type of fuels. The mill operates for 20 h daily and combust 6000 kg biomass every hour which emits 67.67 g/s carbon monoxide (CO) deem as particulate matter coal from exhaust stack. The Telok Datok Area is divided into 225 square kilometers area source, 30 squares (0.5 km) in the east-west direction and 30 squares (0.5 km) in the north-south direction. At the right bottom of Telok Datok Area is the border of State Negeri Sembilan. This covered 36 squares area consists of District Labu and District Port Dickson of State Negeri Sembilan. It is approximately 1 km to the site and operating in large mode for processing palm oil too. Fig. 1 shows the topographical Distribution of Telok Datok area and point source locations in this study.

As emission source, it was considered a virtual stack with 36.63 m height, located in the site of a distance 4 km from the Dengkil Village with a CO emission rate of 6.767×10^7 µg/s. Discharge characteristics and palm oil mill design detail are shown in Table 3.

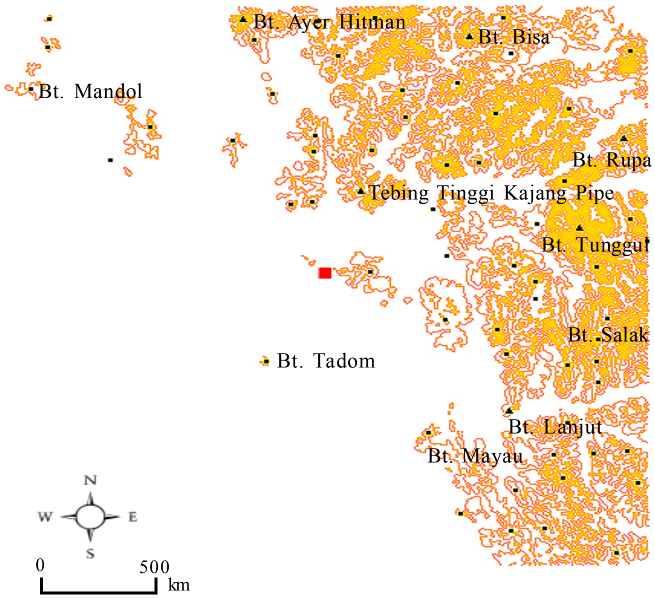

Fig. 1: Topographical distribution of Telok Datok area and point source location (indicated as red factory symbol)

Table 3: Discharge characteristics and palm oil mill design detailed

Parameter	Value
Stack height	36.63 m
Stack diameter	1.2 m
Flue gas exit velocity	17.1 m/s
Gas exhaust temperature	274 °C = 547 K
Operation design	Detailed
Equipment	Water tube boiler
Maximum boiler capacity	44,000 PPH = 19,950 kg/h
Operation duration	20 h
Fuel type	Fibre and shell
Fuel consumption	6,000 kg/h
Palm shell carbon content	52.4 %
Palm fiber carbon content	28.8 %

Data collection

The climatic data of KLIA Sepang Station from January to December 2002 is collected from MMS (Malaysia Meteorological Service) which consisted of dry temperature in degree Celsius, relative humidity in percentage, visibility code, surface wind direction in degree, surface wind speed in m/s, rainfall duration in minute, rainfall amount in millimeter, total cloud cover in octa and solar radiation in MJ/m^2. The design detail data of factory include stack height (m), stack diameter (m), gas exit velocity (m/s), boiler capacity (kg/h), operation duration (hr), fuel type and fuel consumption (kg/h). Fig. 2 shows the step to estimate the particulate matter concentration based on downwind distance in time step of 60 sec or 900 sec that the plume from the factory chimney will disperse and the potential haze occurrence in the affected area.

Gaussian plume model

A Gaussian plume model is used to relate outputs to inputs. In this modeling study, the input variables are the characteristics of pollutant sources (location, emission rate and stack height) and the meteorological conditions (temperature, wind velocity and direction). Output variables are particle concentrations (in this study). The concentration C (in units of µ g m^{-3}) at any point (x, y, z) is given by:

$$C(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z U}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-H_e)^2}{2\sigma_z^2}\right]+\exp\left[\frac{-(z+H_e)^2}{2\sigma_z^2}\right]\right\} \quad (1)$$

where Q is the pollutant mass emission rate in μg s^{-1}, U is the wind speed, x, y, and z are the along wind, crosswind, and vertical distances, H_e is the effective stack height given by the height of the stack plus the plume rise defined below. The parameters σ_y and σ_z measure the extent of plume growth and in the Gaussian formalism are the standard deviations of the horizontal and vertical concentrations respectively in the plume. Table 4 shows six atmospheric stability classes.

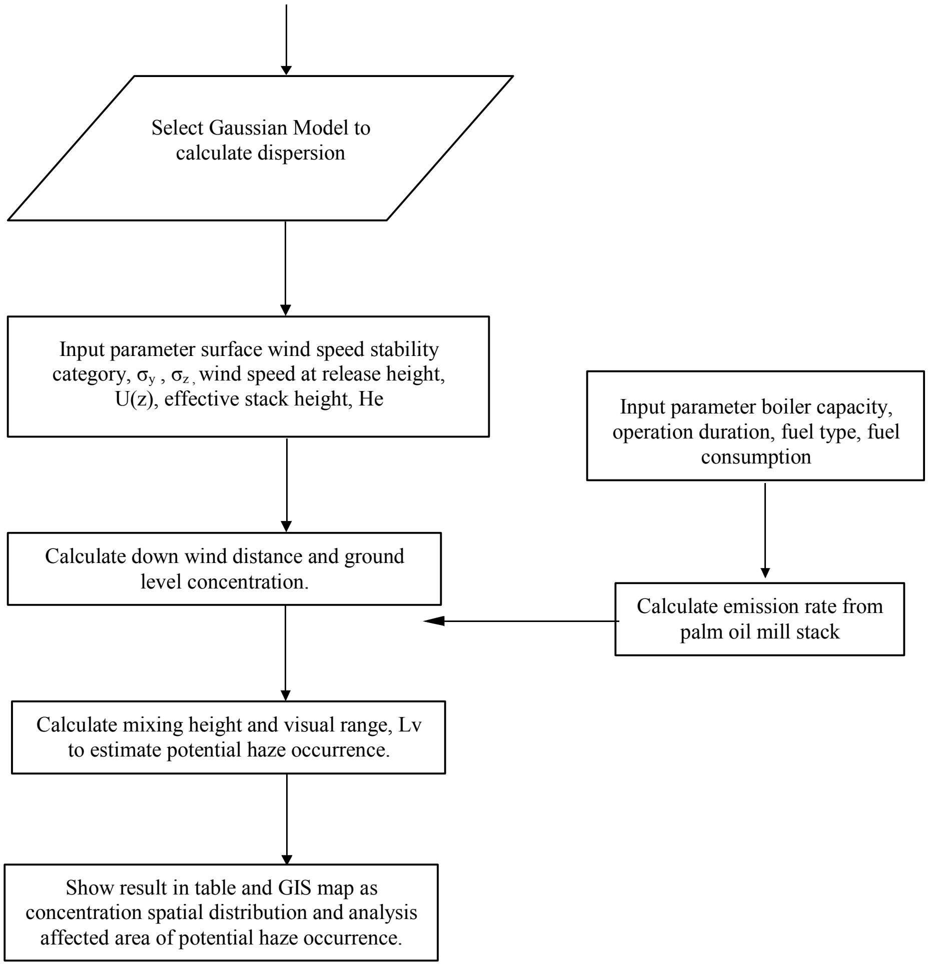

Fig. 2: Work flow of calculation downwind distance and its ground level concentration and estimation of potential haze occurrence

Table 4: Meteorological conditions defining pasquill stability categories

(U_{10}) Surface wind speed (ms^{-1}) at 10 m	Daytime sun, Incoming solar radiation			Night-time cloud cover, thickly overcast	
Class	Strong	Moderate	Weak	> ½ Low clouds (cloudy)	< $^3/_8$ Clouds (Clear)
< 2	A	A - B	B	G	G
2 – 3	A - B	B	C	E	F
3 – 5	B	B - C	C	D	E
5 – 6	C	C – D	D	D	D
> 6	C	D	D	D	D

Source: Turner (1994)
Notes: For A – B, take the average of values for A and B, etc.
1. Night refers to the period from 1 h before sunset to 1 h after sunrise.
2. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night and for any sky conditions during the hour preceding or following night as defined above

Selected case study month: April, 2002

A few selected daily variation of particulate matter concentration that affected by different atmospheric stability based on downwind distance is shown in Table 5. The wind speed in month of April ranges from 4 m/s to 19.5 m/s. The prevailing wind blow at velocity 6.5 m/s associated with dominant direction of South Western and South Southern Westerly. Most of the atmospheric stability is in Pasquill Category of D, almost involved 15 days of the month. Whereas for the atmospheric stability of slightly unstable (Class C) condition allocate 11 days of the month of April. Moderately unstable class B is only observed in day of 8, 20, 24 and 28 (not shown in Table 5).

The strongest wind speed (19.5 m/s) occurs in day 1 of April, the second strongest wind speed (15.5 m/s) happens in day 12 of April while the lowest wind speed (4 m/s) falls in day 20 and 25. When the wind speed e" 9 m/s, the plume will straight away spread out after emitting from the chimney without buoyant up to certain height that cause by inertia effect. Pronounced wind speed more than 9 m/s notice on day 1, 5, 7, 12, 14, 15, 22 and 23 of April.

The peak concentration is 256 µg/m^3 fall on 22 April 2002 under neutral atmospheric condition D with NNW (120°) wind, blow at rate of 11.5 m/s; disperse the plume of particulate matter over 1379 m down wind distance for the first 60 seconds reaching the swamp forest land. The second highest concentration is 215 µg/m^3 be found on 18 April 2002. Moderating wind (6.5 m/s) in NNE (70°) direction, traverse the effluent irregularly over slightly unstable class C ambient air towards 1140 m for the first 60 seconds. Fig. 3 illustrates the dispersion of plume and spatial concentration distributions on 29 April 2002, with the downwind position at step time of 900 seconds and 60 seconds, based on daily meteorological data included wind speed, temperature and the cosine of the difference angles for wind direction, obtained at Sepang Station. It is clear that dispersion rate is more depends on the condition of atmospheric stability than wind speed, as compare to cases in 22 April and 18 April 2002, the wind speed in day 22 is 5 m/s heavier than day 18 but the distance only gives small indifference figure of 239 m and the concentration too with little variant of 41 µg/m^3. Another unfavourable concentration (137 µg/m^3) exist on 7 April 2002, strong wind with speed of 11 m/s toward North Eastern (50°) way, with the lapse rate slight unstable, disperse the particle concentration to 1026 m after 60 seconds the plume drifting.

Study on the haze occurrence potential

When the worst meteorological conditions establish, immediately affected area and livings will be the downwind of the released stack. The worst case situation is when the highest concentrations are likely to occur especially during the period of light winds as described by the stability categories F and G. The assumption that category G will arise has been adopted as a representation of the worst case. It is difficult to decide what should be the height of the mixing layer in very stable conditions (Fisher and Newlands, 2000). Pasquill Stability category G normally appears in time near sunset (from 8pm – 9pm), during late night and early morning hour before dawn. Normally the hour will extend from 8 pm until midnight or early morning if it is calm, and cloud free night with less humidity where less wind minimized downward turbulent mixing of energy, less overcast nights tend to minimize absorption of thermal-IR energy by cloud drops and dry air minimizes absorption of thermal-IR energy by water vapor (Jacobson, 2002). The accumulation of contaminants depends on lapse rate in the temperature profile that defining atmospheric stability condition varies from stable and neutral or unstable. Radiation inversion can also strongly influence early morning pollution concentrations. Calm wind in speed of 2.0 m/s, 2.5 m/s and 3.5 m/s under isothermal atmospheric condition (slightly stable class E) and neutral atmosphere (Class D) towards East, North, South, North Easterly, South Easterly, East North-East and East South-East yields estimated ground level concentrations range from 491 µg/m^3 to 5663 µg/m^3 which fill up percentage of 40.92 % to 471.92 % for haze occurrence forecasting. Frequency of nocturnal radiation inversion below 150 m in height is Day 18 days for month of April. The total number episode days for generate 1 episode lasting at least 2 days (48 hours) is 4 each for April 2002 with the longest endure for 72 hours starting from 21 April to 24 April with the morning low ventilation coefficient range from 527.10 to 2070.40 m^2/s and weak transport wind speed of 2.45 m/s. The result is match with the observation of Abdul Razak (1993) study that inversion and isothermal atmospheric condition predominates during 1 AM to 6 AM throughout the year 2002. The atmospheric stability of extremely stable Class G and slightly stable Class E is interchanging during 1 AM to 6 AM is observed on 1 and 4 January, 8 April, 9 May, 11 and 12 June, 18 Sept as well as 20 October.

Table 5: Selected daily variation of particulate matter's concentration affected by different atmospheric stability based on downwind distance for time interval 900 sec and time interval 60 sec on April 2002

Day	Pasquill Category	Surface Wind Speed (m/s)	Wind Direction (°)	Downwind Distance (m)	Δ H (m)	Concentration (micro g/m^3)	L_v (km)	Percentage Haze Occurrence
1	C	19.5	NNW (110°)	6841.683		3	1600	0.25
	C	19.5	NNW (110°)	10262.524		1	4800	0.08
	C	19.5	NNW (110°)	13683.366		1	4800	0.08
7	C	11.0	NE (50°)	1026.777		137	35.04	11.42
	C	11.0	NE (50°)	2053.554		36	133.33	3.00
	C	11.0	NE (50°)	3080.330		17	282.35	1.42
	C	11.0	NE (50°)	4107.107		11	436.36	0.92
18	C	6.5	NNE (70°)	1140.280	19.972	215	22.33	17.92
	C	6.5	NNE (70°)	2280.561	19.972	52	92.31	4.33
	C	6.5	NNE (70°)	3420.841	19.972	25	192	2.08
	C	6.5	NNE (70°)	4561.122	19.972	16	300	1.33
22	D	11.5	NNW (120°)	1379.998	0	256	18.75	21.33
	D	11.5	NNW (120°)	2759.996	0	74	64.86	6.17
	D	11.5	NNW (120°)	4139.994	0	39	123.08	3.25
	D	11.5	NNW (120°)	5519.992	0	26	184.62	2.17
29	D	8.0	S (270°)	7200	15.207	27	177.78	2.25
	D	8.0	S (270°)	14400	15.207	10	480.00	0.83

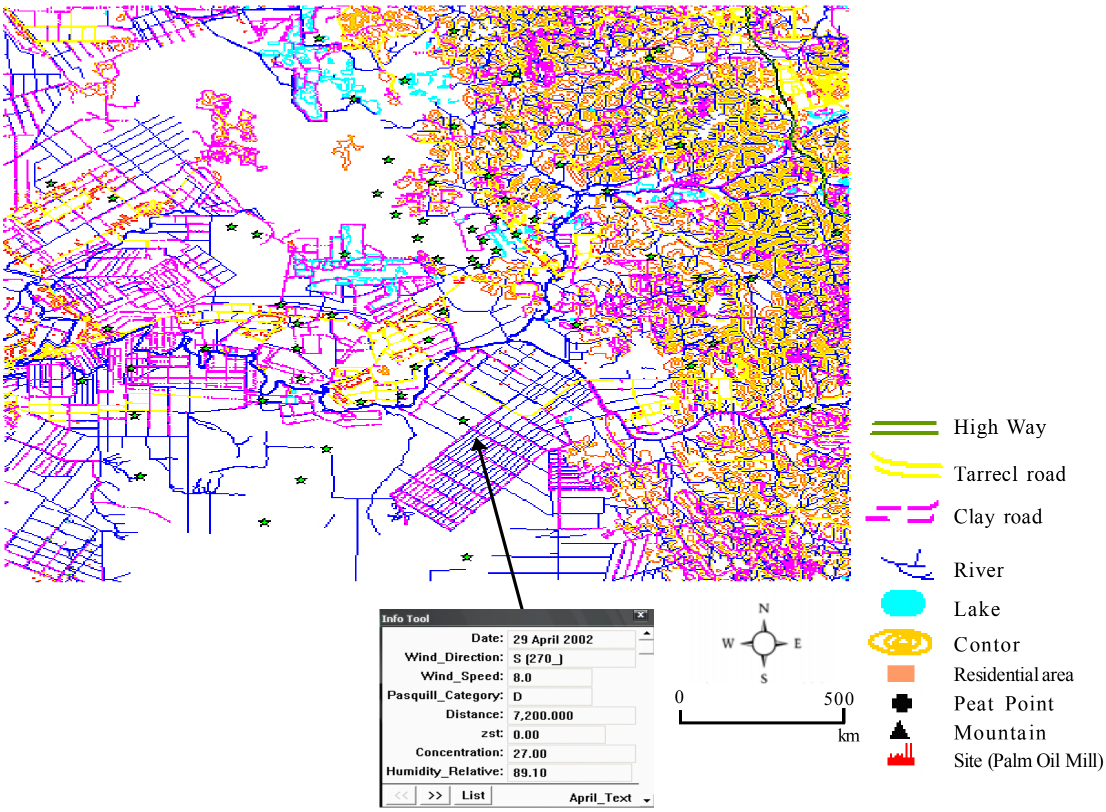

Fig. 3: The distribution of plume dispersion based on downwind distance for time interval 900 sec and time interval 60 sec on 29 April 2002

The ground inversions are usually formed at night, which preserved until sunrise when the wind speed is not high. The dangerous conditions are air stagnation characterized by very weak winds (0 – 1 m/s) and ground inversions (Son'kin, 1973). The totally inversion happens from 1 AM to 6 AM are notice on 6 March, 7 April, 10 May, 16 August, 19 October, 23 and 24 December 2002 with breeze blow at velocity 0.0 m/s, 0.5 m/s, 1.0 m/s and 1.5 m/s from various wind direction. During 11 AM to 2 PM, the atmospheric stability of moderately unstable class B and slightly unstable class C is prevailing with stability class C appears 14 days out of 24 study case day. The worst area adverse dispersion condition downwind of stack emission is situated at portions in between North and East with high terrain focused and densely populated area concentrated when the meteorological conditions favour haze occurrence. In fact, the information on the concentration of contaminants in the air contains a random component due to the nonperiodic fluctuations of the discharges and some other factors, and this can lead to a deviation from the established relationships (Son'kin, 1973).

From Table 5, derive the detail of climatic information that 18 April, 2002 is a windy and sunny day. NNE wind blow at moderate speed of 6 m/s. The relative humidity of the day is 80.8 % and there is precipitation from 3 AM to 7 AM. High humidity in the atmosphere hindrance plume from spread out widely. As represent in Fig. 4, it is expected 17.92 percentages that haze will occurs around 1140 m around North-North Eastern of Palm Oil Mill. This direction is a plain rural area and the residential area is located far 4561 m from site which is in the safety zone of very least percentage of 1.33 to experience hazy air.

Fig. 5 shows the downwind distance concentration for the plume emitted from the palm oil mill for whole April 2002. The concentration distributed in every direction and spread out farther from the stack emission represent that wind blows in various angular degrees with moderate speed during the whole month of April 2002.

DISCUSSION AND CONCLUSION

Spatially-referenced data of Telok Datok area are organized present, analyzed and interpreted to obtain relevant information useful for studying the particulate matter dispersion from a local palm oil mill. Variation in atmospheric stability will affect the concentration in the plume stream as it disperses along the wind direction. Influence various angular angles of wind direction to the downwind distance concentration is not significant though the difference are great in the initial stage.

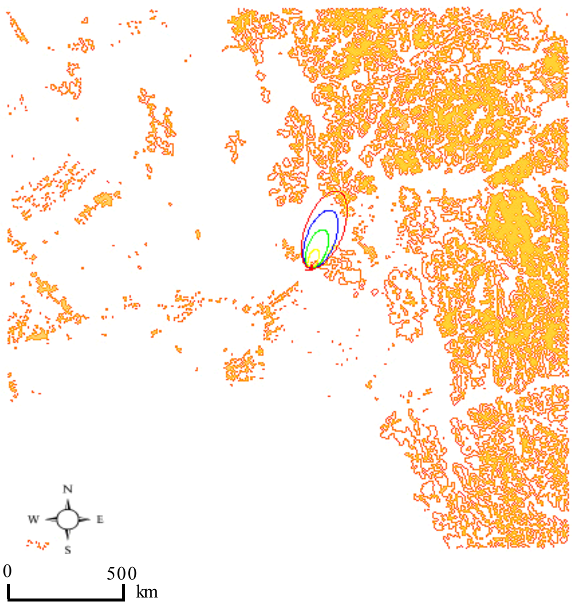

Fig. 4: Potential haze occurrence in the Telok Datok area on 18 April 2002

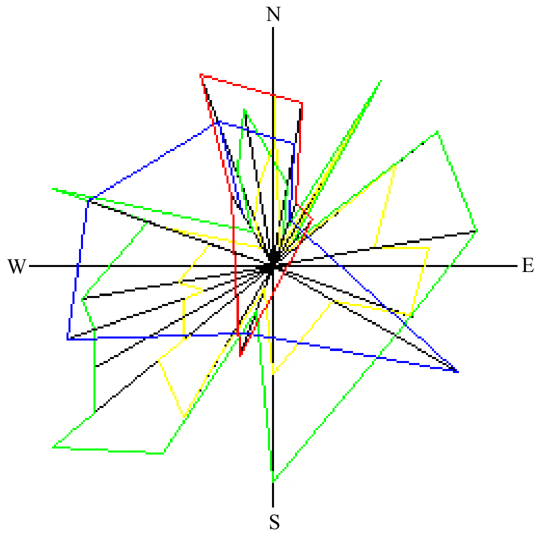

Fig. 5: Plots of downwind distance concentration versus azimuth with time of travel 900 sec (yellow line), 1800 sec (green line), 2700 sec (blue line) and 3600 sec (red line) for the continuous plume of effluent stretching from the palm oil mill on April 2002

Changing in wind speed of the surrounding will definitely alters the concentration in the centerline of the plume flow through horizontal mixing. The stronger the wind velocity, the lower level of the particulate matter concentration within the plume after 900 sec transverse will be. The process of converting data into information is the central to spatial decision making especially in understanding the variation of the particulate matter concentration while the plume disperse over high terrain, valley, internal water body, urban and rural area. The GIS display in the distribution of plume dispersion demonstrates a diverse range of information both spatially and attribute data can be successively integrated within GIS to generate outcomes that are potentially useful to decide potential haze occurrence area.

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