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ENVR S335 Environmental Control, Monitoring And Modeling (Free courseware)

香港公開大學
THE OPEN UNIVERSITY OF HONG KONG

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Chapter 1 Air pollution management

1.1 About this module

Welcome to this free courseware module 'Air pollution management'!

This module is taken from the OUHK course ENVR S335 Environmental Control, Monitoring and Modeling (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&c=C_ETPU&cid=1911540364008&lang=eng), a 10-credit, higher-level course that is part of the BSc and BSc (Hons) degree programmes in Environmental Studies offered by the School of Science and Technology of the OUHK. This course introduces design principles as applied in environmental engineering and plant operations and students are expected to develop their technological knowledge in environmental control, monitoring and management.

ENVR S335 (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&c=C_ETPU&cid=1911540364008&lang=eng) is mainly presented in printed format and comprises ten study units. Each unit contains study content, activities, self-tests, etc for students' self-learning. This module (The materials for this module, taken from Unit 4 of the print-based course ENVR S335, have been specially adapted to make them more suitable for studying online. In addition to this topic on 'Air pollution management', the original unit of the course also includes the topics 'local and regional air pollution', 'global air pollution problems', and 'air quality management and control') retains most of these elements, so you can have a taste of what an OUHK course is like. Please note that no credits can be earned on completion of this module. If you would like to pursue it further, you are welcome to enrol in ENVR S335 Environmental Control, Monitoring and Modeling (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&c=C_ETPU&cid=1911540364008&lang=eng).

This module will take you about 8 hours to complete, including the time for completing the activities and self-tests (but not including the time for assigned readings).

Good luck, and enjoy your study!

1.2 Introduction

This module introduces you to some issues related to air pollution.

We start by defining air pollution and examining the main sources of air pollution. We then classify air pollutants according to origin, chemical composition, state of matter,

and area of impact; and examine the effects of air pollution, particularly the immediate health affects. We conclude by explaining Hong Kong's Air Pollution Index.

1.3 What is air pollution?

Air pollution is not a new problem. But with today's technology, we have added new dimensions to this centuries-old problem. This section defines and describes air pollution.

Air is one of the global commons, owned by no one but used by all. It is a source of oxygen, which is vital to most living creatures including us human beings. Air also provides a source of carbon dioxide, a vital 'food' for plants. Air consists of 78% nitrogen, 21% oxygen, about 0.04% carbon dioxide and various inert gases including helium, argon (almost 1%), xenon, neon and krypton, and minute amounts of other gases.

To fully understand air pollution, you need to also understand the earth's atmosphere.

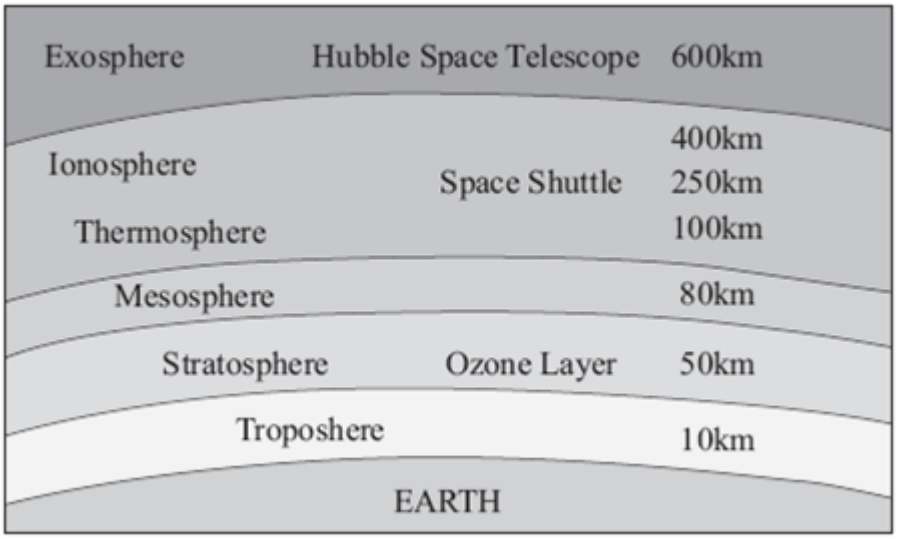

Fig. 1.1: Vertical structure of the atmosphere

More than 80% by mass of the air and virtually all water vapour, clouds and precipitation occur in the lower portion of our atmosphere, the troposphere, which extends to about 10 to 12 km above sea level at mid-latitude. At the poles, the troposphere may go down to about 5 to 6 km above sea level, while at the equator, to about 18 km. The troposphere is very turbulent and has strong vertical air movements. Such turbulence leads to rapid and complete mixing and thus rapid dispersion of pollutants.

This is good on one hand because it thins out the air pollutants emitted, and bad on the other, as it spreads pollutants out and affects other areas. The pollution from forest fires in Indonesia that affected nearby ASEAN countries, and radioactive dust

from the nuclear disaster at Chernobyl was spread across Europe by this turbulence in the troposphere.

The *stratosphere* is a stable layer of very dry air, which extends to about 50 km above the surface of the earth. Little air movement occurs in the stratosphere, and air pollutants that find their way into this layer may stay there for years before they eventually drift back to the troposphere and disperse. The stratosphere is also where ozone absorbs the short-wave ultraviolet energy from the sun and protects us from excessive ultraviolet radiation. This layer, together with the troposphere, accounts for about 99.9% of the total mass of the air; thus when we are talking about air pollution, we refer to the effects in these two layers.

Pollution is an undesirable change in the physical, chemical, or biological characteristics of the air, water, or land that can harmfully affect the health, survival, or activities of humans or other living organisms (Henry and Heinke, 1996, 2 (Henry and Heinke, 1996, 2 - Environmental Science and Engineering, 2nd edn, Upper Saddle River, NJ: Prentice-Hall.)). The term 'air pollution' is used in this course to refer to the presence in the atmosphere of any materials or gases that affect human health or damage the natural environment due to human activities. The term 'environment' refers to both humans and their surroundings. This broad definition is used to emphasize the interrelations between humans and their surroundings, so they should be treated as one single system, as shown in this figure.

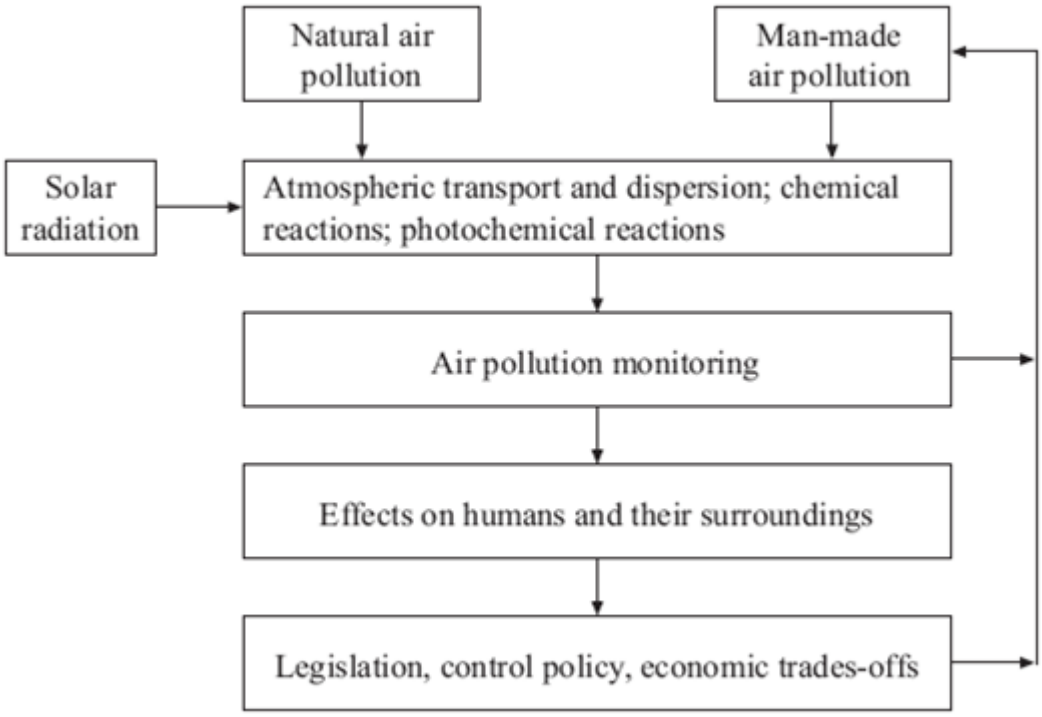

Fig. 1.2: System of air pollution

In order to understand the system of air pollution, you must have some background in chemical engineering to understand the industrial processes that lead to pollution. A background in meteorology will also help you understand why the atmosphere disperses the pollutants into the atmosphere. Knowledge of chemistry helps in understanding chemical reactions that take place in the atmosphere. Familiarity with applied science means you can understand how to monitor and measure the

pollutants in the atmosphere. Epidemiology, sociology and environmental science help in understanding what the effects on human beings and environment will be; and political science, economics, and law lead to an understanding of the types of strategy implemented to control the emissions from the sources.

1.4 Sources of air pollution

There are two main sources of air pollution:

1. Naturally occurring pollutants (such as volcanic eruptions, forest fires, windstorms)
2. Anthropogenic air pollutants (i.e. those created by human activity)

--- sections below will be deleted ---

Table 1.1 lists some examples of natural air pollutants.

Sources	Pollutants
Volcanoes	Sulfur oxides, particulates
Forest fires	Carbon monoxide, carbon dioxide, nitrogen oxides, particulates
Wind storms	Dust
Plants (live)	Hydrocarbons, pollen
Plants (decaying)	Methane, hydrogen sulfide
Soil	Viruses, dust
Sea	Salt particulates

Table 1.1: Natural air pollutants

Environmental Science — Action for a Sustainable Future, Redwood City, CA: Benjamin/Cummings.by Chiras 1994.

Based on the above examples of natural air pollutants, please try to complete the activity below by thinking of other sources of pollutants that you have experienced or heard about.

Pollution also comes from anthropogenic sources. Table 1.2 lists some examples of human made air pollutants.

Sources	Pollutants
Power plants (fixed sources)	Carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, particulates
Transportation (mobile sources)	Carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, particulates and refrigerants
Buildings	Refrigerants
Factories	Dust, hydrocarbons and assorted emissions
Agriculture	Methane, hydrogen sulfide
Nuclear industry (including nuclear power plants)	Radiation, radioactive waste

Table 1.2: Anthropogenic air pollutants

1.4.1 Naturally occurring pollutants

Table 1.3 lists some examples of natural air pollutants.

Sources	Pollutants
Volcanoes	Sulfur oxides, particulates
Forest fires	Carbon monoxide, carbon dioxide, nitrogen oxides, particulates
Wind storms	Dust

Table 1.3: Natural air pollutants

Sources	Pollutants
Plants (live)	Hydrocarbons, pollen
Plants (decaying)	Methane, hydrogen sulfide
Soil	Viruses, dust
Sea	Salt particulates

Table 1.3: Natural air pollutants

Environmental Science — Action for a Sustainable Future, Redwood City, CA: Benjamin/Cummings.by Chiras 1994.

Based on the above examples of natural air pollutants, please try to complete the activity below by thinking of other sources of pollutants that you have experienced or heard about.

1.4.1.1 Activity 1

What other naturally occurring air pollution can you think of? Please give one or two examples in the spaces provided and then check for the feedback by clicking the button below. You may save your answer by clicking "save" on the top right hand corner. When you have done this activity, please continue with the course materials.

1.4.1.1.1 Activity 1 feedback

Other naturally occurring air pollutants include be the leakage of natural gas from extraction wells and nitrogen dioxide formed during lightening storms.

1.4.2 Anthropogenic air pollutants

Pollution also comes from anthropogenic sources. Table 1.4 lists some examples of human made air pollutants.

Sources	Pollutants
Power plants (fixed sources)	Carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, particulates
Transportation (mobile sources)	Carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, particulates and refrigerants
Buildings	Refrigerants
Factories	Dust, hydrocarbons and assorted emissions
Agriculture	Methane, hydrogen sulfide
Nuclear industry (including nuclear power plants)	Radiation, radioactive waste

Table 1.4: Anthropogenic air pollutants

1.4.3 Cross-links between naturally occurring and human-made air pollution

With global deforestation, the recovery ability of our ecosystem is diminishing. We have less forest to 'eat up' the carbon dioxide we breathe out. Together with our extensive consumption of fossil fuels, industry-generated carbon dioxide accumulates, and the greenhouse effect is made worse. Warmer weather results in more frequent forest fires and loss of more forests.

People also set fire to forests to clear land for agriculture. Intentional and accidental forest fires (e.g. from a burning cigarette); and human-made pollutants from factories, power plants and transportation put a burden on clean air and often pose longer-term effects on the biosphere. Pollutants from power plants and transportation are more or less the same as those from forest fires. Factories, depending on the chemicals they use, emit air pollutants that can be toxic, damaging to the stratospheric ozone or add to the greenhouse effect. The refrigerants in air-conditioning, a must in many cities and modern buildings, damage the stratospheric ozone as well as contribute to the greenhouse effect.

Background radiation is a natural occurrence, but the extra amount of radiation, as a result of the diminished filtering effect of our ozone protection layer, also falls into the category of pollution. Likewise, radon emission from rocks and soil is a natural occurrence, but the accumulation of such radioactive gases and particulates due to poor ventilation or use of materials that contain high radon results in pollution.

You may by now be able to distinguish between natural occurrence and pollution, and between natural and human-made pollution. You may have found that the damage from natural pollution can be extensive, but that such occurrences are infrequent,

localized and rather short-term, apart from catastrophic events such as the impact of meteoroids.

How about the air pollution in Hong Kong? It is time for an activity.

1.4.3.1 Activity 2

Using the information in Table 1.3 and Table 1.4, answer the questions below. Remember to check for the feedback and save your answer.

1. Which of the natural air pollutants listed contributes most to air pollution in Hong Kong?
2. Which of the human-made pollutants listed is the most difficult to control in Hong Kong?

1.4.3.1.1 Activity 2 feedback

1. Air pollutants from forest fire contribute most to natural air pollution in Hong Kong. However, due to dust storms in Mainland China, we have recorded higher amounts of small size dust particles in winter. Salt particulates can be a minor problem in the foggy season (Feb-May) of Hong Kong.
2. Nowadays, emitted nitrogen oxides (NO_x) are the most difficult to control since most of them are from vehicles which travel on roads and highways of Hong Kong (i.e. distributed sources and distributed emission hours in the day). Furthermore, emitted pollutants from transportation often react with sunlight and organic radicals to form ozone.

1.5 Classifying air pollutants

Classification of air pollutants can help us understand the nature of a pollutant and therefore the best techniques for managing it. Classification also helps identify the sources, the methods of formation, the forms, and the harmful effects of pollutants. We can then derive methods and techniques to eliminate them from the very beginning, minimize their formation, tackle their existence, educate ourselves and rationalize replacements.

Pollutants can be classified according to their:

- origin
- chemical composition
- state of matter
- area of impact

1.5.1 Origin

Primary pollutants (SO_x, NO_x, hydrocarbons) are emitted directly into the atmosphere and are found there in the form in which they were emitted. The can come from natural and human-made sources. They are substances directly produced by a process, for example, ash from a volcanic eruption, carbon monoxide from motor vehicle exhaust, and methane from plant decay.

Primary pollutants produced by human activity include:

- oxides of sulfur, nitrogen and carbon
- organic compounds, such as hydrocarbons (fuel vapour and solvents)
- particulate matters, such as smoke and dust
- metal oxides, especially those of lead, cadmium, copper and iron
- odours (from chemical such as acetone)
- toxic substances, for example, 1,1,1-trichloroethane, acetone

Often, primary pollutants react with water, with oxygen in the air, or with one another, and spawn a whole new set of pollutants. These pollutants can be called *secondary* pollutants, as they are produced from the chemical reactions of primary pollutants. These reactions are often triggered and powered by energy from the sun; for example, tropospheric ozone is one of the secondary pollutants that makes up photochemical smog. Secondary pollutants may include particulates formed from primary pollutants, and compounds in photochemical smog, such as nitrogen dioxide, ozone and peroxyacetyl nitrate (PAN).

Note that some pollutants may be *both* primary and secondary; that is, they can be emitted directly from a process, and they can be formed from other primary pollutants. For example, ozone is a secondary pollutant when it is formed in a photochemical process in the presence of NO_x and hydrocarbons. Ozone can also be formed as a result of lightning — a natural event — or generated from the printers and copiers in our offices — human-made sources.

1.5.2 Chemical composition

- Some pollutants are *organic* compounds (Traditionally, organic chemical compounds were classified as having molecules that contained carbon).
- Pollutants can also be *inorganic* compounds (which are considered to be of mineral, not biological, origin). However, many compounds that contain carbon are considered inorganic; for example, carbon monoxide, carbon dioxide, carbonates, cyanides, cyanates, carbides, and thyocyanates.

1.5.3 State of matter

- *Particulate* pollutants include dust, fumes, smoke, fly ash, mist, spray
- *Gaseous* pollutants include CO, CO_2, SO_x, NO_x, hydrocarbons, oxidants

Table 1.5 in Activity 3 outlines the different categories of pollutants according to their state of matter and chemical composition.

1.5.3.1 Activity 3

Fill in the missing pieces (marked with **?**) in the table below. Check your answers with the feedback.

Major causes	Subclasses	Typical examples	Control methods
?	Solids	?	Sedimentation, centrifugation, impaction, filtration, fabric filters, electrostatic precipitator, wet scrubber
	?	Mist, spray	
?	Hydrocarbons (HCs)	Hexane, benzene, ethylene, methane	Adsorption, absorption, stripping, condensation, combustion
	Aldehydes and ketones	Formaldehyde, acetone	
	Other organics	Actone, chlorinated hydrocarbons	

Major causes	Subclasses	Typical examples	Control methods
?	Oxides of carbon	?	
	Oxides of sulfur	SO_2, SO_3	
	Oxides of nitrogen	NO_2, NO_3	
	Other inorganics	O_3, H_2S, HF, NH_3 , Rn	

1.5.3.1.1 Activity 3 feedback

Major causes	Subclasses	Typical examples	Control methods
Particulates	Solids	Dust, smoke, fumes, fly ash, Pb	Sedimentation, centrifugation, impaction, filtration, fabric filters, electrostatic precipitator, wet scrubber
	Liquids	Mist, spray	
Gases (organic)	Hydrocarbons (HCs)	Hexane, benzene, ethylene, methane	Adsorption, absorption, stripping, condensation, combustion

Table 1.5: Classification of pollutants by state of matter and chemical composition

Major causes	Subclasses	Typical examples	Control methods
	Aldehydes and ketones	Formaldehyde, acetone	
	Other organics	Actone, chlorinated hydrocarbons	
Gases (inorganic)	Oxides of carbon	CO, CO_2	
	Oxides of sulfur	SO_2, SO_3	
	Oxides of nitrogen	NO_2, NO_3	
	Other inorganics	O_3, H_2S, HF, NH_3 , Rn	

Table 1.5: Classification of pollutants by state of matter and chemical composition

1.5.4 Area of impact

Air pollutants can also be categorized by their area of impact:

- *Ozone depletion substances* affect the stratosphere (these include CFCs, halons, HCFCs).
- *Greenhouse gases* occur in the troposphere (these include CO_2, CH_4, N_2O, CFCs and other hydrocarbons, O_3).
- *Toxins* affect humans and other living creatures (these include dioxins, furans).

1.6 Effects of air pollution

The effects of air pollutants are multi-dimensional. For example:

- Ozone is a harmful air pollutant on ground level, but it also protects us.
- Chemicals such as DDT (*p,p*'-dichlorodiphenyltrichloro- ethane), PCBs (polychlorinated biphenyls), PBBs (polybrominated biphenyls), CFCs (chlorofluoro carbons) were once considered very useful, but later were found to be very harmful.
- Some chemicals, for example, carbon tetrachloride, can be carcinogens/toxins, an ozone depleting substance, and a greenhouse gas, at the same time.
- Other pollutants may be harmful, not only to living organisms, but also to buildings and historical heritage sites. One example is acid gases.

The above-mentioned are just a few examples of the complexity of air pollutants. We now focus on some of the immediate health effects of air pollutants.

1.6.1 Immediate health effects

Immediate health effects are most noticeable during pollution episodes or periods when air pollutant concentrations reach dangerous levels in a short time. Notorious episodes that are documented include those that occurred in the Meuse Valley, Belgium in 1930 when 65 people died; Donora, Pennsylvania in 1948 when 20 died; and London in 1952 when about 4,000 died. These episodes were the result of elevated levels of particulates and sulphur dioxide. Many deaths were among the aged and those with cardiovascular disease.

Air pollutant releases during environmental disasters are even worse. At least 2,000 people were killed during the release of methyl isocyanate from Union Carbide in Bhopal, India. Medical complications from Bhopal are ongoing, just like the after-effects of 'Agent Orange', a defoliant used to destroy jungle during the Vietnam War (1964-75). The number of deaths from the radioactive release from the Chernobyl nuclear plant in 1986 has been estimated to be as high as 15,000.

Air pollution is also linked to bronchial and cardiovascular diseases. It can result in hospitalization and accelerated deaths. Click here (http://www.epd-asg.gov.hk/en/health-advice/health-effects-of-air-pollutants.html) for details of the health affects of particular pollutants on particular members of the community.

Air pollution also creates economic losses through increased medical expenses, lost productivity and loss in tourism and investment as air quality worsens.

The detrimental effects of air pollution have resulted in many countries and cities monitoring pollution levels and reporting a daily air pollution index. Hong Kong's index is the API (Air Pollution Index).

1.7 The Air Pollution Index

In order to indicate to citizens how good or bad the air pollution is, Hong Kong's Environmental Protection Department (EPD) launched the Air Pollution Index (http://www.epd-asg.gov.hk/) (API) programme in 1995.

Air pollution levels are monitored in a number of districts in Hong Kong, and at specific busy roadside locations (see Figure 3 (http://www.epd-asg.gov.hk/english/backgd/quality.html)). Click here (http://www.epd-asg.gov.hk/english/backgd/backgd.html) for more background information on the API and for details of monitoring methods. The API index reflects the air monitoring results of a specific locality. As local weather conditions may affect the dispersion of air pollutants emitted, API predictions can be announced to warn people who are vulnerable to air pollution. Typically, API predictions are given along with the weather forecast.

The API levels are given in Table 1.6

API	Air Pollution Level	Health Implications
0 to 25	Low	Not expected
26 to 50	Medium	Not expected for the general population
51 to 100	High	Acute health effects are not expected but chronic effects may be observed if you are exposed to such levels persistently for a long time.
101 to 200	Very High	People with existing heart or respiratory illnesses may notice mild aggravation of their health conditions. Generally healthy individuals may also notice some discomfort.
201 to 500	Severe	People with existing heart or respiratory illnesses may experience significant aggravation of their symptoms. There may also be widespread symptoms in the healthy population (e.g. eye irritation, wheezing, coughing, phlegm and sore throats).

Table 1.6: API Levels

Air Pollution Index and Youby EPD.

The API levels were established to reflect the health effects of air pollutants with respect to the concentrations of ambient RSP, sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) and nitrogen dioxide (NO2) over a 24-hour period. An API of 100 corresponds to the short-term Hong Kong Air Quality Objectives (http://www.epd-asg.gov.hk/english/backgd/hkaqo.html) (AQO) which were established under the Air Pollution Control Ordinance.

An API level at or below 100 would mean that the levels of the named pollutants are in the satisfactory range over the 24-hour period and have posed or would pose no

acute or immediate health effects. However, air pollution consistently at 'high' levels (API of 51 to 100) in a year may mean that the annual HKAQO for protecting long-term health effects could be violated. Therefore, chronic health effects may be observed if one is persistently exposed to API of 51 to 100 persistently for a long time.

An API level in excess of 100 means that levels of one pollutant or more are in the unhealthy range. In this case, the EPD would announce any precautionary action that needs to be taken.

1.7.1 API calculation

A network of air monitoring stations has been established in Hong Kong (the stations are shown in Figure 1.3) and real-time air quality data taken from each monitoring station are transmitted via telephone lines to the air quality data processing centre in the EPD office for the calculation of API.

Fig. 1.3: The Hong Kong air quality monitoring network

Air Quality Monitoring Network of Hong Kongby EPD.

API sub-index level	Relationship with HKAQO	Corresponding concentrations ($\mu g/m^3$)							
		RSP 24-hr	SO_2 24-hr	SO_2 1-hr	NO_2 24-hr	NO_2 1-hr	CO 8-hr	CO 1-hr	O_3 1-hr
0	-	0	0	0	0	0	0	0	0
25	50% Annual HKAQO / 25% HKAQO	28	40	200	40	75	2500	7500	60
50	Annual HKAQO / 50% HKAQO	55	80	400	80	150	5000	15000	120
100	HKAQO	180	350	800	150	300	10000	30000	240
200	-	350	800	1600	280	1130	17000	60000	400
300	-	420	1600	2400	565	2260	34000	90000	800
400	-	500	2100	3200	750	3000	46000	120000	1000
500	-	600	2620	4000	940	3750	57000	150000	1200

Table 1.7: API sub-index levels & their corresponding concentrations

Air Quality Monitoring Network of Hong Kongby EDP.

To view readings of the API for the last 24 hours, click here (http://www.epd-asg.gov.hk/english/24pollu_fsp/24pc_fsp.html).

1.8 References

Below are the resources referred to or cited by the developer(s) of the original unit:

Chiras, C C (1994) *Environmental Science — Action for a Sustainable Future*, Redwood City, CA: Benjamin/Cummings.

Henry, J G and Heinke, GW (1996) *Environmental Science and Engineering*, 2nd edn, Upper Saddle River, NJ: Prentice-Hall.

1.9 Conclusion

This module introduced you to some issues related to air pollution.

We began by defining air pollution and discussing how it interacts with the earth's atmosphere. We then examined the system of air pollution.

Next, we looked at the main sources of air pollution: describing both naturally occurring and human-generated pollutants.

We then classified air pollutants according to their origin, chemical composition, state of matter, and area of impact. We also examined the multi-dimensional effects of air pollution, particularly the health affects.

We concluded by explaining Hong Kong's Air Pollution Index

If you would like to learn more on this subject, you are welcome to enrol in *ENVR S335 Environmental Control, Monitoring and Modeling* (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&c=C_ETPU&cid=191154036400&lang=eng) offered by the School of Science and Technology (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcSubWeb&l=C_ST&lid=191133000200&lang=eng) of the OUHK.