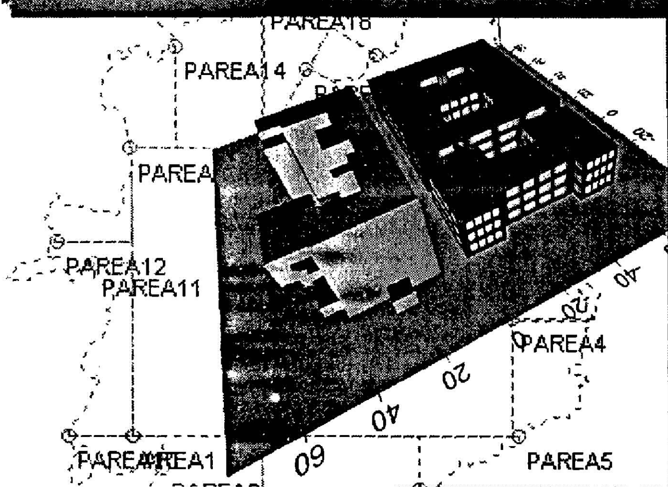
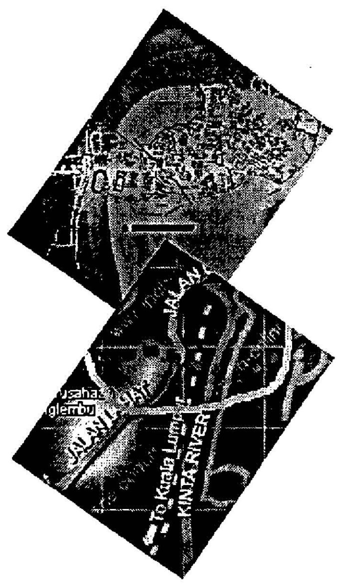


Air And Noise Modelling For A Healthy Environment

KNOWLEDGE ORGANISATION

- KOH HOCK LYE
School of Mathematical Sciences



AIR AND NOISE MODELLING FOR A HEALTHY ENVIRONMENT

INTRODUCTION

Fundamental to any knowledge organisation technique is modelling. A good model will not only indicate the types of data to collect in a given application, but will also allow for efficient utilisation of the knowledge stored. Unfortunately, there is no universal technique for knowledge modelling that will work for all domains. Modelling for a given domain requires in-depth knowledge of the problem at hand and the parameters influencing the solution to the problem. Where in knowledge-based systems, certain domain can be 'forced' to fit some standard knowledge organisation models (e.g. ontologies), it is not the case for many other problem domains where the parameters involved may be much more dynamic (say, with unpredictable changes) or the number of core parameters to be considered may itself be subject to changes depending on external conditions. Although yet to be considered as a direct application of knowledge management, the domain of Environmental Modelling may provide some insight into such kind of problems and perhaps will one day shed some light on knowledge organisation in not so well-behaved problem situations.

The Environmental Quality (Clean Air) Regulation 1978 was enacted under the Malaysian Environment Quality Act 1974, following the enactment of the Clean Air Act of the United States of America. The US Environmental Protection Agency (USEPA), entrusted with the responsibility for protecting air quality in the USA, is the prime agency spearheading research on the science of air quality and its policy and enforcement in that country. In a recent publication, USEPA reported that vehicles are the major contributors to air pollution, with on-road and non-road engines and vehicles contributing 79% of carbon monoxide (CO) and 53% of nitrogen oxide (NO). Another significant contributor to air pollution is fuel combustion for power generation. The report also noted that cars and motorcycles have the highest emission rates of CO, contributing on average 20 gm of CO per mile travelled per vehicle. Worldwide, an estimated three million premature deaths annually are attributed to air pollution. To provide a benchmark for the protection of human health, ambient air quality safety standards (not to be exceeded), as shown in Table 1, have been established by several countries and agencies including WHO and USEPA.

Mathematical modelling has gradually evolved to become an important tool in environmental research, in ecosystem rehabilitation and in various activities related to the preservation of the ecosphere, such as environmental impact assessment and global warming research. Over the past three decades, research teams in USM have steadily enhanced capacity building and research capability to conduct water and air pollution modelling studies to help achieve compliance with safety standards, to protect human health and to preserve and enhance ecosystems. A write-up on the modelling of the aquatic environment and aquatic ecosystems can be found in Volume 3 of this series. In addition, current research on modelling of the hydrology, aquatic environments and ecosystems of Tasik Harapan, located in USM's main campus, will soon be published in a separate volume under the *Siri Kampus Sejahtera* publications.

This paper will hence focus on air and noise quality and will briefly summarise past achievements in air and noise quality modelling in USM, with a view to further development.

Table I: Ambient Air Quality Standards (not to be exceeded) by WHO, USEPA, UK and Malaysia

Pollutant	Averaging Time	WHO Standards	USEPA Standards	UK Standards	Malaysian Standards
Carbon monoxide (CO)	8 hour	10 mg/m^3	9 ppm or 10 mg/m^3	n. a.	10 mg/m^3
	1 hour	30 mg/m^3	35 ppm 40 mg/m^3	n. a.	35 mg/m^3
Nitrogen dioxide (NO_2)	Annual	40 $\mu g/m^3$	0.053 ppm 100 $\mu g/m^3$	40 $\mu g/m^3$ 21 ppb	n. a.
	24 hour	200 $\mu g/m^3$	n. a.	n. a.	n. a.
	1 hour	418 $\mu g/m^3$	n. a.	150 ppb 287 $\mu g/m^3$	320 $\mu g/m^3$
Particulate Matter PM_{10}	Annual	60 $\mu g/m^3$	50 $\mu g/m^3$	40 $\mu g/m^3$	50 $\mu g/m^3$
	24 hour	n. a.	n. a.	n. a.	n. a.
	1 hour	150 $\mu g/m^3$	150 $\mu g/m^3$	50 $\mu g/m^3$	150 $\mu g/m^3$
Sulphur dioxide (SO_2)	Annual	50 $\mu g/m^3$	0.03 ppm 80 $\mu g/m^3$	20 $\mu g/m^3$ 8 ppb	105 $\mu g/m^3$
	24 hour	125 $\mu g/m^3$	0.14 ppm 365 $\mu g/m^3$	125 $\mu g/m^3$ 47 ppb	n. a.
	1 hour	n. a.	n. a.	350 $\mu g/m^3$ 132 ppb	350 $\mu g/m^3$

MODELLING ROAD CARBON MONOXIDE IN PENANG

Traffic fumes are responsible for a large number of cases of chronic bronchitis and asthma in the country. Concerned over the potential hazards that traffic-generated air pollution might pose to health, a research team in USM monitored and modelled CO levels in several major roads in Penang in 1990–1991, the results of which are presented in Figure 1. It is obvious that the CO levels in all the roads remained around or above 5 ppm for more than 8 hours in a day. These levels of CO are deemed unsatisfactory as they are near the 8-hour CO safety standard of 10 ppm (which should not be exceeded) presented in Table 1. Congested roads are clearly a prime contributor to air pollution in city roads, yet there are no signs that this undesirable situation will improve in the future. Hence, efforts are needed to ensure that pollutants such as CO on roads in Penang will stay well within the safe level.

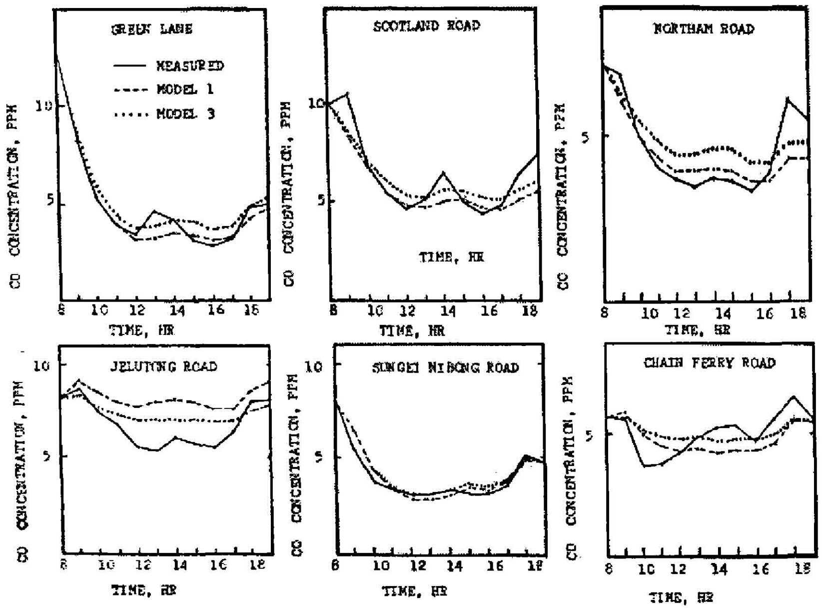


Figure 1: Measured and Modelled Hourly CO Concentrations for Major Roads in Penang

USM CAMPUS AIR MODELLING STUDY

The sources of air pollution are not limited to emissions from traffic only. Emission from other sources such as chimneys also contribute significantly to overall air pollution. Sponsored by the USM *Healthy Campus Program*, a study was completed to monitor and model air pollution emitted from the School of Chemical Sciences (SCS) in USM to assess its potential impact on the health and safety of occupants in the New Science Complex (NSC) adjacent to SCS. The main objective was to safeguard the health and safety of USM campus, in line with the concept of *a university in a garden*. For this purpose, the popular air pollution model ISCST3, developed by USEPA, was used to model the dispersion of pollutants from SCS. ISCST3 is based upon the steady state Gaussian Plume model, in which the hourly concentration at downwind distance x (m) and crosswind distance y (m) is given by Equation 1.

$$\chi = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \qquad (1)$$

Here, Q = pollutant emission rate (mass per unit time)

K = a scaling coefficient to convert calculated concentrations to desired units (default value of 1×10^6 for Q in gs^{-1} and concentration in μgm^{-3})

V = vertical term

D = decay term

σ_y, σ_z = standard deviation of lateral vertical concentration distribution (m)

u_s = mean wind speed (ms^{-1}) at release height

The outcome of air pollution dispersion, in general, is significantly dependent on four parameters: meteorological conditions, emission parameters, terrain topography and building wake effects. Figure 2 shows the contour plot for (a) toluene concentrations on the top level and (b) methanol concentrations on the fifth floor in µg/m^3 due to the emissions from SCS. The modelling study concluded that the emissions of chemicals from SCS will not pose a health hazard to the occupants in SCS and NSC as the emission rates are low. Further, sampling of airborne chemicals from the ground floor up to the top floor of the NSC building indicates that the peak concentrations are merely one-hundredth (or less) of the safe concentrations specified in the Occupational Safety and Health (OSHA) Regulations 2000 for all pollutants of concern. Finally, the exposure level of volatile organic compounds (VOC), as shown in Figure 3, measured on all 16 volunteers from the NSC complex are well within the PEL (Permissible Exposure Limits) as specified in OSHA Regulations 2000. Hence it may be concluded that the emissions from SCS pose no health hazards to occupants in NSC.

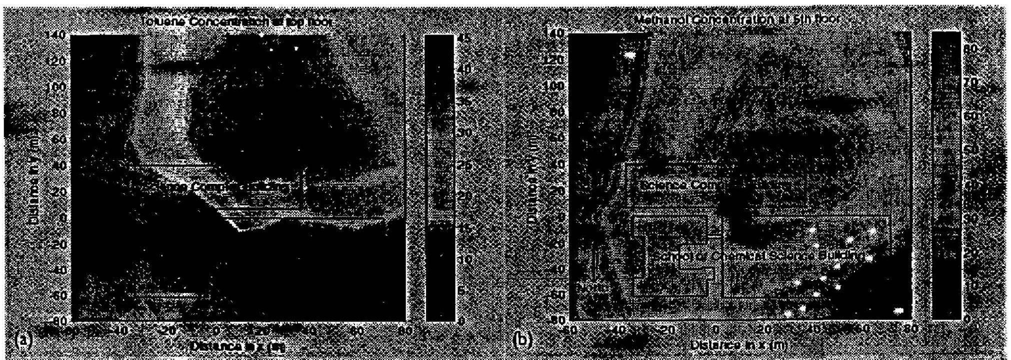


Figure 2: 2D Plot for (a) Toluene Concentrations on Top Level and (b) Methanol Concentrations on Fifth Floor in µg/m^3

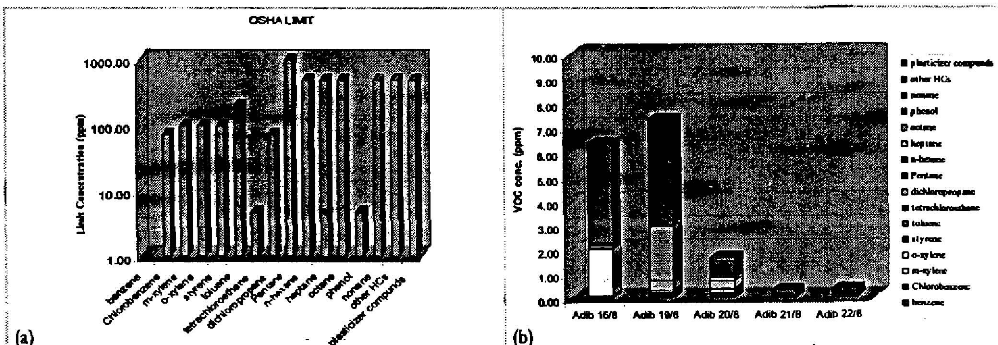


Figure 3: (a) OSHA Permissible Exposure Limit (PEL – ppm TWA) and (b) Level of Daily Exposures of VOC on Staff in the New Science Complex Building

EFFECTS OF BUILDING DOWNWASH

The monitoring and modelling analysis completed in 2003, as discussed above, convincingly concluded that the emissions of chemicals from SCS did not pose health hazards to the occupants in the nearby buildings. However, the effects of downwash due to building wakes were not considered in the 2003 modelling exercise. Downwash is the result created by the turbulence that occurs to a flow as it passes over the gap between buildings. Hence, as a precautionary measure, a follow-up study was completed in 2004 to model air pollution dispersion in the presence of building downwash near NSC. The model used in this simulation was the ISC-AERMOD View, developed by Lakes Environmental Software in conjunction with USEPA, in which the effect of downwash is given by Equation 2, where C_N is the concentration with downwash taken into consideration.

$$C_N = \frac{BfQ \exp\{(-1/2)(y/\sigma_{yc})^2\}}{(U_H H_C W'_B)} \qquad (2)$$

Here, H_C = height of the downwind recirculation cavity (m)

f = fraction of plume mass captured by the near wake

W'_B = building width scale through which the plume is mixed in the recirculation cavity (m)

σ_{yc} = horizontal dispersion coefficient for downwind recirculation cavity (m)

B = empirical constant (recirculation factor for near wake concentration)

U_H = ambient wind speed at building height (m/s)

The models used are the most advanced currently available. Figure 4 illustrates 2D and 3D views of SCS and NSC while Figure 5 portrays the dichloromethane concentration contours at (a) 0 m, (b) 15 m and (c) 25 m above ground level in NSC. Figure 6 plots dichloromethane concentrations versus downwind distance from the source at (a) 0 m, (b) 15 m and (c) 25 m above ground level, with positive distance indicating southerly downwind direction. As can be seen from Figure 6, the downwash effects increase the concentration at ground level in the downwind direction. On the other hand, at the height of the chimneys (15 m), the concentration oscillates with distance, reflecting the effects of downwash. Finally, at 10 m above the chimneys' height (25 m), downwash tends to diminish the concentrations. Nevertheless, the effect of downwash has no significant impact on the overall concentration levels. In short, the emissions of chemicals from SCS do not pose health hazards to occupants in the surrounding buildings, even in the presence of downwash.

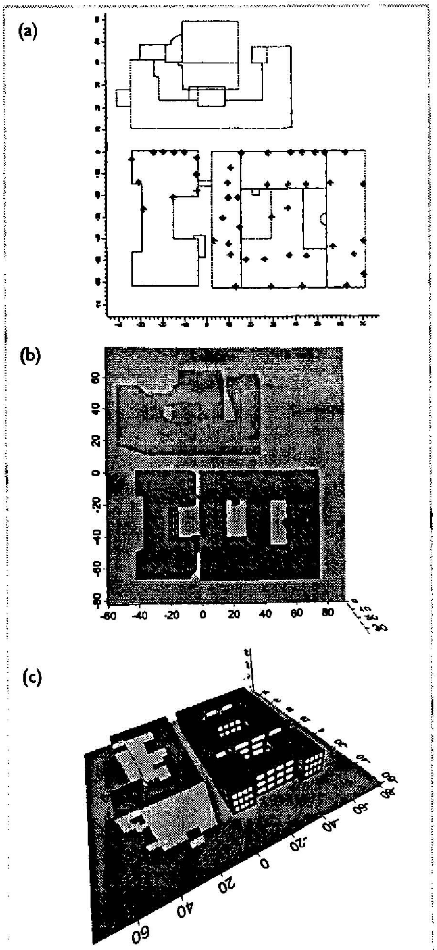


Figure 4: View of the Buildings in
(a) 2D with X=(0, 0) [dots refer to chimneys]
(b) 3D from Top and
(c) 3D from Sideway, USM SCS and NSC

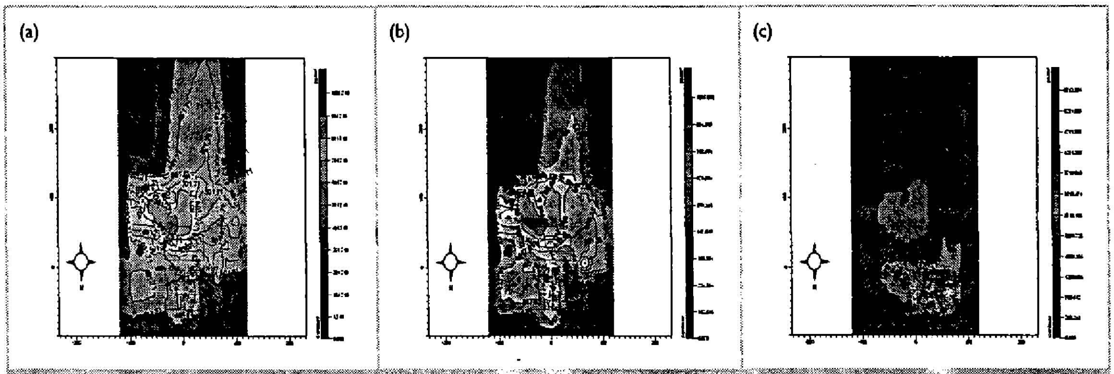


Figure 5: Dichloromethane Concentrations at (a) 0 m, (b) 15 m and (c) 25 m above Ground Level of USM NSC

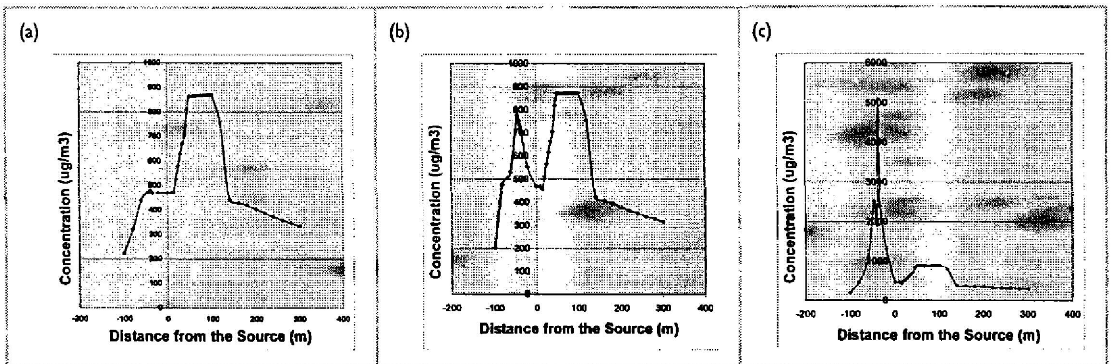


Figure 6: Dichloromethane Concentrations at (a) 0 m, (b) 15 m and (c) 25 m above Ground Level versus Downwind Distance from the Source

KERETAPI TANAH MELAYU BERHAD (KTMB) AIR POLLUTION MODELLING

KTMB plans to develop a double track rail link between Malaysia and China. It is anticipated that a major train stop will be built in the town of Batu Gajah, in which major service and repair of locomotives will be provided in the workshop within the railway station complex. As part of an EIA procedure, KTMB engaged a team of researchers from USM to conduct a modelling analysis of the potential impact of this development on water and air quality. One major consideration that had to be addressed concerned the air pollutants emitted from locomotive engines undergoing service and repair. Figure 7 demonstrates the simulated PM_{10} concentrations at ground level in the vicinity of the locomotives under testing or servicing. Figure 7a refers to the potential scenario without a chimney while Figures 7b and 7c show the PM_{10} concentrations if the exhaust is emitted through a chimney with the height of 5 m and 9 m respectively. Based upon these simulation results, it may be deduced that the levels of PM_{10} might pose a hazard to workers servicing the locomotives if the pollutants were released without a chimney. However a chimney with the height of 5 m is adequate to reduce PM_{10} concentrations at ground level to a concentration deemed safe according to Table 1. Other simulation results, not shown in this paper, also indicate that the PM_{10} generated from the double track train operation in Batu Gajah will not pose any hazard to residents living in the neighbourhood.

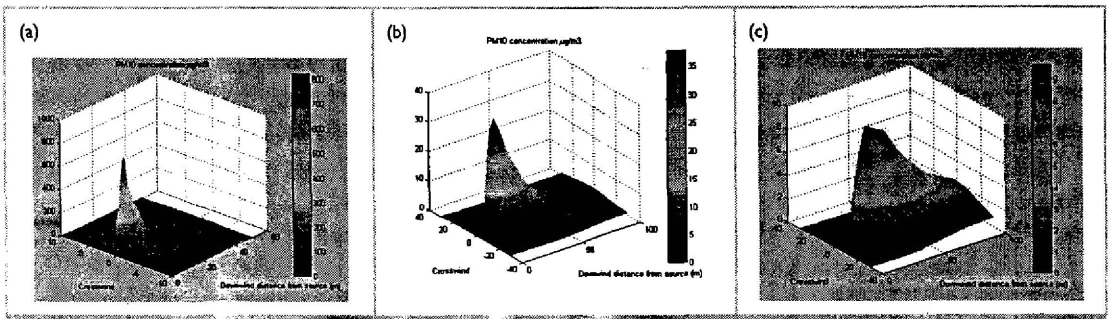


Figure 7: PM_{10} Distributions in 3-D, with Exhaust Heights of (a) 1.5 m, (b) 5 m and (c) 9 m

TRAFFIC-GENERATED AIR POLLUTION

The operation of the double track rail link with a major stop in Batu Gajah may potentially increase the traffic in Batu Gajah and nearby Ipoh City. Hence, a simulation analysis was performed to assess the potential impact of traffic-generated CO on the nearby residents. Figure 8a is a schematic sketch of Jalan Lahat in Ipoh, while Figure 8b shows the simulation results regarding CO concentrations arising from the exhaust pipes of vehicles travelling along Jalan Lahat. Based upon these simulation results, it may be deduced that the CO levels are well within the safety standards as indicated in Table 1. This methodology of modelling the potential impact of traffic-generated air pollution may be extended to other study sites such as the Penang Outer Ring Road (PORR) and highways.

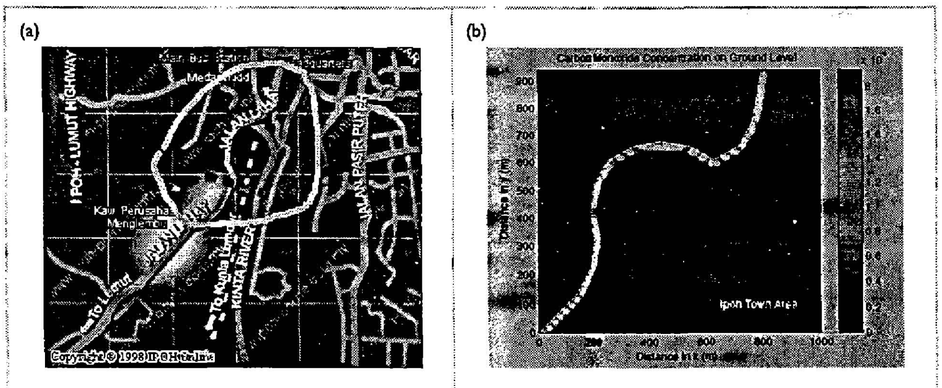
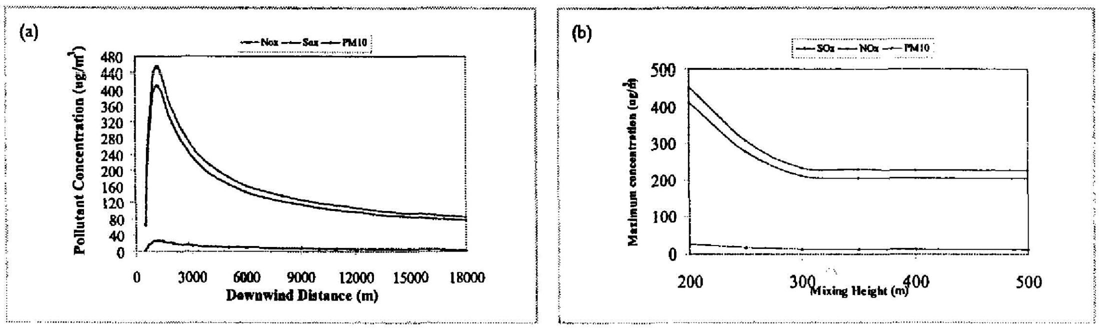


Figure 8: (a) Map of Jalan Lahat, Ipoh and (b) Contour Plot for Carbon Monoxide Concentrations in µg/m³ on Ground Level Due to Mobile Sources (Jalan Lahat)

KHARTOUM POWER STATION

Combustion of coal and fossil fuels contributes a significant quantity of sulphur monoxide (SO), NO and PAH into the atmosphere. There is a plan to build a 250 MW power station to serve the needs of the city of Khartoum in Sudan. As part of the financing requirements, the World Bank required an EIA, with the assignment being given to USM, to be performed on the potential impact of emissions from this power station on the citizens of Khartoum. Figures 9a and 9c indicate that the most affected area is within a distance of 1 km to 4 km downwind of the power station



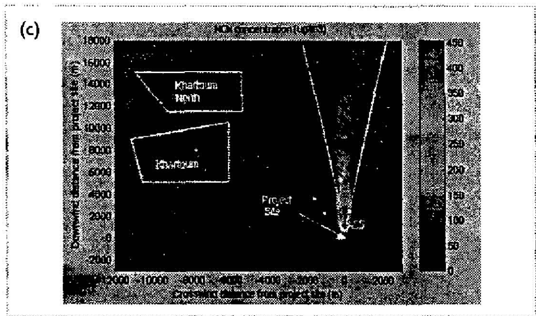


Figure 9: (a) Pollutant Concentrations along Downwind Direction, (b) Effect of Mixing Heights on Simulated Pollutant Concentrations and (c) 2D Plot for NO_x Concentrations under Worst Case Scenario (wind direction = 0)

and that for a significant distance of up to 18 km downwind, the pollutant concentrations for NO_x and SO_x remain above 80 g/m^3, a level deemed high enough to pose a potential hazard (Table 1). Mitigation measures are therefore needed, which include raising the emission height of the stack and installing pollution control devices such as scrubbers and precipitators. Sensitivity analysis was performed to assess the impact of atmospheric mixing height on the distribution of the pollutants. Figure 9b shows that the pollutant concentrations at ground level are sensitive to a mixing height below 300 m and that above 300 m of mixing height, the ground level concentrations are independent of the mixing height. The implications are that variations in mixing height, normally above 300 m around Khartoum, would have no impact on air pollution distribution at ground level due to emissions from the power station.

OPEN BURNING OF TYRES

Open burning has become a common occurrence in Malaysia, and has contributed to repeated occurrences of severe air pollution. Hence a team of researchers at USM, sponsored by an FRGS Grant, embarked on a project aimed at modelling air pollution due to open burning. As crucial data relating to open burning are not available in Malaysia, the team resorted to using data from the USA, with particular reference to the open burning of tyres. In the USA, the open burning of hazardous wastes, including scrap vehicle tyres, is prohibited. As tyres are highly combustible, accidental and unintentional tyre fires occur frequently and can continue to burn for months. For this modelling case study, we chose the Rhinehart fire in Winchester, Virginia that burned continuously for nearly 9 months from 1983 to 1984. The fire, of unknown origin, started on 31 October 1983 in a dumpsite that contained 5 million scrap tyres, spread over an area of 1.6 ha. This fire continued to burn until 4 July 1984. Data used in this study included emission factors for open burning of tyres, for several heavy metals including lead, which was the pollutant of concern in this modelling study. Other pollutants of concern included SO_x, NO_x, VOC and PAH. Figure 10a shows the wind rose used in the simulation, for the nearby Washington DC Dulles international airport for the period 1983 to 1984. Figure 10b shows the simulated lead concentration contours, indicating a maximum value of 10 µg/m^3, which exceeds the safe standard set by the WHO for lead, which is 0.5 µg/m^3 for a 24-hour averaging period. Further, simulation results indicated that the lead concentrations remained hazardous for residents living within a radius of 1000 m. The national institute for Occupational Safety and Health (NIOSH) was commissioned to evaluate safety for fire workers and nearby residents. Air samples collected by NIOSH between 4 and 9 November 1983 indicated concentrations of lead in the plume reaching 11 µg/m^3, a level that was consistent with the simulation results obtained. Other criteria pollutants such as CO, SO_x, NO_x and VOC also posed potential hazards to fire workers. The success of this modelling analysis provided a basis for further research to be conducted by the team regarding the hazards of open burning in Malaysia.

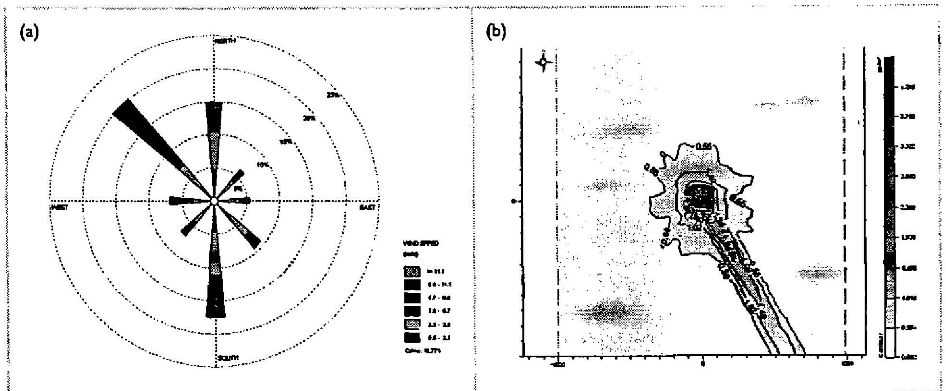


Figure 10: (a) Wind Rose for Washington DC Dulles International Airport, Virginia and (b) Contour Plot of Pollutant Concentrations of Rhinehart Fire

FOREST FIRES

Forest fires, as part of a natural process of renewal, may be harmful as well as beneficial. Forest fires occur frequently in Malaysia and neighbouring countries, contributing to frequent episodes of severe air pollution. Sponsored by an FRGS grant, a team of researchers recently modelled air pollution due to forest fires. A typical forest fire produces a mixture of gaseous pollutants, the composition of which depends on the characteristics of the fire and on the fuel materials. Data needed for this modelling analysis include, among others, biomass characteristics of forest fires, emission ratios for relevant pollutants and the height of the fire flames. For data needed, we resorted to the Hayman Fire, which occurred in Park County, Colorado, USA, from 8 June till 28 June 2002. A modelling analysis was performed by the USM team to assess the impact of this fire on the surrounding areas, with particular reference to CO. Figure 11a shows the Hayman Fire area topography, available from USDA Forest Service Report 2003, while Figure 11b depicts the shape and boundary of the 21 area sources used for ISC-AERMOD View simulations. The total area of the forest fire covered 559 km^2, with a fuel loading of 67 Mg/ha. Figure 12a shows concentrations of CO for a 1-hour averaging time, subject to neutral and calm conditions, while Figure 12b shows the concentrations of CO for a 1-hour averaging time, subject to wind rose conditions prevailing between 8 and 28 June 2002. The simulation indicates that the maximum CO concentrations were below the WHO standard for CO for a 1-hour averaging time. Hence, this forest fire did not appear to emit CO at a rate sufficiently high to pose hazards to the neighbourhood. The experience gained from this research will be used to model air pollution due to forest fires that might occur in Malaysia, and to formulate strategies for mitigation.

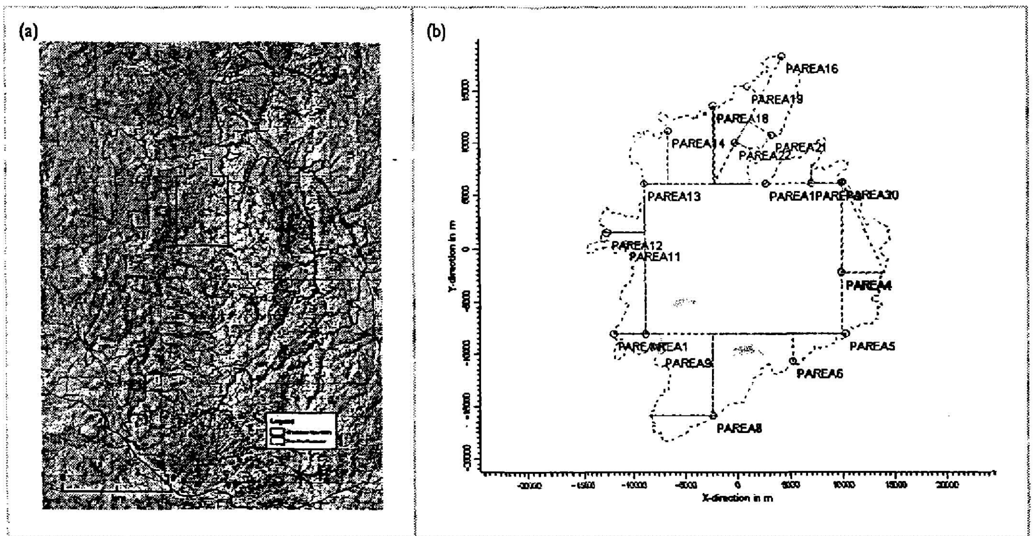


Figure 11: (a) Hayman Fire Area Topography (Source: USDA Forest Service, 2003) (b) Shape and Boundary of 21 Area Sources in ISC-AERMOD View

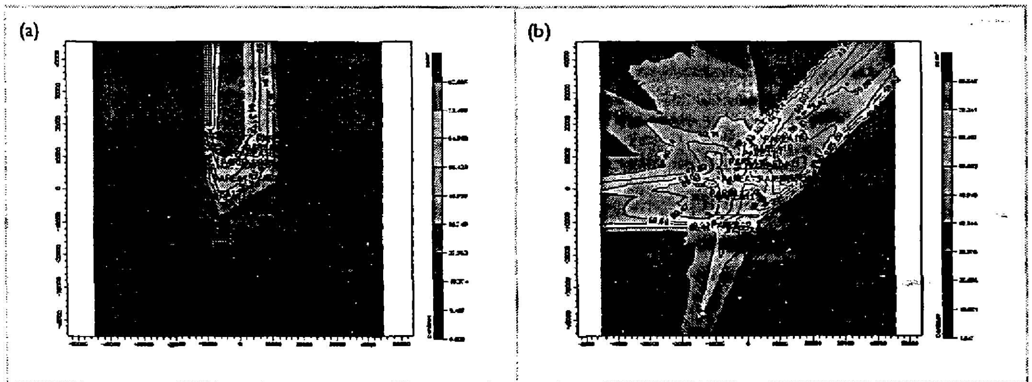


Figure 12: (a) Concentrations of Carbon Monoxide for 1 Averaging Hour with Neutral and Almost Calm Condition and (b) Concentrations of Carbon Monoxide for 1 Averaging Hour with Wind Rose from 8 to 28 June 2002

ATMOSPHERIC TRANSPORT OF EVERGLADES MERCURY

Contamination of fish by mercury has become a potential threat to human health worldwide, particularly fish that live in enclosed wetlands, such as rice fields. The Florida Everglades is a vast wetland of 10,000 km^2 located in southern Florida of the United States of America. Bioaccumulation of mercury in the aquatic food chain in the Florida Everglades has been a concern for several decades. High mercury burdens of 2.5 mg/kg have been recorded by the Florida Department of Health in the largemouth bass in the Everglades, a level that is deemed unsafe by all health-based standards. The major sources of mercury in the Everglades wetlands are reported to have been derived from industrial combustion and waste incineration, transported through the atmosphere over different length scales. A recent study suggested that over 90% of the annual budget of mercury in the Everglades Protection Area is contributed from atmospheric deposition, amounting to 35.3 $\mu g/m^2/yr$, of which local emissions contribute some 50%. Hence, it is instructive to model the atmospheric transport of mercury generated within the Greater Everglades Area from various sources, mostly from combustion. For this purpose, the ISC-AERMOD View is used. Figure 13a shows the contour of mercury concentrations in the air and Figure 13b shows the dry deposition rate, which suggest that the annual simulated total mercury deposition is about 17 $\mu g/m^2/yr$. The model results are then used to model mercury uptake by sulfur reducing bacteria, and subsequently by animals higher up the trophic levels to assess the impact of mercury contamination on the entire ecosystem, the results of which are reported elsewhere. We intend to extend this research to model potential contamination of fish by mercury in Malaysian waters, including rice fields, and to assess the potential health risk.

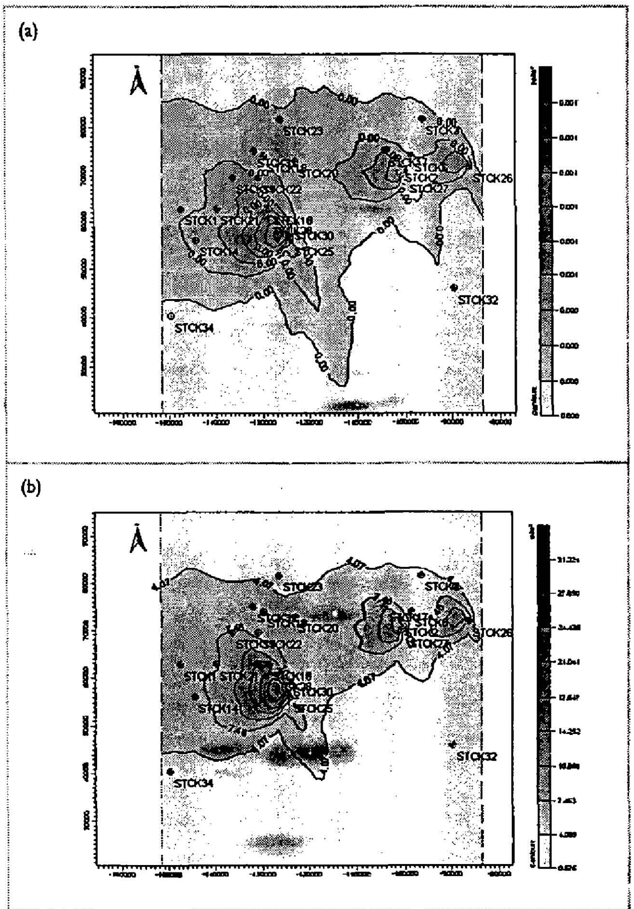


Figure 13: Contour Plot of the (a) Pollutant Concentrations and (b) Dry Deposition in the Florida Everglades

NOISE MODELLING IN OFF-SHORE PLATFORMS

Noise pollution may lead to hearing loss and emotional stress for a person who is exposed to excessive noise for a long duration. This problem is particularly acute for those who work and live long hours in an environment with high noise levels, such as an off shore platform. Noise pollution, for the purpose of practical application, is characterised by its sound intensity, which is measured on a logarithmic scale, and by sound pressure levels, expressed in units of decibels (dimensionless). For offices and conference rooms, an acceptable sound level is 45 decibels (written 45 dB). A quiet residential neighbourhood should have a noise level of 40 dB or less. Figure 14 shows the sound levels in 3-D and overlay onto Autocad image of a 30 m by 50 m platform, with 6 sound point sources of 85 to 95 dB, arranged in the south-east quarter. The sound level around the north-west quarter is about 65 dB, which is not suitable for living areas. Hence noise reduction devices should be used to reduce the levels to 45 dB. Researchers at USM are currently working to improve on the noise modelling modules for application in noise abatement for highways and indoor buildings, including those within USM and its vicinity. Noise pollution will become a major source of discomfort, as indicated by a recent survey by the US Transportation Safety Board. Hence our research focus on noise abatement technology and modelling will intensify in the near future to reflect the University's commitment towards the attainment of a healthy environment.

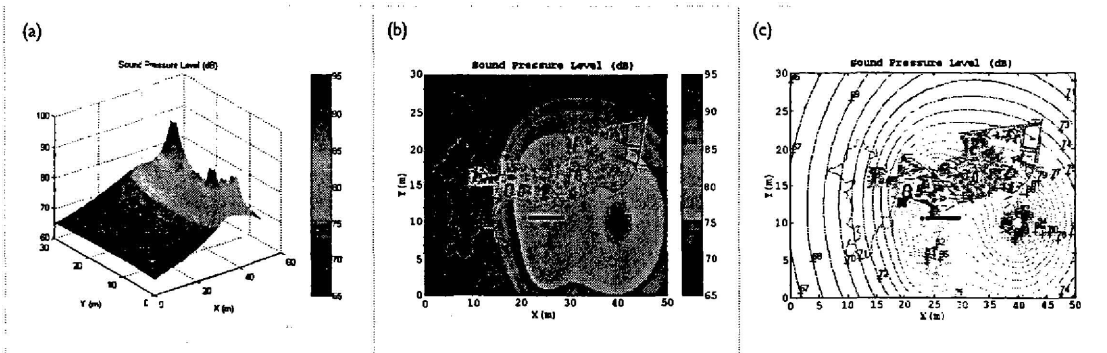


Figure 14: Contours of Sound Levels in (a) 3-D, (b) 2-D and (c) Overlay onto Autocad Image

CONCLUSION

The modelling group in USM has steadily built up the human resources and the capability to conduct research and consultancy in water, air and noise modelling. It is hoped that the activities of the group will be further enhanced in the future to contribute towards the improvement of modelling techniques and capability and the creation of a healthy environment.

ACKNOWLEDGEMENT

Financial support provided by the FRGS Grant 203/PMATHS/670054, the Healthy Campus project grant 309/JKORP/442400 and others is gratefully acknowledged.