DP IB Environmental Systems & Societies (ESS): SL

8.3 Urban Air Pollution

Contents

Causes of Urban Air Pollution

What is urban air pollution?

- Human activities that release harmful substances into the atmosphere cause urban air pollution
  - Pollutants in the air can come from many sources and impact both human health and the environment
- Common pollutants include:
  - **Nitrogen oxides (NOx)**
  - **Sulphur dioxide (SO_2)**
  - **Carbon monoxide (CO)**
  - **Particulate matter (PM)**
    - Particulate matter refers to tiny solid particles or liquid droplets in the air
    - These particles can come from dust, soot, smoke, and vehicle emissions
- Particulate matter can be classified by size:
  - **PM2.5**: fine particles with a diameter of 2.5 micrometres or smaller
  - **PM10**: larger particles with a diameter of 10 micrometres or smaller

Primary pollutants

- Primary pollutants are harmful substances that are:
  - **Directly emitted from a source**
  - **Immediately active** in the atmosphere
- They enter the air through various activities like burning fossil fuels, industrial processes, or natural events such as volcanic eruptions

Sources of primary pollutants

- **Natural sources**:
  - Some air pollutants come from **natural events** that occur without human involvement
    - **Forest fires**: release smoke, ash, and particulate matter into the air

- **Dust storms**: strong winds lift dust from dry areas, which spreads to cities
- **Volcanic eruptions**: these produce large amounts of SO_2 and ash

- **Anthropogenic (human-made) sources**:
  - Many pollutants in urban areas come from **human activities**, especially those involving the burning of fuels
    - **Burning fossil fuels**: emissions from vehicles, power plants, and factories produce NOx, SO_2, CO, and PM
    - **Agricultural burning and deforestation**: these release large quantities of smoke, dust, and other pollutants into the atmosphere
    - **Construction sites and roads**: create dust and PM from the movement of machinery and vehicles
    - **Industrial processes**: factories release pollutants like NOx and PM from smokestacks and chemical processing

Common pollutants from urban activities

- The most common pollutants in urban areas are usually linked to the **combustion of fossil fuels**
  - Particulate matter (**PM2.5 and PM10**): tiny particles from exhaust fumes, industrial activities, and construction dust
  - **CO**: released by cars and industrial processes that burn fuels
  - **NOx**: produced by vehicle emissions and power plants
  - **SO_2**: released mainly by burning coal and oil

Secondary pollutants

- Secondary pollutants are **not emitted directly** but **form in the atmosphere** when primary pollutants react with other chemicals
  - **Tropospheric ozone (O_3)**: forms when nitrogen oxides (NOx) react with sunlight
    - It is a major component of urban smog

Examples of urban air pollution

- **Beijing, China**: often experiences high levels of **PM2.5**, mainly due to coal burning for energy and industrial activity
- **Los Angeles, USA**: struggles with **ozone pollution** due to a high number of vehicles and sunny weather, which speeds up the reaction that forms ozone
- The burning of crops, industrial activity, and vehicle emissions frequently cause severe **air pollution** in **New Delhi, India**

Air Pollution Management Strategies

- Air pollution management strategies are designed to **reduce harmful emissions** and **improve air quality** in **urban areas**
- These strategies focus on:
  - **Reducing** the sources of pollution
  - **Promoting** cleaner technologies
  - **Encouraging** sustainable urban living

Reducing the use of fossil fuels

- One of the most effective ways to manage urban air pollution is to reduce the **reliance** on fossil fuels
- This includes:
  - Promoting the use of **renewable energy sources** like wind, solar, and hydro to power cities
  - **Improving public transport** systems in cities to reduce car usage, e.g.
    - Electric buses
    - Efficient metro systems
  - Creating infrastructure for **cycling,** e.g.
    - More cycle lanes
    - Cycle-hire schemes
  - Pedestrianising city centres

Emission zones and car restrictions

- Emission zones are areas where only vehicles meeting certain **environmental standards** are allowed to enter
  - **Low Emission Zones** (LEZs) restrict high-polluting vehicles, reducing air pollution in the city centre
  - For example, **London** has an Ultra Low Emission Zone (ULEZ) where only vehicles meeting strict emission standards can drive
- Some cities also restrict car use on certain days or at peak times to decrease congestion and emissions

Catalytic converters

- Catalytic converters are devices fitted to car exhaust systems that **reduce harmful emissions**
  - They contain catalysts that speed up chemical reactions to convert pollutants like nitrogen oxides and carbon monoxide into less harmful gases such as nitrogen and carbon dioxide
  - In many countries, it is **compulsory** for vehicles to have catalytic converters

Growing trees and natural screens

- Trees and green spaces play an important role in **filtering pollutants** from the air
- Trees can reduce air pollution and improve air quality by:
  - Absorbing carbon dioxide
  - Trapping particulate matter
- **Natural screens** such as hedges, tree lines and green walls can also help reduce pollutants near roads and buildings

Green walls and green roofs

- Green walls and green roofs are covered with vegetation and can improve air quality by filtering pollutants
  - They also help regulate temperature, reducing the urban heat island effect

Acid Rain

Acid Rain Formation

- Acid rain refers rainfall that has a pH lower than normal rainwater
  - Regular rain has a pH between 5 and 5.5, meaning it is naturally slightly acidic
  - Acid rain is more acidic, has a pH lower than 5, and is frequently the result of human activity

Chemical reactions leading to acid rain

- **Nitrogen oxides (NOx)** and **sulphur dioxide (SO_2)** are the main gases responsible for acid rain
  - These gases react with water and oxygen in the atmosphere to form nitric acid and sulfuric acid

Formation of nitric acid

- Nitrogen oxides are mainly produced from **vehicle exhausts**
- The reactions are as follows:
  - Nitrogen monoxide (NO) reacts with oxygen (O_2) to form nitrogen dioxide (NO_2)

$$2NO + O_2 \rightarrow 2NO_2$$

- The nitrogen dioxide then reacts with water (H_2O) and oxygen in the air to produce nitric acid (HNO_3)

$$4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3$$

Formation of sulphuric acid

- Sulphur dioxide is produced by **burning fossil fuels** and reacts with water in the atmosphere
- The reactions are as follows:
  - Sulphur dioxide (SO2) dissolves in rainwater, producing sulphurous acid (H_2SO_3)

$$SO_2 + H_2O \rightarrow H_2SO_3$$

- The sulphurous acid is then oxidised by oxygen in the air to produce sulfuric acid (H_2SO_4)

$$2H_2SO_3 + O_2 \rightarrow 2H_2SO_4$$

Types of deposition

- **Wet deposition** refers to acidic precipitation falling to Earth in the form of **rain**, **snow**, **or fog**
- Sulphuric acid and nitric acid can also combine with ash and other particles present in the air, forming **dry particles** (i.e. acidic dust and gases)
  - **Dry deposition** occurs when these particles settle on surfaces, including vegetation, buildings, cars and soil

Acid Rain Impacts

Impacts on ecology

Impacts on terrestrial habitats

- Acidic deposition from acid rain accelerates the **leaching** of essential **nutrients** from soil, such as calcium, magnesium and potassium
  - Leaching of these nutrients reduces their availability for plants
  - This leads to **nutrient deficiencies**
  - This reduces plant growth and overall ecosystem **productivity**
- Acidic rain can **increase soil toxicity**
  - This can occur by **mobilising** harmful metals like aluminium
  - This damages plant roots and affects their ability to absorb water and nutrients
- Acid rain causes **direct damage to foliage**
  - This weakens trees, making them more vulnerable to disease and harsh weather
- Coniferous forests, e.g. forests of pine or spruce trees, are sensitive to acid rain
  - This is due to their shallow root systems and thin bark
  - Acid rain also damages their foliage and **inhibits nutrient absorption**

Impacts on freshwater habitats

- Acid rain can make water bodies more acidic
- This is due to a process referred to as **solubilisation of aluminium**
  - Acid rain causes aluminium, which is normally bound in the soil, to dissolve
  - This allows the aluminium to enter nearby water bodies
- This aluminium is **toxic to aquatic life**, such as fish and freshwater invertebrates
  - Fish gills can become coated with aluminium
    - This makes it harder for them to breathe
  - Some invertebrates with **exoskeletons** may have difficulty maintaining their protective shells
    - They rely on calcium to build and maintain their hard outer shells
    - When acid rain increases the acidity of water, it reduces the availability of calcium and other minerals that these organisms need
    - This makes it harder for them to properly develop or maintain their exoskeletons

Impacts on buildings and infrastructure

Corrosion of construction materials

- Acid rain erodes materials like **marble, limestone, steel, and paint** used in buildings and monuments
- Marble and limestone both contain calcium carbonate ($CaCO_3$)
- The calcium carbonate reacts with sulphuric acid or nitric acid, causing stonework to corrode and weaken
  - For example, the **Taj Mahal** in India, made of marble, has shown signs of erosion and discolouration due to acid rain
  - Acid rain has also had an impact on historical statues and structures, such as those in Rome and Greece

Impacts on human health

Respiratory issues

- Acid rain does not **directly** harm humans
- However, **nitrate** and **sulphate particles** from acid rain can cause **respiratory problems**
  - **PM2.5 particles** (tiny air pollutants) from acid rain can enter the lungs
  - This leads to:
    - Tissue damage
    - Lung inflammation
    - An increased risk of conditions such as asthma and bronchitis
  - As a result, areas with heavy industrial activity, such as parts of China and Eastern Europe, experience greater respiratory health risks

Acid Rain Management Strategies

- There are three main levels of pollution management strategies:
  1. Changing human activity
  2. Regulating and reducing quantities of pollutants released at the point of emission
  3. Cleaning up the pollutants and restoring the ecosystem after pollution has occurred
- These levels can also be applied to acid rain management strategies
  - Acid rain requires effective pollution management strategies to mitigate its harmful effects on the environment and human health

1. Altering human activity

- Reducing the consumption of fossil fuels is a key strategy to minimise acid rain
  - Encourage the use of alternative energy sources, such as **renewable energy**, can significantly reduce emissions of sulphur dioxide and nitrogen oxides
- International agreements and national governments play a vital role in:
  - Promoting sustainable practices
  - Supporting the development of clean technologies
  - Lobbying for emissions reductions

2. Regulating and monitoring pollutant release

- Government regulations and **monitoring systems** are essential to **control** and **reduce** the release of pollutants that contribute to acid rain
  - Coal-burning power plants and vehicles are major sources of sulphur dioxide and nitrogen oxide emissions
  - Installing pollution control devices such as **scrubbers** and **catalytic converters** can effectively remove these pollutants from emissions

3. Clean-up and restoration measures

- In areas heavily affected by acid rain, certain strategies may be used to mitigate the damage caused
  - For example, **spreading ground limestone** or **lime** in acidified lakes and rivers can **neutralise acidity** and restore the water's pH balance
- Restoring damaged ecosystems can also be achieved through re-colonisation efforts, such as **planting acid-tolerant vegetation**
  - This can help restore ecological balance to these damaged ecosystems