Syarahan Inaugural

DO WE HAVE ENOUGH CLEAN AIR TO BREATHE ?

PROF. DR. MUHAMAD AWANG
Fakulti Sains dan Pengajian Alam Sekitar
Universiti Putra Malaysia

UNIVERSITI PUTRA MALAYSIA

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Professor Dr. Muhamad Awang

Abstract

The Clean Air Regulations of 1985 and related amendments provided the legislative mandate and defined the processes for the establishment of the Recommended National Air Quality Guidelines 1989. The purpose of the guidelines is for the protection of human health and public welfare (primary), and ecosystems (secondary) against any known or anticipated adverse effects from sulphur dioxide (SO_2), nitrogen oxide (NO_2), particulate matter (PM_{10}), ozone (O_3) and carbon monoxide (CO). In recognition of the need to periodically review the effectiveness of the guidelines, the Ministry of Science, Technology and the Environment developed a plan and mechanisms through its research and development programmes at 5-year intervals through the intensification of research in priority areas (IRPA). The first part of this lecture reviews some scientific work carried out through the IRPA programme by researchers between 1979 and 1999 specifically in the areas of changes in atmospheric chemistry due to anthropogenic activities and their impacts on the environment. Evidently, there were limitations with serious implications about our air quality. A number of very important conclusions derived from the air quality monitoring data were subjected to further elucidation. Further assessments are needed, not only on the physico-chemical properties of atmospheric pollutants, but also on the impacts of air quality on human health, animal and aquatic life, agricultural crops and forest species, and their economic implications. Subsequently, the lecture attempts to answer the question of the adequacy of our research on air pollution. Other answers related to the question of effectiveness of established guidelines for the purpose of planning and management are also addressed. The lecture also suggests that future research programmes (basic, applied and policy) should be focussed on the long-term impacts of episodic transboundary haze on human health and overall ecosystems based on local and regional meteorological patterns. The research should emphasize on the development of tools for assessing technology options in line with regulatory and voluntary environmental management requirements that promote the sustainability of locally related industries. Policy research on sustainable land-use (especially agricultural) practices in the region should also be emphasized. Thus, future research programmes should be multidisciplinary in nature. Each major research programme should consists of a 'coordinator' component that would integrate and synthesize all information and data generated from all individual studies to form a coherent understanding of the links among the sources, impacts and management strategies.

INTRODUCTION

Over the last few decades Malaysia and other countries in the Southeast Asian region have undergone rapid social, economic and environmental transformations, and more recently economic down turn. Viewing from both sustainable development and global change perspectives, this region has been regarded as a "hot spot" (Lebel and Steffen, 1999) due to rapid industrialization, urbanization and high rates of population, economic growth, along with the on-going modifications to coastal areas and tropical rain forests. Regional economies, especially their industrial sectors, have grown so strongly during the recent decades.

According to Asian Development Bank (ASEAN 1997), industries' contribution to the GDP of the ASEAN region between 1970 and 1996 has increased from 25% to more than 40%, and industrial out put increased 25 times during the same period. More than two-thirds of the GDP appeared to be contributed by the manufacturing and services sectors with an expansion of annual rate of more than 19% since 1980. The activities are highly influenced by the trade and investment policy encouraged by the countries in the region as has been fuelled by the development of export-oriented industries financed by foreign investment. Empirically, the total capital inflows had increased from US13.8 billion in 1980 to US 33.8 billion in 1990 and US 101.9 billion in 1996, with the share of net foreign direct investments rising from just below 0 in 1980 to 30% in 1990 to 54% in 1996.

According to Knight (1998) although the economic crisis in the region in 1997 and 1998 had sharply reduced capital flows, the trend towards increasing globalization of financial markets is expected to continue in the longer term. Moreover, trade flows have also grown very rapidly. ASEAN exports grew at an annual rate of 10.9%, while at the same time imports grew at 8.4% (ASEAN, 1997) which has led ASEAN to be the fastest growing markets for exporting countries and the fastest growing export region in the world for almost two decades. Simultaneously, the share of intra-ASEAN trade had remained at less than 20%, but in the 1990s grew to about 25%, with annual growth exports averaging almost 29% between 1993-1996 and falling to only 4.6% in 1997 as a result of the financial crisis (Severino, 1998).

Urbanization and industrialization processes have facilitated not only rapid increases in economic growth, changes in consumption pattern, material wealth and living standard, but also environmental consequences. Thus, industrialization and urbanization has been recognized as the two most important processes of change in Malaysia and the region. It was estimated that 65 million people were living in coastal urban areas of ASEAN in 1980, and this was expected to double by 2000 (ASEAN 1997). These key processes of transformation interact with intensification and expansion or contraction of agricultural practices in the rural hinterland trigerring resource demands on terrestrial and aquatic environment and producing wastes and pollution as by-products. Evidently, local and regional atmospheric pollution both from industry and from land-clearing activities is an important regional environmental problem and emerging issue. Heilig (1995) recognizes that land use changes to urban and industrial uses, including those to support transport and communication infrastructure, are much more important than the relatively small areas extent of these land uses may suggest. In addition, changes in life-style associated with urbanization, apart from consuming land for recreation and other non-agricultural uses, also drives changes in rural land use.

Observations of the long-term trends of atmospheric pollution in industrial and urban areas clearly indicated that local and trans-boundary emissions played very important roles in determining the status of the atmospheric environment in Malaysia. During the non-haze episode (normal condition), vehicular emissions accounted for more than seventy percent of the total emissions in the urban areas, exhibiting two distinct daily peaks in the diurnal variations. The morning 'rush-hour' peak is mainly due to vehicular emissions, while the 'late evening peak' is mainly attributed to meteorological conditions including atmospheric stability, wind speed and others. Suspended particulate matter often referred to as particulate matter (PM_{10}) is the main pollutant. Unlike other pollutants such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3), the PM concentrations at a few sites often exceeded the recommended Malaysian Air Quality Guidelines (MAQG). Daily average emissions of the pollutants in rural areas are generally low, and found to be much lower than those in the Klang Valley and never exceeded the critical levels for damage to sensitive crops or natural forest species as a result of direct atmospheric exposure.

In contrast, short term observations utilizing continuous monitoring systems during haze episode due to forest fires in the months of September-October 1991, October 1994, and April-November 1997 clearly indicated that the whole country had experienced high level of suspended particulate matter (Pm_{10}). Large forest fires in parts of Sumatra and Kalimantan during the haze period, as clearly evident in satellite images were identified as the probable key sources of the wide spread heavy haze that extended across Southeast Asia from Indonesia, through Singapore, Malaysia, Southern Thailand and Brunei. The nature, extent and impacts of forest fires and haze are discussed below.

Nature of forest fires

Within a framework of technical cooperation between the Government of Malaysia and the Republic of France, a team of multi-disciplinary remote sensing experts coordinated by MACRES (Malaysian Centre for Remote Sensing) was assigned to work on the 1997 forest fires and smoke haze. The study utilizes high spatial resolution spot satellite data and low-resolution satellite images (NOAA AVHRR satellite) for the purposes of disaster prediction, early warning, and damage assessment in the Southeast Asian region (Mahmood and Bolhassan, 1998) with special reference to Banjarmasin (Kalimantan) and South Sumatra. In the case of maximum evolution of fire in Banjarmasin, the total area burnt by 7 August 1997 reached 50,550 ha which represented approximately 20% of the study area. Whilst a total of 1,380,814 ha in South Sumatra accounted for 14.6% of the study area (9,415,375 ha). Mahmood and Bolhassan (1998) also pointed out that the burnt areas affected two land-cover types:

a) inside the cultivated perimeter, exhibiting geometric boundaries following the limits of the fields, and of the deforested areas-which is considered to be as the normal process of field clearing before cultivation,

b) in natural vegetation areas with the fire patterns being more complex, prominently follows roads and tracks which had greater impact on the natural ecosystems.

Analysis of fires demonstrated that fire patterns could be broadly related to different structures of vegetation. The direction of fire propagation seemed to be related with the opening of the natural vegetation, such as drain channels, tracks and roads. Fire propagation followed the natural pattern of networks, such as rivers and sparing dense forest patches. In areas dominated by agricultural activities, the natural vegetation, sparse forests and bushes were bordering the river networks, connected by spots of dense forest covers. In this situation, the fire patterns followed these lines of natural vegetation resulting in propagation of fires over long distances, and appeared to be related to the prevailing wind direction.

Meteorological Factors in Relation to Haze Episode

During the cloud seeding operations between September and November 1997 conducted by Malaysian Meteorological Service Department and the Royal Malaysian Air Force (Lim and Ooi, 1998), the height of haze appeared to be well mixed from the ground level up to the haze top. Maximum observed haze height in the region (Peninsular Malaysia, Sarawak, Southern Sumatra and Kalimantan) varied from 7,000 to 14,000 feet, with the maximum thickness observed on 23 September 1997 corresponding to the highest air pollution index ever recorded. Lim and Ooi (1998) also observed that in consonance with the strong positive anomaly of sea level pressure particularly over the eastern Indonesia – northern Australia region, equatorial southeast Asia was dominantly influenced by southwesterlies and southeasterlies in the lower troposphere. In addition, southeasterly in the southern hemisphere in September 1997 was particularly strong as compared with that of the same month in 1996. This has led to the penetration of southeasterlies far northwards into the northern hemisphere, replacing the normally observed southwesterlies from the Indian Ocean and the Bay of Bengal. Geographically, both the Peninsular Malaysia and East Malaysia lie in the downstream end of the southeasterlies which advected smoke particulates from the forest fires in southern Sumatra and Kalimantan. Consequently, the steady and strong southeasterlies during the month of September 1997 culminated into the most severe haze event encountered, and by November 1997, the appearance of easterlies had virtually cleared the haze in Malaysia.

The study also revealed that a major El Nino event began in March 1997 (Lim and Ooi, 1998). The event which was regarded to be equal or worse than that which occurred in 1982-83 and was expected to fade away by June 1998. According to World Meteorological Organization (WMO, 1990), being close to the core of the El Nino activity, Indonesia normally receives deficit precipitations from June to November associated with such extreme El Nino situation. Climatologically, the southern parts of Sumatra and Kalimantan have rainfall peaks in the months of March/April to be followed by a relatively dry period from June to September. Therefore, land clearing and open burning are usually carried out over there after the peak rainfall period. Unfortunately, the major El Nino event in 1997 has not only dwindled the rainfall, but also brought along the severe and extended drought, causing the biomass burning especially that of peat fires to become uncontrollable and extensive. This major El Nino event had also led to significant low-level wind anomalies favourable for the mass transport of the smoke particulates out of southern parts of Sumatra and Kalimantan towards the Malaysian and the South China Sea region. The severe haze episode had significant impact on global radiation received, which in turn, through its feedback mechanism, further stabilized the atmosphere. A closer examination of the temperatures during normal and hazy days revealed that the temperature in the layer between 700 and 600 hPa underwent stronger diurnal variation during the hazy day. This phenomenon reflects the result of radiational heating during the day and radiational cooling during the night in the vicinity of the haze top, and the equivalent potential temperature structures on hazy days relatively more unstable as compared to normal days.

Physico-chemical Characteristics of Haze

Scanning electron microscope (SEM) analysis of haze particles showed that majority of these particles were smaller than 2.5 μm in diameter in the form of liquid droplets (Zulkifly *et al.*, 1998). The percentage of particles that are less than 5 and 2 μm were about 30% and 20% of the inhalables, respectively (Sulaiman *et al.*, 1998). Based on elemental analysis, the particulates contain among others Na, K, Ca, Pb, Al, Mn, Zn, Cu, Fe, Cd, Ni, Si, Ti and V (Wood *et al.*, 1998). Polycyclic aromatic hydrocarbons (PAHs) concentrations which is the sum of concentrations of nine major non-alkylated compounds (fluoranthene, pyrene, benzo(e)pyrene, benzo(a)anthracene, chrysene, benzofluoranthenes, benzo(a)pyrene, indeno(c,d)pyrene and benzo(ghi)-perylene were predominantly present in the particulates (Zakaria *et al.*, 1998) which confirms that the biomass burning due to forest fires are the main sources of haze.

Malaysian Air Quality Guidelines (MAQG) and Air Pollution Index (API)

The choice of air quality parameters that define the status of air quality in Malaysia is governed by the established Malaysia Ambient Air Quality Guidelines (MAQG) of 1989 issued by the Department of Environment as summarised in Table 1. The listed concentration values are regarded as being the "safe levels". Subsequently, the air pollution index (API) was introduced as an index system for classifying and reporting ambient air quality in Malaysia (Awang *et. al.*, 2000). The API reference value of 100 has been set based on the MAQG, 1989 "safe levels" values (Table 2). Notably, the API values have been divided into five (5) ranges, based on possible health effects, viz. "good, moderate, unhealthy, very unhealthy and hazardous". The API for a given time period is calculated based on the sub-index values (Sub-API's) for all the five air pollutants included in the Malaysian API system. These pollutants are sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO), particulate matter below 10 micron in size (PM_{10}). The sub-API's are in turn calculated based on the relevant data collected from the Continuous Air Quality Monitoring Stations (CAQMS) operated by Alam Sekitar Malaysia Sdn. Bhd. (ASMA). The air quality data is regularly subjected to standard quality control processes and quality assurance procedures. The reported API value is based on the highest of the five Sub-APIs calculated for that particular time period. The predominant air pollutant parameter contributing towards a particular API value is normally indicated alongside the respective API value. During the 1997 haze episode, the predominant air pollutant parameter was PM_{10} sub-index. A similar approach in monitoring ambient air quality is also commonly adopted worldwide, including the

United States and several other countries, thereby promoting a uniform and comparable Air Quality Index system

Table 1 Malaysia: Selected Ambient Air Quality Guidelines (DOE 989)

Parameter	Concentration (API = 100)	Averaging Time
CO	9.0 ppm	8 hours
O_3	0.10 ppm	1 hour
NO_2	0.17 ppm	1 hour
SO_2	0.04 ppm	24 hours
PM_{10}	150 μg/m^3	24 hours

Table 2 Malaysia: Ambient Air Quality Guidelines

Air Pollutant	Guideline/ (Pseudo Standard)	Averaging Time	API
SO_2	0.04 ppm 0.13 ppm 0.19 ppm	24 hr 1 hr 10 hr	100
O_3	0.10 ppm 0.06 ppm	1 hr 8 hr	100
NO_2	0.17 ppm	1 hr	100
CO	30 ppm 9 ppm	1 hr 8 hr	100
PM_{10}	150 $\mu g/m^3$	24 hr	100

NATION WIDE AIR QUALITY ASSESSMENT (1979-1999)

Suspended Particulate Matter, Sulphur Dioxide and Lead

The status of air quality in Peninsular Malaysia according to the landuse and level of compliance based on studies conducted by the DOE from 1981 to 1983 demonstrated that serious problems existed only in highly urbanised areas. Of particular importance were dust fall-out, suspended particulate matter and lead in the air along congested roadsides. Those problems were largely attributed to the emissions from motor vehicles. The air quality over most of the areas monitored failed 50% or more of the time to comply with the previous proposed standard for total suspended particulate of 75 μg/m^3 (24-hour average). Notably, the standard was not met 99% of the time in Kuala Lumpur near Pudu Raya and in fact not a single area monitored was free from dust pollutions at all times. Similarly, lead (Pb) in the air continued to be present at rather high levels, particularly in the central business district of Kuala Lumpur. In 1982, the standard (1.5 μg/m^3 at 24-hour average) was not met 75% of the time. However, in the case of sulphur dioxide, it satisfactorily met the previous standard (50 μg/m^3 at 24-hour average) in the areas monitored between 1981 and 1983.

On the temporal patterns of SPM, NO_x, and CO, two distinct peaks in the diurnal patterns were observed during the four 'seasons' (December 1984- March 1985; April- May, 1985; June-September, 1985 and October-November, 1985). They coincided with the northeast monsoon, transitional period, the southwest monsoon and the other transitional period, respectively. These peaks were evident in the morning hours and late evenings. The morning peaks corresponded fairly well with the morning traffic rush hours as there was a strong indication that vehicular emissions may be the main contributory source, as shown by increases in NO and CO. The levels of NO and CO were observed to be higher during the morning peaks compared to the evening peaks. The finding was in agreement with the study conducted by Kimura (1986) on the relationship between traffic density and CO concentrations. Sham (1979a) also pointed out that the mixing height and wind velocity which were usually still low in the morning reduced the dispersive capacity of the pollutants. It has been suggested that the generally lower concentrations during the day could be attributed to greater vertical mixing and relatively stronger winds occurring during that period, resulting in the dilution of the pollutants especially from those of low level emissions. Moreover, Kimura (1985) in numerical simulation study of the air flow around Kuala Lumpur showed the occurrence of strong sea breezes and large vertical diffusivity during this period of the day. That could explain why, despite the after office rush hours, there was no distinct peak at that time of the day. On the other hand, the evening peaks appeared to be more influenced by the low mixing height and decreased wind speed (Sham, 1979a). As such, pollution buildup could occur despite the generally lower emission rate. Although these patterns differed slightly between the sampling sites, they exhibited remarkable similarity by the seasons. The levels of SPM tend to be lower during the rainy October-November period, partially due to particulate washout effects and also to the absence of strong ground based inversions (Inouye and Azman, 1986).

In a separate study on fine and coarse atmospheric particle concentrations in Kuala Lumpur between 1988 and 1990, Rashid *et al.,* (1997) showed that the highest monthly mean concentration was observed between January and March with a second peak occurring in July-August, while the levels tend to decrease in June and December. Earlier, Chow and Lim (1984) observed that maximum and minimum levels of particulate concentrations corresponded respectively with the relatively dry and wet seasons experienced in the region. They also suggested that scavenging effects of rainfall on particulate appeared to be one of the important contributing factors besides frequency of calm conditions and wind directions in determining the air quality in the region.

The diurnal variations in NO, NO_2 and O_3 concentrations during the four seasons observed by Azman, Inouye and Awang (1988) exhibited a typical photochemical pollution situation. The peak was first reached by NO followed by NO_2 and finally by O_3 several hours later. Subsequently, the after office hour traffic injected an additional burden of NO into the atmosphere which scavenged the remaining traces of O_3 by early evening and followed by the NO and other primary pollutants re-accumulated for the remainder of the night. This phenomenon seemed to suggest that the photochemical smog formation was first possible to occur in the city. On the contrary, Sham (1979b) suggested that optimum conditions necessary for its formation may be lacking due to the high humidity and the unlikelihood of the said pollutants to be trapped at times of maximum radiation by a subsidence inversion, as they often are in Los Angeles. Nonetheless, while humidity may affect oxidant formation both directly and indirectly, the magnitude of these effects has not been conclusively established.

A distinct feature observed in those studies was the occurrence of a peak in the SPM concentration some time in the middle of the year. It had occurred at a time when the duration of rainless days had continued for a fairly long time. This prolonged dry spell, coupled with the formation of strong ground based inversions, and the accompanying local meteorology, were believed to have accounted for the high particulate levels. However, during the months of May and September-December, which included the transitional periods, the concentrations of SPM appeared to be rather low values. This could be attributed to the greater incidence of rain days during those months as well as the probable absence of strong ground based inversions. In the case of NO_x and O_3, there were no clear seasonal variation, whilst CO remained fairly unchanged throughout the months, as motor vehicles density in the city, or at least in the vicinity of the sampling site, did not vary significantly throughout the study period. It is interesting to note that the levels of sulphur dioxide concentrations registered very low readings with monthly average ranging only between 2 to 5 ppb.

Total Suspended Particulates and Sulphate Aerosol

The long-term trends in particulate emissions from 1989 through 1995 indicated that Johor Bahru, George Town and Kuala Lumpur at certain times of the year exceeded the level of the current MAQG for total suspended particulates. Kuala Terengganu and Kuching maintained much lower levels than the level stipulated in the guidelines (90 μg/m^3) (DOE, 1996). The occurrence of the peaks during those years (1991, 1992 and 1994) has been attributed primarily to unusual meteorological conditions, coupled with local emissions and forest fires that were conducive for particulates to be accumulated in the region. The ambient conditions during 1989 to 1995 provided a range of variability, which were suitable for revealing the impacts of meteorological fluctuations. It was obvious that particulate emission levels peaked around August to October, which coincided with dry season and air stagnation (wind velocity, 3 m/s). Evidently, the increase in particulate emission was a result of an increase in a number of acres of land burnt from wildfires and also due to exhaust emissions and from construction sources which have increased over the last few years, particularly in the Klang Valley.

In a separate study of daily samples from July 1988 to December 1990, atmospheric aerosols were segregated into fine (aerodynamic diameter less than 2.5 μm) and coarse particles (2.5 - 10 μm) and were analysed for total elemental concentration (Rashid *et al.*, 1997). The analyses showed that the total elemental concentration of atmospheric aerosols consist of 19%, 33%, and 53% fine particle, coarse particle and total particle fractions respectively. Approximately 70% of As, Br, K, Na, Pb, S, and V were found in the fine fractions. While S and Si constituted the largest % elemental concentration which were 61% and 44% in the fine and coarse particles size fractions respectively. Source apportionment studies also showed that soil and marine sources contributed 21% and 5% of the total fraction while the remaining 74% of the aerosol concentration is yet to be explained. The results also showed that the daily fine particle (FP), coarse particle (CP) and total particle (TP) aerosol concentrations ranged from 12.2 μg/m^3 to 164 μg/m^3, 3.06 μg/m^3 to 32.6 μg/m^3, and 16.6 μg/m^3 to 183 μg/m^3 respectively. The mean daily concentrations were 35.4 μg/m^3, 14.2 μg/m^3 and 49.7 μg/m^3 respectively, and 40% of the daily total particle concentration samples exceeded the 50 μg/m^3 annual mean MAQG. The FP constitutes 71% of the total particulate concentration. It has been suggested that a high degree of correlation between the FP and the TP particle concentrations confirms the preponderance of FP in the area, while the low correlation between FP and CP concentrations indicates the difference source and/or meteorological influence upon these different types of particle concentration. Fine particulates are linked to high temperature processes related to industrial or vehicular emissions, whilst the coarse results from resuspension of dust materials through constructions and earthwork activities into the atmosphere.

Subsequently, Ayers *et al.*, (1997) focussed on the haze event that occurred in Southeast Asia in September 1994. Their study showed that the general chemical nature of the haze aerosol at Petaling Jaya was that the PM_{10} component consisted approximately one quarter inorganic components, one quarter elemental carbon and one half organic material. Acid ammonium sulphate is the major component in the inorganic fraction. Moreover, even the "background" levels of PM_{10} at Petaling Jaya, at around 50-60 $\mu g/m^3$, were primarily due to anthropogenic emissions. It was argued that if forest fires were the primary cause of the three fold increase in PM_{10} loading during the extremes of the haze event, then the aerosol composition data during that period would be dominated by biomass burning components. Tracers included in those samples were elemental carbon, aerosol potassium and gaseous NO_2. Furthermore, the time series of aerosol components indicated correlation with the PM_{10} series during the haze event, suggesting a definite smoke component. Moreover, the time series of traces not related to biomass burning, such as sulphate and lead showed significant correlations with PM_{10}. The study suggested that there were a number of different source-receptors (including biomass burning source) modulated by local and regional meteorology. Consequently, interpretation of the haze peaks in terms of a variety of strong local sources will be very difficult. In addition, Ayers *et al.,* (1997) concluded that smoke from fires at the two locations (Sumatra and Kalimantan) specified in the model was predicted to have reached Petaling Jaya during the haze event period although the temporal pattern of the modelled smoke transport to Petaling Jaya was not identical with the PM_{10} record. It was anticipated that the two fires modelled may have played a part in the extreme haze peak near mid-September, but did not play a major part in the extreme PM_{10} peaks at the height of haze event at the end of September.

In another separate study, the DOE together with MMS (Malaysian Meteorological Service) and DANCED determined the origin, formation and composition of aerosol haze in Malaysia (DOE, 1997a). Approximately 200 representative samples collected by the MMS for total suspended particulate and PM_{10} measurements during the haze episode in 1994 and in the non-haze years 1995 and 1996 have been analysed using Particle Induced X-ray Emission technique at the National Environmental Research Institute (NERI) in Denmark. The objective of the study was to apportion the sources of the 1994 haze episode based on two mechanisms that have been proposed for the explanation of the haze episode. The first mechanism relates to the more stable atmosphere conditions that exist in the dry season. This would allow the rather continuous emissions from traffic and industry to build up high local concentrations of pollutants. This could explain why the heavy industrialised Klang Valley during haze episodes often was more polluted than other parts of the country. However, it does not explain why some localities with little traffic and industries such as Kuching in Sarawak, in some years were polluted with suspended particulate matter at levels of the same magnitude as in Klang Valley or even higher. The second mechanism relates to fire in South Sumatra and Kalimantan forests, which occur almost every year in the dry season, and in some years tend to get out of control.

The results of the analysis ruled out the first mechanism as there was poor correlation with lead (Pb) which is the marker for local pollution. The good correlation with sulphur supports, on the other hand, the causal relation with forest fires or other biomass burning, as sulphur and potassium are the essential constituents in biomass. The SPM/sulphur ratios found at geographically widespread locations in the Peninsular Malaysia (Penang, Kuantan, Klang Valley and Johor) were very much the same, corresponding to almost constant contents of sulphur in the SPM (mass ratio 7-8%). This point to a common origin (and/or type) of source, perhaps the reported forest fire in South Sumatra. The high levels found in the Klang Valley could be due to the combined effects of the geographical vicinity of the source area, an unfortunate position in the prevailing direction of wind flow, and may be some trapping of the biomass burning plume in the valley. The sulphur content found in Kuching was markedly lower (4%). This pointed to a different biomass burning source, probably fires in Kalimantan.

Sulphur Dioxide and Nitrogen Dioxide

While the particulate levels showed distinct peaks during the dry periods of the month, especially during the haze episodes, this was not the case of gaseous pollutants. It was observed that there were no distinct variations in the nitrogen oxide (NO) and nitrogen dioxide (NO_2) levels. Long-term trends of sulphur dioxide and nitrogen dioxide recorded in Kuala Lumpur, Petaling Jaya and Shah Alam between 1992 and 1995 demonstrated that monthly concentrations of these two pollutants did not exceed the MAQG. However, both NO_2 and SO_2 concentrations monitored in Petaling Jaya were consistently higher (20-40 ppb and 15-30 ppb, respectively) than those in Kuala Lumpur and Shah Alam stations.

Ozone

Ozone (O_3) is a secondary pollutant. O_3 precursors are volatile organic compounds (VOC) and nitrogen oxides (NO_x) from point sources, particularly in large urban areas. The formation of O_3 through photochemical oxidation process is influenced by sunlight and temperature. O_3 exhibits strong day-to-day variation and sometimes virtually undetectable. Temporal variability could be over hourly, diurnal, synoptic, weekly, seasonal and long-term time scales which is influenced by anthropogenic activities and meteorology. Low wind speeds (< 3 m/s) promote the build up of high local O_3 concentrations. The availability of NO, and non-methane hydrocarbons from local emissions such as vehicles and other anthropogenic activities must be considered to be among the contributing factors. Highest daily O_3 maximum occurred in the late afternoon, exhibiting high O_3 concentrations between around 1100 and

1500 hr. In addition, there were distinct differences in the daily O_3 profiles on haze episode and non-haze episode days. The rate of O_3 depletion during the haze episodes was very much slower and took a longer time to reach a minimum level compared with normal conditions. The occurrence of factors conducive for O_3 production such as high atmospheric stability, high insolation and temperature coupled with the availability of NO_x (>90% constituted of NO_2) and non-methane hydrocarbons during the haze episode might have led to a higher rate of O_3 formation. Such phenomenon were reflected in October 1991 and September-October 1994 haze episodes (40-97 ppb).

As mentioned earlier, other than a few events largely influenced by the periodic haze-episodes in the Southeast Asian region, the air quality in Malaysia is generally within the recommended level or recommended guidelines throughout the year. In 1996, only two out of 13 places monitored were affected by dust, in terms of particulate matter less than 10 μm in size (PM_{10}), but only for 0.2 per cent or less of the time. For 99.8 per cent of the time, the air was considered "clean". In addition, only two sites were affected by sulphur dioxide (SO_2) largely due to our heavy dependency on high sulphur fuel for industrial production and electric-power generation. The monitoring data also showed that only one of them at a heavy industrial site was found to have a significant level of SO_2 accounted for 17 per cent of the time. Furthermore, two sites were badly affected by O_3 for 0.4 and 0.2 per cent of the time, because of their geographical peculiarity being at the back of highly urbanized valleys, namely Klang and Nilai. Another site, though not affected by O_3, had to carry the burden of nitrogen dioxide (NO_2), but only less than 10 per cent of the time.

In 1997, the generally good quality air prevailing throughout the country had been adversely affected largely by the forest and peat fires in the region (DOE, 1997b). All the 29 (CAQMS) stations, except the latest one in Miri, Sarawak which came into operation only in October 1997 onwards, had recorded hourly measurements of PM_{10} exceeding the MAQG, 150 $\mu g/m^3$. It was up to 15 per cent of the time for the year or about 1300 total number of hours recorded in Kuala Lumpur, and two other most affected places were Klang (12%), and Gombak (10%). Although the measurements exceeding the acceptable level were less than those places in Klang Valley, Kuching recorded about 8 per cent, and it registered the highest API ever recorded in Malaysia which was 839 over 24 hour average on September 23rd, 1997. The maximum API values registered at other places in the country were less than 460. At least 5 of those 22 places monitored for sulphur dioxide were burdened not only by the dust and the minute particulate hanging over the lower atmosphere, but also adversely affected by this contaminant, up to 16 per cent of the time at the Prai Industrial Estate in Pulau Pinang. Four other affected areas were Pasir Gudang-Johor (2%), Kajang-Selangor (0.4%), Johor Bahru-Johor (0.2%), and Shah Alam- Selangor (0.1%).

During the haze episode, the authorities, either public or the private sector, were concerned over the synergistic effects of pollutants. Of particular importance, particulate plus SO_2 could be fatal, as experienced in London smog of early December, 1952, with 4000 deaths, where the concentrations of sulphur dioxide exceeded 0.10 ppm and reached almost 0.75 ppm (Awang, *et al.*, 1998). Fortunately, such an episode did not develop in Malaysia. The formation of O_3, a secondary pollutant did affect particularly those places within highly urbanized valleys, namely Selayang-Gombak (1.3%), Kajang (0.7%), Shah Alam (0.6%), Kuala Lumpur (0.2%), Klang (0.1%) as well as Johor Bahru (0.1%), Ipoh (0.01%) and Pasir Gudang (0.01%). In Kuala Lumpur, and not the other places, the measurements of CO and NO_2 exceeded the acceptable levels for 0.2 and 0.01 per cent of the time, respectively. These were due to motor vehicle emissions.

As the effects of El Nino ceased to prevail, the overall conditions did improve in 1998, except at some places during the early parts of the year, due to local peat-forest fires in Miri, Sarawak. Thirty per cent of the time in Miri, the measurements of PM_{10} exceeded the acceptable concentrations of 150 $\mu g/m^3$, Kota Kinabalu (0.4%), Sibu (0.3%), Seberang Jaya (0.3%), Gombak (0.3%), Pengkalan Chepa (0.1%) and Kota Bahru (0.02%). Other places, though not adversely affected by the particulate, continued to register SO_2 measurements exceeding the acceptable level of 0.04 ppm for 24-hour averäging time, namely, Prai Industrial Estate (5.1%), Prai Seberang Jaya (3.1%), Johor Bahru (2.35%), Pasir Gudang (2.0%) and Nilai 0.2%; (all in % of total monitored time).

The absence of haze in 1998 and 1999 with improved visibility, and thus more sunshine received were also the triggering conditions for greater frequencies of formation of photochemical oxidant, namely O_3 at the back of highly urbanized valleys. As expected, 50 percent of the places monitored for O_3 were adversely affected. There were up to 1.8 per cent of the time at Shah Alam, Gombak (1.1%), Kajang (0.7%), Klang (0.4%), Kuala Lumpur (0.4%), Nilai (0.2%), Bukit Rambai (0.2%), Johor Bahru (0.1%), Pasir Gudang (0.1%), Jerantut (0.03%), Prai Seberang Jaya (0.02%) and Kuantan (0.02%) were affected. As at 31st August 1998, only in Kuala Lumpur the measurements of NO_2 exceeded the acceptable level of 0.17 ppm (over one hour averaging time) for 0.1% of the time. As drawn from the annual status of air quality, the most serious form of localized air pollution was the formation of O_3. In the order of decreasing degree of seriousness were the other pollutants: SO_2, PM_{10}, CO, and NO_2. A similar pattern was observed between September 1998 and August 1999. The overall air quality throughout the country was "good" and again very much affected by the local and regional meteorological conditions and the incidence of forest fires.

Effects on Agricultural Crops and Forest Species

Although growth limitations of agricultural and forest species due to air pollution in the mid latitude countries have been well documented (Awang, 1979), there has been no documented evidence that such problems exist in Malaysia. The atmospheric pollutants which have the greatest potential for affecting the growth of crops and trees are oxides of sulphur, nitrogen and photochemical oxidants such as O_3 and peroxyacyl nitrate. As mentioned earlier, concentrations of these pollutants are frequently above the levels that could alter the biochemical and physiological processes of sensitive crops.

The nature and the amount of damage caused to crop plants by atmospheric pollutants depends on the inherent toxicity of the particular gas, duration, intensity and frequency of exposure, environmental conditions, the proportion that is taken up by the plant and their physiological and biochemical responses. In addition, plant cultivars can vary widely in response to O_3 and other atmospheric pollutants. As pointed out by many researchers, dose-response equations generated from a single cultivar may not represent adequately the response of the species as a whole. However, it has been established that high concentrations of atmospheric pollutants, primarily in the form of O_3 can significantly reduce the yield of major agronomic crops over large areas, especially in North America and Europe due to the alteration of biochemical and physiological processes such as inhibition of photosynthesis and ultracellular disorganization. Studies have incorporated the measurement of physiological parameters and also growth and yield to establish the contribution of photosynthesis to changes in final economic yield in response to air pollutants (Awang, 1979).

The specific sensitivity of plants to several air pollutants has resulted in the use of plants as indicators to detect, recognize and monitor air pollution. The nature of the symptoms depends on the plant species, type and concentration of the air pollutant and exposure period. It has to be stressed that the responses elicited by the plants represents the end results of the integration of influences by many factors so that it would not provide specific information on the concentrations of pollutants in the atmospheric environment compared to data generated by physicochemical measurements utilizing sophisticated and expensive equipments. Nonetheless, indicator plant systems could be an inexpensive substitute for physical/chemical measuring devices. Furthermore, it is easily reproduced, readily multiplied and capable of producing several different response modes, as inherent genetic variability allows a range of responses by the species or cultivars to a particular pollutant stress.

Transboundary haze originating from biomass burning and local emissions have shown that during the haze episode, O_3, TSP and particulate matter with a diameter less than 10 μm (PM_{10}) are the major atmospheric pollutants which might potentially affect the growth, development and yield of agricultural crops due to O_3 phytotoxicity and reduction in light intensity. In this respect it is important to emphasize that although the haze episode was a temporary phenomenon, it could however, coincide with a critical stage of development of sensitive crop plants as the growing season of many major cash crops in Malaysia takes place between July and August. These observations also suggest that there were strong daily variations among the pollutants. Although the concentrations of oxides of sulphur and nitrogen were low, it is always possible that a combined presence of these two pollutants with O_3 may have a different effect and could have a significant impact on growth and performance of agricultural crops and forest species.

Several studies were designed to establish whether such pollutant levels will result in yield losses in economically important crops. Emphasis was placed at producing dose-response relationships for economically important yield parameters. Among the series of experiments carried out over the past two decades were as follows:

a) Selected agricultural and forest species were exposed to SO_2 and NO_2 either singly or in combination in specially designed controlled environment fumigation chambers (Awang *et al.,* 1987). Growth response, leaf injury and other related physiological parameters (photosynthesis, stomatal conductance, respiration, chlorophyll content and transpiration rates) were recorded before and after fumigation treatment.

   Results of the physiological responses of different plant species showed that the pattern of changes in the parameters studied varied among the plant species. Forest species exhibited that the rates of photosynthesis and respirations responded differently. Low concentrations of SO_2 (<0.03ppm) induced stomatal opening which led to the stimulation of transpiration and photosynthetic processes, and vice versa for higher SO_2 concentrations. At 0.7ppm of SO_2 all species produced acute injury particularly on the young leaves, exhibiting marginal and interveinal necroses. *Pometia pinnata* was found to be the most sensitive among the forest species tested.

   A similar pattern was observed for oil palm seedlings (Muhamad and Latif, 1989). Photosynthetic and respiratory activities were significantly affected when the seedlings were subjected to SO_2 concentration higher than 0.25ppm and foliar injury began to develop after 5 days of exposure (0.25ppm/2h/day/5days). The destruction of chlorophyll was highly associated with foliar injury and K^+leakage.

Growth response of groundnut (*Arachis hypogaea* L.) to SO_2 and NO_2 at different levels of N and S in root media demonstrated that deficiencies of S and N in the soil could be compensated through foliar uptake by exposing the plant to higher SO_2 and NO_2 concentrations. There was a strong correlation between reduction in assimilate supply due to pollutant stress on photosynthetic activity and the root nodulation activity. On the effects of SO_2 and NO_2 either singly or in combination on the growth performance of cocoa mirids (Awang *et al.*, 1991) it appears that low levels of atmospheric pollutants induced the growth rate of the mirids. The results suggest that the subsequent occurrence of biochemical and physiological changes due to pollutant stress on cocoa shoots served better food sources for the insects.

b) A wide range of plant species was established under uniform environmental conditions prior to fumigation treatment as suggested by Manning and Fedder (1980). They were subsequently exposed to SO_2 and NO_2 (either singly or in combination) in a fumigation chamber (Awang *et al.,* 1987). The rating system for quantifying and evaluating plant responses to air pollutants was adopted following Manning and Fedder (1980) and Ashmore *et al.,* (1980).

Results of the study showed that the concentration of individual gases lower than 0.25ppm $S0_2$ and 0.40ppm NO_2 did not produce any visible injury under short term fumigation. However, severe injury developed during exposure to the lower concentrations of a mixture of the gases. In addition, an unexpected dose-response characteristic, with reduction in effects at particular concentrations was also observed in certain species. There were differences in sensitivities among the plant species resulting in significant differences in the intensity of morphological symptoms that developed. Acute SO_2 injury exhibited interveinal and marginal bleaching (brown or white). This bleaching was bifacial and began as water-soaked dark areas on either young and fully expanded leaf or on relatively older leaf. Some leaves (different species) depicted a "herring bone" effect. In the case of NO_2 there was no reliable or typical diagnostic symptom. Acute NO_2 injury resembled the SO_2 injury and a similar pattern was observed in combined effects (SO_2 + NO_2). However, O_3 sensitive tobacco cultivar (BEL-W2) which elicits specific symptoms to O_3 (weather fleck) responded differently to these pollutants. Although different symptoms of SO_2 and NO_2 injury were demonstrated by different species, a positive correlation between the degree of leaf injury and pollutant concentration and exposure time was clearly indicated. A quantitative analysis based on a rating system was established for evaluating species response (Table 3). These differential sensitivity among the plant species could be categorized into sensitive, moderate and resistant groups. Calculated injury was correlated with observed injury, although variations in other environmental factors could affect the relationship (Awang and Abdullah, 1998).

c. Since O_3 is considered to be one of the major pollutants during the haze episode, the O_3 super-sensitive (BEL-W3) and O_3-resistant (BEL-B) tobacco cultivars (*Nicotiana tabacum* L.) have been selected in the investigation for use as biomonitors. Originally, the BEL-W3 cultivar was developed in Beltsville Agricultural Research Station, Beltsville, Maryland to determine the cause of *tile abiotic disease* known as weather fleck and later it has been widely used in many countries as an indicator of the presence of phytotoxic concentrations of O_3. A similar approach has been adopted for the study. For the purpose of comparative evaluation of relative susceptibility, the local cultivar (KEL) which is normally used by the tobacco industry in Malaysia was also incorporated into the study.

Table 3 Plant Sensitivity Classification – Effects of Air Pollutants

A) Plants were fumigated with an average of 0.30 ppm $S0_2$ for 3 hours/day.

Sentivitive	**Moderate**	**Resistant**
Kedondong/Great hog plum	Belimbing/Star fruit	Manggis/Mangosteer
(*Spondias cytherea*)	(*Averrhoa carambola*)	(*Garcinia angostana*)
Rambutan	Durian	Ciku/Sapodilla
(*Nephelium lappaceum*)	(Durio zibethinus)	(*Achras zapota*)
Bunga Ati-ati.Coleus	Cempedak	Getah/Rubber
(*Coleus* sp.)	(*Artocarpus interger*)	(*Hevea brasiliensis*)
Timun/Cucumber	Koko/Cocoa	
(*Cucumis sativus*)	(*Theobromaecacao*)	
Sawi putih	Siantan/lxora	
(*Brassica* sp.)	(*Ixora javanica*)	
Bendi/Okra	Bunga Raya	
(*Hibiscus esculentus*)	(*Hibiscus rosa-sinensis*)	
Lettuce	Terong/Brinjal	
(*Lactuca sativa*)	(*Solanum melongena)*	
Petunia	Kangkung	
(*Petunia hybrida*)	(*Ipomoea reptans*)	
Tomato	Kelapa sawit/Oil palm	
(*Lycopersicon esculenttum*)	(*Elaeis guineensis*)	

B) Plants were fumigated with an average of 0.40 ppm NO_2 for 3 hours/day

Sensitive	Moderate	Resistant
Rambutan	Kedondong/Greathogplum	Manggis/Mangosteen
(*Nephelium lappaceum*)	(*Spondias cytherea*)	(*Garcinia mangostana*)
Belimbing/Star fruit	Bendi/Okra	Ciku/Sapodila
(*Averrhoa carambola*)	(*Hibiscus esculentus*)	(*Achras zapota*)
Durian	Koko/Cocoa	Jambu Batu/Guava
(*Durio zibethinus*)	(*Theobroma cacoa*)	(*Psidium guajava*)
Cempedak	Kelapa sawit/Oil palm	Getah/Rubber
(*Artocarpus interger*)	(*Elaeis guineensis*)	(*Hevea brasiliensis*)

C) Combination of 0. 129ppm SO_2 and 0.20ppm NO_2.

Sensitive	Moderate	Resistant
Mangga	Jambu batu/Guava	Penaga laut
(*Mangifera indica*)	(*Psidium guajava*)	(*Calophyllum inophyllum*)
Kedondong/Great hog plum	Koko	Manggis/Mangosteen
(*Spondias cytherea*)	(*Theobrome cacao*)	(*Garcinia mangostana*)
Durian	Cempedak	Kopi
(*Durio zibethinus*)	(*Artocarpus interger*)	(*Coffea liberica*)
Rambutan	Duku langsat	Limau manis
(*Nephelium lappaceum*)	(*Lansium domesticum*)	(*Citrus sinensis*)
Kedondong/Great hog plum		Limau kasturi
(*Spondias cytherea*)		(*Citrus microcarpa*)
Rambutan		Cengkeh
(*Nephelium lappaceum)*		(*Eugenia. aromatica*)
Bunga Ati-ati.Coleus		Ciku/Sapodilla)
(*Coleus* sp.)		(*Achras zapota*)
Timun/Cucumber		
(*Cucumis sativus*)		
Sawi putih		
(*Brassica* sp.)		
Bendi/Okra		
(*Hibiscus esculentus*)		
Lettuce		
(*Lactuca sativa*)		
Petunia		
(*Petunia hybrida*)		
Tomato		
(*Lycopersicon esculentum*)		

Foliar injury in the form of reddish-brown stippling on the adaxial leaf surface of the older leaves began to develop after ten days of exposure . A similar symptom of bifacial lesions has been reported in earlier studies by Manning and Fedder, (1980) and other workers where under field conditions, the lesions are usually dark at first and tended to bleach after exposure to O_3. A close examination of injury development of BEL-W3 showed that the first symptoms started with small water-soaked areas appearing between the veins, followed by silvery bleaching and finally turning into yellowish-silver mottling.

Initially, percentage of injured leaf area of BEL-W3 was more than 10% while BEL-B and KEL were relatively small (in the range of 5% and 2%, respectively). The number of injured leaves per plant and the percentage of injured leaf area increased with an increase in duration of exposure. The percentage injured leaf area clearly indicated that BEL-W3 was the most susceptible cultivar, while BEL-B and KEL were less but equally susceptible to O_3 injury. As was expected, the control plants grown in charcoal-filtered air exhibited no O_3 injury throughout the experimental period.

Results suggest that a minimum dosage required to cause visible injury to BEL-W3 was a 2 to 3h exposure at 50-60 ppb and the O_3 injury threshold in ambient air was 40-50 ppb for 3 to 4h. Indeed, ambient O_3 concentrations recorded during the experimental period fluctuated between 20 and >90 ppb (hourly mean maximum concentration). This would have been high enough to cause extensive visible injury to the O_3-sensitive cultivars since temperature, light intensity and relative humidity were always high.

It has been suggested that since O_3 is a normal constituent of the atmosphere, BEL-W3 may be injured when the concentrations are only slightly above normal background concentrations. In addition, if low concentrations of SO_2 or other pollutants are present, the threshold concentration of O_3 may be reduced further due to synergistic action of SO_2 and O_3 which produces a similar injury. Since the study was carried out under natural environmental conditions, other pollutants were also present. Mixtures of these pollutants can give different impacts from those of' single pollutants. Co-occurrences of' pollutants in the ambient atmospheric environment may lead to either synergistic, additive or antagonistic effects on the plants. These findings may justify the results of the present observation which evidently produced leaf injury under relatively low concentrations of O_3 and other related pollutants.

On the impact of O_3 and other atmospheric pollutants on photosynthetic activity, it was clearly indicated that after ten days of exposure, the net photosynthesis (Pn) was significantly lower than those o f control plants. The data also exhibited the existence of variations between the cultivars. The control plants demonstrated consistently higher levels of Pn which attained their peak (18.6 μmol $CO_2/m^2/s$) just before noon and began to decline to a minimum (2.5 μmol $CO_2/m^2/s$) at 1600h. At peak (1200h), analysis of variance revealed a significant reduction of Pn related to ambient exposure, and displayed reductions of 70.1 % for BEL-W3, 53% for BEL-B and 21% for KEL cultivar, respectively. BEL-W3 showed a significant reduction in Pn as compared to BEL-B and KEL. However, there was no significant difference between BEL-B and KEL except for the measurement at 1200h of the same day.

In the absence of visible injury, it can be concluded that under the influence of O_3 and possibly other atmospheric pollutants occurring in the present study, physiological and biochemical processes have been altered (Ashmore *et al.*, 1980) prior to the occurrence of visible injury. Theoretically, as O_3 enters into substomatal intercellular space, it dissolves in the waterfilm of the moist cellular surfaces and dissociates rapidly, releasing oxygen together with a number of free radicals and ions such as HO_2, HO^+, OH^-, O^-, and OH_2^{-2} which can subsequently oxidise various cellular metabolites and affects membranes integrity. Photosynthesis might be reduced prior to foliar injury becoming visible. In addition, in the absence of foliar injury, the amount of subtle injury, also does not limit the self-internal repair process to occur through physiological mechanisms.

c) A wide spread concerned about the long-term effects of climatic change on vegetation is partly due to an increase in atmospheric carbon dioxide concentration and tropospheric O_3 together with a number of other trace gases. It is widely accepted that rising CO_2 will have a profound effect on plant growth and productivity due to the increase in photosynthetic capacity while maintaining the reduction in photorespiratory rate and increase in water use efficiency (WUE) as a result of partial stomatal closure which reduces water loss per unit CO_2 assimilated. However, under a long-term condition, the initial stimulation of photosynthesis appeared to be a temporary phenomenon and found to be not always reflected in the final yield. Elevated CO_2 could also accelerate the growth performance of plants due to changes in source-sink characteristics which alter the carbon-partitioning pattern (Tang, *et al.*, 1999).

Alterations in the activity of ribulose bisphosphate carboxylase-oxygenase and in the capacity to regenerate ribulose biophosphate and to synthesize starch and sucrose have all been shown to exert control over photosynthetic rate. Temporal responses of these control processes in relation to day and night as well as growing season variations resulted in temporal changes in assimilate export from leaves of plants which have been growing at a range of CO_2 mole fractions.

Experiments have also clearly demonstrated that the allocation of carbohydrates changes markedly in response to CO_2-mediated changes in photosynthesis. In young leaves, when the photosynthetic rates is low (at low CO_2 mole fractions), carbohydrates storage in the leaves exceeds export and is primarily as sucrose. This feature is reversed as CO_2 concentration increases, with greater export and storage of leaf starch. The plants growing at low CO_2 and which predominantly accumulate sucrose also grow slower.

While generating carbon dioxide through a combustion of fossil fuel, other pollutant gases are also produced into the atmosphere. These gases include oxides of nitrogen (NOx), sulphur (SO_2), carbon monoxide (CO) and various precursors for the formation of photochemical oxidant (O_3 and PAN) such as non-methane hydrocarbons. Studies on deleterious effects of these atmospheric pollutants on vegetation are well documented. Of particular importance is the co-occurrences of O_3 and other pollutants in the atmospheric environment that caused a severe damage to the plant as mentioned earlier. Reports on the effects of low level of O_3 either singly or in combination with other pollutants such as SO_2 and NO_2 revealed that alterations and disruption in biochemical and physiological processes due to the presence of peroxide radicals and other free radicals has led to growth impairment and yield reductions of sensitive crop species.

The co-occurrences of elevated CO_2 and O_3 and their effects on plant species have been of a major concern in the temperate regions over the last two decades. However, such studies are relatively scarce pertaining to tropical crop species. A series of experiments was designed to examine the changes in chlorophyll fluorescence (based on Kautsky effect) which reflect the physiological status of plants due to pollutant stress (Maggs *et al.*, 1992). Results of the study were as follows:

Chlorophyll Fluorescence

F_o (Ground fluorescence)

Initially (even after 15d and 23d of exposure) there was no significant changes in values for Fo, though a slight depression occurred in plant treatment with 50 ppb/0_3-350 ppm CO_2. The difference between the treatments was only significant (after 37 and 43d of exposure) with a further decline in O_3 treated plants (both in elevated and filtered ambient air CO_2 concentration). However, there was no significant difference between elevated and ambient filtered air, suggesting that the young plants with high development stages exhibited less sensitivity to O_3. It has been reported elsewhere that in young leaves, stomatal conductance was reduced substantially in responses to O_3 as it affected stomata directly and subsequently, limits the photosynthetic activity due to reduction in CO_2 uptake.

As the plant age progresses, the response to O_3 became more pronounced. In matured and senescent leaves, the effects of O_3 are mainly due to reduced carboxylation, as Rubisco is more sensitive to O_3 than is CO_2 diffusion. This result was in contradiction with other findings as F_o in plants under O_3 stress normally produce higher fluorescence yield or remain constant. This ground fluorescence, which is thought to derive from the pigment antenna, very often increases under stress condition. This is seen when photosynthetic electron transport is blocked by herbicides or when chlorophyll reaction centre of photosystem II is photoxidatively destroyed. It may also be attributable to the stomatal closure or opening induced by O_3 that depicted the F_o response.

There have been conflicting reports on the differential effect of O_3 on carboxylation and CO_2 uptake. At low O_3 concentration, both opening and closure of stomata have been observed. It is also suggested that the absolute height of F_o depends very much on the chlorophyll content of the leaf per leaf area unit as it is the major determinant of the shape of the fluorescence spectrum. Decreasing or lowering the chlorophyll content will increase F_o or maximal fluorescence F_m because the reabsorption of emitted fluorescence by the remaining chlorophyll is lower. For this reason, the absolute values of F_o and F_m, are only then valid parameters, when the chlorophyll content remained the same before and after stress treatment.

F_m and F_v (Maximal Fluorescence Yield and Variable Fluorescence)

The results also revealed that Fm appeared to be in agreement with other findings. Plants treated with O_3 and filtered air ambient CO_2 concentration showed higher reduction in fluorescence yield as compared to other treatments. It was significantly reduced even only after 23d of exposure, and further reductions were observed with progressing leave age (43d of exposure). On the other hand there was no significant difference between the treatments of elevated CO_2 and ambient CO_2 concentrations subjected to free O_3 air. However, the trend showed that elevated CO_2 might have reduced the O_3 effects, particular after 43d of treatment.

Changes in variable fluorescence ($F_v = F_m - F_o$) induced by O_3 were clearly indicated in plant treated with ambient filtered air CO_2 concentration. On contrary, plants treated with elevated CO_2 and O_3 exhibited significantly less reduction in F_v, despite the fact that there was no significant difference between elevated CO_2 with O_3 treatment and elevated CO_2 alone.

The results suggest that there were some detectable changes or alterations in the level and the emission spectrum of fluorescence of plants exposed to O_3 at different CO_2 concentrations. Presumably, both intensity and amplitude of characteristic transient level (IDPSMT) has changed, whereby, fluorescence intensity at I was raised while at P was reduced and at T was increased. Consequently, the amplitude of fluorescence transient of DP-rose and DP- and MT- decline, implying that photosynthetic activity was reduced in plant subjected to O_3 fumigation.

It has been proposed that the elevation of I level is partly due to some portion of Q was brought to a reduced state by the pollutant toxicity (in this case O_3) as initially it is controlled by redox state of Q, a primary electron acceptor of PS 11, while a diminished rise in DP was due to the inactivation of water splitting enzyme system which is involved in the depression of formation of trans-thylakoid proton gradient which is responsible for photoreduction of Q, through reductant from water.

Under stress conditions, fluorescence (slow component of Kautsky effect) will decrease from the maximum to the steady-state and becomes increasingly lower as the steady-state fluorescence continuously rise. As a result of this, when there is stress on photosynthesis, the variable fluorescence (F_v), declines. It has been observed on shifts in fluorescence emission peak intensity between 720 nm to 690 nm in PS I preparation in response to alterations in redox condition which reflect changes in energy trapping routes.

F_v/F_m

There were no significant effects between the treatments on F_v/F_m values. However, it was clearly indicated that there was a definite pattern in response to exposure to CO_2 and /or O_3. It appears that exposure of plants to elevated CO_2 caused a considerable effect in alleviating the O_3 toxicity. In fact, plants exposed to O_3 together with filtered ambient air CO_2 concentration exhibited significantly lower F_v/F_m after 23d of exposure compared to other treatments.

Growth and Above-Ground Dry Matter Production

Elevated CO_2 markedly stimulated plant growth. The mean percentage of growth increment was 30% higher than those exposed to ambient CO_2 concentration after 42d of exposure. There was no significant effect of combined elevated CO_2 and O_3 on dry matter production. However, 15% growth increment was observed for exposure to elevated CO_2 than those of exposed to ambient CO_2 and O_3.

A detectable reduction in the above-ground dry matter production was only observed after 28d of exposure. A similar pattern was observed in average tiller weight and also stem dry weight. Whilst there was no significant effect of elevated CO_2 either singly or in combination with O_3 on leaf, there was significant difference in the number of tilllers. This suggest that the increased in above-ground biomass production was primarily due to the growth stimulation of stem and tiller as shown by plant height.

Growth stimulation was also observed in root dry weight of elevated CO_2 plants. In contrast, O_3 significantly ($p<0.05$) reduced root growth. Differential effects on shoot and root growth were reflected in a lower root: shoot ratio in O_3 treated plants. On the other hand, there was significant increase in root: shoot ratio in plants exposed to elevated CO_2 .

Relations between Photosynthetic Capacity and Dry Matter Production

Combination of all data (not shown here) on fluorescence yield reductions (negatively correlated with photosynthetic capacity) from each treatment were significantly and positively correlated with reduction in dry matter production. Both decreases and increases in photosynthetic capacity were accompanied by similar changes in vegetative growth performance. The results appeared to suggest that O_3 exhibited slightly larger effect on photochemical reaction components in the absence of higher CO_2 concentration.

Higher percentage of foliar injury (O_3 fleck) was also observed in plants exposed to O_3 with filtered air ambient CO_2 in comparison to those exposed to ozone in the presence of elevated CO_2 concentration. In short, elevated CO_2 alone could *increase dry matter production and reduce O_3 injury. However, growth of plants* exposed to a combination of the gases was not significantly different from that of plants treated with CO_2 but was markedly greater than that for plants exposed to O_3 at ambient CO_2.

It is therefore suggested that O_3 has a greater effect on photosynthetic capacity, consequently, reducing the dry matter production in the absence of higher CO_2 concentration. However, further studies need to be carried out in order to elucidate whether the O_3 will have a greater effect on carbon allocation and /or the stomatal conductance to CO_2 or the photochemical reactions under the elevated CO_2.

d. Impact of 1997 Haze Episode On Human Health

The major air contaminant during the 1997 haze period in Malaysia was suspended particles, whereas gaseous pollutants were not significantly different compared to normal days. During the period, PM_{10} concentration rose beyond the MAQG (1989) level in almost all areas monitored. It increased 4-fold higher in Klang Valley, and up to 20 times higher in Kuching. In parallel to the scenario, Hospital Kuala Lumpur recorded an increase in cases of upper respiratory tract infections (URTI), asthma and conjunctivitis; three diseases directly affected by the haze. The increase in asthma cases was found to have a two-day lag behind the Malaysian API as reported by the Ministry of Health Malaysia in 1998. However, no changes were observed for mortality cases during the haze period.

For respiratory diseases, Selangor recorded a significant increase in the total number of cases during the September haze period. Asthma cases increased from only 912 in June to more than 5000 in September 1997. The total number of Acute Respiratory Infections (ARI) cases shot up from about 6000 to more than 30,000 during the same period. However, the number of cases gradually decreased towards the June value as the concentration of PM_{10} began to decrease after September. In Kuching, Sarawak, a significant increase in the number of these cases was also observed due to extreme API readings during the last half of September 1997. However, when the air quality was almost back to the values of non-haze period in October, the incidence of the cases returned to normal. The trend indicated that short-term exposure to high levels of PM_{10} was detrimental to human health. However, the effect was apparently reversible. In addition, no increase in mortality was reported during the period.

Besides respiratory diseases, there was also a significant increase in conjunctivitis during the haze period. In Selangor, the total number cases increased from only 207 in June to as high as 3496 cases in October 1997. The same trend was also observed in Sarawak. In addition, the daily incidence of conjunctivitis in Sarawak during September was found to have a positive correlation with the API (representing PM_{10} concentration).

The data suggest that the adverse effects of haze on human health could be attributed to the elevated PM_{10} levels in the ambient air and not likely to be due to other pollutants. Despite the reversibility of the acute effects observed, it is believed that exposures to haze might have a long term effect on the community.

Besides the health data, a spirometry study done on sixteen-year old school children in Kuala Lumpur (KL) also revealed that long term exposure to a relatively higher PM_{10} concentration led to decreased lung functions and increased prevalence of respiratory symptoms. The school children in KL were naturally exposed to $103.27\mu g/m^3$ ambient PM_{10}, while the control group (matched for age, gender, height, weight and smoking habits) was naturally exposed to only $47.35\mu g/m^3$ PM_{10}. Significant reduction in spirometry parameters such as the vital capacity (VC), forced vital capacity (FVC) and forced expiratory volume (FEV_1) was observed in the KL school children.

Higher prevalence of respiratory symptoms was observed in Kuala Lumpur school children population; the most commonly reported symptoms were chest tightness, followed by breathing difficulties, morning phlegm and coughs. In both groups, females were found to be more susceptible to the exposure, showing higher percentage in the prevalence of the respiratory symptoms. Therefore, the result suggests that prolonged exposure to a relatively high concentration of PM_{10} (even though below the set safety limit) is associated with reduced lung function and increased respiratory symptoms in school children.

There is ample evidence to suggest that the most susceptible group to exposure to air pollutants are the elderly and very young children, while youngsters are among the most resistant. However, the study clearly indicated adverse effects of the exposure on the 16-year olds (the most resistant age group).

In addition, a preliminary survey carried out among secondary school children in KL and Klang revealed that less than 50% of these school children went for medical treatment each time they fell sick. Therefore, the total number of respiratory cases reported in the clinical health data had actually underscored the exact degree of adverse effects caused by the haze on our community. However, despite this bias, significant increases in the haze-related diseases were still observed.

Although analysis of the health and spirometry data revealed that short-term exposure to very high PM_{10} led to increased cases of related diseases, the effect was apparently reversible. Nevertheless prolonged exposure to PM_{10} even below the MAQG could reduce the lung function and increased the prevalence of respiratory symptoms. The studies conclude that the concentration of PM_{10} and the period of exposure may determine the nature of the adverse effects to human (Awang *et al.*, 2000)

MANAGEMENT OF AIR QUALITY

Continuous Air Quality Monitoring (CAQM) Network And Value-Added Data

Under the privatisation programme of the government of Malaysia , a network of 50 CAQM's is being built and established for the first 5-year period, 1995-2000, and operated and owned by ASMA for a 20-year period, 1995-2015. As of September 30, 1998, 37 CAQMS have been commissioned and in operation effectively (Awang, *et. al.*, 2000).

According to the DOE (personal communication), the main rationale of the privatised monitoring network is cost-saving. For the same volume and quality of data, the Government of Malaysia would save at least 85% of the annual cost of operations, as the average cost per unit data is to be reduced from RM40 to RM6. Further more, the DOE receives the data through electronic means, on-line, 24 hours a day at least for 85% of the time in a month. Subject to DOE concurrence, such data are also accessible to other environment-related authorities, researchers, and concerned private citizens, especially those whose health may be sensitive to air pollution. Once the network is fully established and stabilized, the Government of Malaysia would share on equal basis any net proceeds generated from the value added to the data, and as such, the DOE may eventually receive the data virtually for "free".

The data, other than to help establish the status of quality in Malaysia, are invaluable to both the regulator, in particular the DOE, and the industry at large. To DOE, any regulatory action has its scientific basis, and should not be construed as an exercise of "whim and fancy". To the industry, and other polluting sectors of the economy, the same credible and timely data should provide the early signal for self-regulation as promoted by the Government of Malaysia as part of the 1998 Budget strategy for the environment. Other than relying on stricter enforcement, the private sector can also play an important role in promoting new mechanisms for protecting the environment. One that offers considerable promise is a series of environmental management standards (Awang, 1999) known as ISO 14000, being developed and introduced under the auspices of the International Organization for Standardization in Geneva. The adoption and implementation of such a standard where there is a clear and positive stake in participating, hold more promise for change than the traditional top-down approaches we have seen (Awang and Hassan, 1998).

FUTURE CHALLENGES ON RESEARCH IN AIR POLLUTION

Air Pollution and Health: Basic Research Strategies

Humans as well as animals and plants have evolved elaborate protective mechanisms including detoxification and homeostatic regulation to survive. However, when the protective mechanisms are disrupted or "overloaded", we face various consequences (Kolluru,1996). Humans are directly exposed to air pollutants via three routes: the respiratory (nose and mouth), cutaneous and ocular routes. Therefore, the immediate effects of expire to high air pollution should first be observed in these systems. Inevitably, studies on the effects of short-term exposure to various kinds of air pollutants have been focussed on the systems. Numerous research conducted worldwide left us with the least doubt that worsening air quality is detrimental to human health, even at concentrations well below the safety guidelines. Most of the research were conducted based on the following strategies (Noor *et al.*, 1998):

Risk assessment

In order to estimate the cause and effect relationship between air pollution and health, risk assessment on the communities has to be carried out. Although risk assessment is not a magic bullet for dispensing with all environmental problems but only a common sense approach, a composite of disciplines with scientific underpinnings, it is about decision making after considering various environmental and community aspects (Kolluru,1996). It can play a meaningful role in defining, prioritizing and managing environmental risks with full considerations in its advantages and limitations as well as the practicality of its applications. Essentially, risk is the chance of injury, damage or loss. Therefore, to put oneself "at risk" means to participate either voluntarily or involuntarily in an activity or activities that could lead to injury, damage, or loss. Exposure to environmental contaminants is an example of involuntary risk.

Generally, risk assessment refers to evaluation of the harmful effects to human health or the environment that result from exposure to harmful contaminants. Risk assessment is also defined as the process of estimating the probability of occurrence of undesirable event and the magnitude of its consequences over specified time period. It involves four basic steps; a) data compilation and evaluation, b) exposure assessment, c) toxicity assessment and d) risk characterization (Awang, 1999).

a. Data compilation and evaluation

The objective of this step is to verify that the data are appropriate for use and are considered to be representative of current conditions. For research on air pollution and health, two important sets of data required are, i) air quality data including PM_{10}, $S0_3$, CO, $N0_2$, 0_3; and ii) health data including out-patient and in-patient cases treated in every hospital.

b. Exposure assessment

This step is to estimate the type and magnitude of exposures to the pollutants of potential concern that are present in a particular area. It involves i) characterization of the exposure settings i.e. the physical environment and potential land use scenarios, ii) identification of exposure pathways and iii) quantification of exposures.

The exposure assessment also determines who is, or is likely to be in contact with the pollutants. Exposure to contaminants can occur via inhalation of air or absorption through the skin via dermal contact at varying degrees by multiple pathways (Kolluru, 1996).

c. Toxicity assessment

The purpose of toxicity assessment is to estimate the potential of the selected pollutants in causing adverse effects on the populations and to provide an estimate of the relationship between the extent of exposure and the adverse effect; the dose-response relationship (Kolluru, 1996). A good first step of risk assessment (data compilation) will determine the effectiveness of toxicity assessment. The health end- points of air pollution and health studies differ according to the pollutants of concern. Normal short-term epidemiological studies are concerned with respiratory symptoms, URTI and conjunctivitis, whereas long-term studies include cancer and cardiovascular diseases.

Besides epidemiological studies, toxicity assessment also requires laboratory studies, which include controlled studies on human, or normally on animal models. Data on animal models are then very carefully extrapolated to men. This part is done mainly to reveal the mechanisms of action of the pollutants. Knowledge about the mechanisms of toxicity will give us the clues on how to protect ourselves from the exposure to air pollution if it is likely to occur in our area.

According to Kolluru (1996) terms of exposure quantification, three sets of variables are required, i) pollutants concentration at exposure points, ii) contact rates i.e. magnitude, frequency, duration, and iii) biological characteristics of receptors i.e. body weight, age, sex, race and medical history. From these variables, the intake or exposure dose could be estimated.

Toxicity assessment involves a lot of efforts and costs as it will provide us with maximum information on every aspect about the effects of air pollution on health, prior to the establishment of recommendations with scientific underpinnings.

d. Risk characterization

This is the final step of risk assessment, where all outputs from steps 1 to 3 are reviewed and assessed. It summarizes and presents the baseline risk assessment results. As pointed out by Kolluru risk characterization is the interactive process of extracting and integrating decision whereby relevant information from the hazard, dose-response studies and exposure evaluations are formulated, rendering it comprehensible to a diversity of users.

Two common approaches used worldwide to evaluate the effect of air pollution on health are epidemiological and toxicological studies. The former investigates the causes and the elements contributing to the occurrence of a disease in a population. On the other hand, toxicological study involves investigating and understanding how substances cause biological harm on organisms. Air quality data and health data sets are very important to start these studies. This approach, coupled with Kolluru's method of risk assessment could be implemented in Malaysia. The steps to be taken in carrying out such studies are as follows:

Step I: Preliminary studies

Air quality and human morbidity data should be compiled and evaluated to determine their patterns and associations. From the evaluation of these data sets, we could determine the diseases related to local pollutants, identify the most susceptible groups, and also locate the area most affected by the pollutants. This would form the base for performing further studies.

Currently, air quality is almost perfectly monitored in our country, even though there are only 57 monitoring stations covering both the Peninsular Malaysia and Sabah and Sarawak. However, by the year 2000, at least 100 stations will be established (Awang *et al.*, 1998) throughout the country. The agency in-charge provides the public with daily API readings through the internet, and they do have detailed hourly data at least for the five criteria air pollutants of major concern: PM_{10}, 0_3, $N0_2$, $S0_2$ and CO. The data are systematically compiled and could be retrieved whenever necessary.

Unfortunately, human morbidity data especially outpatient data, including hospital visits for various kinds of diseases are still very traditionally kept on papers and in files, without standardized forms. A lot of scientific evidence had been put forward to show that there is a very strong positive association between the air pollution levels and the number of hospital visits and admission. In addition, evidence also show that two very high-risk groups are the very young and the elderly (more than 65 years of age). It has also been found that different races and gender have different levels of resistance towards exposure to various pollutants. Since these are established facts accepted by all scientific communities, our compiled data should at least include these parameters. Therefore, it is imperative that the health data should be compiled daily and must be age, race and gender specific. To this end, upgrading our public health system should be one of our targets in the near future.

Among the bias in our present health information available is the lack of data from general practitioners (private hospitals and clinics). This can be overcome by implementing new regulation requiring private hospitals and clinics to send in reports of patient visits to the Ministry of Health). There is also inadequate information compiled on outpatient data in government hospitals. They use a standardized format for compilation purposes to include all information required to ensure quality and reliable health data is suggested.

Step 2: Epidemiological studies

From the air quality data, we could predict when the next air pollution episode is to occur. From the health data, we could determine what the related diseases are. A more detailed evaluation of the data could also provide some clues on the extent of the effects such as predicted increases in morbidity for certain diseases. Therefore, with the data on hand, one of the most immediate actions that could be undertaken is to ensure adequate facilities and medication in all hospitals to face the problem when it occurs.

Once the diseases, the susceptible groups and the areas most affected are determined, more epidemiological studies could be carried out on those groups. Studies of related diseases on communities in areas of high pollution versus low pollution should be carried out to further confirm the effect of exposure to air

pollution on human health. Besides epidemiological studies on respiratory symptoms, spirometry studies could also be done in the areas.
(Suggestion: Studies could be performed on school children in selected areas. The studies could be incorporated into school projects (science projects) where students could perform spirometry tests monthly during normal days and weekly/daily on high pollution days. Symptom diaries could also be distributed to these students by their teachers, and collected every week. The Ministry of Health and Ministry of Education could cooperate to ensure the success of such studies).

Numerous scientists had concluded that the most susceptible groups to exposure to air pollutants are the very young, the elderly and also those with preexisting diseases. To study the very young, kindergartens and nurseries could be good targets. The same methodology applied to school children could be implemented here. The same approach could also be applied to the elderly communities in foster homes. Continuous epidemiological monitoring on these sub-populations will provide a reference trend of association between air pollution and health among Malaysian populations.
(Suggestion: Concerted efforts from authorized bodies to run continuous studies at the particular places).

Morbidity studies are more clinical and should be organized by clinicians, rather than epidemiologists. Those with pre-existing diseases with regular check-ups are the most appropriate study groups. Since air pollution is always associated with respiratory and cardiovascular diseases, the National Heart Institute (IJN) might be a good place to search for health data apart from government hospitals. The related bodies need to upgrade their compilation systems, try to obtain a trend of those diseases on monthly, annual or daily basis if necessary. These data will then be compared with the ambient air quality data obtained from other sources.
(Suggestion: Government hospitals and GPs should cooperate in organizing such studies. Data from both are needed to gain better evaluation of the reported cases).

Step 3: Toxicity studies

From step 1, the diseases of possible association with the ambient air quality could be determined. To assess the mechanisms of the effect of air pollutants on human health, two approaches are normally carried out, i) controlled human exposure, and ii) animal exposure studies. To assess the effect of real exposure to air pollution, personal samplers are used in a number of volunteers.

Exposures to animal models could be done using a single pollutant, or a mixture of pollutants at any concentration. The various study designs (Lambert *et al.*, 1993; Moreno, *et al.* 1986; Kodavanti *et al.*, 1998) available for this kind of studies would provide us with ample information to better understand the mechanisms of toxicity, the target organs and the synergistic/additive/ antagonistic effects of the pollutants. Studies done on different levels of pollutants contribute to the knowledge of the extent of the adverse effects the pollutants might cause to the animals. If carefully extrapolated to human, these studies would greatly assist in determining the safety limit of exposure to the pollutants in our community (Kolluru,1996).

Summary of strategies

Steps 1-3 involve many different bodies, both government and private agencies. Therefore, we definitely need one main committee to act as the compilation center of all these data. The committee will do the risk characterization, reassess and do further assessment on available data, and put forward meaningful, scientifically verified reports on the effects of air pollution on human health. The committee will also come out with recommendations of new guidelines that will better suit our community based on all the scientific information obtained from all the agencies involved.
(Suggestion: Set up a national committee to organize the study. It must include at least one epidemiologist/public health personnel, scientists and a statistician as the supervisors).

In the near future, Malaysia needs to carry out its own risk assessment with regards to exposure to existing air quality (Awang, 1999). Therefore, a few systems need to be upgraded, while others might have to be developed. Two major variables needed to assess the immediate effect of air pollution on human are the air quality and the hospital data. Therefore, it is proposed here that the Department of Environment and the Ministry of Health should discuss on the compatibility of their data so that they could be incorporated into a good assessment output to represent the effects of air quality on our community. On the other hand, to make them comparable with those of other research, our data should at least represent every aspect reported previously by others, if not more. One of the major problems faced by epidemiologists dealing with health data is the bias of neglecting visits to private medical practitioners. Therefore, a new regulation might be needed for those clinics to submit their daily reports to the Ministry of Health.

CONCLUSION

This lecture provides a rapid assessment on the quality of the ambient air in Malaysia and its potential impact not only on agricultural crops and forest species but also on human health based on the continuous air quality data collected from various agencies including local universities, research institutions, MMS, the DOE and ASMA for the period 1979-1999. Both types of air pollution, their sources, and the affected areas have been established. Based on the above assessment, it could easily be deduced that the emissions of unburnt hydrocarbons from motor vehicles and other oil and gas works were the most serious source of air pollution in Malaysia. Equally serious were the emissions of SO_2 due to high-sulphur fuel dependency for industrial production and electric-power generation, as found in Prai, Pasir Gudang, Johor Bahru, and the Klang Valley. Other than generated from the biomass burning within the country or beyond national boundaries, much of the dust and fine particulates were contributed by the inefficiency of diesel-powered vehicles, on and off the road. The expected nature and extent of response, spatially and temporally, from various sectors of economy can be easily guided by the on-line availability of air quality data against the MAQG established by the DOE. Vigorous R & D efforts should be geared towards establishing long-term effects of air pollution despite its apparent reversible acute impact on human health and also on the long term implications of tropical rainforest ecosystem in the region (Tang *et al.,* 1996), particularly on light-demanding species (Tang *et al.*, 1999).

The importance of research on air pollution and health in a fast-developing country like Malaysia cannot be underestimated. The future and well being of the nation depend on the decision and policies made today, which must be based on research data. Therefore, research strategies on air pollution and health must be clearly formulated and a concerted effort must be mobilised to organise and execute the plans.

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