ASM REPORT

LESSONS FROM SUNGAI KIM KIM, PASIR GUDANG

05 APRIL 2019. A top view of Sungai Kim Kim after toxic chemical were dumped into the Sungai Kim Kim, sickening thousand of people who inhale noxious fumes in Johor. Photo by Adi Haririe

ASM REPORT

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2019

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LESSONS FROM SUNGAI KIM KIM, PASIR GUDANG

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Organisations

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Jabatan Pengairan dan Saliran Malaysia
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Sekolah Menengah Kebangsaan Pasir Puteh
Sekolah Kebangsaan Kota Masai 1
Sekolah Kebangsaan Pasir Puteh

Main References for the Report

Kes Pembuangan Haram Sisa Kimia di Sungai Kim Kim
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Head, *Unit Kesihatan Pekerjaan dan Alam Sektar (KPAS)*
Bahagian Kesihatan Awam, Jabatan Kesihatan Negeri Johor

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List of Acronyms

AEGL	Acute Exposure Guideline Level
ASM	Academy of Science Malaysia
BAKAJ	*Badan Kawal Selia Air Negeri Johor*
CHRA	Chemical Health Risk Assesment
CIMS	Chemical Information Management System
EHS	Environmentally hazardous substances
EQA	Environmental Quality Act
GHS	Globally Harmonized System
GPT	Gross pollutant traps
IARC	International Agency for Research on Cancer
IRBM	Integrated River Basin Management
IWRM	Integrated Water Resources Management
JAS	*Jabatan Alam Sekitar*
JBP	*Jabatan Bomba dan Penyelamat*
JKKP	*Jabatan Keselamatan dan Kesihatan Pekerjaan* (DOSH)
JKN	*Jabatan Kesihatan Negeri*
JPS	*Jabatan Pengairan dan Saliran*
KKM	*Kementerian Kesihatan Malaysia*
MEA	Multi-lateral Environment Agreement
MESTECC	*Kementerian Tenaga, Sains, Teknologi, Alam Sekitar dan Perubahan Iklim*
MPPG	*Majlis Perbandaran Pasir Gudang*
SK	*Sekolah Kebangsaan*
SMK	*Sekolah Menengah Kebangsaan*
TMDL	Total Maximum Daily Load
UTM	*Universiti Teknologi Malaysia*
VOC	Volatile organic compound

Executive Summary

The national headlines of toxic gas poisoning incidents affecting thousands of innocent schoolchildren in Pasir Gudang, not once but twice, back to back in March and June of 2019, shocked the Malaysian public. Calls from many quarters demanded immediate action by the government to find and close down the source of the gases, to treat the affected victims, to catch and charge the culprits, and to stop recurrence of the tragedy in the future. The Academy of Sciences Malaysia (ASM) Task Force on Sungai Kim Kim and Pasir Gudang Incidents was formed with the support of the Minister of Energy, Science, Technology, Environment and Climate Change (MESTECC) to investigate the source of the toxic gases and to recommend steps to prevent recurrence in the future.

The shocking events started in March when a total of 5,039 people were treated for various symptoms like nausea, dizziness and shortness of breath. An investigation by the HAZMAT team discovered chemical wastes illegally dumped into Sungai Kim Kim River. A major clean-up ensued and the toxic chemical poisoning incident was declared over on 4 April 2019. However, more cases of nausea, dizziness and shortness of breath were reported in June 2019. This time, 1,178 people were affected, and most of them were children.

The close proximity of the mixed light, medium and heavy industrial factories to large residential areas, which is the inevitable result of the growing industry taking up the largest proportion (38%) of the land and encroaching into residential areas; and the reduction of the buffer zone for heavy industry to only 500m, had increased the risk of a major industrial accident that could badly affect the surrounding public. In addition, the three rivers in the area, Sungai Kim Kim, Sungai Masai and Sungai Tukang Batu are found to be already polluted in 2017, which increases the risk of more illegal dumping of chemical waste in them.

Most of the victims, schoolchildren in the third and fourth floors of the school buildings, reported smelling acrid odour and experiencing vomiting, nausea, dizziness, short of breath, eye irritation, chest pain, sore throat and cough, which is consistent with the effects of a mixture of toxic gases, later identified as acrolein, acrylonitrile, methyl mercaptan and benzene. Schoolchildren are more vulnerable compared to adults because they have greater lung surface area that could absorb more chemicals easily.

Currently, the acceptable conditions for acrolein, acrylonitrile and methyl mercaptan that would classify them as pollutants under EQA 1974 are not yet established. They are therefore legally not "pollutants". Cumulative releases might exceed the loading capacity in the environment even if individual releases satisfy the acceptable conditions. The definition of environmentally hazardous substances (EHS) is too general and vague and not tied to their hazardous characteristics. In a previous study, "A Study to Strengthen the Governance Hazardous Chemicals in Malaysia", it was found that there is no national chemical inventory, no clear mechanism to reduce/eliminate chemical risks at the national level, and no central coordinating entity to manage upstream chemicals.

The Task Force checked with records at *Jabatan Keselamatan dan Kesihatan Pekerjaan (JKKP)* Johor whether any of the toxic gases were stored or used in large quantities at the premises of chemical companies in order to identify the culprit. Information on chemicals stored at the company's premises could be found in the Chemical Information and Management System (CIMS). However, currently, chemical factories only report in the CIMS storage of imported and manufactured chemicals exceeding one metric tonne but not the chemicals they buy from local companies. The information in CIMS was found by the Task Force to be incomplete because it is not audited often enough. Additional information on hazardous chemicals stored or used by chemical factories can be found in Chemical Health Risk Assessment (CHRA) but the information was not freely available at JKKP for Task Force viewing.

Illegal dumping of chemical wastes in Sungai Kim Kim was initially blamed, but this conclusion is untenable because evaporation of heavy gases from the ground would not have enough buoyancy or the momentum to reach the upper floors. Furthermore, the river was already clean in the second incident. The preponderance of cases in the upper floors indicates that the actual source could be elevated such as from a stack in a nearby chemical factory.

The actual source(s) could be identified by analysing the concentrations data and deducing the most probable area where the source(s) are located. The concentrations data measured by MultiRAE and Gasmet devices were integrated with meteorological data and then backward trajectories of the gases were calculated using Gaussian plume model until maximum concentrations were reached at the point sources. Finally, the probability density function of the point sources for each gas was calculated using the kernel density method.

From the coverage of the highest density contours, it is concluded that the most probable location of the sources of acrolein, acrylonitrile and methyl mercaptan is in the Pasir Gudang industrial area bounded by Jalan Pasir Gudang, Jalan Emas and Jalan Pekeliling. It is also concluded that the most probable location of the sources of benzene is in the Pasir Gudang industrial area bounded by Johor Bahru East Coast Highway, Jalan Pekeliling, and Pasir Gudang Highway. Immediate action would be to perform an audit on the companies located within these two areas to ascertain their actual chemical inventory and consequently identify the parties responsible.

Based on the findings, the Task Force outlined several recommendations for ministries and agencies to implement in order to avoid a recurrence of toxic gas poisoning incidents in the future.

To better identify the source of toxic chemical releases, data collection should be more thorough, consistent and complete. Air pollution and meteorological data could be merged with the health data from the *Jabatan Kesihatan Negeri* (JKN) in order to determine the pollutant exposure threshold before symptoms manifest. The modified back trajectory modelling could be modified for denser than air toxic gas, which would be more realistic. The location of the possible sources could be determined more accurately by matching pollutant concentration time series with time series generated by an unsteady-state air pollution dispersion model, CALPUFF from every stack in the most probable area 1 and 2. A more sophisticated instrument to quickly detect more types of toxic chemicals in the environment should be used.

Drones could be used to measure gases in the affected area and map the altitude and location using GPS. Chemical fingerprinting investigations should be conducted to determine the exact composition of the toxic fumes. It is possible that there are more toxic chemicals affecting the victims besides the four gases monitored.

Acceptable conditions for toxic gases that would classify them as pollutants under the Environmental Quality Act (EQA) 1974 should be established. Since acceptable conditions are for individual releases, the cumulative releases that might exceed the total loading capacity of any toxic gas should also be regulated. The definition of EHS should be amended to be more specific to include coverage of their hazardous characteristics as well. Chemicals reported in the CIMS should also include chemicals obtained through a local supplier in a circular economy. Large toxic gas releases and chemical spills should be reported immediately to *Jabatan Bomba dan Penyelamat* (JBP), *Jabatan Alam Sekitar* (JAS), JKKP, and JKN for them to execute the emergency response plan to protect the public from harm. Since the minimum buffer zone between chemical factories and the residential areas is only 500m, it is recommended that the minimum buffer zone should be increased to 1 - 1.5km.

The Task Force recommends the adoption of the proposals from "A Study to Strengthen the Governance of Hazardous Chemicals in Malaysia". In order to strengthen chemical governance, CIMS under JKKP should be integrated with the EHS Notification and Registration System under JAS. A more radical recommendation is to establish a statutory body to govern chemicals management such as a Chemicals Management Commission.

Integrated Water Resources Management (IWRM)/ Integrated River Basin Management (IRBM) should be implemented at the macro level for seamless integration of drains, rivers and the sea. The adequacy of current infrastructure should be updated by imposing Total Maximum Daily Load (TMDL) for sediments and pollutants for critical locations. Current technology of circular economy and zero waste should also be considered. It is suggested that Johor Waters Enactment 1921 be streamlined to the need for IWRM/IRBM and to include pollution management, and environmental rehabilitation and sustainability of water bodies.

The Task Force also adopts the recommendations in the final report of "Stormwater Management Master Plan for Pasir Gudang 2010" to build sediments basins for sediment control, wetlands and bio-retention system for pollution control, gross pollutants trap (GPT) and local detention tanks for flood storage.

1.0 INTRODUCTION

In March 2019, Pasir Gudang became national headline and captured the country's attention after thousands of people, most of them schoolchildren, were reported to have experienced severe breathing difficulties, fainting, vomiting, dizziness and muscular cramps in the hands and legs after smelling an acrid and burning odour, presumably from toxic gases/vapours. Many of the victims were sent to hospitals for emergency medical treatment, and a few of them were admitted into the hospital for further observation and treatment. Soon after the tragedy, an illegal chemical waste dumping was discovered at a nearby river, Sungai Kim Kim, which was immediately assumed by the authorities to be the source of the toxic gases/vapours affecting the schoolchildren. A major clean-up of the river was ordered by JAS in order to stop any further emission of toxic gases from the chemical wastes.

However, just a few months later in June 2019, more schoolchildren were reported to experience similar symptoms in a larger number of schools in the area. This time no chemical dumping was detected at Sungai Kim Kim because it had been cleaned after the first incident. The second incident cast some doubts on whether the source of the toxic gases was the Sungai Kim Kim's chemical waste or whether there was another source that had evaded detection.

Although the number of cases was not as high as the Sungai Kim Kim incident, it was enough to cause alarm among the Malaysian public when it became national headline news. It precipitated calls by many quarters on the government to end the tragedy in Pasir Gudang by finding and prosecuting the culprits and to take steps to prevent it from happening again.

1.1 PASIR GUDANG – AN OVERVIEW

1.1.1 Land Use of Pasir Gudang

Pasir Gudang, Johor is home to one of the largest and earliest ports in the country. Many factors such as the existing infrastructure support, deep water and abundance of soil for land reclamation made the area the natural place for building a port. The thriving maritime industry in Pasir Gudang was the main catalyst driving the development of the industrial area and the new township. It was first established in 1973 with the initial opening of 110 hectares of industrial area (National Archives of Malaysia, 2019). Information from Pasir Gudang City Council (MBPG) shows that currently there are 801 mixed (light, medium and heavy industries) industrial factories in the municipal area. The distribution of land use in Pasir Gudang is shown in Figure 1. The figure shows that the land use for industry takes up the largest portion of Pasir Gudang land area (38% or 1,775 hectares).

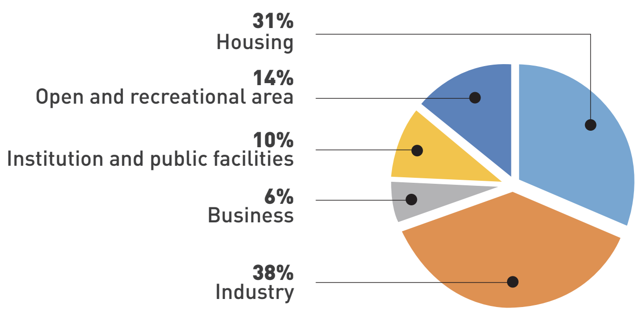

Figure 1 Area of Land Use in Pasir Gudang (hectare)
(Source: Pasir Gudang City Council, 2019)

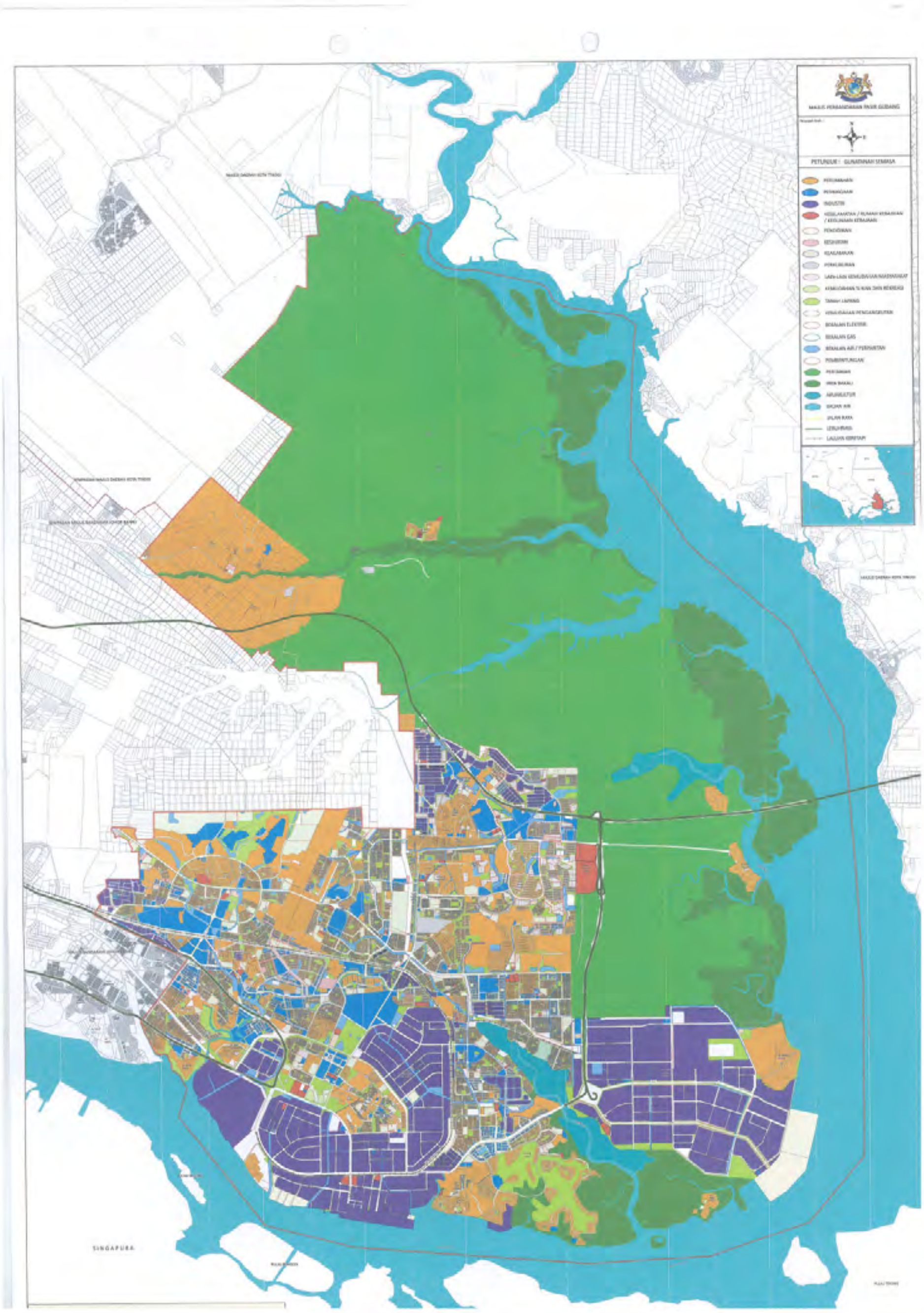

Figure 2 Structural Plan of Pasir Gudang
(Source: Pasir Gudang City Council, 2019)

Furthermore, as seen in Figure 3, the proximity of housing areas, public institutions and facilities, which include schools, to the industrial area is one of the main contributory factors that led to the Sungai Kim Kim and Taman Mawar toxic gas poisoning incidents. The vicinity of almost 2,005 industrial factories to a highly populated residential area in Pasir Gudang has been a ticking time bomb for a major industrial disaster from accidental release of toxic or flammable chemicals to the neighbouring residential areas for a long time. Almost half a million residents live just next door to various heavy industries, including 254 chemical plants. Currently, as shown in Table 1, the buffer zone for heavy industry is only 500m, which was reduced from 1500m in the early 1990's.

Table 1 Current Buffer Zone for Various Types of Industry

Types of industry	Buffer zone (metre)
Small	50
Intermediate	250
Heavy	500

(Source: Guidelines for Siting and Zoning of Industry and Residential Areas 2012 *Jabatan Alam Sekitar*)

1.1.2 River Systems and Stormwater Drainage in Pasir Gudang

Pasir Gudang is bounded by Sungai Kim Kim to the east, Sungai Masai to the west, and by Selat Tebrau to the south, as shown in Figure 3. The Sungai Kim Kim and Sungai Masai river systems are just south of the Sungai Johor river basin, located to the west of Sungai Johor estuary. All rain and surface water that flow within them find their way to Sungai Kim Kim or Sungai Masai. The two river basins are very much smaller than either the basins of Sungai Johor or Sungai Tebrau. Figure 4 is a Google Earth map showing the location of Pasir Gudang, an intensively developed industrial estate, wedged between Sungai Kim Kim and Sungai Masai river systems.

Figure 5 shows the detailed layout of the smaller river basins within Pasir Gudang. There are many other smaller river basin systems in between Sungai Kim Kim and Sungai Johor. Sungai Tukang Batu, whose water quality is Class 5 or highly polluted, is at the extreme south of the area and drains into the Straits of Johor at Pelabuhan Pasir Gudang.

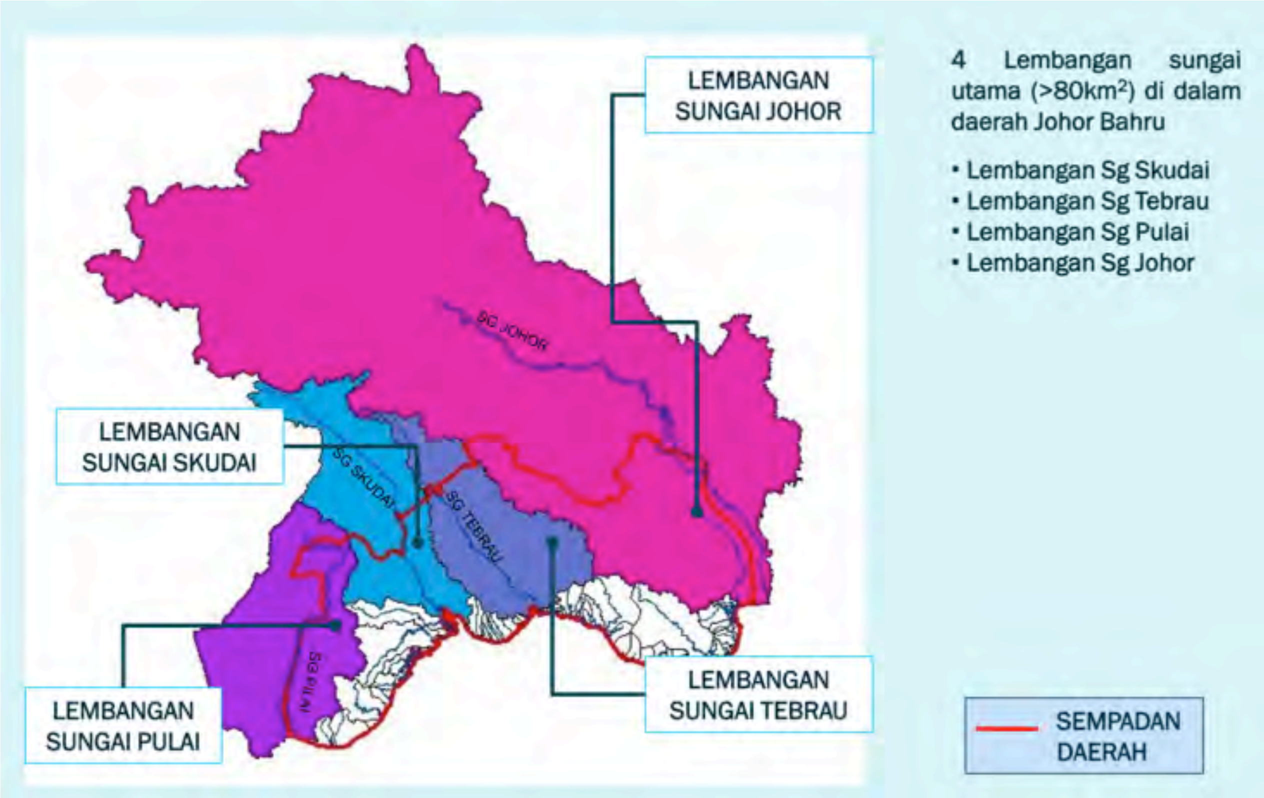

Figure 3 River Basins Within the District of Johor Bahru
(Source: *Jabatan Pengairan dan Saliran*)

Figure 4 Pasir Gudang Industrial Area
(Source: Google Earth map)

Figure 5 Detail of River Systems of Pasir Gudang
(Source: *Jabatan Pengairan dan Saliran*)

1.1.3 Existing Regulatory Framework for Environmental Pollution

Acceptable Conditions for Pollutants in EQA 1974

In Malaysia, the definition of 'pollution' under the Environmental Quality Act (EQA) 1974 was amended in 2012 into a more quantifiable condition based on acceptable conditions of emission, discharge or deposit of environmentally hazardous substances, pollutants or wastes, rather than the previous descriptive condition based on alteration on the environment caused by environmentally hazardous substances, pollutants or wastes.

The EQA 1974 amendment in 2012 would strengthen JAS' enforcement division in prosecuting individuals/ companies that cause the "pollution" as defined under EQA 1974. For example, the acceptable condition for mercury emission for the chemical and petrochemical industries in the gazetted Environmental Quality (Clean Air) Regulations 2014 based on the provisions of Sections 21 and 51, is 0.05 mg Nm^{-3} that must be monitored periodically. This means that any mercury emission that exceeds 0.05 mg Nm^{-3} is considered as 'pollution' under the EQA 1974. However, the main drawback is not all chemicals have their acceptable conditions quantified and gazetted.

Environmentally Hazardous Substances (EHS) in EQA 1974

Under the EQA 1974, EHS is defined as any substances that could cause pollution. Since this definition of EHS in the EQA 1974 is broad and vague, the coverage of substances that could cause pollution is very subjective. The definition of EHS should be amended by incorporating the characteristics of substances, regardless of whether they could cause pollution.

In early January 2019, JAS informed stakeholders of its intention to amend the EQA 1974 such that the definition of EHS is tied to a list of chemicals in Multi-lateral Environment Agreement (MEAs) on chemicals such as the Rotterdam Convention, Stockholm Convention and Minamata Convention. This amendment is intended to establish the legal frameworks in Malaysia to ratify the MEAs. The initiative is good, but then it has narrowed down the scope of EHS as preventive measures in EQA 1974.

1.2 OVERVIEW OF INCIDENTS

1.2.1 Sungai Kim Kim Incident (March 2019)

The first deadly toxic gas poisoning incident occurred in three waves. In the first wave that began on 7 March 2019, there were 71 reported cases, mostly schoolchildren at two schools, Sekolah Kebangsaan (SK) and Sekolah Menengah Kebangsaan (SMK) Taman Pasir Putih. Most of the victims reported feeling nausea, dizziness and shortness of breath. A few children also experienced eye irritation, chest pain, sore throat, coughing, fever and vomiting. This was followed by a second wave that began on 11 March 2019 right after heavy rainfall. A third wave that began on 13 March 2019 affected more than a thousand victims, most of whom were schoolchildren. Most of the affected schoolchildren were in classrooms on the third and fourth floors. A total of 5,039 individual cases in 12 schools were reported.

By tracing the source of the odour and using MultiRAE Detector to detect the gas, HAZMAT Johor discovered a massive illegal chemical waste dumping under a bridge in Sungai Kim Kim, 1km upstream from SK Taman Pasir Putih on 7 March 2019. On further measurements using Gasmet DX4030 by HAZMAT Melaka, the presence of acrylonitrile, acrolein, benzene, hydrogen chloride, toluene, xylene, ethylbenzene and D-limonene were detected (Scientific Committee on Chemical Dumping in Pasir Gudang, 2019).

The authorities immediately concluded that the illegal dumping of the chemical wastes in Sungai Kim Kim triggered the first and second waves. The massive cleaning and removal of toxic chemical wastes and contaminated soils were the cause of the third wave.

MPPG, JAS dan *Jabatan Pengairan dan Saliran* (JPS) personnel jointly removed 2.5 tonnes of the chemical wastes in the river by pumping and contaminated soils by excavation at the dumping site. They also contained the chemical wastes from spreading downstream by deploying a boom across the river. Syarikat 5E Resources Sdn Bhd (5ERSB) was employed to remove the chemical wastes and contaminated soils, and to clean the river.

JBP Johor ordered the evacuation and closure of all 111 schools in Pasir Gudang on 13 March 2019 until further notice in order to prevent further occurrence of the toxic gas poisoning and to facilitate investigations on the source of the gases. Investigations on the chemical wastes dumping on Sungai Kim Kim has resulted in the charging of two directors and an employee of a tyre-processing company in the Johor Bahru Sessions Court on 11 March for illegally disposing of chemicals in Sungai Kim Kim (Bernama, 2019).

The first toxic chemical poisoning incident was declared over on 4 April 2019. However, another incident recurred in June 2019.

1.2.2 Pasir Gudang Incident (June 2019)

The second toxic gas poisoning incident also apparently occurred in three waves. The first wave began on 20 June 2019 at Sekolah Agama Taman Mawar and SK Pasir Gudang 4, affecting 29 school children. The schools reported schoolchildren were having breathing difficulties and vomiting. This was followed by a second wave that began on 22 June 2019 and a third wave that began on 30 June 2019 affecting more than a thousand victims, most of whom were schoolchildren. Most of the affected schoolchildren were in classrooms on the third and fourth floors. Most schoolchildren experienced vomiting, nausea, dizziness and shortness of breath. A few also experienced eye irritation, chest pain, sore throat, coughing and fever. A total of 1,178 individual cases in 22 schools were reported.

There were more badly affected schools in the second incident than in the first incident. The 20 affected schools were SMK Tanjung Puteri Resort, SK Kopok, SK Tanjung Puteri Resort, SK Taman Pasir Putih, SMK Pasir Putih, SK Pasir Gudang, SK Pasir Gudang 4, SMK Taman Nusa Damai, SK Pasir Gudang 3, SK Taman Bukit Dahlia, SK Kota Masai, SMK Bandar Seri Alam, SK Taman Scientex, SMK Taman Megah Ria, SK Taman Nusa Damai, SK Taman Rinting 3, SK Taman Cendana, SMK Kota Masai, SK Desa Cemerlang and SK Taman Rinting.

Four toxic gases, acrolein, acrylonitrile, methyl mercaptan and benzene were detected using Gasmet by JAS personnel and the schools. The source of the toxic gases could not be determined from the chaotic distribution of concentrations data. However, chemical waste dumped in Sungai Kim Kim could be ruled out because it had been disposed of and Sungai Kim Kim was clean during the incident. No other new chemical waste dumping site was discovered.

2.0 METHODOLOGY

On 17 July 2019, the first meeting of the ASM Task Force was held to determine the course of action. Stakeholders and experts in the relevant fields were identified and invited to contribute data and share their initial findings up to that point of time. Data requests were also made to the relevant agencies such as *Kementerian Kesihatan Malaysia* (KKM), JAS, JKKP, MPPG, JPS and Universiti Teknologi Malaysia (UTM). In the course of this study, the members of the Task Force gathered four times to discuss the progress.

2.1 DATA COLLECTION

2.1.1 Toxic Gas Concentration Data

The following data were obtained from *JAS Negeri Johor:*

- Concentrations data of the three toxic gases that were recorded using Gasmet DX4030 at 42 schools from 17 - 18 March 2019
- Concentrations data of VOCs that were recorded using the MultiRAE Detector at 111 schools from 4 - 14 July 2019
- The air pollution data, which also include benzene and meteorological data from JAS' continuous monitoring station/mobile station (station ID: CA34J) from January 2018 to the present

The concentrations data by MultiRAE and Gasmet are merged with the meteorology data using their timestamps.

2.1.2 Epidemiological Data of Toxic Gas Incidents

The following epidemiological data on the Sungai Kim Kim and Pasir Gudang incidents were obtained from Dr Thilaka Chinnayah, Chief for *Unit Kesihatan Pekerjaan dan Alam Sekitar, Bahagian Kesihatan Awam, Jabatan Kesihatan Negeri Johor*:

- Chronology of events of toxic gas poisoning
- Number of reported cases according to age, ethnicity, gender, employment, symptoms and medical treatment
- Name and location of affected schools
- Name and location of affected residential areas
- Time series epidemiological curves of toxic poisoning cases

DATA COLLECTION

AGENCIES / TASK FORCES

Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC)

- Department of Environment
- Agensi Remote Sensing Malaysia
- Malaysian Meterological Department

Ministry of Health Malaysia (MOH)

- Johor State Health Department

Ministry of Education Malaysia (MOE)

- Johor State Education Department

Ministry of Human Resources Malaysia (MOHR)

- Jabatan Keselamatan dan Kesihatan Pekerjaan

Ministry of Water, Land and Natural Resources (KATS)

- Jabatan Pengaliran dan Saliran Negeri Johor
- Jabatan Mineral dan Geosains Malaysia

UTM Scientific Committee on Chemical Waste Dumping in Pasir Gudang

Pasir Gudang City Council (MBPG)

FIELD TRIP

SK Kota Masai 1, SK Pasir Puteh,
SMK Tanjung Puteri Resort & SMK Pasir Puteh

2.1.3 Chemical Governance Data

The following chemical governance data were obtained from JKKP Johor:
• Inventory of chemicals at chemical companies in the CIMS
• Inventory of chemicals at chemical companies in their CHRA reports

2.1.4 Scientific Study of Sungai Kim Kim Incident

The scientific study of the incident was obtained from Professor Abdull Rahim Mohd Yusoff, Chairman of the Scientific Committee for Illegal Chemical Dumping in Pasir Gudang, UTM. The study concludes that the source of the toxic gases in the first incident was from the illegal chemical waste dumping in Sungai Kim Kim.

2.2 FIELD TRIP

The ASM Task Force visited Pasir Gudang area to meet the first responders and authorities directly involved in the incidents on 26 to 27 August 2019.

On arrival in the morning of 26 August 2019, the Task Force visited the illegal chemical waste dumping site under a bridge across Sungai Kim Kim that is 1km upstream of the location of the first incident. This was followed by a visit to SK Kota Masai 1, where the Task Force interviewed the Headmaster on the chronology of the first toxic gas incident and the response of the school and the authorities.

In the afternoon, the Task Force went to the Faculty of Science, UTM to attend a meeting chaired by the Dean, Professor Abdull Rahim Mohd Yusoff and shared the latest findings with the following agencies:
1. *Jawatankuasa Saintifik Kes Pembuangan Haram Sisa Kimia di Pasir Gudang, UTM*
2. *Jabatan Kesihatan Negeri Johor*
3. *Jabatan Alam Sekitar Negeri Johor*
4. *Jabatan Keselamatan dan Kesihatan Pekerjaan Johor*
5. *Jabatan Pendidikan Negeri Johor*
6. *Jabatan Pengairan dan Saliran Johor*
7. *Jabatan Mineral dan Geosains Johor*
8. *Jabatan Meteorologi Malaysia Johor*

The next day (28 August 2019), the Task Force visited three more schools:
1. SK Pasir Puteh
2. SMK Tanjung Puteri Resort
3. SMK Pasir Putih

The Task Force interviewed the Principals of the SMKs and the Senior Assistant of the SK on the chronology of the toxic gas incidents and the response of the school and the authorities.

All of the schools corroborated the chronology of events, the observed symptoms and the preponderance of the cases on the third and fourth floors as reported by KKM and JAS.

2.3 DATA ANALYSIS

2.3.1 Preliminary Analysis of Concentrations Data

A preliminary analysis was done to utilise concentrations of VOC (volatile organic compound) data measured by the MultiRAE detector from 4 - 14 July 2019 at the 111 schools and concentrations data of the three gases measured by the Gasmet DX4030 at 42 schools from 17 - 18 March 2019. Integrating the data from the Jabatan Alam Sekitar air quality station (station ID CA34J) with the MultiRAE and Gasmet measurements, the possible sources at each school can be estimated using wind speed and direction. The linking parameter between the two datasets is the timestamp of the measurement.

The assumptions made for this analysis are that the VOC is carried directly downwind without lateral or vertical dispersion and that the winds did not meander. It is important to note that 84 out of 111 schools (77%) recorded VOC concentrations below the detection limit. Therefore, this analysis is focused on the spikes in the VOC concentration.

2.3.2 Detailed Analysis of Concentrations Data

In a more detailed analysis, using the merged data, the backward trajectories of the gases were calculated. This is done by first calculating the downwind distance of the maximum concentration using the Gaussian Plume Model. The dispersion parameters, or the sigma's (σ), were estimated using the solar radiation and wind speed data and the Pasquill's atmospheric stability classes. The solar radiation is also used to linearly interpolate the boundary layer height for the minimum and maximum range of 300m to 1000m.

Once the distance with the maximum concentration was calculated, it is combined with wind direction to estimate the downwind source using polar coordinates mapped into Universal Transverse Mercator and latitude-longitude coordinates. This generates multiple sources (> 250 sources) in the Pasir Gudang area. Thus, to summarise the sources into a legible plot, the kernel density method is used to combine the sources into "density" contours that highlight the locations with the highest number of occurrences of the multiple sources. The colour range is from red (approximately 250) to yellow (approximately 10).

3.0 ANALYSIS AND FINDINGS

3.1 SOURCES OF TOXIC GASES

3.1.1 Type of Toxic Gases Found

The Sungai Kim Kim incident reported the presence of acrylonitrile, acrolein, and benzene gases. On the other hand, the gases reported in the second incident were acrylonitrile, acrolein, and methyl mercaptan. These chemicals are most likely used by paint, plastic processing and pesticide factories.

3.1.2 Analysis of Air Pollution Transport at Sg Kim Kim and Pasir Gudang Incidents.

The three toxic gases detected in both incidents are denser than air. The specific gravities with respect to the dry air of methyl mercaptan, acrylonitrile and acrolein are 1.66, 1.9 and 1.9, respectively. Dry air's specific gravity is 1.0 and its density is 1.25kg Nm^{-3}.

If the source of the emission was from evaporation of the illegal chemical waste located at ground level such as on the surface of the Sg Kim Kim in the first incident or from the surface of open drums at the chemical waste disposal company's premises, the gas mixture would be at the same temperature of surrounding ambient air.

The density difference of the gas mixture with the surrounding air would impart on the gas plume created by the evaporation flux a net negative buoyancy force that would keep it mostly near the ground close to the source.

Assuming the vertical drag force of the air through which the gas plume moves could be neglected, the net buoyancy force in the vertical direction on the gas plume is the difference between the gravitational and the buoyancy forces of the displaced air by virtue of Archimedes' Law which is given by

$$F_B=(\rho_A - \rho_G)\, V_P\, g \quad (1)$$

where F_B is the net buoyancy force, ρ_A & ρ_G are the densities of air and gas respectively, V_P is the volume of the gas plume and g is the gravitational acceleration. A quick calculation on the least dense gas methyl mercaptan would yield a negative net buoyancy per unit volume of about -8.09 Nm^{-3}.

Table 2 Effects of the Reported Hazardous Gases

1 Chemical : Acrolein

Effects of short-term exposure Lachrymation. Irritates eyes, skin and respiratory tract. Inhalation of high concentrations may cause lung oedema (See Notes). Effects may be delayed. Medical observation is indicated. Inhalation: Burning sensation. Cough. Laboured breathing. Shortness of breath. Sore throat. Nausea. Symptoms may be delayed.	**Effects of long-term exposure** Acrolein is not classifiable as to its carcinogenicity to humans (Group 3).
	Acute Exposure Guideline Level (AEGL) 2 (8hr) (ppm): 0.1
Acute Exposure Guideline Level (AEGL) 1 (8hr) (ppm): 0.03	**IDLH Value (ppm):** 2
Acute Exposure Guideline Level (AEGL) 3 (8hr) (ppm): 0.27	**Measured concentration at site (ppm):** 1.51-3.80

2 Chemical : Acrylonitrile

Effects of short-term exposure
Irritates eyes, skin and respiratory tract. May affect central nervous system. Exposure far above Occupational Exposure Limit (OEL) could cause death. Effects may be delayed (See Notes). Medical observation is indicated. Inhalation: Dizziness. Headache. Nausea. Shortness of breath. Vomiting. Weakness. Convulsions. Chest tightness.

Acute Exposure Guideline Level (AEGL) 1 (8hr) (ppm):
N/A

Acute Exposure Guideline Level (AEGL) 3 (8hr) (ppm):
5.2

Effects of long-term exposure
Repeated or prolonged contact may cause skin sensitization. Affects the central nervous system and liver. It is possibly carcinogenic to humans (IARC Group 2B).

Acute Exposure Guideline Level (AEGL) 2 (8hr) (ppm):
0.26

IDLH Value (ppm):
60

Measured concentration at site (ppm):
1.18-2-8

3 Chemical : Methyl Mercaptan

Effects of short-term exposure
Irritates eyes and respiratory tract. May affect central nervous system. May result in respiratory depression. Exposure at high levels could cause unconsciousness. Exposure at high levels could cause death. Effects may be delayed. Medical observation is indicated. Inhalation: Cough. Sore throat. Dizziness. Headache. Nausea. Vomiting. Unconsciousness.

Acute Exposure Guideline Level (AEGL) 1 (8hr) (ppm):
N/A

Acute Exposure Guideline Level (AEGL) 3 (8hr) (ppm):
22

Effects of long-term exposure
Dermatitis can occur with chronic exposure.
It has not been classified for carcinogenic effects

Acute Exposure Guideline Level (AEGL) 2 (8hr) (ppm):
7.3

IDLH Value (ppm):
150

Measured concentration at site (ppm):
0

4 Chemical : Benzene

Effects of short-term exposure
Irritates eyes, skin and respiratory tract. If this liquid is swallowed, aspiration into the lungs may result in chemical pneumonitis. May affect central nervous system. This may result in lowering of consciousness. Exposure far above the OEL could cause unconsciousness and death. Inhalation: Dizziness. Drowsiness. Headache. Nausea. Shortness of breath. Convulsions. Unconsciousness.

Acute Exposure Guideline Level (AEGL) 1 (8hr) (ppm):
9

Acute Exposure Guideline Level (AEGL) 3 (8hr) (ppm):
990

Effects of long-term exposure
Leukaemia –IARC Group 1
Aplastic anemia

Acute Exposure Guideline Level (AEGL) 2 (8hr) (ppm):
200

IDLH Value (ppm):
500

Measured concentration at site (ppm):
1.56-4-32

Source: International Labour Organization (ILO), International Chemical Safety Cards (ICSCs), The National Institute for Occupational Safety and Health (NIOSH), US Environmental Protection Agency, World Health Organization, Agency for Toxic Substances and Disease Registry

Notes:
Acute Exposure Guideline levels (AEGLs) (United States Environmental Agency, 2019)
Level 1: Notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
Level 2: Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
Level 3: Life-threatening health effects or death.

IARC
Group 1: Carcinogenic to humans
Group 2A: Probably carcinogenic to humans
Group 2B: Possibly carcinogenic to humans
Group 3: Not classifiable as carcinogenic

If the advecting wind velocity is around 2 ms^{-1} and that the vertical wind velocity is around 1 ms^{-1}, and if one hour had passed after the release, the plume would have spread around more horizontally along the direction of the wind flow than in the vertical direction because the vertical plume velocity, w is negative due to the negative buoyancy of the gas.

It would also experience a drag force in the opposite direction of its flow by the surrounding air proportional to its projected area and the square of its velocity, which would slow it down. It would also undergo entrainment into the surrounding air, which is a function of its initial momentum and Froude Number, Fr_D which is given by

$$\mathrm{Fr}_D = \frac{u_i}{\sqrt{D_i g\,(\rho_G - \rho_A)/\rho_A}}$$

where u_i is the initial velocity and D_i is the diameter of the gas plume.

However, if the source of the gas plume is evaporation from the chemical waste as had been argued previously, the negative buoyant plume would have little buoyancy, the low initial velocity lowers the Froude number and plume momentum; and gravity is the dominant force on the plume. The plume would not move very far but would tend to diffuse around the Sungai Kim Kim and to stay on the ground. Hence, it is expected that only the residences in the immediate vicinity of the Sungai Kim Kim would have been affected by the emission.

During the discussion sessions with the Principals and Senior Assistants of the schools affected by the Sungai Kim Kim and Pasir Gudang incidents, the Task Force was informed that most of the affected schoolchildren were in classrooms on the third and fourth floors of the school building. This is not consistent with the assumption that the source was the evaporative plume from Sungai Kim Kim since the plume had too little momentum and too negative a buoyancy to hit the upper floors of the school but would instead only be more concentrated near the ground. Hence one would expect that the classrooms at the lower floors to be affected rather than those on the upper floors. Moreover, the schools are located on higher ground and are some distance away from Sungai Kim Kim.

In the next section of this report, modelling and simulation work based on all the measured concentrations of the gases during the second incident will show that there is a higher probability that the possible source of the emission is more from the two main chemical industry areas of Pasir Gudang and not from Sungai Kim Kim.

Based on these two factors, there is an urgent need to reassess the initial deduction that the source of the air pollution associated with the Pasir Gudang incidents is associated with the illegal chemical waste dumping in Sungai Kim Kim and the evaporation of the toxic heavier than air gases such as methyl mercaptan as the major source. The spikes of toxic gases concentration that were observed during the incident are more consistent with a puff release instead of a continuous release from chemical waste evaporation as previously argued.

A more consistent source would be an elevated one such as a stack from where a toxic gas puff release would have sufficiently enough momentum to transport the heavier than air gas puff over a longer distance and would still have the height to hit the third and fourth floors. Receptors on the ground in the immediate vicinity were not affected, but those on higher ground and upper floors were hit by the puff as it grew and propagated as a density current.

Based on the probability density function of multiple sources obtained by the back trajectories of measured concentrations in the modelling work in the next section that point away from Sungai Kim Kim and the fact that the affected schoolchildren were on the upper floors only where the evaporative plumes could not have reached because of the physical argument related to the transport of denser than air gases, it could be concluded the most likely source is from an elevated point such as a stack and the gas release is a puff and not a continuous release.

The physical process of this density flow must be modelled differently than normal Gaussian neutral density flow since the governing factors are its momentum at emission, the gas buoyancy and the Froude number (Albertson et al., 1950).

3.1.3 Identifying the Location of the Sources of the Toxic Gases

Results of Preliminary Analysis of Concentrations Data

The objective of the preliminary analysis is to determine the location of possible sources of VOCs and the three toxic gases using the merged meteorological and concentrations data from the MultiRAE and Gasmet devices. Time series plots are used to show the trend of the gases in relation to the wind speed at the schools (Figure 6).

The analysis reveals that, within the 10-day measurement period, there exist two sets of VOC pollution episodes: the first before 10 July 2019 and the second after 10 July 2019. It also shows that the wind speed affects VOC in which higher speeds dilute the concentration but carries the pollutant further over a longer distance, but lower speed raises the concentration and carries it over a shorter distance. However, the concentration also depends on the proximity of the source, where higher concentrations suggest sources that are nearer to the point of sampling.

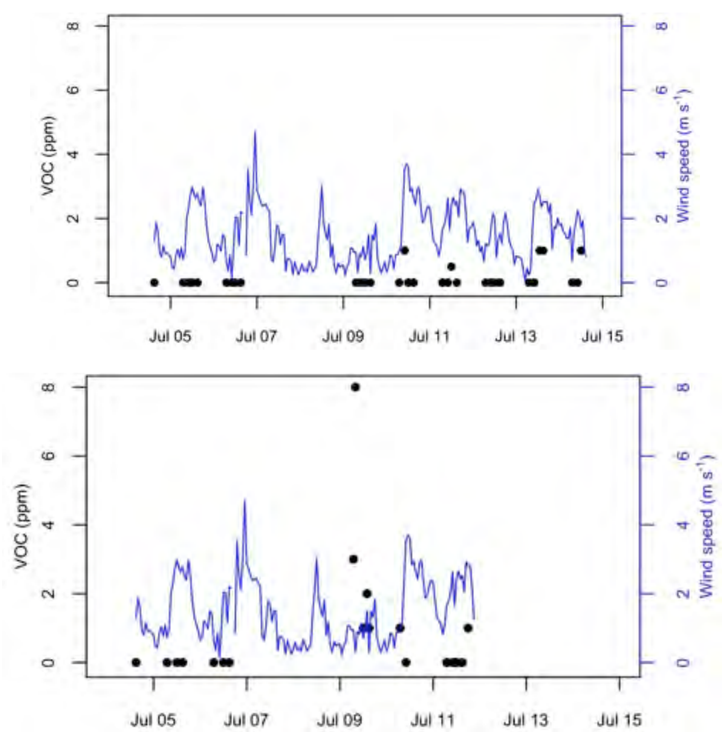

Figure 6 The VOC (ppm) and Wind Speed (m s^{-1}) Time Series from 4 to 14 July 2019 at SK Kong Kong Laut (top panel) and SK Kopok (bottom panel)

A bivariate polar plot is then used to distinguish the location of the potential sources of VOC (Figure 7). The examples shown in the figure are for SK Kong Kong Laut and SK Kopok. The identification is done by combining VOC concentration, wind speed and wind direction into a single polar-coordinate plot. Higher wind speeds suggest longer distance travelled by the VOC where wind speed of 1 m s–1 would cover 3.6km in one hour. Thus, the possible location of the source or sources could be ascertained.

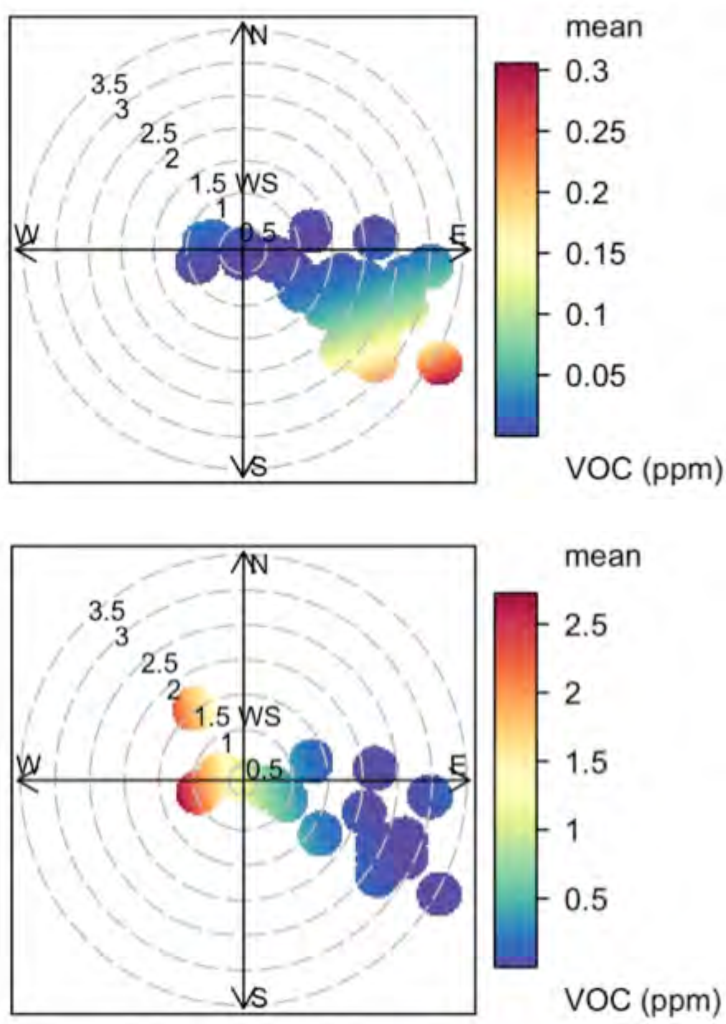

Figure 7 Bivariate Polar Plot for the VOC (ppm) from 4 to 14 July 2019 at SK Kong Kong Laut (top panel) and SK Kopok (bottom panel)

A cursory study of sources is done by mapping the coordinates of the schools and the distances and directions obtained from the bivariate polar plot analysis on Google Earth maps (Figure 8). Although some of the sources could overlap, this result shows that there could be multiple VOC sources throughout the Pasir Gudang area.

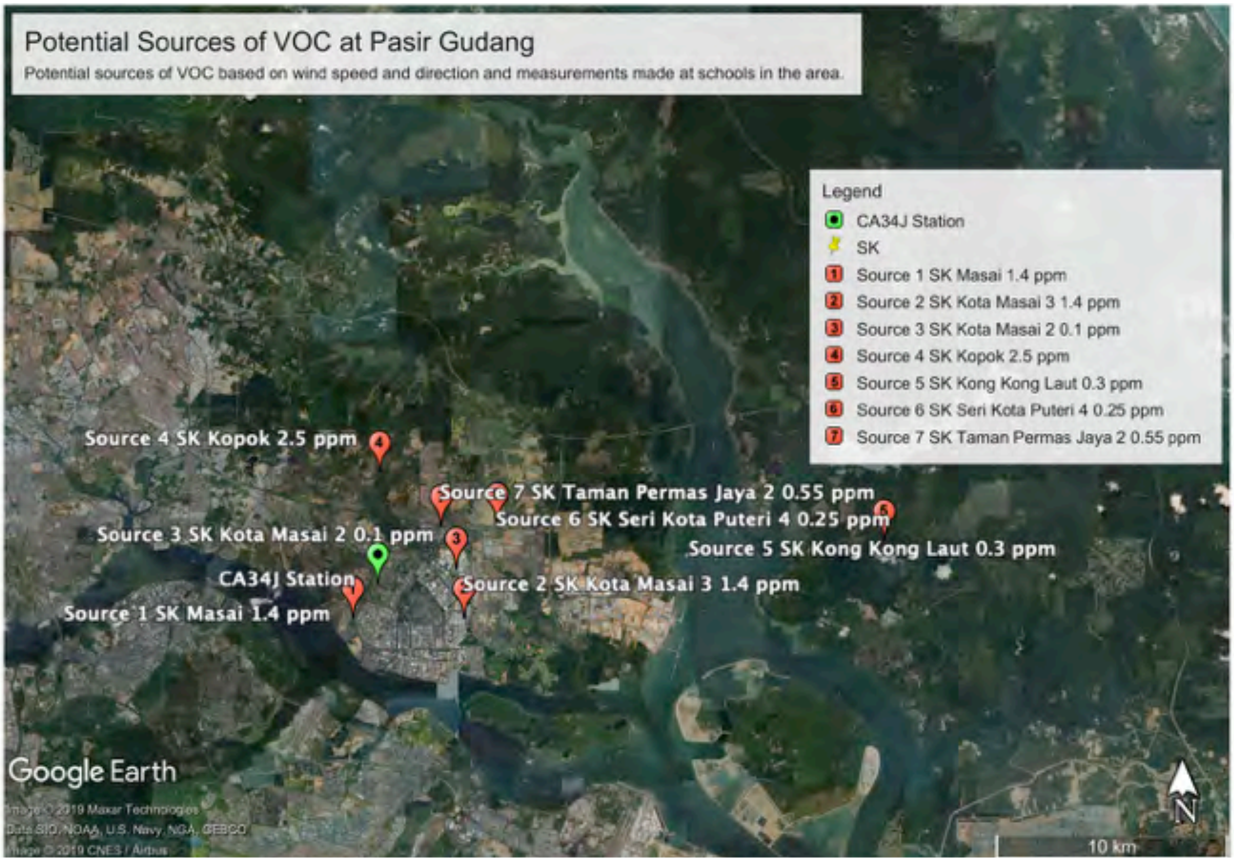

Figure 8 Location of Potential Sources of VOC that is Based on the School's Location, Wind Speed and Direction and VOC Measurements Made at Schools in Pasir Gudang Area

Fine-Tuning the Back Trajectory Modelling

The findings of the previous section are utilised further to produce probable locations of the sources by using basic meteorological principles (atmospheric stability and boundary layer height) and the kernel density function (or probability density function). The detailed analysis used a modified back trajectory modelling method, which combined the Gaussian Plume Model and the kernel density method with the MultiRAE and Gasmet measurements made at multiple locations in the Pasir Gudang area.

The Gaussian Plume Model, which was corrected using the boundary layer height and local meteorological data, was utilised to calculate the distance of the highest concentration from a possible source and mapped it to the MultiRAE and Gasmet measurements. This provided multiple locations (approximately 250 locations) of possible sources similar to what was observed in Figure 8.

The many possible sources were then integrated using the kernel density method so that it could be summarised into contour plots showing the most likely location of the source or sources. Figure 9 shows the most likely location of the source of VOC. Figures 9.1, 9.2, 9.3 and 9.4 also show similar locations of the sources of acrolein, acrylonitrile, benzene and methyl mercaptan respectively. The level denotes the number of point sources at a location. The area covered by the contours was large because the locations of gas measurements were distributed widely.

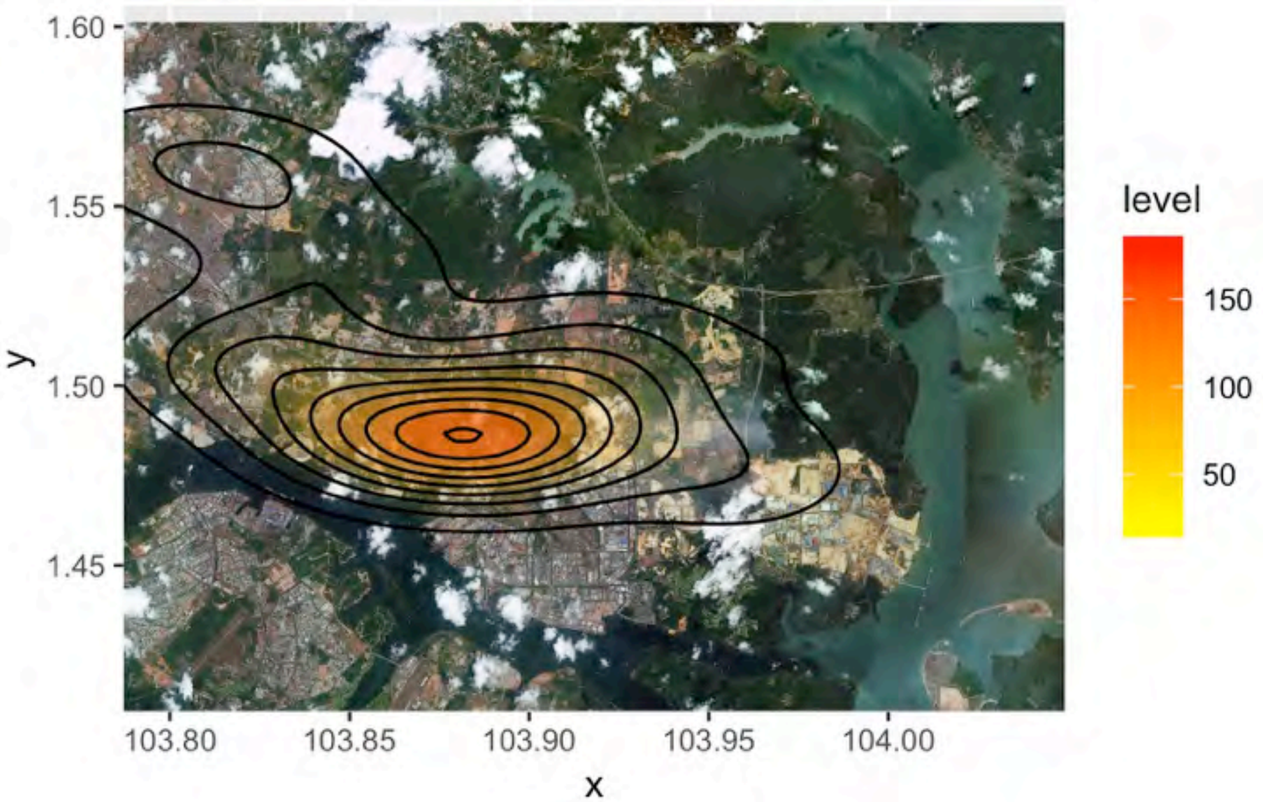

Figure 9 The Potential Source of Air Pollution Based on the MultiRAE Readings at 111 Schools in Pasir Gudang Using the Modified Back Trajectory Modelling Method

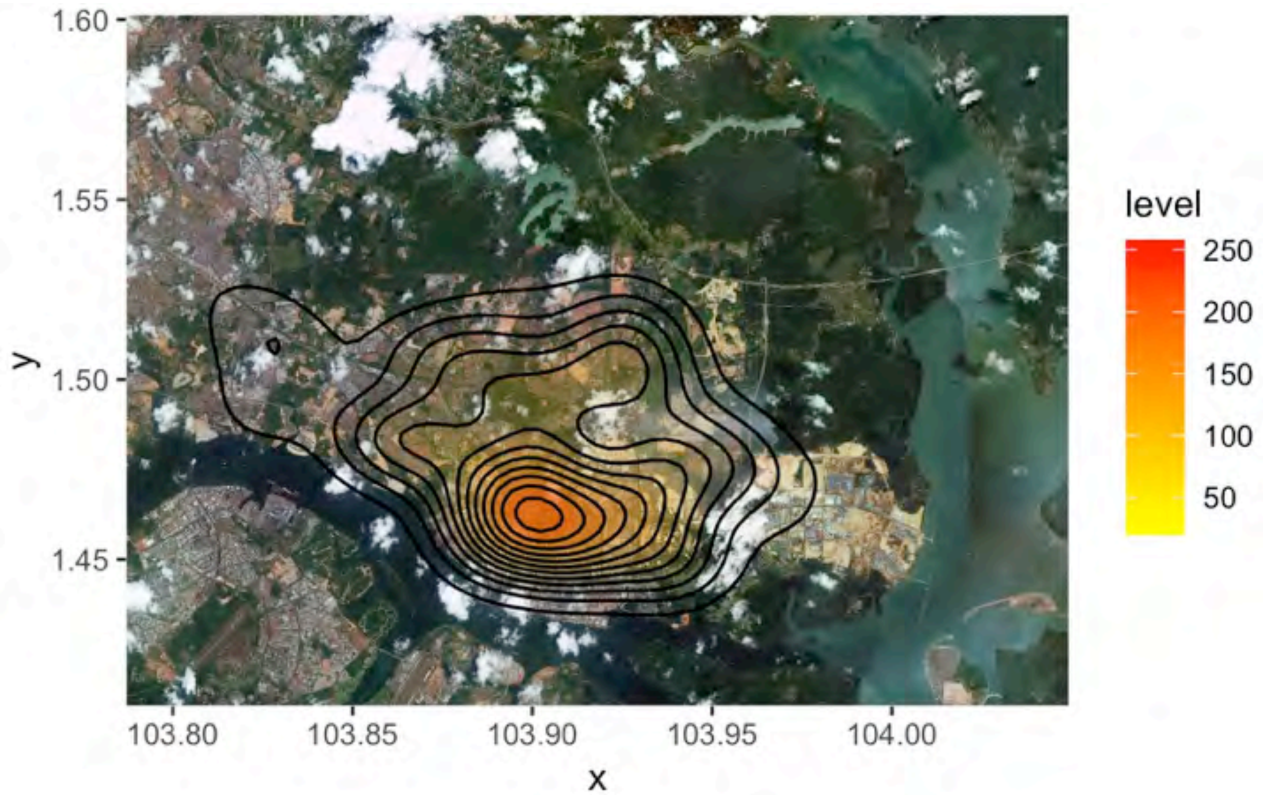

Figure 9.1 The Potential Source of Air Pollution (Acrolein) in Pasir Gudang Using the Modified Back Trajectory Modelling

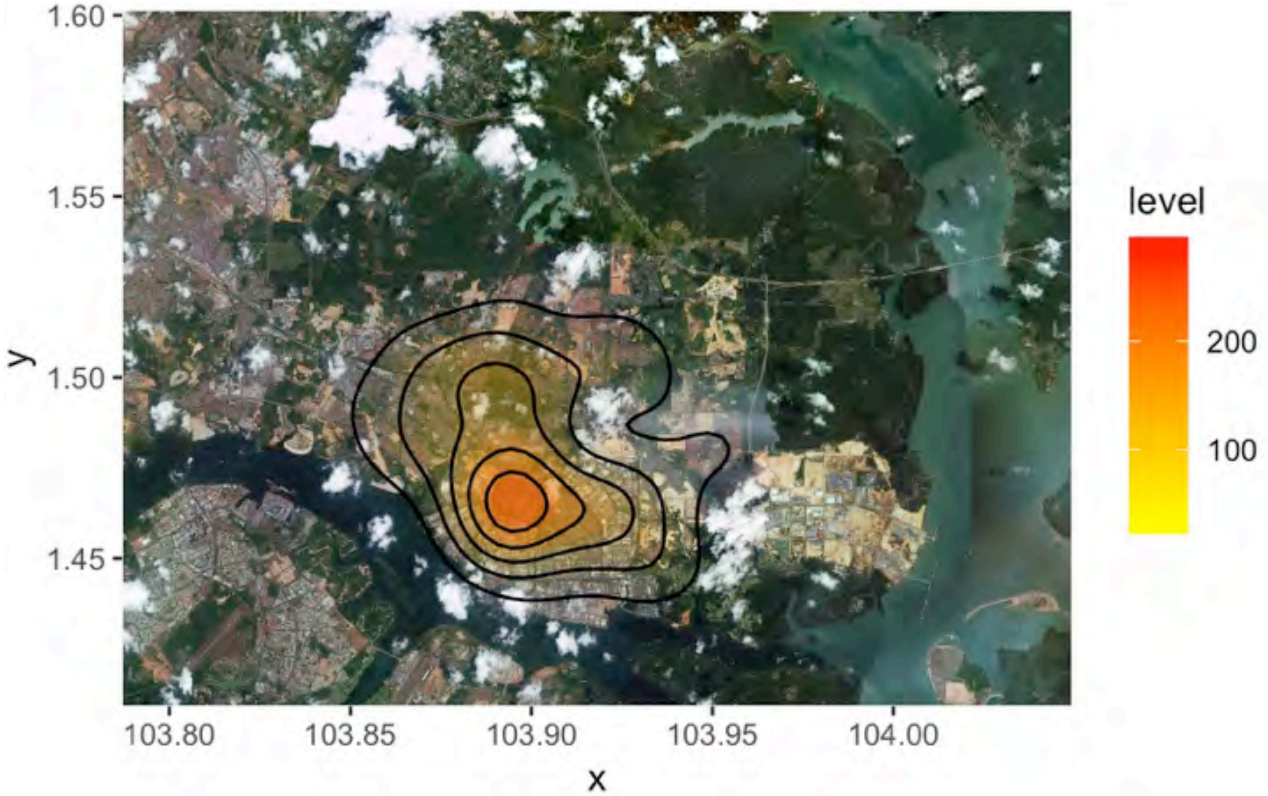

Figure 9.2 The Potential Source of Air Pollution (Acrylonitrile) in Pasir Gudang Using the Modified Back Trajectory Modelling

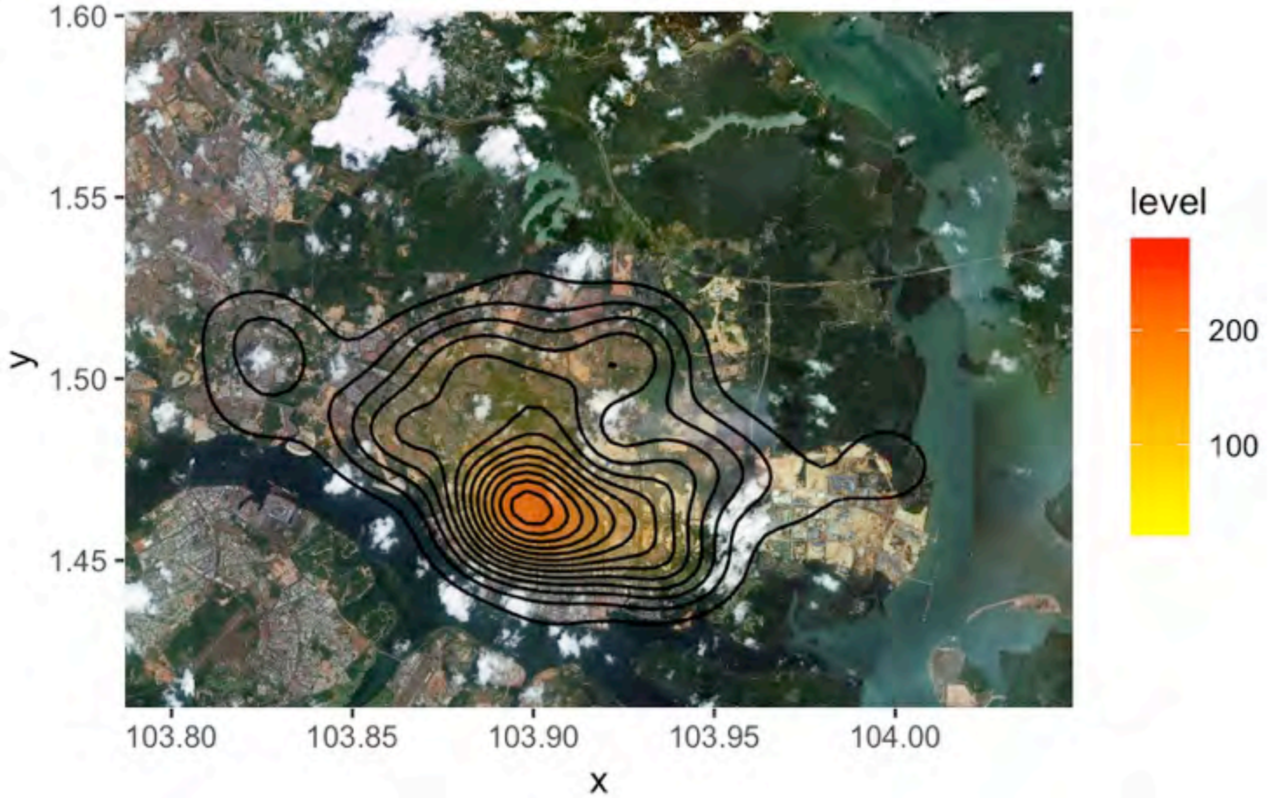

Figure 9.3 The Potential Source of Air Pollution (Benzene) in Pasir Gudang Using the Modified Back Trajectory Modelling

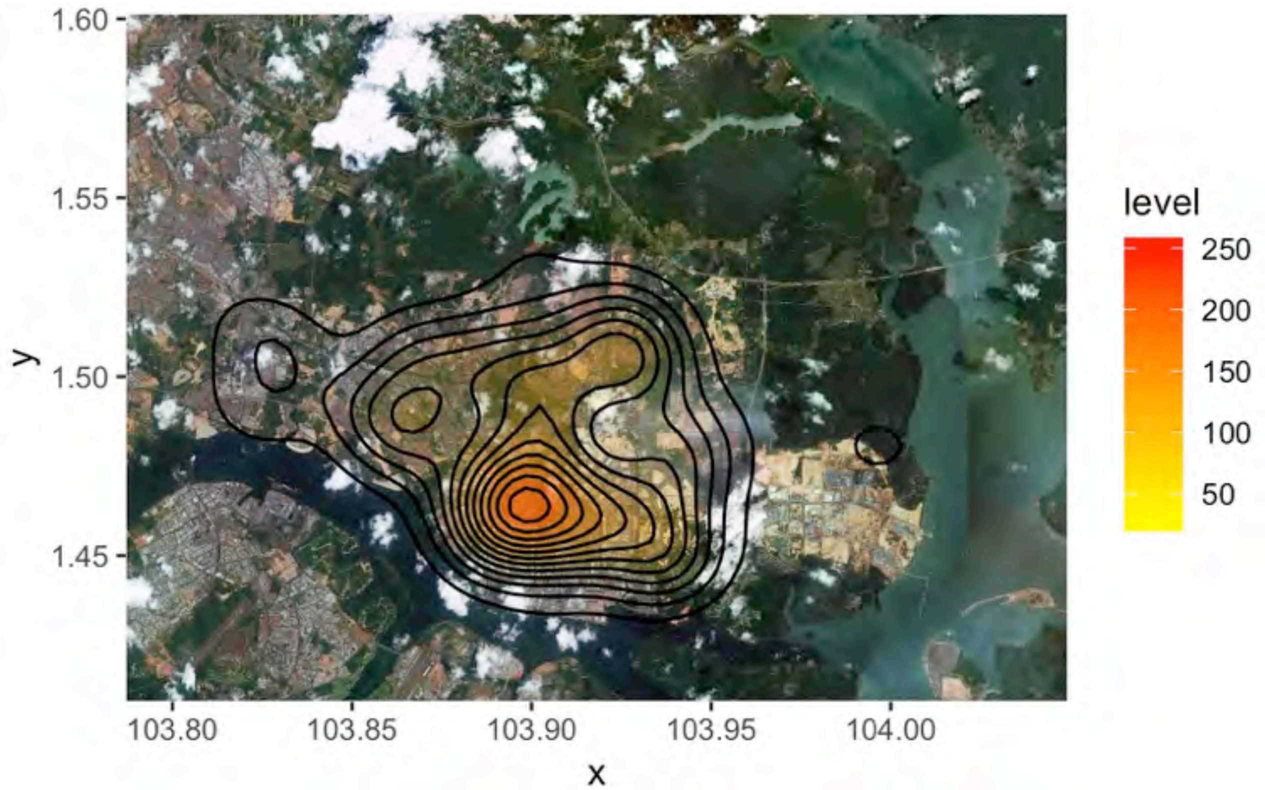

Figure 9.4 The Potential Source of Air Pollution (Methyl Mercaptan) in Pasir Gudang Using the Modified Back Trajectory Modelling.

By superimposing the results of the modified back trajectory modelling with the map of Pasir Gudang, two possible sources were determined as shown in Figure10. The results of this detailed analysis show that the majority of the sources originate from two areas:

- The Pasir Gudang industrial area bounded by Jalan Pasir Gudang, Jalan Emas and Jalan Pekeliling for the acrolein, acrylonitrile, methyl mercaptan
- The Pasir Gudang industrial area bounded by Johor Bahru East Coast Highway, Jalan Pekeliling, and Pasir Gudang Highway for benzene

Area 1 :
acrolein, acrylonitrile, and methyl mercaptan (red)

Area 2 :
benzene (yellow)

Figure 10 The Potential Source of Air Pollutants Determined Using the Modified Back Trajectory Modelling

Source: This finding is from the modified back trajectory modelling method from the Gasmet and MultiRAE measurement by the Department of Environment.

3.2 ADVERSE HEALTH EFFECTS

3.2.1 Sungai Kim Kim Incident (March 2019)

The Sungai Kim Kim incident was Malaysia's largest chemical emergency that affected around 5,000 people. This incident was initially assumed to have been triggered by the illegal dumping of chemical waste into the river. The chemicals detected in the environmental samples are acrylonitrile, acrolein, benzene, hydrogen chloride, toluene, xylene, ethylbenzene and D-limonene. Hence the affected victims were exposed to multiple toxic chemicals during the episode.

The symptoms seen in the reported cases were dizziness, shortness of breath, nausea, eye irritation, chest pain, sore throat, coughing, fever and vomiting. These symptoms were typical signs of exposure to volatile organic chemicals. Some of the clinical samples were positive for cyanide detection, which explained the exposure to acrylonitrile. Cyanide could be produced either by the breakdown of acrylonitrile in the human body or by the degradation of acrylonitrile over a few hours in the environment.

3.2.2 Pasir Gudang Incident (Jun 2019)

This incident began on 20 June 2019 and affected 1,178 people. Although acrylonitrile, acrolein, methyl mercaptan and benzene were positively detected in the environmental samples, the sources of these chemicals are yet to be identified. Similar to the Sungai Kim Kim incident, the cases were exposed to multiple toxic chemicals as indicated by the environmental monitoring data.

The symptoms exhibited in the cases include vomiting, dizziness, short of breath, coughing, chest pain, eye irritation, sore throat, fever, diarrhoea and abdominal pain. These symptoms were all typical signs for exposure to volatile organic chemicals and consistent with the effects of acrolein, acrylonitrile, methyl mercaptan and benzene, as shown in Table 2. There is also a possibility that some of the victims were showing signs of mass psychogenic illness.

Symptoms of Affected Schoolchildren in Both incidents

In the first incident of Sungai Kim Kim, most of the cases were seen and treated as outpatient cases at the various health centres under the *Pejabat Kesihatan Daerah* (PKD). The remaining cases were hospitalised mostly in government hospitals. For the second incident at Taman Mawar, the number of cases was far less; however, the pattern was similar in which most cases were referred to the district clinics. Among the highest symptoms reported in both incidents are dizziness, throat pain, nausea, eye irritation, chest pain, shortness of breath, and fever. However, the vomiting is more prevalent in Pasir Gudang incident.

Although both incidents reported the same type of clinical presentation, it should be noted that vomiting was more prominent in Pasir Gudang (second) episode whereas shortness of breath was more dominant during the first episode (Sungai Kim Kim). In terms of severity, the first episode was more severe compared to the second episode. The difference may be due to differences in chemical(s) exposure as well as the concentration of chemical(s) exposed.

Similarities Between the Two Incidents

Schoolchildren were mainly affected in both incidents. As compared to adults, they have greater lung surface area:body weight ratios and higher minute volumes:weight ratios that facilitate faster absorption of the chemicals. The schools that were involved in the incidents are situated on higher ground and the affected schoolchildren were mainly in classrooms in the upper levels. In both incidents, the medical cases were precipitated by reports of strong odour which was also influenced by strong wind.

3.3 CHEMICAL GOVERNANCE

3.3.1 Toxic Gas as Pollutants or Environmental Hazardous Substances (EHA) in EQA 1974

In the Pasir Gudang incident, three chemicals were identified in the air, namely methyl mercaptan, acrylonitrile and acrolein. There are no acceptable conditions for these chemicals that had been established by the Minister under the amended EQA 1974. Although there were efforts to refer to the US Environmental Protection Agency's Acute Exposure Guidelines Levels (AEGL) for airborne chemicals, nonetheless these values are merely references and not mandatory acceptable conditions. Hence, with the absence of acceptable conditions defined under EQA 1974, it is difficult to consider these chemicals found in the air of Pasir Gudang as "pollution" under EQA 1974.

3.3.2 Definition of "Pollution" and Environmentally Hazardous Substances (EHS) in EQA 1974

The focus previously is on existing legal framework in defining "pollution", it is important to realise that due to rapid economic development in many countries, emission and discharge of chemicals into the environment is often allowed with the condition that such chemical releases will not alter, either directly or indirectly, any part of the environment or in other words become a pollutant. Since the definition of "pollution" in the main Act is broad, the regulations gazetted under the main Act could establish the acceptable conditions that would quantify the allowable amount of chemical release.

Besides, although acceptable conditions can be seen as a safety net to the environment, these conditions are for individual release and not cumulative release. In some circumstances, although respective individual releases by numerous industries in an industrial area are below the acceptable condition, the cumulative concentrations might exceed the loading capacity of the environment. Over time, it can lead to a severe situation by causing an outbreak or disaster (Figure 11).

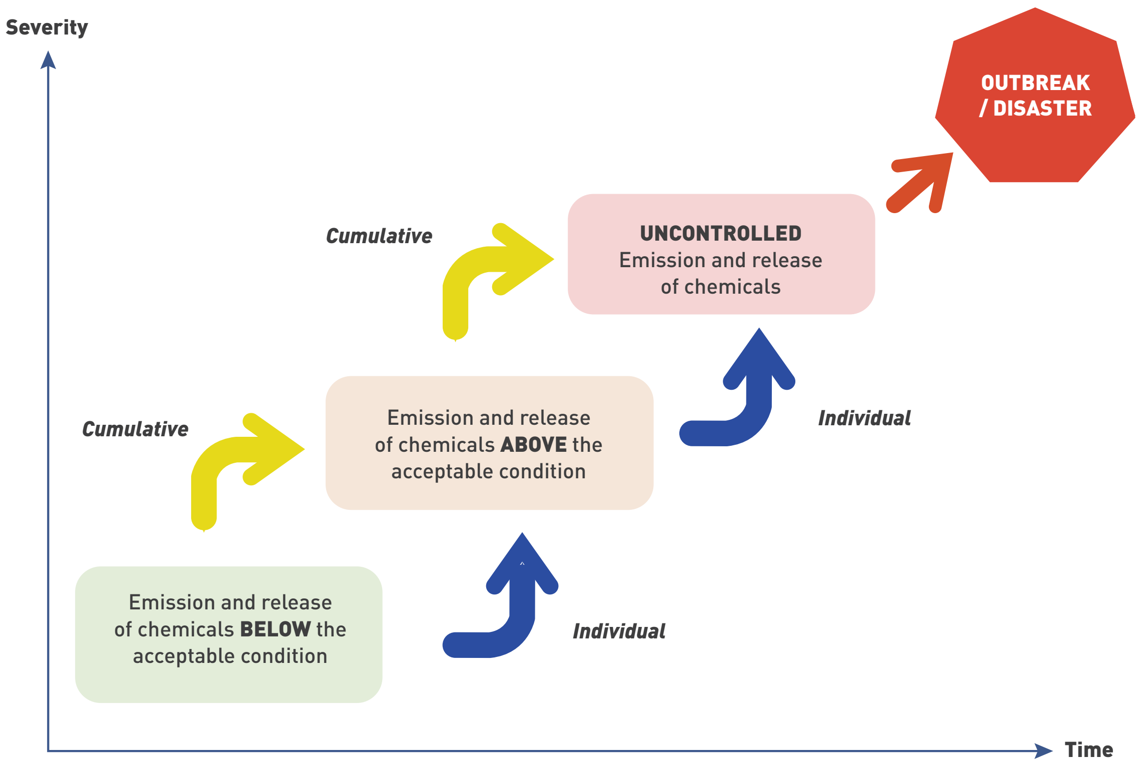

Figure 11 Relationship Between Outbreak/Disaster and Chemical Release into the Environment

Although the EHS listing is crucial to support Malaysia's initiatives and efforts in ratifying MEAs related to chemicals it is not sufficient that the EHS definition is solely based on the listing. The EHS definition should be broadened to include coverage of their characteristics, while the listing can be one of the tools under the broad definition of EHS.

3.3.1 CIMS and CHRA under JKKP

The Task Force checked the records at JKKP Johor whether any of the four toxic gases, acrolein, acrylonitrile, methyl mercaptan and benzene were stored or used in large quantities at the premises of chemical companies in order to identify which company was the origin of the toxic gas release. Information on chemicals stored at the company's premises could be found in the CIMS. However, the main drawback of CIMS is that currently, chemical factories only report storage of imported and manufactured chemicals exceeding 1 metric tonne but not the chemicals they buy from local companies in the circular economy. As a result, the information in CIMS does not give a complete account of the chemicals stored in the company premises. The information in CIMS was therefore found by the Task Force to be incomplete because chemicals bought internally are not listed and it is not audited on the ground often enough by JKKP. Additional information on hazardous chemicals stored or used by chemical factories could be found in CHRA reports, but the information is not freely available at JKKP for Task Force viewing. In addition, very few companies have submitted their CHRA reports because they are only required to do it whenever JKKP officials visit them to audit the company.

3.3.4 Chemical Governance in Malaysia

The life cycle of chemicals has six stages, namely manufacture, import, transport, storage, use and handling, and disposal (Figure 12). Emission and release of chemicals at different stages of the life cycle is possible, as illustrated in Figure 13.

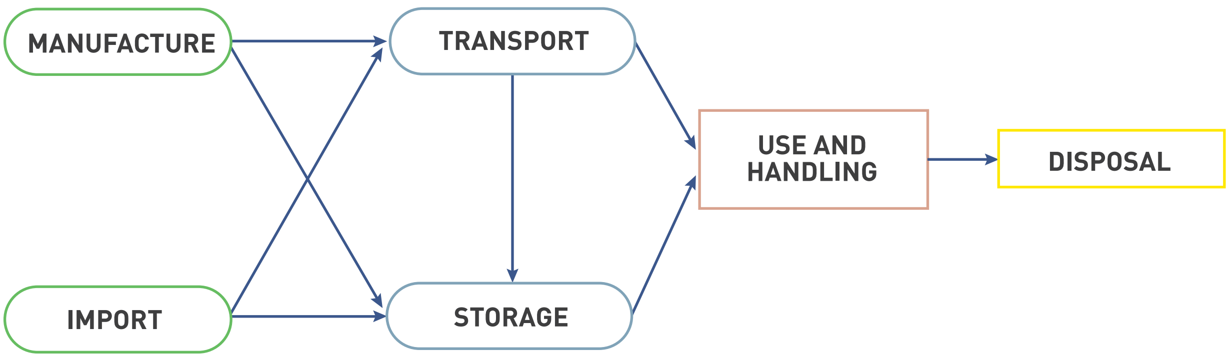

Figure 12 Life Cycle of Chemicals

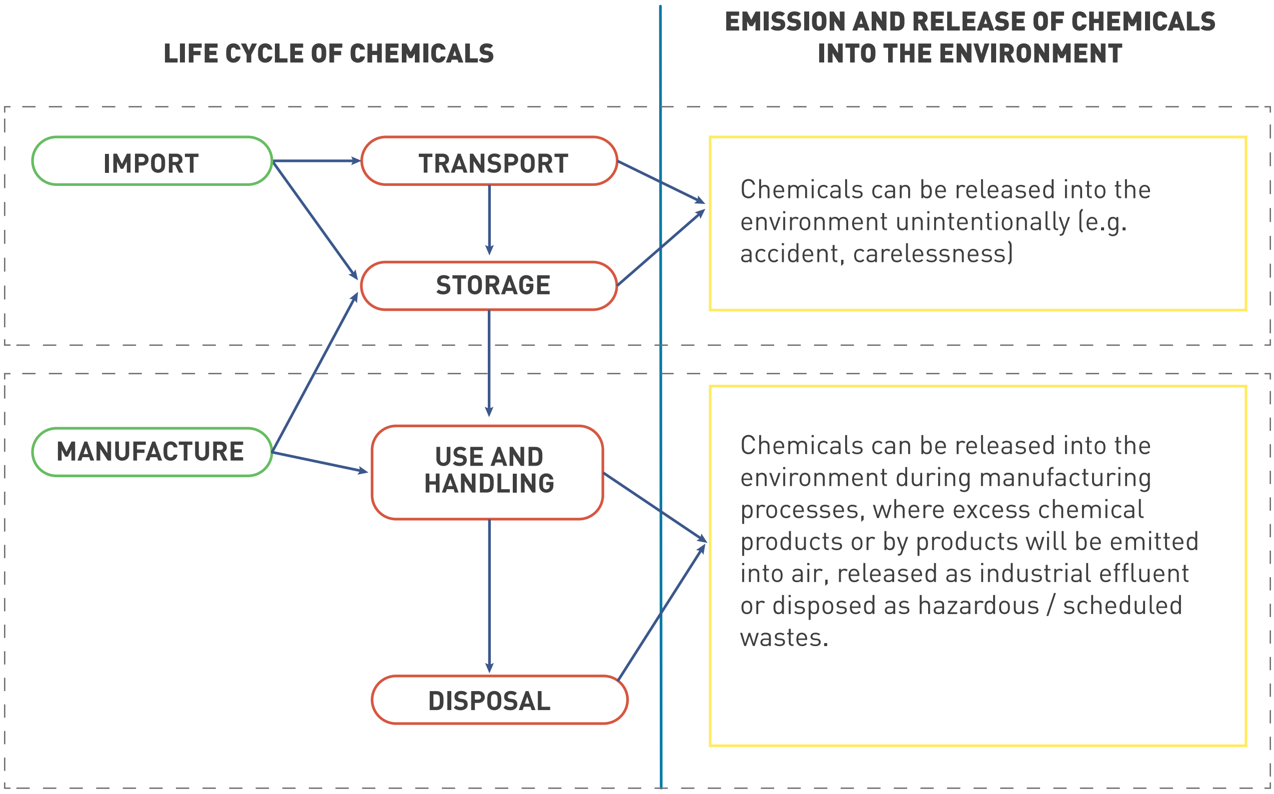

Figure 13 Emission and Release of Chemicals in Different Stages of Life Cycle

As chemical releases could occur at any stage of their life cycle, there is a need to have holistic, integrated and comprehensive chemical governance in place to manage chemicals and hazardous substances.

In 2018, the Environmental Management and Climate Change Division under MESTECC (formally under Ministry of Natural Resources and Environment) conducted a study known as "A Study to Strengthen the Governance of Hazardous Chemicals in Malaysia". The study found three main challenges for chemical governance in Malaysia, which are:

1. Absence of national chemical inventory
2. No clear mechanism to reduce/eliminate chemical risks at the national level
3. No central coordinating entity to manage upstream chemicals

3.4 WATER GOVERNANCE

Current State of Waterways in Pasir Gudang, Johor

Table 3 below shows 51 of the most polluted rivers in Peninsular Malaysia as classified by JAS in 2017. Both Sungai Kim Kim and Sungai Masai are listed as polluted rivers of Class 3 and Class 4 respectively. Sungai Tukang Batu that drains into Pelabuhan Pasir Gudang south of the area is the most polluted river at Class 5. Although there are no records of the status of the smaller rivers, they are most probably polluted as well and classified between Class 3 and Class 5.

Table 3: Water Quality Status 2017 of monitored rivers in the Peninsular

No.	Class 3 Rivers Needed Intensive Treatments	Class 4 Rivers Irrigation purposes only	Class 5 Rivers Water highly polluted
1	Sungai Juru, Pulau Pinang	Sungai Jawi, Pulau Pinang	Sungai Tukang Batu, Johor
2	Sungai Pinang, Pulau Pinang/Kedah	Sungai Rambai, Pulau Pinang	
3	Sungai Perai, Pulau Pinang/ Kedah	Sungai Jelutong, Pulau Pinang/ Kedah	
4	Sungai Nyamok, Perak	Sungai Kereh, Pulau Pinang/ Kedah	
5	Sungai Serokai, Perak	Sungai Partama, Pulau Pinang/ Kedah	
6	Sungai Wangi, Perak	Sungai Raja Hitam, Perak	
7	Sungai Air Busuk, Selangor/ KL	Sungai Kuyoh, Selangor/KL	
8	Sungai Belongkong, Selangor/ KL	Sungai Kerayong, Selangor/KL	
9	Sungai Bunos, Selangor/KL	Sungai Ulu Choh, Johor	
10	Sungai Buloh, Selangor	Sungai Melana, Johor	
11	Sungai Merlimau, Melaka	Sungai Danga, Johor	
12	Sungai Seri Melaka, Melaka	Sungai Latoh, Johor	
13	Sungai Simpang Kanan, Johor	Sungai Perembi, Johor	
14	Sungai Semberong, Johor	Sungai Masai, Johor	
15	Sungai Skudai Johor	Sungai Buluh. Johor	
16	Sungai Chemangar, Johor	Sungai Kempas, Johor	
17	Sungai Semenchu, Johor	Sungai Ayer Merah, Johor	
18	Sungai Kim Kim, Johor	Sungai Segget, Johor	
19	Sungai Anak Sedili, Johor	Sungai Bala, Johor	
20	Sungai Sarang Buaya, Johor	Sungai Sebulung, Johor	
21	Sungai Sanglang, Johor	Sungai Plentong, Johor	
22	Sungai Melatai, Pahang/Johor	Sungai Tebrau, Johor	
23	Sungai Jebong, Pahang/Johor	Sungai Pandan, Johor	
24	Sungai Alor Lintah, Kelantan	Sungai Tampoi, Johor	
25		Sungai Sengkuang, Johor	
26		Sungai Alor B, Kelantan	

(Source: *Jabatan Alam Sekitar*, 2017)

4.0 RECOMMENDATIONS

Based on the findings, the Task Force offers several recommendations for ministries and agencies to implement in order to avoid a recurrence of the incidents in the future.

4.1 IMMEDIATE ACTIONS

4.1.1 Immediate Actions by JAS and JKKP

To better identify the sources of the toxic gas releases, there is an urgent need for thorough investigations of hazardous chemical wastes disposal and storage in the chemical factories located within the two areas identified in Section 3.1.3

The Task Force recommends that both JKKP and JAS should take steps immediately to determine whether the chemical factories adhere to the current regulations under EQA 1974 and OSHA 1994.
JAS should immediately

1. Investigate all the chemical factories for intentional and accidental releases of toxic gases and spills of liquid hazardous chemicals that could affect the environment and the public.
2. Audit the hazardous chemical waste disposal records of the same chemical factories to determine whether their hazardous chemical wastes are disposed of properly according to Environmental Quality (scheduled wastes) Regulations, 2005 under EQA 1974.
3. Prosecute the same chemical factories that are found to breach Environmental Quality (scheduled wastes) Regulations, 2005 under EQA 1974.

JKKP should immediately

1. Investigate intentional and accidental releases of toxic gases and spills of liquid hazardous chemicals within the premises of the same chemical factories that could go beyond the fences of the factories and affect the environment and the public.
2. Audit all hazardous chemical storage at the same chemical companies as reported in the CIMS in order to determine whether they have reported all of their chemicals in storage as required by CLASS Regulations 2013 under OSHA 1994.
3. Audit the CHRA of the same chemical factories to ascertain the existence of chemicals not reported in the CIMS.
4. Prosecute chemical factories that are found to breach CLASS Regulations 2013 under OSHA 1994.

In order to facilitate rapid joint multi-agency investigations during a chemical emergency, the Task Force recommends that

1. JAS and JKKP offices should be located in hazardous industrial areas like Pasir Gudang.
2. The number of air pollution stations in hazardous industrial areas must also be increased.
3. The air pollution stations should be linked electronically to both offices to facilitate continuous monitoring of air pollution in the area.

4.1.2 More Sophisticated and Accurate Equipment to Measure Air Pollutants

The Task Force recommends that JAS use more sophisticated and accurate mobile instruments that could identify many types of hazardous chemicals in the air so that the appropriate emergency response plan for the specific mixture of hazardous chemicals identified by the instrument could be executed effectively.

1. The sophisticated instrument is the Gas Chromatograph/Mass Spectrometer (GCMS) with flame ionisation (FID) and photoionisation detectors (PID) and appropriate and reliable sampling systems. A mobile version of the GCMS could be used on-site during chemical emergency incidents.
2. The instrument has high maintenance costs and requires highly trained chemists and lab technicians to operate and maintain effectively.

3. In addition to air, other media such as soils, water and food should also be assessed for contamination of any toxic chemical.

4.1.3 Improvement of Back Trajectory Modelling to Account for Denser Than Air Gases

The modified back trajectory model used in the present report were used effectively in identifying the most probable area where the sources were located.

The Task Force recommends that a more accurate model is developed to increase the resolution of locating the actual sources of the pollutant.

1. Since the toxic gases are denser than air, the modified back trajectory model that is based on light gases could be improved by incorporating the density of denser than air gases/vapours of the hazardous chemicals to better identify the sources of the toxic gas releases.
2. This denser than air characteristic would provide a more realistic prediction of their trajectories, which would be expected to persist near the ground as they advect downwind.

4.1.4 Improvement of Time Series Modelling to Account for Spikes in Concentration Measurement

Since there are spikes in the measurements of the toxic gases, the Task Force recommends that the position of the possible sources should be determined more accurately by matching the pollutant concentration time series with the modelled time series generated by an unsteady state air pollution dispersion model that could simulate the concentration spikes.

1. An excellent unsteady state air pollution dispersion model that could be used is CALPUFF.
2. The dispersion modelling could be done from every stack of the chemical factories located in the most probable areas identified in Section 3.1.3.
3. The results could then be compared with the time series of the measured concentrations data at the schools.
4. Further studies should include the careful analysis of the air pollution and meteorological data that are merged with the health data from the JKN Johor. The results of the study could be used to determine the pollutant exposure threshold before symptoms could manifest.

4.1.5 Mass Hysteria/Psychogenic Illness

There were reports from the school teachers of possible mass hysteria among the affected schoolgirls. It had been reported that mass hysteria, also known as epidemic hysteria or Mass Psychogenic Illness MPI could be triggered by an odour in mass hysterical reactions in schools (Jones et al., 2000). The last incident of mass hysteria in Malaysian schools was reported by Hwang in 1986. Culture and gender seemed to influence its manifestations.

In order to treat effectively the schoolchildren suffering from mass hysteria, the Task Force highly recommends that a further study is undertaken immediately to ascertain the possible occurrence of mass psychogenic illness among the affected schoolchildren during both incidents.

4.2 SHORT-TERM ACTIONS

4.2.1 Adverse effects of Hazardous Chemicals

It is very important that multidisciplinary approach be taken in the investigation of major disasters of this nature in the future. Knowledge of potential chemicals involved is critical in early emergency response and treatment as well as in determining diagnostic investigation. The severity of the adverse effects of multiple toxic gases that were seen in the incidents warrants the implementation of better methods of assessing them since exposure to multiple chemicals simultaneously may have additive or synergistic toxicity. The Task Force therefore recommends:

1. Chemical fingerprinting investigations should be conducted to determine the actual components of the toxic gas mixture in order to establish more accurately the source of the toxic chemicals and to determine the impact of the chemicals on human health.
2. A more sensitive test should be used for clinical analysis in blood and urine.
3. Measurement of biomarkers/metabolites should also be done to confirm the exposure to specific toxic gases.
4. The follow-up test by JKN Johor should include neuropsychological test based on the type of chemicals involved to identify the suitable biomarkers.
5. Clinical practice guideline on the management and investigation of chemical exposure could be drawn up. The following equipments are recommended in handling these type of gases (Table 4).

Table 4: Suggested Personal Protective Equipment

No.	Chemicals	Respirator cartridge 3M respirator guide 2018	Chemical Glove Ansell 8th edition
1.	Acrolein	Organic vapour (full face)	Butyl (ChemSafety)
2.	Acrylonitrile	Organic vapour	Laminated film/ PVA/ Butyl/ Viton
3.	Methyl Mercaptan	Organic vapour	
4.	Benzene	Organic vapour	Laminated film/ Viton

4.3 MEDIUM-TERM ACTIONS

4.3.1 Amendment of Definition of "Pollution" in EQA 1974

Since the amendment of "pollution" in EQA 1974 that took place in 2012 has restricted the scope of "pollution", the Task Force recommends that the Minister amend the definition of "pollution" based on the definition that was found in EQA 1974 before the amendment in 2012 to broaden the scope of "pollution".

4.3.2 Determination of Acceptable Conditions for Environmental Hazardous Substances (EHS) in EQA 1974

In order to strengthen prosecution of air pollution cases involving toxic gases, the Task Force recommends the Minister to quantify the acceptable conditions for all EHS so that any EHS that is present in the air above the acceptable conditions value could be considered as a "pollution" under EQA 1974, and the responsible parties could be prosecuted more effectively.

4.3.3 Amendment of Definition of Environmental Hazardous Substance (EHS) in EQA 1974

Since the existing broad definition of EHS in the EQA 1974 could be interpreted subjectively by the industry, and JAS intends to amend the EHS definition to tally with the list of chemicals that are regulated by several MEAs, the Task Force recommends that the definition of EHS under EQA 1974 be amended such that EHS is defined based both on the intrinsic hazardous chemical characteristics and the MEA listing.

Since JKKP has adopted the Globally Harmonised System (GHS) of Classification and Labelling of Chemicals (third revised edition), which is also has been adopted by the EU, Japan, New Zealand and China, The Task Force recommended that JAS also adopts the intrinsic hazardous chemical characteristics in GHS in the amended definition of the EHS under the EQA 1974.

The recommended definition of EHS is:

Environmentally Hazardous Substances (EHS) is defined as "any natural or artificial substances including any raw material, whether in a solid, semi-solid or liquid form, or in the form of gas or vapour, or in a mixture of at least two of these substances, that have one or more of the following intrinsic properties below:

1. Explosiveness
2. Flammability
3. Capacity to oxidiSe
4. Corrosiveness
5. Toxicity (including chronic toxicity)
6. Ecotoxicity (with or without bioaccumulation)
7. When contact with water, emit flammable or toxic gases
8. Hazardous to the ozone layer
9. Bioaccumulation in the environment
10. Persistent in the environment

Table 5 : Correlation Between the Intrinsic Properties of EHS and the Hazard Classes under GHS

Intrinsic properties of EHS	Hazard classes under GHS
Explosiveness	• Explosive
Flammability	• Flammable gases • Flammable aerosols • Flammable liquids • Flammable solids • Self-reactive substances and mixtures • Pyrophoric liquids • Pyrophoric substance • Self-heating substances and mixtures
Capacity to oxidise	• Oxidising gases • Oxidising liquids • Oxidising solids • Organic peroxides
Corrosiveness	• Corrosive to metals • Skin corrosion • Eye damage
Toxicity (including chronic toxicity)	• Acute toxicity (oral, dermal and inhalation) • Skin irritation • Eye irritation • Skin sensitisation • Respiratory sensitisation • Germ cell mutagenicity • Carcinogenicity • Reproductive toxicity • Specific target organ toxicity (single exposure) • Specific target organ toxicity (repeated exposure) • Aspiration hazard
Ecotoxicity (with or without bioaccumulation)	• Aquatic toxicity (acute) • Aquatic toxicity (chronic)
When in contact with water, emit flammable gases	• Substances and mixtures, when in contact with water, emit flammable gases
Hazardous to the ozone layer	• Hazardous to the ozone layer

*Note: the properties 'When contact with water, emit toxic gases' and 'Bioaccumulation or persistent in the environment' is not addressed in the GHS. However, provision should be in place as the GHS will be revised every 2 years.

4.3.4 Amendments of the CLASS Regulations 2013 under OSHA 1994

1. Since currently only chemicals that are imported and manufactured are reported in CIMS, the Task Force recommends that the CLASS Regulations 2013 should be amended such that chemicals obtained through a local supplier in the circular economy must be reported in CIMS.
2. CHRA reports should be deposited mandatorily at the JKKP and not only produced when JKKP officials conduct an audit of the company.
3. Chemical factories should be compelled to report any accidental or intentional large toxic and flammable gas releases and large chemical spills from leakages immediately to JBP, JKKP, JAS and JKN for the agencies to execute the emergency response plan to protect the public from harm.

4.3.5 Amendments to the Buffer Zone Distance for Chemical Factories in the Guidelines for Siting and Zoning of Industry and Residential Areas 2012

Since the minimum buffer zone between chemical factories and the residential areas in the Guidelines for Siting and Zoning of Industry and Residential Areas 2012 is only 500m, the Task Force recommends that the minimum buffer zone distance between chemical factories and residential areas in the guideline be amended to between 1000m to 1500m.

4.4 LONG-TERM ACTIONS

4.4.1 Integrated Chemical Governance

The Task Force recommends MESTECC to implement the following proposals from a previous study, "A Study to Strengthen the Governance of Hazardous Chemicals in Malaysia", that would strengthen chemical governance through an integrated approach by

1. Integrating the CIMS under JKKP and the EHS Notification and Registration System under JAS
2. Establishing a statutory body to govern chemicals management such as a Chemicals Management Commission

4.4.2 Integrated Water Resources Management (IWRM)/Integrated River Basin Management (IRBM)

Even though this Task Force eliminated the Sungai Kim Kim pollution as a possible source of the toxic chemicals, water governance is still an important aspect in order to keep the pollution level of Pasir Gudang at its minimum.

The Task Force therefore recommends Pasir Gudang's waterways should be managed in the following way:

1. Since the source of water for either domestic, industry or agriculture are from water bodies such as rivers and lakes/ponds/reservoirs, the implementation of IWRM/IRBM must be approached at the macro level, but implemented at the micro/field level, so that there is seamless integration of minor, major and stormwater drains with rivers flowing into the sea.
2. Macro level integrated planning at State or Regional level must involve all agencies such as *Badan Kawal Selia Air Negeri Johor* (BAKAJ), MPPG, JPS, JAS and Plan Malaysia to work together within a single platform such as in support of the Johor Sustainability Policy 2016 (Economic Planning Unit Johor, 2016).
3. Adoption of the final report of Stormwater Management Master Plan for Pasir Gudang 2010 (Department of Irrigation and Drainage, 2010) (Figure 14) to build:
   a. 24 sediments basins for sediment control
   b. 23 wetlands for pollution control
   c. A bio-retention system as an alternative for pollution control
   d. More than 50 GPT for coarser sediments and floatables
   e. Four local detention tanks for 15000^{m3} flood storage

4. Upgrading of the existing 12.4km drains and construction of 2.3km of new drains. Review the adequacy of current infrastructure and update to current standards such as imposing TMDL (Total Maximum Daily Load) for sediments and pollutants for critical locations along with selected control points.
5. Update the infrastructure requirements with current technology that is being used globally such as incorporating the concept of circular economy and zero waste. Some case studies are available in a report published by the Economic and Social Commission for Asia and the Pacific (ESCAP) titled "Water and Green Growth in Asia and the Pacific" (United Nations Economic and Social Commission for Asia and the Pacific, 2015).
    a. Case Study 1 - "Integrated Urban Water Management in Beijing" would be relevant to MPPG.
    b. Case Study 2 - "Innovating Pollution Control and Industrial Symbiosis to Realise China's 'Circular Economy'" (p. 11-13) is an example that can be emulated by the industries within Pasir Gudang and elsewhere.

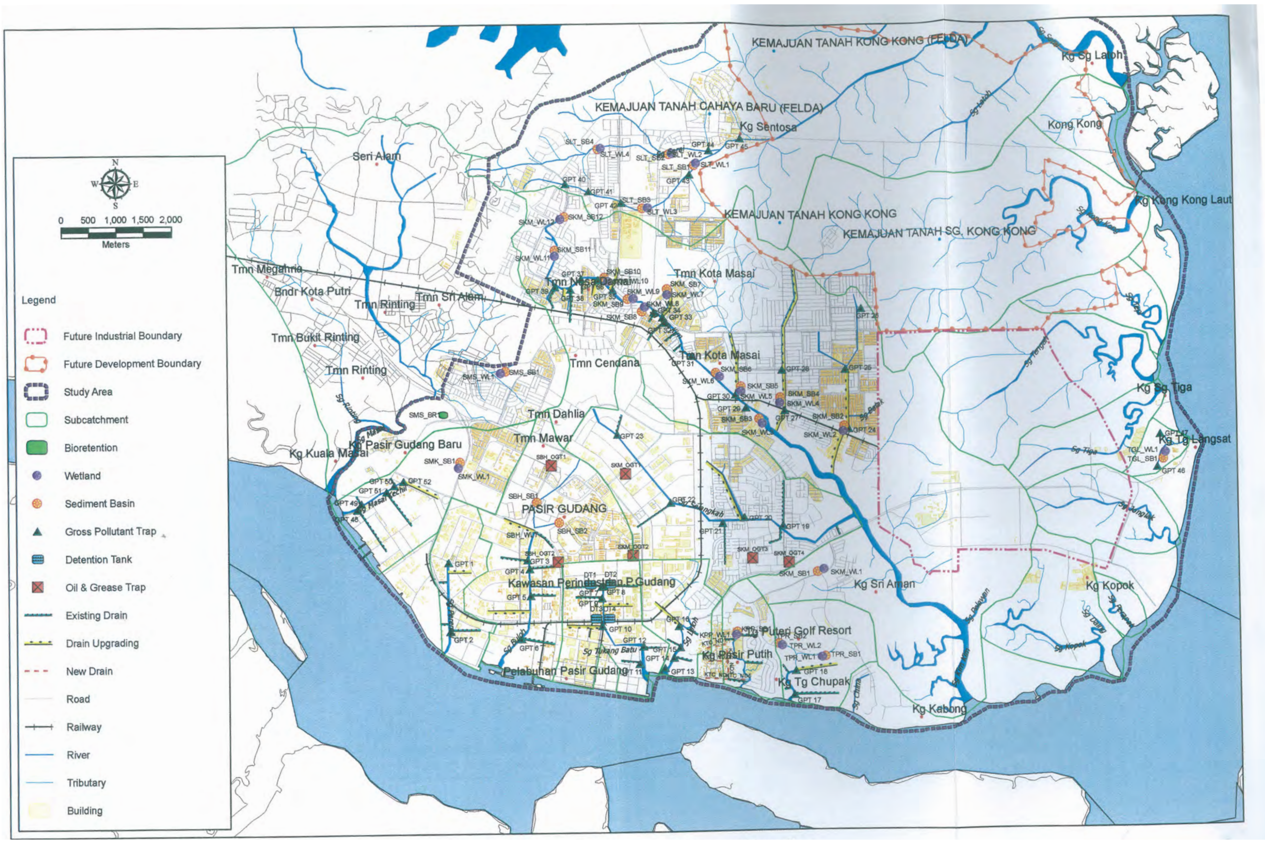

Figure 14 Recommended Stormwater Management Master Plan 2010 for Pasir Gudang
(Source: *Jabatan Pengairan dan Saliran*)

6. Review the Johor Waters Enactment 1921 (Enactment 66) to streamline the need for an Integrated Water Resources Management, to focus on all aspects of water resources management and water services management:

a. Pollution management and environmental rehabilitation and sustainable management of water bodies

b. Provide a cross-cutting platform for all related agencies for discussion and implementation as well as strengthening the monitoring and enforcement through the provision of adequate resources such as funding and manpower

5.0 CONCLUSION

The main tasks of the Task Force are to identify the sources of the toxic gases afflicting the schoolchildren in Pasir Gudang and to recommend a plan of action to be implemented by the relevant ministries and agencies to prevent its recurrence in Malaysia.

The toxic gases were positively identified as acrolein, acrylonitrile, methyl mercaptan and benzene. The symptoms experienced by the schoolchildren of vomiting, nausea, dizziness, shortness of breath, coughing, sore throat and muscular cramps, were consistent with the adverse effects of inhaling these gases.

The initial conclusion that the source of the toxic gases was from illegal dumping of chemical wastes in Sungai Kim Kim has been ruled out because dense gas from the ground did not have enough buoyancy and momentum to hit the upper floors and Sungai Kim Kim was clean when the second incident occurred.

Back trajectory analysis using concentrations, meteorological data and Gaussian plume modelling yielded multiple point sources. Probability density was then calculated using kernel density method. The area within the highest density contours would contain the most probable location of the sources.

It can be safely concluded that the most probable location of the sources for acrolein, acrylonitrile and methyl mercaptan is in the area bounded by Jalan Pasir Gudang, Jalan Emas and Jalan Pekeliling. The most probable location for the source of benzene is in the area bounded by Johor Bahru East Coast Highway, Jalan Pekeliling, and Pasir Gudang Highway.

Based on the findings, the Task Force has outlined several recommendations for ministries and agencies to implement in order to avoid a recurrence of the incidents.

There is an urgent need for immediate thorough investigations of intentional and accidental releases of toxic gases and liquid hazardous chemical spills, hazardous chemical storage and wastes disposal in the chemical factories by both JAS and JKKP.

A more sophisticated and accurate instrument such as the gas chromatograph/mass spectrometer (GC/MS) is urgently needed to identify many hazardous chemicals in the air, and other media such as water, soil and food.

A more accurate modified back trajectory model should be urgently developed to account for denser than air gases. An unsteady state air pollution dispersion model such as CALPUFF could be used to locate the sources more accurately.

A further study should be undertaken immediately to ascertain the possible occurrence of mass hysteria or mass psychogenic illness among affected schoolchildren during both incidents.

In the short term, better methods of assessing adverse health effects of simultaneous exposure to multiple chemicals should be developed such as chemical fingerprinting, more sensitive test for clinical analysis in blood and urine, measurement of biomarkers or metabolites which should be follow-up with a neuropsychological test.

The definition of "pollution" should be amended by reverting to the definition in the original EQA 1974 before the amendment in 2012 to retain the broad scope of "pollution". Acceptable conditions for EHS under EQA 1974 should be quantified urgently that would turn them into "pollution" if they are exceeded.

The definition of EHS under EQA 1974 should be ammended such that it is based both on the MEA listing and the intrinsic hazardous chemical characteristics in the Globally Harmonised System (GHS) of Classification and Labelling of Chemicals that had also been adopted by JKKP.

The minimum buffer zone for chemical factories should be increased from 500m to 1000-1500m to provide sufficient protection to the public from toxic gas releases.

In the long term, CIMS under JKKP should be integrated with the EHS Notification and Registration System under JAS. A statutory body to govern chemicals management such as a Chemicals Management Commission should be established.

IWRM / IRBM should be implemented at the macro level for seamless integration of drains, rivers and the sea. Recommendations in the final report of Stormwater Management Master Plan for Pasir Gudang 2010 to manage sediments and pollution in the drains and river systems of the Pasir Gudang area should be implemented.

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