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RESEARCH ARTICLE

Biogeochemistry of Toxic Gas in the Aquatic Subsystem of Selected Peat Swamp Area in Kuala Pahang

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ABSTRACT - Peat land is formed by the accumulation of partially decomposed and undecomposed organic material such as mosses and plants under anaerobic waterlogged situation, it is considered as the most dominant type of organic soils that formed under wetland conditions through centuries. When dead plants are unable to decompose in the flooded environment, the aquatic subsystem in peat swamp area can be affected due to the chemical breakdown process slower than the production of biomass which forming the peat domes. Through this study, the biogeochemistry of toxic gases in peat land including Sulphur Dioxide (SO_2), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2) and Ozone (O_3) are analysed by using Aeroqual AQM 65 instrument. All the data recorded are then being converted into Air Pollutant Index (API) value which is recognized by Malaysia Ambient Air Quality Guidelines (MAAQG) is widely applied in Malaysia since year 1989 by using a specific mathematical formula. Moreover, the target study place is located at Kuala Pahang, Pekan where contains copious of peat swamp areas. The trends of biogeochemistry of toxic gases at peat swamp area for the past whole year are demonstratively reviewed through graphical representation in this context for identifying the air quality condition at peat swamp area.

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1. INTRODUCTION

Peat forest is a good place for tourism recreation and cultural heritage, land-based products and food provision and it acts as a biodiversity protection. The unique hydrology system in tropical peat swamp forests provides a critical shield against drought in the dry season and insurance against flooding during rainy season [1]. The peat soil is soft and very wet since it has wetland habitat growing on its surface where contains high water table near the surface of land. The accumulated peat soil layers are considered as a soft spongy substratum with low fertility, low bulk density, low bearing capacity and usually high acidity due to the leaching of organic compounds [2]. The partially decomposed organic matter which will form dome-shaped "ombrogenous" raised bogs which have ability to absorb and hold water by capillary forces [3]. Meanwhile, the raised bogs are fed by less nutrient precipitation as the nutrients were bought into the bog by surface and ground water [4].

Peatland can be described as a terrestrial carbon storehouse that stores huge amount of carbon in the plant biomass and necromass as known as the dead organism matters [5]. University of Leicester (2016) has briefly summarized six principle types of peatlands namely Blanket mires, Raised mires, String mires, Tundra mires, Palsa mires and Peat swamps [6]. As in Southeast Asia region, Malaysia is a high rainfall country which its tropical forests are considered as tropical peat swamp forest, estimated 11% out of world's tropical peatlands which are geologically formed less than 5000 years old as shown in Figure 1 [7]. According to Hamid, Z. A., 2019, 7.5% of Malaysia land is covered by peat soils which consists total land area for about 2.56 million hectares. Sarawak contains the highest percentage of peatland in Malaysia which is 1.7 million hectares (69 %), followed by Peninsular Malaysia 643,000 hectares (26 %) and lastly Sabah consists of 117,000 hectares of peatlands for almost 5 % [8].

Malaysia's peat swamp forests are critical and having variety of benefits for recharging groundwater, minimizing flood risk, preserving water supplies, providing forestry, fishery and other natural resources. Nowadays, several areas of peatland in Malaysia are experiencing self-ignition due to the dry weather during drought season which contributed to air pollution. Meanwhile, vast areas of peat swamps forest in Southeast Asia have been systematically cleared, drained and burned away in a rapid rate for the purpose of agricultural activities, construction settlement and economic development. The damaged peatlands are a major contributor for emissions of greenhouse gas as abundant of carbon dioxide gas is being released from peat swamp area [9] because the peatlands are the most efficient carbon sink and the largest terrestrial carbon storehouses on the planet [10].

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Figure 1. The distribution of peatland in Southeast Asia

2. LITERATURE REVIEW

2.1 Peat Swamp Forest

The natural peat swamp forest is existing in anaerobic condition, however, after the human actions of draining the peat lands, the peat becomes aerobic causing the decomposition takes place [11]. When the peatlands are drained, the partially decayed vegetation is being decomposed in the absence of oxygen gas, resulting in the emission of methane (CH_4). On the other words, methane gas is produced as a byproduct during the breakdown of plants debris in water saturated condition [12]. Drained peatland constitutes as a significant source of methane gas through the processes of methanogenesis and methane oxidation despite of releasing carbon dioxide gas. The methane gas is either remains at the surrounding of the peatland areas or being emitted to the atmosphere air as shown in Figure 2. Hence, peatlands are a natural main source of methane gas which is one of the significant greenhouse gases. The peatlands have been regularly drained, cleared, and large-scaled burned away for construction, recreational and plantation purposes. Human constructs drainage canal in peat forests for wastewater disposal, transportation of timber to possessing points on rivers and conversion to plantation for oil palm, wheat, rice and other vegetation. These anthropogenic actions not only alter the landscape, it can also disrupt the natural processes in peat swamp ecosystem and eliminate the globally-threated and range-restricted species of flora and fauna, which will eventually deteriorate the natural habitat of peat swamp forests causing environmental degradation. The worst example of land clearing for the purpose of rice paddy plantation is the Indonesia Mega Rice Project in year 1996. The project is planned to turn one million hectares of unproductive and sparsely populated peat swamp forest into paddy fields in Central Kalimantan [13]. Consequences, this area is suffering from extensive fire in order to clear the crop residues before the new farming process starts, and this process is indeed a true ecological catastrophe that causing serious haze and worsen the air quality at Southeast region for almost every year. In this scenario, the Earth System was in crisis as the uncontrollable environmental pollution will eventually defile any living creatures on the Earth [14].

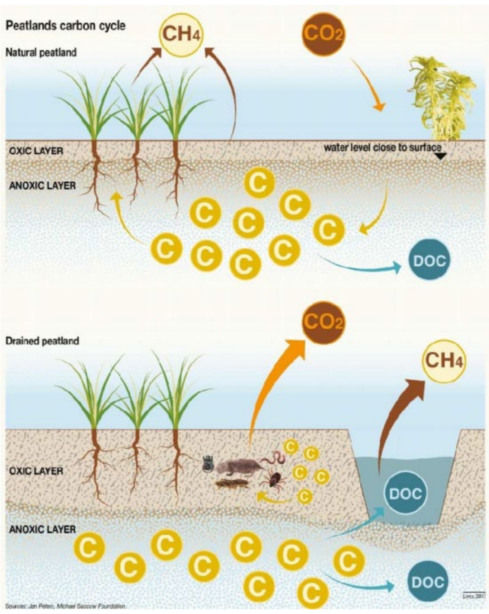

Figure 2. Carbon cycle in peatlands

2.2 Peat Forest Fires

According to the University of Leicester (2016), the exploitation and drainage of peat swamp forests will result in wildfires, land subsidence and disruption of worldwide carbon balance [15]. In contrast, the peatlands are originally function for regulating the release of greenhouse gases by storing abundant of carbon in the soil [16]. However, due to the overuse of peatlands, a surrogate measure of carbon dioxide will be diffused to the atmosphere causing health threat towards public and resulting in temperature arise and global warming [17]. In addition of the southwest monsoon wind, the peat fire spread is extensive and uncontrollable, as it can burn for a long period for days or weeks and even a year. This is because the fire is burning downwards into the thick layer of peat over a great range where are inaccessible to be protected by the rainfall. Initially, the oxygen is being limited to reach the organic material due to high water tables in peat swamp area. However, once the peatlands are being drained, the organic materials are exposure to oxygen again and thus increasing the risk of peat fires due to the release of long-term stable carbon storage [17]. The fires are smoldering deeply underground and it can burn millions of hectares in one day. Once the weather is favorable for fire burning, the fire still can ignite again especially during drought season [5]. Consequently, the drained peat soils are extremely flammable and easily to be burned unpredictably and the peatland fire is incredibly difficult and impossible to be extinguished. As a result, the peat wildfires diminish the natural resources and produce a hazy environment causing unhealthy air pollution level. Therefore, the Department of Environment (DOE) has raised concern to identify and closely monitor the peat swamp forests in order to prevent the happening of peatland fires [18].

2.3 Impacts of Air Pollution

Air pollution occurs when unnecessary additives enter the atmosphere air such as toxic gases, smoke and dust particles which will degrade the quality of air [19]. The sources of these pollutants can be viewed from the aspects of agricultural activity, industrial sector, construction project and emission of vehicles. Majority of farmers prefer the slash-and-burn method for the agricultural land clearances because it is effective and save cost. Furthermore, the industrialization is unavoidable for the development and advancement of a country. Those businessmen involved are focusing to gain profit without considering the results of negative impact caused by industrial activities. In consequences, the bad quality of atmosphere air will be a serious threat towards human health as it can cause short-term and long-term health effects. Despite of being dangerous to human health, the air pollution will lead to severely ecological effects and incurable environmental degradation.

Several health problems were being identified by World Health Organization (2018) in order to estimate the burden of disease from air pollution, and the results show air contamination is consistently ranking as the global top five risk factor for mortality and disability. The air pollution is one of the major contributors to global disease burden which can cause death as it is carcinogenic to human beings which is confirmed by International Agency for Research on Cancer (IARC) [20]. From the statistic of Institute for Health Metrics and Evaluation's Global Burden of Disease project, outdoor and indoor air pollution take a heavy toll on being the fourth highest leading risk factor for early death internationally and causing around 6.67 million death globally in year 2019 which are respectively 4.5 million deaths contributed by outdoor air pollution and 2.3 million died from indoor air pollution. In short, globalization and urbanization have impaired pristine environments and their ability to foster a healthy life.

The characteristic and behavior of peatland is focused in this study in order to determine the reason of self-burning issues. The reaction of toxic gases from air pollution with existing gases at peat swamp area is a main topic to be investigated. Determination on air pollutant concentration is important to monitor the API especially in peat swamp area.

3. METHOD

3.1 Study sites

The study area for determining the biogeochemistry of toxic gases was at Pekan in the Pahang state southeast region. Pekan is surrounded by one of the largest blocks of undisturbed mixed peatlands in Peninsular Malaysia with 90,000 hectares of peat swamp forest out from 230,000 hectares of total landscape (39.13%). The study site was selected at Pekan because peat forest experience peat fires in almost every year. The site was located at the main campus of University Malaysia Pahang al-Sultan Abdullah (UMPSA) at Pekan with coordinate 3.5437 °N, 103.4289 °E as shown in Figure 3(a). It has been labelled with "UMP Air Quality Monitoring Station" and located beside the weather station.

Several parameters were taken into consideration for selecting the location of air monitoring site to ensure the accuracy and correctness of data including logistical consideration, limitation of site access, security measures, power supply availability and telecommunication. The selection site was being avoid to be located nearby pollutants from local emissions such as motor vehicles, machinery generators, unsurfaced roads and nearby construction area or power generation boiler which will emit extraneous gases. The location of air monitoring site should not be neither distorted with air flow because the atmospheric condition such as wind pattern within the site would affect the data sampling, nor it should not be installed in adjacent to the buildings or bushes that will disturb the wind flow. The minimum degree of air flow must more than 120° for ensuring the air movement is uninterrupted in order to enhance the accuracy of data. A wise consideration for selecting the air monitoring site will contribute to a desirable outcome of air pollution monitoring.

Figure 3. (a) Study Area at Kuala Pahang, Pekan; (b) Aeroqual AQM 65

3.2 Air Monitoring Instrument

An air sensor technology namely Aeroqual Cloud is used to monitor the real time air quality data through internet. Aeroqual Cloud provides air monitoring infrastructure and air pollution measurement capabilities especially for emergency response, school and childcare safety, roadside vehicle emissions, industrial areas, mapping smog formation and distribution. It has different types of sensor-based air monitoring equipment such as outdoor air quality test kit, micro air monitoring station, urban air quality monitor and air monitoring station with integrated calibration. It can trigger alarms over SMS and email to the users whenever the air quality turns to unhealthy level.

The equipment used in this study is a continuous ambient air monitoring station namely Aeroqual AQM 65 as illustrated in Figure 3(b) which provides real time measurement of common pollutants to WHO air quality standards. The AQM 65 has a great demand among different units especially industrial operators, government environmental agencies and air quality consultants and researchers for the purpose of monitoring urban and national air quality networks. It can be implemented in research studies, consultancy projects, industrial perimeter monitoring and short-term monitoring of peatland hot spots. In addition, it is being utilized by the transport authorities for mobile vehicle-mounted monitoring, traffic information systems and other near road project of motorways and street canyons. The advancement of AQM 65 can be viewed from the aspects of measuring noise and meteorological parameters such as temperature, humidity, pressure, rainfall, wind speed and direction. It is mighty for possessing great and impressive strength to detect up to twenty particulate pollutants and different types of gaseous at the same time.

3.3 Air Pollution Level

In order to determine the air pollution level, Malaysia has adopted API in year 1996 for the ambient air quality measurement. This is to provide an easy and better understanding about air pollution to public with simple understood ranges of value to indicate the air pollution level. API is established with reference to Pollutant Standard Index (PSI) developed by the U. S. Environmental Protection Agency. Besides, it concludes a mean of reporting the quality of air instead of indicating the actual concentration of air pollution level as stated in Figure 4. Table below shows the API with its corresponding air pollution level.

API	AIR POLLUTION LEVEL
0 - 50	Good
51 - 100	Moderate
101 - 200	Unhealthy
201 - 300	Very unhealthy
301 - 500	Hazardous
500+	Emergency

Figure 4. API Standard

According to the Department of Environment (DOE), the API value is calculated based on average concentration of these pollutants in atmosphere air over a given period. The criteria air pollutants adopted in API system including SO_2, NO_2, O_3 and CO, PM_{10} and $PM_{2.5}$. Then, the value obtained is being standardized by using a specific mathematical formula as in Table 1-4 in order to produce a non-unitary value namely sub-index. Meanwhile, the dominant pollutant which means the highest relative sub-index will be considered as the API reading.

Table 1. Calculation for SO_2

Concentration	Equation for API
X < 0.04	API = conc. x 2500
0.04 < X < 0.3	API = 100 + [(conc. – 0.04) x 384.61]
0.3 < X < 0.6	API = 200 + [(conc. – 0.3) x 333.333]
X > 0.6	API = 300 + [(conc. – 0.6) x 500]

Table 2. Calculation for NO2

Concentration	Equation for API
X < 0.17	API = conc. x 588.23529
0.17 < X < 0.6	API = 100 + [(conc. – 0.17) x 232.56)]
0.6 < X < 1.2	API = 200 + [(conc. – 0.6) x 166.667]
X > 1.2	API = 300 + [(conc. – 1.2) x 250]

Table 3. Calculation for CO

Concentration	Equation for API
X < 9	API = conc. x 11.1111
9 < X < 15	API = 100 + [(conc. – 9) x 16.66667]
15 < X < 30	API = 200 + [(conc. – 15) x 16.66667]
X > 30	API = 300 + [(conc. – 30) x 10]

Table 4. Calculation for O3

Concentration	Equation for API
X < 0.2	API = conc. x 1000
0.2 < X < 0.4	API = 200 + [(conc. – 0.2) x 500]
X > 0.4	API = 300 + [(conc. – 0.4) x 1000]

4. RESULT AND DISCUSSION

4.1 Concentration Limit and API of Toxic Gases

Figure 5 demonstrates the trend of toxic gases from April 2019 until March 2020. From April 2019 until March 2020, the concentration of SO_2 was normally maintaining at 0.001 ppm until 0.005 ppm where the API was normally within the range from 2.5 until 12.5. However, there was a sudden rise of API on 29th July 2019 as the value of API is exceeded 100 and the situation is continued for two months long until 24th September 2019. The concentration values within this period exceeded 0.04 ppm as the limit value for human health protection under SO_2 category. The API values within this period were recorded more than 100 which indicate the unhealthy level for health concern. Despite from this period, the API values were maintaining less than 50 which is considered good and it has little or no risk to the environment and human health. Focus on 29th July 2019 until 24th September 2019, the SO_2 concentration value was abruptly increasing. The maximum API value within this period even reached to 128.5 with concentration of 0.114 ppm.

According to the results recorded by Aeroqual AQM 65 equipment, the lowest API of NO_2 was null on 2nd February 2020 whereas the peak API is 198.37, occurred on the 12th August 2019 and its concentration was 0.593 ppm. The concentration of NO_2 in Kuala Pahang is varied and changeable. As starting from April 2019, the API is maintained in good and moderate level but there was a drastic change happened at the beginning of August 2019 until the end of September, which the health concern for API turned to unhealthy level. Some of the concentration values exceeded 0.17 ppm as the limit value for human health protection under NO_2 category. Within the study period, the highest concentration value for CO was 0.708 ppm during 5th October 2019 which do not exceed the limit value recommended by MAAQG of 9 ppm. Meanwhile, the lowest API value was 0.01 during 14th May 2019. The API of CO for the past whole year was less than 50 which is identified as good level of health concern with the standard of API adopted by Malaysia. The pollutant concentration for CO category was safe to human health and the environment.

In the present study, the lowest concentration of O_3 for the past whole year is null at 25th September 2019. The highest value of O_3 concentration is 0.047 ppm was being 4 times recorded at monitoring station which were on 21st July 2019, 10th, 21st and 23rd March 2020. Meanwhile, the maximum API value for these four days is 47. The API value of O_3 is roughly consistent without any drastic change. According to MAAQG recommended by DOE, the limit standard for O_3 category is 0.10 ppm, and the results taken do not exceed the limit value hence it is generally not harmful to human health.

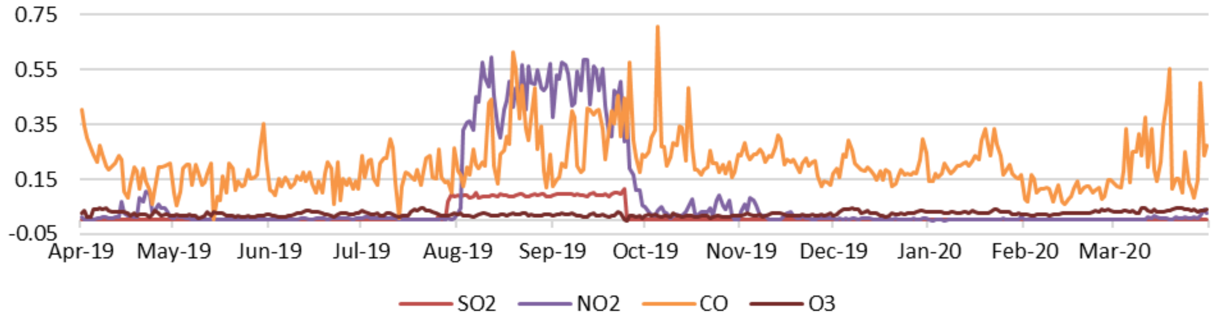

Figure 5. Concentration of toxic gases at peat swamp area

4.2 Air Pollution Index of Toxic Gases

API reading is important for monitoring the air quality as the standard of pollution is determined by WHO whose role as a credible and trusted global health authority. The higher API value is assumed to be unhealthy towards human health condition, especially the high-risk people who is having heart and lungs complications such as asthma. By observing the API value, we can understand the current or previous air quality in specific area as well as analyzing the trend of toxic gases. Figure 6 concludes the API value of air pollutants criteria in this study. It has been proven that the API of NO_2 and SO_2 are relatively high during the open burning season at Indonesia. Meanwhile, the lowest API contributor is CO. Despite of the period of transboundary haze, we can assume that the highest API contributor shall be O_3 in the event that the air quality in peat swamp area is not affected by transboundary haze.

The daily maximum value of API is selected by choosing the highest sub-index among six air pollutants. The daily highest relative sub-index is selected among the air pollutants as the maximum daily API value. According to Department of Environment, API value which exceeding 100 is considered as unhealthy level. There is around 18% of API exceeded 100 which is considered as unhealthy level whereas the major contributors are SO_2 and NO_2. Meanwhile, 6% of API within the range of 51-100 is categorized in moderate level of air pollution standard. And lastly, it is about 76% of API value less than 50 which is identified as good level of health concern with no risk to human health. There is around 18% of API exceeded 100 which is considered as unhealthy level, 6% of API within the range of 51-100 which is categorized in moderate level and lastly, it is about 76% of API value less than 50 which is identified as good level of health concern with no risk to human health.

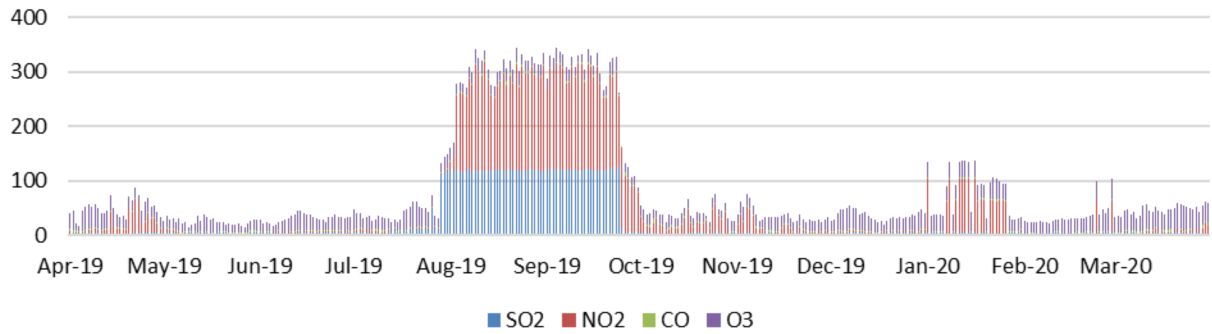

Figure 6. Air pollution index of toxic gases at peat swamp area

5. DISCUSSIONS

The increasing of NO_2 is assumed to be caused by the transboundary haze from Indonesia due to the slash and burn clearances of agricultural farms. As we all know, agricultural activity is essential in sustaining human life and it has been widely practiced as our source of food come. The agriculture industry is indeed a main economy driven to gain income since it is crucial in economic development. Majority of the population in Indonesia makes their living from agriculture activities as it could bring considerable income. Therefore, the agriculture practices have become an indispensable way for Indonesia farmers to bring considerable profit. Due to anaerobic condition in peat land, the organic matters keep decomposing day by day over millennia resulted in building up large carbon storage in peat swamp area. The vegetation and plantation in peat swamp areas will eventually accumulate as peat and lock up carbon dioxide absorbed from the atmosphere. In consequence, peat lands could store exceptionally high amount of carbon as peat as the carbon sinks into ground and remains locked in the soil. Considering the peat swamp area stay undrained, the carbon storage in peat land underground will remain in stable condition. If the peat land has been drained, it will react with oxygen and the microbes will be broken down and thus releasing the carbon into atmosphere air.

The reaction of sunlight with other precursor pollutants such as volatile organic compound and oxides of nitrogen (NO_x) is the major factor to produce O_3 under photochemical reaction. The presence of sunlight is steady throughout the past whole year because Pekan is located at the east coast area which is facing directly to the sunrise in every morning. Moreover, hot weather and drought season will increase the level of photochemical oxidants with the presence of winds and abundant of sunshine. Inhalation of O_3 can trigger a variety of health problems and reduce the lung function by damaging the lining of lungs. Despite of causing health problems, O_3 at ground level could destroy the natural ecosystems by damaging vegetation of plantation growth and productivity. During April until July 2019 and October 2019 to March 2020, SO_2 was almost remain unchanged with negligible vary and its amount is quite low compared to other toxic gases. Besides, NO_2 was also maintained below 0.05 ppm despite of the period of Indonesia haze event. It can be deemed that SO2 and NO_2 are steady and consistent for normal period at peat swamp area, in the event of no incident of forest fire. Compared to CO and O_3, the concentration values of SO_2 and NO_2 are relatively lower despite of the period of manmade biomass burning period.

Meanwhile, the concentration of O_3 is the most stable among all toxic gases as the graph shows gently fluctuation over the past whole year. The overall concentration of CO is higher except for the timing of forest fire event which was being overtaken by NO_2. The concentration limit of CO is unstable compared to the other gases. From the line graph, we can see that the concentration value of CO experiences ups and downs. WHO states that O_3 can be destroyed by the chemical reaction with NO_2 and then deposit into ground, and this statement is proven during July 2019 until October 2019, the concentration values of O_3 were becoming lower in contrast the concentration values of NO_2 were gradually turning higher during the same period. In summary, the trends of the SO_2, NO_2 and O_3 concentration limit can be predicted to be consistent and steady without forest fire ignition or other pollutant sources.

6. CONCLUSION

This paper demonstrates that long-term measurements at site are important to estimate the trend of different toxic gases to predict more precisely future changes in API value and the fate of peatlands under future climate scenarios. The analysis of data collected for one year led us to conclude that the concentration limit of SO_2, NO_2 and O_3 consistent and steady without forest fire ignition or other pollutant sources. On the other hand, the concentration limit of CO is unstable compared to the other gases, and it varies depending on the forest climates, in particular it is higher during the timing of forest fire event. These conclusions suggest that the air monitoring equipment is awaited to be installed worldwide for a better monitoring and controlling of Air Pollutant Index. Hence, the sustainable development is highly desirable for promoting a friendly environment especially improving the air quality. However, all citizens must take responsibility to prevent air contamination.

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AUTHOR CONTRIBUTIONS

C.S. Teoh, H.E. Eng: Data curation, Writing- Original draft preparation.

F. Ismail: Writing- Reviewing and Editing.

A.S. Abd Razak: Conceptualization, Methodology, Software.

S. Sulaiman: Supervision.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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