Environmental Chemistry

Introduction

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Environmental Chemistry

Lecture outline

Pollution perspective
Major pollutants
Effects of pollutants on ecosystems
Fate and behavior of chemicals in environment
Environmental toxicity testing
Environmental monitoring
Instrumentations
Introduction

**Environmental components**

**Geosphere / lithosphere**
Solid earth, including soil, which supports most plant life

**Biosphere**
Living entities on Earth

**Hydrosphere**
Earth’s water

**Atmosphere**
Thin layer of gases that cover Earth’s surface

ECOLOGY
The study of ecosystem
Ecosystem

- Encompasses both living (biotic) and non-living (abiotic) components of an area – a combination of the community and physical and chemical components of the local environment.
- The major feature of this ecological level is the strong interaction between the biotic and abiotic components.
- Major processes:
  - Nutrient recycling
  - Energy flow
Ecosystem processes

Energy flow:

- Energy sources
- Photosynthesis
- Primary production
- Secondary production

Natural process
**Major components & sub components**

**Environmental components**

<table>
<thead>
<tr>
<th>Abiotic</th>
<th>Hydrosphere (ocean, lake, river, groundwater)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lithosphere (solid earth, soils)</td>
</tr>
<tr>
<td></td>
<td>Atmosphere</td>
</tr>
<tr>
<td>Biotic</td>
<td>Living organisms (animal, plant, fungi, bacteria, virus)</td>
</tr>
<tr>
<td></td>
<td>Dead organic matters</td>
</tr>
</tbody>
</table>

Lecture notes on Environmental Chemistry by Prof. Zaini Ujang. zaini@utm.my

INSTITUTE OF ENVIRONMENTAL & WATER RESOURCE MANAGEMENT (IPASA)
Environmental components

Geosphere ↔ Atmosphere

Hydrosphere ↔ Biosphere

TECHNOLOGY
Pollution Perspective

Multiple sources
- Natural
  - Volcano
  - Dust
  - \( CO_2 \) from respiration and fire
- Man-made

Urbanisation and industrialisation enhanced pollution
Degradation of self-purification processes
Pollution Perspective

*Manufacturing processes- from problems maker to problem solver*

- Reactants
- Contaminants (impurities)
- Reaction media (water, organic solvents)
- Catalysts
- Manufacturing process
- Products & useful by-products
- Discharges that may require treatment
- Reclaimed by-products
- Wastewater
- Solids & sludges
- Atmospheric emissions

Reactants

Manufacturing process

Products & useful by-products

Discharges that may require treatment

Reclaimed by-products

Wastewater

Solids & sludges
Pollution Perspective

Paper production, usage and disposal

Wood from forest
- Deforestation
- Soil erosion

Pulp & paper manufacturing
- Persistent organic pollution

Paper usages
- Solid waste

Environmental pollution generation
Pollution Perspective

*Burning of paper and other organic materials*

- Asthma
- NO$_2$
- Carcinogens
- Heat
- SO$_2$

Global warming

- CO$_2$
- Greenhouse effect

Fire

Acid rain

O$_2$ + H$_2$O $\rightarrow$ H$_2$SO$_4$
Pollution Perspective

*Pollution from water to air to soil to water to air to soil to ...*

- Water pollution control
- Atmosphere
- Acid rain
- HUMAN BEING
  - Sludge
  - Soil pollution
  - Pollution of surface water
Ecological systems, disturbances & pollution

Concept of tolerance
Each species tolerate to a range of optimum for physicochemical factors:
  - temperature
  - pH
  - light
  - nutrients
  - biological factors (food, competitors and predators)

Each species is most successful in that area where ranges of optima for different factors overlap to the greatest degree

Each species within a community and habitat has different and unique niche
Ecological systems, disturbances & pollution

Concept of disturbance
Discrete, punctuated killing, displacement or damaging of one or more individuals or colonies that directly or indirectly creates an opportunity for new individuals to be become established (Sousa, 1984)

Causes a temporary or permanent shift in the community

Risk assessment can be used to identify the risk after disturbances
Ecological systems, disturbances & pollution

Concept of pollution
Any change in the natural quality of the environment brought about by the following factors:
- chemical
- physical
- biological

Normally, pollution causes by activities of man

Physical factors
- change naturally in short term (flood, fire, storms, etc.)
- longer term change (e.g. climate change)
- man’s activities (building, drainage, forest clearance)
Ecological systems, disturbances & pollution

**Chemical factors**
Changes through elevation of concentration of substances, e.g.
- nutrients  eutrophication
- toxic substances  health risk
- organics  reduce quality of raw water supply

**Biological factors**
Biological processes like predation or grazing, non-predatory effects like digging and man-induced events like tree felling, hunting etc.
- reduce species niche  ecological imbalance
- cutting trees  reduce oxygen generation capability

**Note:**
*Eutrophication: Enrichment of nutrients in water bodies*
Ecological systems, disturbances & pollution

Most pollution, disturbances can be recovered

The ability to recover and rate of recovery are dependent on the regime of disturbance:

- Nature of disturbances
- Size of the disturbed area
- Magnitude and duration of the event (intensity of disturbing force)
- Timing and frequency of the disturbance
- Predictability of the disturbance
- Turnover rate (average time required to disturb the entire area)
Major pollutants

Water, Atmosphere, Soil

- Sulphur dioxide
- Nitrogen oxides and nitrate
- Sewage
- Agricultural waste
- Warfare
- Pesticides
Centralized (and combined) WWTP

Non-treated industrial WW

Partly treated industrial WW

Public sewer

Municipal WW

Urban runoff

Stormwater
Sewage in rural and remote areas

Kitchen
Bathrooms
Toilets

Storm drain
Septic tanks
Major pollutants \textit{Water, Atmosphere, Soil}
Major pollutants \textit{Water, Atmosphere, Soil}

\textit{After the Friday prayer we'd go fishing naturally.}
Major pollutants *Water, Atmosphere, Soil*
Number of water pollution sources by sector to Malaysian rivers \textit{(DOE, 2001)}

- Sewage plants (6,693)
- Manufacturing industries (5,086)
- Pig farming (909)
- Agro-based industry (472)
Status of river basin water quality \textit{(DOE, 2002)}

![Bar chart showing the status of river basin water quality with three parameters: BOD, Am-N, and SS. The chart indicates levels from clean to polluted.](Image)
BOD loading by major sources, 1997-2001
Water pollution in perspective …
Water pollution in perspective ...
### Interim River Water Classes

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Classes</th>
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<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
<td>IV</td>
<td>V</td>
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<tr>
<td>Am-Nitrogen</td>
<td>0.1</td>
<td>0.3</td>
<td>0.9</td>
<td>2.7</td>
<td>&gt;2.7</td>
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<td>BOD</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>12</td>
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<td>50</td>
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<td>&gt;100</td>
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<td>DO</td>
<td>7</td>
<td>5-7</td>
<td>3-5</td>
<td>&lt;3</td>
<td>&lt;1</td>
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<tr>
<td>pH</td>
<td>6.5 - 8.5</td>
<td>6-9</td>
<td>5–9</td>
<td>5–9</td>
<td>-</td>
</tr>
<tr>
<td>Color (TCU)</td>
<td>15</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TDS</td>
<td>500</td>
<td>1000</td>
<td>-</td>
<td>4000</td>
<td>-</td>
</tr>
<tr>
<td>TSS</td>
<td>25</td>
<td>50</td>
<td>150</td>
<td>300</td>
<td>&gt;300</td>
</tr>
<tr>
<td>FC(per 100ml)</td>
<td>10</td>
<td>100</td>
<td>5000</td>
<td>5000</td>
<td>-</td>
</tr>
<tr>
<td>TC(per 100ml)</td>
<td>100</td>
<td>5000</td>
<td>20,000</td>
<td>50,000</td>
<td>&gt;50,000</td>
</tr>
</tbody>
</table>
Pollution Distribution in Segget Catchment, JB

<table>
<thead>
<tr>
<th>Locations</th>
<th>Contributors</th>
<th>Loading (Ton/d)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Rubbish Trap</td>
<td>Industries</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sewage</td>
<td>0.9</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Non Pollution Sources</td>
<td>0.4</td>
<td>11</td>
</tr>
<tr>
<td>Estuary</td>
<td>Industries</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sewage</td>
<td>1.5</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Non Pollution Sources</td>
<td>0.7</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3.5</td>
<td>100</td>
</tr>
</tbody>
</table>
Effects of pollutants on ecosystem

Introduction to food webs
Some specific examples
Risk versus benefits
Development of safer chemicals
Effects of pollutants on ecosystem

*Introduction to food webs*

Food chains are dependent upon primary producers which input energy.

Primary energy input is derived from photosynthesis (CO$_2$ converted to complex carbohydrates utilising sun’s energy):

\[
\text{CO}_2 + \text{H}_2\text{O} \quad \xrightarrow{\text{sunlight}} \quad \text{CH}_2\text{O} + \text{O}_2
\]

The problem: energy transfer is not efficient (energy loss as heat)
Effects of pollutants on ecosystem

Introduction to food webs

Figure 2.1 Pyramid representation of the trophic levels and their interactions.
Effects of pollutants on ecosystem

*First law of thermodynamics*

Energy can be transferred from one type to another but cannot be created or destroyed

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{H}_2\text{O} + 6\text{CO}_2 + \text{Energy} \]
Effects of pollutants on ecosystem

*Second law of thermodynamics*

No process involving an energy transformation will spontaneously occur unless there is a degradation of the energy from a concentrated form into a dispersed form.
Effects of pollutants on ecosystem

Schematic representation of interrelationship between 2 food chains

- Fox
  - Ptarmigan
    - Thundra vegetation
  - Insects
    - Sandpiper
Effects of pollutants on ecosystem

*Complex food web showing the trophic levels*

```
Trophic level
1
2
3
4
```

- Dwarf willow
- Lemming
- Shaggy-haired vole
- Insects
- Snowy owl
- Migratory birds
### Effects of pollutants on ecosystem

*7 trophic levels showing examples of organisms*

<table>
<thead>
<tr>
<th>Trophic level</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (P)</td>
<td>Primary producer</td>
<td>Spyrogyra, oak tree</td>
</tr>
<tr>
<td>2 (C1)</td>
<td>Primary consumer (herbivores)</td>
<td>Daphnia, elephant</td>
</tr>
<tr>
<td>3 (C2)</td>
<td>Secondary consumer (carnivores)</td>
<td>Water spider</td>
</tr>
<tr>
<td>4 (C3)</td>
<td>Tertiary consumer</td>
<td>Trout, wolf</td>
</tr>
<tr>
<td>5 (C4)</td>
<td>Quarternary consumer</td>
<td>Birds of prey</td>
</tr>
<tr>
<td>S</td>
<td>Saprophytes</td>
<td>Bacteria, fungi</td>
</tr>
<tr>
<td>D</td>
<td>Decomposers</td>
<td>Bacteria, earthworm</td>
</tr>
</tbody>
</table>
Effects of pollutants on ecosystem

The use of dead organic matter

Dead organic matter → Microorganisms
  e.g. bacteria → Detritus feeding organisms
  e.g. earthworm

Plants → Predators
  e.g. Blackbird

Predators → Raptors
  e.g. Sparrow hawk
Fate & behaviour of chemicals in environment

*E.g. Dichlorodiphenyltrichloroethane (DDT)*

Very hydrophobic molecule which acts by interfering with ion transport systems in neuronal cell membrane
Inhibits neurotransmission → kills animals at certain dose
DDT (introduced in 1950s) is not species specific in its effects
DDT and related insecticides, endrin, dieldrin and aldrin are called ORGANOCHLORINE PESTICIDES
DDT revolutionised farming practices
DDT was developed by Swiss entomologist – Paul MÜller
Nobel Prize in 1948!
Banned in the mid-1960s in most developed countries
# Fate & behavior of chemicals in environment

*DDT in food chain in the USA*

<table>
<thead>
<tr>
<th>Diet</th>
<th>DDT residues (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.0005</td>
</tr>
<tr>
<td>Plankton</td>
<td>0.04</td>
</tr>
<tr>
<td>Sheepshead minnow</td>
<td>0.94</td>
</tr>
<tr>
<td>Pickeral</td>
<td>1.33</td>
</tr>
<tr>
<td>Heron</td>
<td>3.57</td>
</tr>
<tr>
<td>Herring gull</td>
<td>6.00</td>
</tr>
<tr>
<td>Osprey (eggs)</td>
<td>13.8</td>
</tr>
<tr>
<td>Merganser</td>
<td>22.8</td>
</tr>
<tr>
<td>Cormorant</td>
<td>26.4</td>
</tr>
</tbody>
</table>

Woodwelll et al. (1967) *Science*, 156, 821
Risk versus benefits …

Life is a risky business!
Concept of risk is complex

\[
\text{RISK} = \text{HAZARD} \times \text{CHANCE (OF EXPOSURE)}
\]

Hazard = intrinsic property of a substance or an activity
Occupational Safety and Health Act
Risk associated with exposure to chemicals is recent
Risk and benefit is not similar to all
Risk versus benefits …

Is recycle is the solution to sustainable waste disposal and management?
Development of safer chemicals

Organochlorines (OCs) are dangerous to environment because of its indiscriminate toxicity

Environmental friendly chemicals?

E.g. pyrethroid insecticides

Pyrethrum is a mixture of several pyrethroids present in powdered *Chrysanthemum cinerariaefolium*, including pyrethrin, pyretol, pyrethrotoxic acid, pyrethrosin and chrysanthemine

Widely planted in Kenya

Pyrethroids act by modulating the gating characteristics of the sodium channel on neuronal membrane although the exact mechanism of the interaction between pyrethorid molecule and membrane sodium channel is not fully understood
Development of safer chemicals

Chemicals and products are to be disposed at high cost, or discharge to environment without proper treatment at all.
Environmental toxicity testing

Toxicity testing in perspective

Extrapolating the results of toxicity test in rats (and other animals to humans)
The best is to use human body
Ethical problems, especially in pharmaceutical industry
Scope and limitations
Oestogenicity assay
Toxicity tests on animals and plants
Environmental impacts assessment
Environmental monitoring

Why monitor environmental contaminants

Methods

Meaning of analytical results

Analytical techniques

Identification of environmental contaminants

Inorganic contaminants

Immunoassays