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FIRE RISK AND HEALTH IMPACT ASSESSMENT OF A MALAYSIAN LANDFILL FIRE

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ABSTRACT

Landfill fires are a growing problem for the environment and safety at the global level. In recent years, certain incidents of landfill fire have occurred in Malaysia, describing the need to assess the risk of fire ignition and its consequences in Malaysian landfills. The objectives of this study are to analyze the source of ignition for landfill fire in Malaysia using the Fault Tree Analysis (FTA) and to discuss the consequences of this fire using the BowtieXP. In addition, ALOHA software is used to assess the health risk impact of landfill gas emissions. The results of the analyzes helped to propose countermeasures to reduce the risk of fire in landfills. From the findings of this study, several causes of surface landfill fires have been found within Malaysia by using FTA such as flammable gas emission, combustible material, uncompressed residual waste, naked flame, smoking, and weather. The consequences of the landfill fire determined by BowtieXP software are negative effects on health due to emissions that can be toxic mostly, and forest fire. The concentration of seven gases emitted from landfill fires was tested using ALOHA software. The four gases CO, CO_2, NH_4, and CH_4 have recorded a high concentration in comparison with the air quality regulatory limits, which means adverse effect on health. At the same time, the rest of the gases namely NO_2, SO_2, and H_2S have shown lower concentration (ppm), mean null effect on health. Local government, environmental protection authorities and other regulatory bodies should work together with the management of landfill sites to make landfills safer for the community and the environment.

***Keywords**: ALOHA, Bowtie, Fault Tree Analysis (FTA), Health impact, Landfill fire, Malaysia landfill.*

1.0 INTRODUCTION

A landfill is a prudently engineered depression in the ground where burial waste is put into. Landfills were the most prevalent method of organized waste disposal. Open dumping is practiced in most cases and occurs at about 50 percent of total landfills. The purpose of constructing landfills for waste management is to avoid any liquid interaction between the waste and the environment, particularly underground aquafer [1]. Malaysia has a total of 297

landfill sites including existing and close landfill sites [2]. The number of landfills currently operating is 166, while the number of closed landfills is 131 [2].

In Malaysia, the current municipal management of solid waste cannot adequately handle the increasing volume and diverse composition of solid waste because of lack of resources or technical expertise [3]. Malaysian landfills are prone to fires during the drought and high-temperature season [4]-[5]. The source of the landfill fires is unknown and when the plastic burns, for example, it produces toxic gases, and this negatively affects people living near the landfill. Consequently, landfill fires possibly cause adverse air pollution dispersion to surround areas. Accidents on the landfill site are already happening. If not tackled, accidents will increase with potentially disastrous consequences. Landfill fires emit toxic gases that are harmful to public health and the environment, depending on the composition of the MSW. These emissions may pose a risk to human health, especially among vulnerable populations, such as the elderly, children, pregnant women, and people with pre-existing chronic respiratory conditions [6]. Other researchers used ALOHA software to analyze the gas emission data from the landfill [7]. FTA is an important method for analyzing the safety system [8]. The approach, therefore, starts with a top event, and works backward to the different scenarios that can cause the accident. We used the FTA for cause analysis, and to know the consequences of the landfill fire we used the Bowtie analysis. The research will focus on the causes of Malaysian non engineered landfill burning and the consequences that occur because of these fires using Fault Tree Analysis (FTA) and Bowtie Analysis. In addition, the focus will be on the effect of gases emitted from landfill fires on the health of workers and residents near the landfill area, the distance and the concentration of gases emission would be determined by using ALOHA software

2.0 METHODOLOGY

The research aimed to identify the source of fire ignition which leads to landfill burning by using FTA. Then, to determine the possible consequences of Malaysian landfill fire by using BowtieXP. After that, the health impact of gases released from landfill fire was assessed by using ALOHA software. Since this project relied on software simulator ALOHA, qualitative methods BowtieXP and FTA analysis, some of the parameters are needed. Also, some significant input data are collected to run the ALOHA software and analyze the results. All the data are accurate and taken from previous research papers and regional meteorological agencies. The study site was a landfill located in Gombak, Batu Caves, Selangor, Malaysia, (Latitude: 2.924295, Longitude: 101.757257). Malaysia has a great number of landfills which are surrounded by densely populated, urbanized, and the most industrialized areas in the country. As the center of administration, industrialization, commerce, finance, and culture, Malaysia is experiencing rapid population growth. Figure 1 shows the location of the landfill, which would be characterized in this study.

Figure 1 Location of the landfill for the study (Google Earth, 2020)

Some significant input data are needed to run the ALOHA software and for the analysis of the results. The atmosphere data were collected from reliable sources of meteorology and previous research papers presented in Table 1.

Table 1 Atmosphere input data [9, 10]

Parameter	Value	Unit
Atmospheric Temperature	30	°C
Atmospheric Pressure	Ambient	bar
Wind Speed	2	m/s
Humidity	90	%
Solar Radiation	1	kw/m2
Ground Roughness	Open Country	-
Inversion Height	No Inversion Height	-
Stability Classes	E	Pasquill Stability

The source strength was selected as a direct source, which is the most appropriate type in this case study available such as commercial software. The chemical and physical properties were based on the default of ALOHA Software. The site location was assigned in the geolocation of the landfill, and building type was selected as sheltered double storied as the same as the surrounded area of the landfill. The mass of the gas, release rate and duration were considered as a worst-case scenario due to the lack of available information from the landfill.

3.0 RESULTS AND DISCUSSION

This section contains the results of the methods, with the results explained separately for each software.

3.1 Fault Tree Analysis

Fault tree analysis is one of the proven techniques to assess the failure rate of different systems. Many researchers have used it to assess fire risk. In this study, the qualitative method of FTA was used. The top event identified here in this FTA was Malaysia landfill fire. Malaysian landfill fire initiated as any landfill fire worldwide. Malaysian landfill fire was a combination of fuel, Ignition, and air that is always present. There are three intermediaries' events, fifteen base events, and one house event included in the FTA analysis (Figure 2).

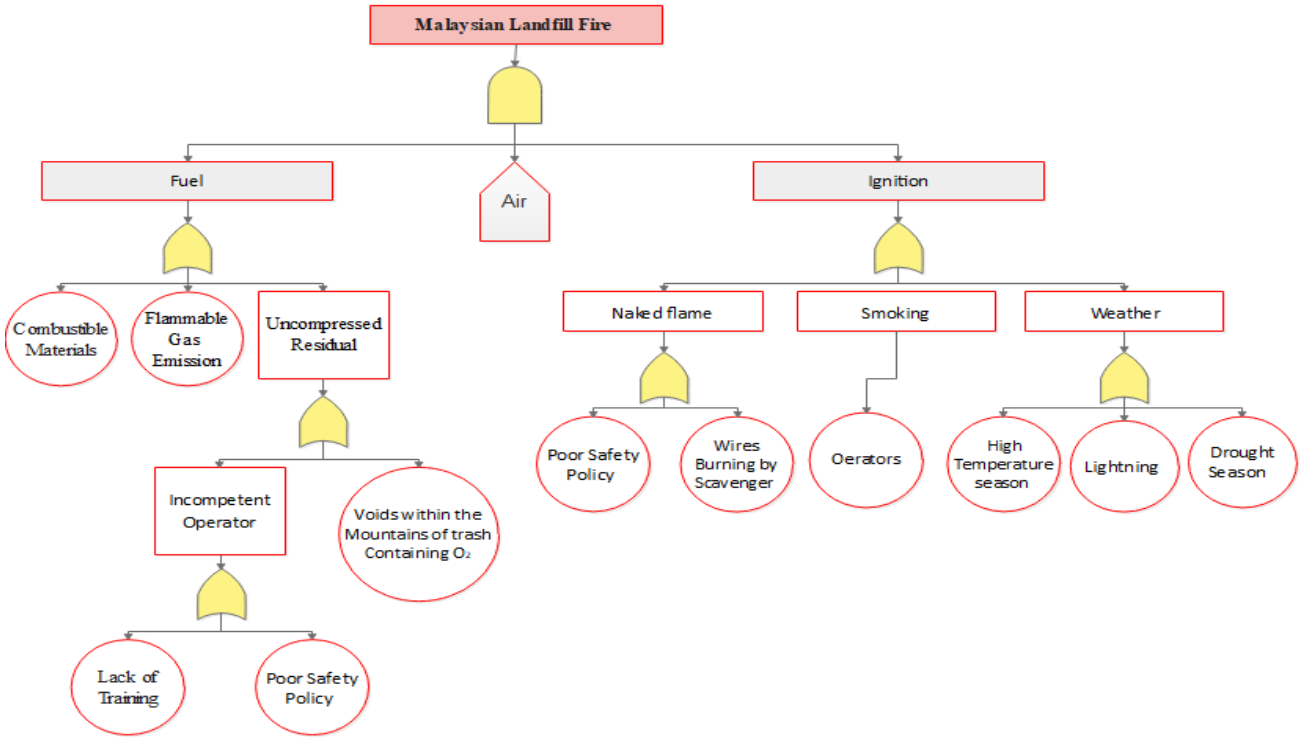


Figure 2 Fault Tree Analysis for Malaysian landfill fires

The fuel in the landfill fires comes whether from combustible material, flammable gas emission, or uncompressed residual. The combustible materials presented in the landfill are garbage composed of waste material. As it is composed of all these materials that means it can be the fuel of Malaysian landfill fires. The second fuel is flammable gas emission that researchers stated that the organic material has its decomposition reaction. in terms of landfill gas emissions, the major components of gases emitted were hydrogen sulfide, methane, and Sulphur dioxide [11]. Underground fires also can create large gaps in the landfill site, which can lead to cave-ins in the landfill site. In addition, flammable and poisonous gasses such as CO are produced [12]. Uncompressed residual is another significant fuel source for landfill fire. It happened because of an incompetent operator or void within the mountain of trash contained oxygen. The incompetent operator is because safety is not a priority for the landfill site manager and lacks the operator training that in some cases the operator does not know how to use the site vehicle probably. Landfill material when decomposed creates flammable gas and when the landfill has uncompressed material, there will voids of oxygen within the material and the mixture of the oxygen due to the voids and gases from uncompressed material together with heat can ignite the mountain of trash. This fire is called depth landfill fire. Moreover, voids can be produced due to earthquakes and weathering effects as rain [13].

Atmospheric oxygen can reach the waste mass through the exposed flanks and build up in a gap in the waste mass created by inadequate location or waste compaction. Under certain conditions, a stack effect can be produced which increases the amount of air entering the path [12].

Three methods lead the landfill fuel ignited, whether naked flames, smoking, or Malaysian weather. In naked flams happened when the scavengers burning the wires to extract the metal and poor safety policy inside the landfill. The major problem is that insufficient application of cover material causes odor from waste decomposition, smoke, and other danger from open burning, either spontaneously or done purposely by scavenger [11]. Smoking is the second important ignition source of landfill fire. There are many incidents in history, for instance, in Northampton shire, England, where surface landfill fires have occurred. The reasons cited by the operators and collected from the fire service records included smoldering waste received on-site and, smoking site personnel [12]. Staff and users at the dumpsite can trigger fires by careless smoking, which can trigger the combustion of waste. Spontaneous combustion of materials was also observed at the dumpsite [15]. Deliberate fires are sometimes used by the operator of the dumpsite to decrease waste volume. Landfills include refuse, such as waste from the trees, dry field, leaves, and branches. Such products are often intentionally set on fire to reduce the amounts of waste, minimize maintenance costs, and increase the operational life of a dumpsite [14].

Fires on the part of the landfill managers or users due to human error. Landfill operators and users may cause fires by reckless smoking which can start landfill fire. Furthermore, since some hazardous materials may ignite when mixed, operators must not pour reactive materials into the landfill [15]. Malaysia is a country with hot weather therefore in dry seasons, there can be excessive heat accumulated in the landfill causes fast ignition of combustible material.

Spontaneous combustion is caused by decomposition of waste and an increase in the oxygen content of the landfill, which is responsible for the rise in bacterial activity and temperatures, according to fire management in the United States. Those 'hot spots' able to encounter methane gas pockets and lead to fire [15]. In addition, lightning is a serious ignition source because thunderstorm is common in Malaysia and can start a fire in a landfill. In summer and late afternoons and early evenings, the fires began with lightning peak. For instance, the January 2006 West Virginia coal mine explosion, which took twelve lives, was the worst in America. In recent years, there are some fires started from lightning. Nine firefighters died in a helicopter crash in August 2008 when they were rescued from a California wildfire ignited by lightning [16]. Work by Cayan and Dettinger explain factors that apply to wildfire frequency, size timing, such as fuel availability, climate patterns, especially lightning, but also precipitation, wind, and humidity. They observe that at the hottest, driest times of the year, the fire season appears to begin and end earlier in the Southwest than the Northwest and the wildland fires are more common [17].

3.2 BowtieXP Analysis Result

Bowtie tool is used to explain the cause and effect of landfill fire in this study. The top event here in Malaysia landfill fire and the hazard is landfill fire. The following Figure 3 contains the result of the BowtieXP software analysis. Bowtie tool is used to explain the cause and effect of landfill fire in this study. The top event here in Malaysia landfill fire and the hazard is landfill fire. There are several threats identified in this bowtie that can cause the Malaysian landfill fire including combustible material, flammable gas emissions, uncompressed residue, incompetent operator, naked flames, smoking, and weather effects. The barrier is placed against each threat to prevent the fire from happening in the landfill. For uncompressed residue, the barrier is to compress the material fully. For an incompetent operator, training and strong safety policy is required that can help increase the skill level of the operator, and enforcement of the policy can help to make sure that safety is being comprised. A naked flame is another threat that can be prevented by using prohibition on entry to the suite by the scavengers who create fire to extract metals. Controlled access can discourage entry of such people. Smoking by the operators and visitors is another threat for landfill fire to happen. This should be controlled by policy and monitoring. Weather is another important parameter affecting the landfill fire and if lightning arrester is installed it can be prevented. The consequences of the landfill fire are identified as health impact and environmental impact. The people around the site of the landfill will be affected by the fire due to emissions that can be toxic. Health impact can be reduced by barriers like removal of toxic material before damping the material, provision of Personal protective equipment (PPE) to the operators, emergency evacuation plan for the community, and air monitoring for early warning. The forest fire is another important consequence of landfill fire which can be prevented by placing the site away from the forest and if there is a forest nearby, a fire break should be built is maintained. Furthermore, a good and immediate fire response can prevent forest fire from happening.

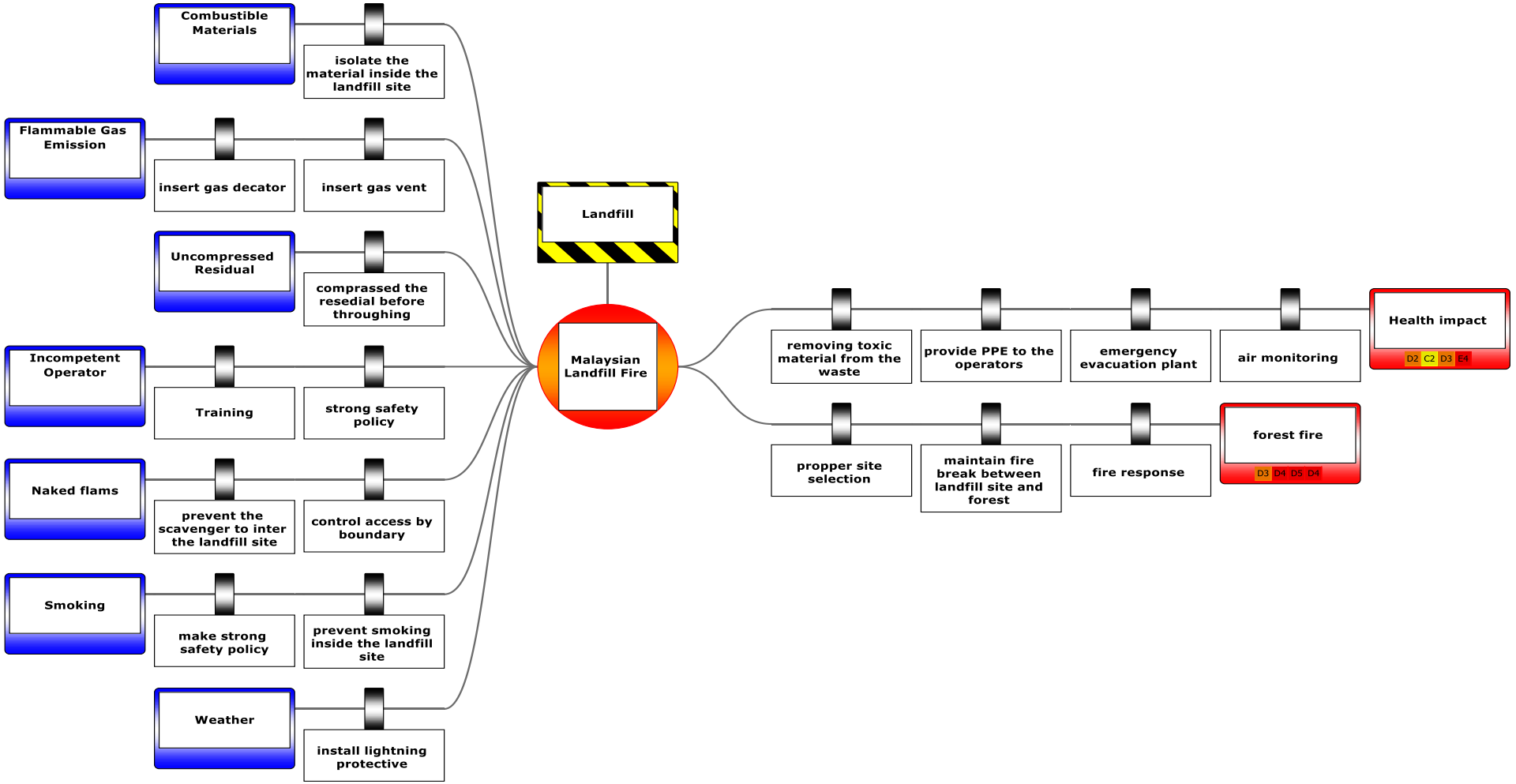


Figure 3 BowTieXP Analysis for Malaysian landfill fire

3.3 ALOHA

Figure 4 illustrates the zones distribution that will be used to explain ALOHA analysis models for different gas emissions in the landfill fire. The (Zone 1) is the most dangerous zone, where flame pockets could happen.

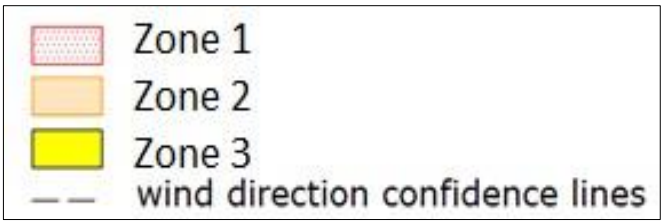
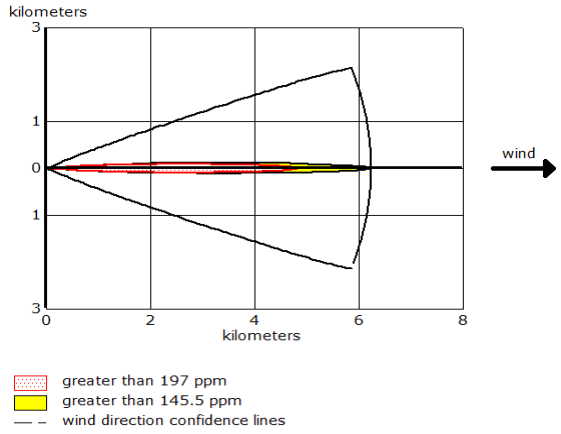
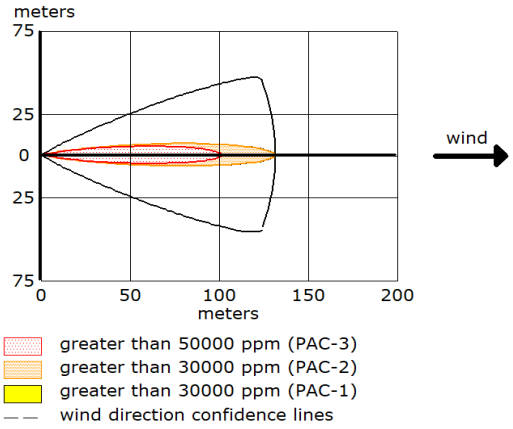


Figure 4: Type of ALOHA Zones

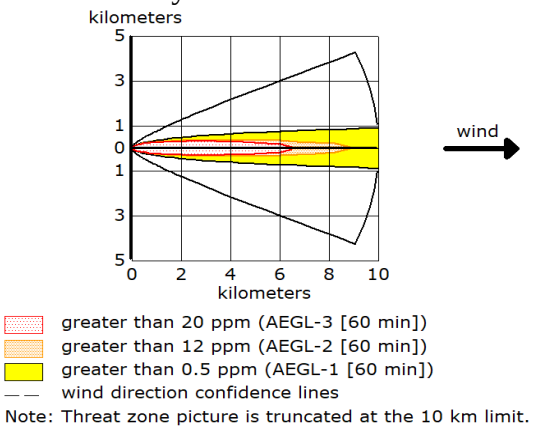
There were seven gases examined in a row including carbon monoxide, carbon dioxide, nitrogen dioxide, Sulphur dioxide, ammonia, methane, and hydrogen sulfide. The chemical and physical properties were based on the default of ALOHA Software. The results for each gas will be presented from the ALOHA software and explained in detail as well as Figure 5.



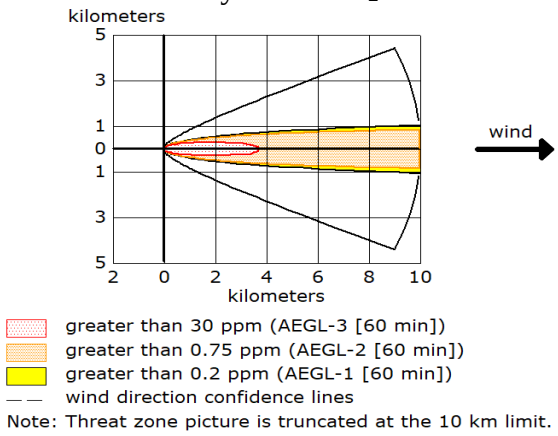
ALOHA Analysis for CO emission



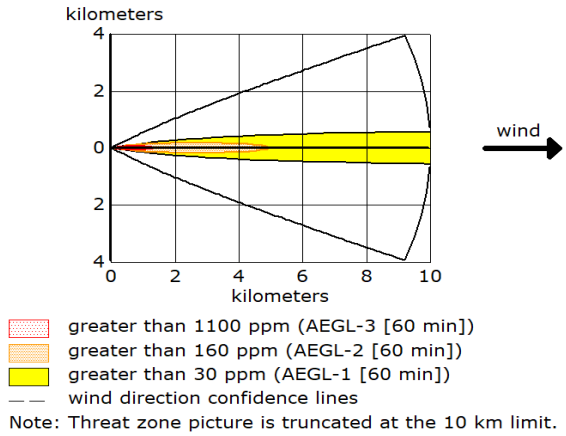
ALOHA Analysis for CO_2 emission



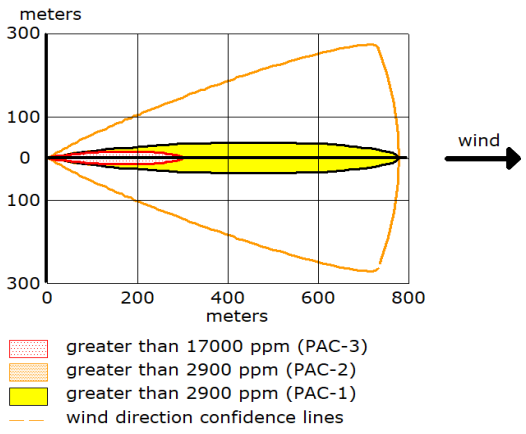
ALOHA Analysis for NO_2 emission



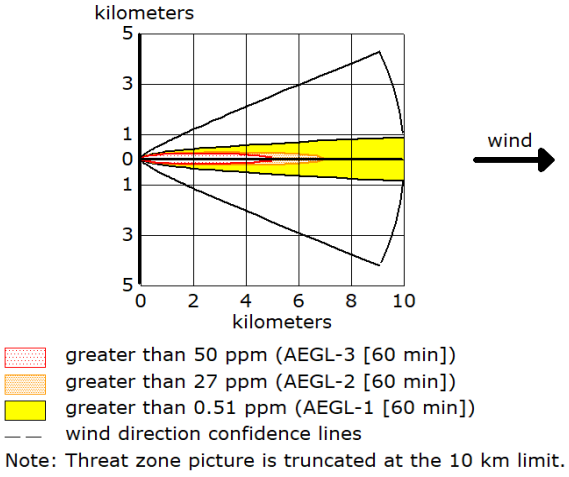
ALOHA Analysis for SO_2 emission



ALOHA Analysis for NH_3 emission



ALOHA Analysis for CH_4 emission



ALOHA Analysis for H_2S emission

Figure 5: ALOHA Analysis for gases emission from the Malaysian landfill fire

According to ALOHA software result in Table 2, the finding has shown the maximum distance with the concentration of the gases in ppm in comparison with the air quality regulatory limits. For instance, the four gases CO, CO_2, NH_4, and CH_4 have recorded a high concentration in comparison with the air quality regulatory limits [18]-[19]. On the other hand, the rest of the gases namely NO_2, SO_2 and H_2S have shown lower concentration (ppm). The difference in the diffusion distance and concentration of the gases due to the difference in the chemical and physical properties of each gas.

Table 2: ALOHA software result

Parameters / Units	Distance	Landfill Site	Air quality regulatory limits [18]-[19]
CO ppm	6.2km	145.5 ppm	10 ppm
CO_2 ppm	125m	3000 ppm	397 ppm
NO_2 ppm	10km	0.5 ppm	40 - 60 ppm
SO_2 ppm	10km	0.2 ppm	100 ppm
NH_3 ppm	10km	30 ppm	< 25 ppm
CH_4 ppm	750m	2900 ppm	1000 ppm
H_2S ppm	10km	0.51 ppm	10 ppm

The levels of CO in the study area is 145.5 ppm, which shows that the CO concentration present in the atmosphere were more than the regulatory limit of 10 ppm [18]-[19]. Carbon monoxide is colorless, odorless, but highly toxic. It combines the production of carboxyhemoglobin with hemoglobin. A carboxyhemoglobin level of 50 percent may result in coma, seizures, and death.

The CO_2 level in the study area is 3000 ppm, which indicates that the Carbon dioxide concentration present in the atmosphere was 7.5 times higher than the regulatory limit of 400 ppm [18]-[19]. The concentrations of ten percent or more of carbon dioxide can cause unconsciousness or fatality. Lower concentrations can lead to headaches, sweating, rapid respiration, increased breathing, shortness of breath, dizziness, mental agitation, visual disturbance, or trembling. The severity of those symptoms depends on exposure concentration and duration.

In the study area, the amount of methane is 2900 ppm, which indicates that the molecules present in the atmosphere are more than twice the regulatory limit of 1000 ppm [18]-[19]. CH_4 is the component of landfill gas which poses the highest danger of explosions. Methane may displace oxygen in the blood at a concentration of 1000 ppm. The average safe methane concentration recommended by the National Institute for Occupational Safety and Health (NIOSH) for operators during the 8-hour cycle is 1000 ppm.

The concentration of ammonia fires inside the vicinity of the dumpsite is 30 ppm. Recorded readings a bit higher than the 25-ppm legal authority [18]-[19]. The NH_3 is an immediate hazard to life in high concentrations. Ammonia is inflammable with lower explosive limits of 15 percent and its upper explosive limit is 28 percent.

The concentration values recorded for NO_2, SO_2, and H_2S are below the regulatory limits for dumpsite fires. Consequently, the three gasses may not affect the health of the workers and the inhabitants of the landfill, unlike the other gases.

The following Figure 6 and 7 show the spread of gases from the landfill area to the neighboring areas, which are considered residential areas. It can be observed that, carbon monoxide, which has a concentration of 3000 parts per million and spreads in the atmosphere up to a distance of 125 meters. Also, methane gas spreads a little more distance, reaching 750 meters at a concentration of 2900 ppm. At the same time, the concentration of carbon monoxide gas is 145.5 ppm, and it spreads up to a distance of 6.2 kilometers. Ammonia gas is the most prevalent with a distance of 10 km and a concentration of 30 ppm.

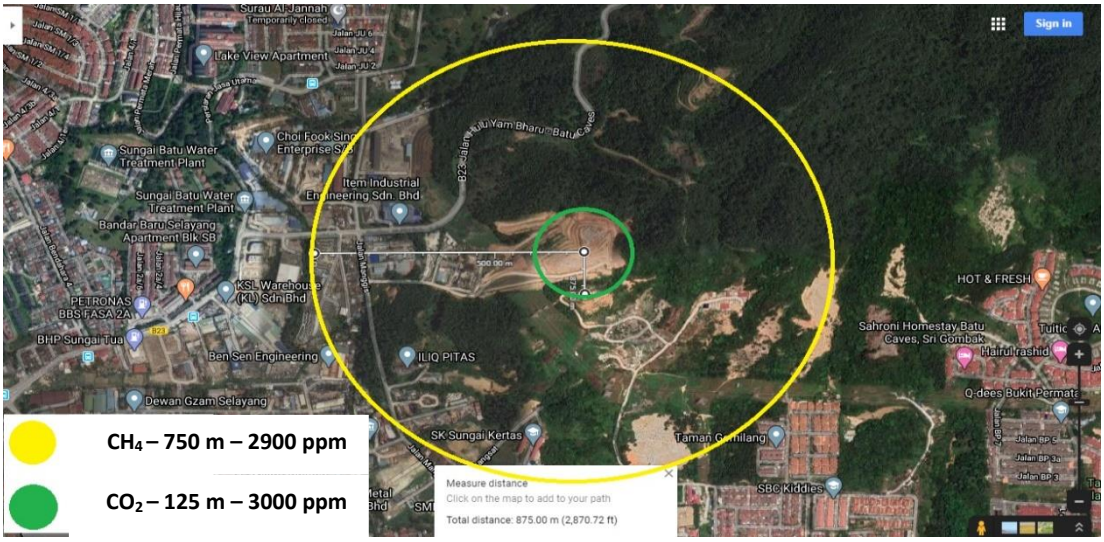


Figure 6: ALOHA Source Point for the worst-case scenario of CO_2 & CH_4

Figure 7: ALOHA Source Point for the worst-case scenario of NH_3 & CO

4.0 PREVENTION OF LANDFILL FIRE

Fire mitigation measures will minimize the risk of property loss and injury, death, and environmental and health risk due to waste fires. The mitigation costs are typically less costly than fire suppression and clean-up costs. Fire prevention practices are often required by law, especially for larger sites. Effective waste disposal management and adequate methane gas detection and collection are among the keyways of preventing waste disposal [13].

Fire risk assessment is a key part of fire prevention, as pre-fire planning resources need objective instruments that monitor whether a fire has a higher risk of occurring or if it has a higher risk of negative effects [20]. Traditional fire threat systems are based on weather indexes dependent on weather stations regularly calculated variables. Atmospheric conditions are however only one element of fire risk, and human aspects, fuel loads, and humidity status should be addressed, as well as the stakes of values [21].
Store waste controls, incompatible segregation, waste, small inventory, safe distances between stocks. Links to firefighting operations are the main priority areas to tackle the danger of deposit fires for long periods of continuous temperature control of storage materials [12].

In order to minimize the fire risk of deposit fire in Malaysia, several preventive steps are proposed below:

1. A physical boundary (wall) around the landfill should be built to prevent the fire from spreading outside or entering the landfill. This wall can also prevent the entry of scavengers. There should be guarded entry point for site personals and visitors to enter and leave the site, which can prove to be an important safety measure for landfill fires. Apart from the gates and walls, notice board, bund, and ditches should be Installed for a clearer demarcation of the landfill site boundary [13].
2. To protect the environment and human health, the operator's efficient management of the landfill is necessary to prevent the occurrence of fires.
3. Disposal of chemical waste in all waste dumps via the thorough inspection and control of incoming waste should be prohibited. [22].
4. To prevent landfill fire, waste should be sufficiently compacted before dumping in the landfill [9]. To avoid the creation of hot spots, buried waste should also be periodically compacted [22].
5. As methane is highly inflammable and could pose a fire hazard, it should be installed at gas collection and control systems at sites to collect landfill gas which can be flammable to convert methane into environmentally less harmful gasses or converted to energy [23].
6. Accidental or unexpected events contribute to the same output as when regular activity takes place but change the scale of the outputs. Accidents typically increase emissions, reduce, or prevent the recovery of electricity. The principal risk of landfill accidents is the biological degradation process that takes place inside the landfill. The risks are surface and underground fires, the risk of explosion, and accidental emission of leachate from sites of containment landfill [23].

7. Landfill operators must always classify various kinds of waste entering the facility. It is required to prevent the distribution and co-disposition of toxic waste at the landfill site. They should be allowed to reject any waste until it is found to be safe and appropriate at the landfill.[1].
8. A plan of remediation to stop explosive build-ups must also be implemented by the landfill operator [24].
9. Malaysia's government is urgently considered to explore issues related to improving the techniques of waste management and to work cooperatively with the private sector in the implementation of sustainable landfill management [25].
10. Inaccurate landfill management must be monitored, and non-compliance prevented by the regulatory authorities. Waste management managers must also comply with the rules and regulations [26].
11. Applicable for measuring carbon monoxide to enable early detection of sub-surface fires should be new integrated pollution prevention and control regulation (IPPC) [27].
12. Most local operators indicate that any potentially hot waste needs to be damped before it is transported to the site. Operators can and may have declined loads that smolder or have a fire risk [12].
13. The use of the layering technique by building the pile height slowly, around one foot a month, as another method suggested to prevent fires in large storage piles [28].
14. Better control of procurement of cover material and use of heavy machinery to ensure proper completion of daily covering activities and a better understanding of covering technologies [20]
15. To prevent the widespread and difficult extinction of fires, early intervention is very important [29].
16. Improving quality standards, implementing safety management modernization modes, and developing effective fire incident prevention legislation and regulations [6].
17. It would be crucial to establish an emergency response plan to evacuate individuals from the landfill, especially those who are most vulnerable to pollutants including infants, older adults, and pregnant women, and persons with chronic respiratory diseases from highly concentrated gases [29].

The above mention preventive measures should be implemented by the regulatory authorities to reduce the landfill fires in Malaysia.

5.0 CONCLUSION AND RECOMMENDATIONS

In this current work, several causes of surface landfill fires have been found by using FTA within Malaysia such as combustible material, flammable gas emission, uncompressed residual, air, naked flamed, operator smoking, and Malaysian weather. The consequences of the landfill fire determined by BowtieXP software are a negative effect on health due to emissions that can be toxic mostly, and forest fire. The concentration of seven gases emitted from landfill fires was tested using Aloha software. The four gases CO, CO_2, NH_4, and CH4 have recorded a high concentration in comparison with the air quality regulatory limits [27,

28], which means adverse effect on health. On the other hand, other gases namely NO_2, SO_2, and H_2S have shown lower concentration (ppm), mean null effect on health.

This study serves as a foundation step for further research regarding this topic. As recommendation for future studies, researchers need to get access to more landfill sites across Malaysia for data collection and analysis. This will result in better understanding about the similarity and differences of the outcomes due to fire. More detailed sampling and followed by thorough characterization of the samples will enhance the understanding of the health and environmental hazards that can possibly be posed by the landfill fire.

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