

CHAPTER ONE

Ecological Concepts and Natural Resources

Environmental Engineering is the application of scientific and engineering principles to assess, manage and design sustainable environmental systems for the protection of human and ecological health. Environmental Engineering encompasses a range of specialties including:

- Environmental chemistry, microbiology, geology, and ecology
- Hydrology and water resources
- Water quality
- Water and wastewater treatment processes
- Solid and hazardous waste management and Remediation
- Air pollution and air quality control
- Mathematical modeling of environmental processes
- Environmental toxicology and risk assessment
- Environmental impact assessment
- Sustainable engineering systems
- Environmental engineering laboratory

1.1 Components of the environment

The natural environment consists of four segments- ***atmosphere, hydrosphere, lithosphere and biosphere.***

Atmosphere: The atmosphere is the protective blanket of gases surrounding the earth, which sustains life on earth and saves it from hostile environment of outer space. It filters out tissue-damaging ultraviolet radiation. The atmosphere plays a key role in maintaining the heat balance of the earth, through absorption of infrared radiation emitted by the sun and re-emitted from the earth. The atmosphere is the source of oxygen and carbon dioxide. It also supplies nitrogen which nitrogen-fixing bacteria and ammonia manufacturing plants utilize to yield chemically bound nitrogen essential for life. Furthermore, it is a vital carrier of water from oceans to land, as part of the hydrologic cycle.

Hydrosphere: The hydrosphere includes all types of water resources- oceans, seas, rivers, lakes, streams, reservoirs, polar ice caps and ground water. About 97 % of the earth's water supply is in the oceans, where the high salt content does not permit its use for human consumption. About 2 % of the water is locked in the polar ice caps and glaciers, while only 1 % is available as freshwater (rivers, lakes, streams, and ground water) for human consumption and other uses.

Lithosphere: This is the outer shell of the earth, comprising the crust and the uppermost layer of the mantle. It consists of minerals occurring in the earth's crust and the soil. The latter comprises a complex mixture of minerals, organic matter, air and water. The soil is the most important part of the lithosphere.

Biosphere: This denotes the realm of living organisms and their interactions with the environment, viz. atmosphere, hydrosphere and lithosphere. It comprises a number of specific ecosystems.

Ecosystem: is an ecological system that consists of interacting biotic and abiotic components. The biotic components include plants, animals and microbes. The abiotic component comprises physicochemical substances, i.e. basic inorganic elements and compounds such as oxygen, water, carbon dioxide, phosphates and gradients like temperature, wind, moisture, etc. The dynamic nature of the ecosystem due to the interactions between and interdependence of the various components is shown in Fig. 1.1. Ecosystems occur in space and exist in time- they have breadth, width and depth, plus a past as well as a present and a future.

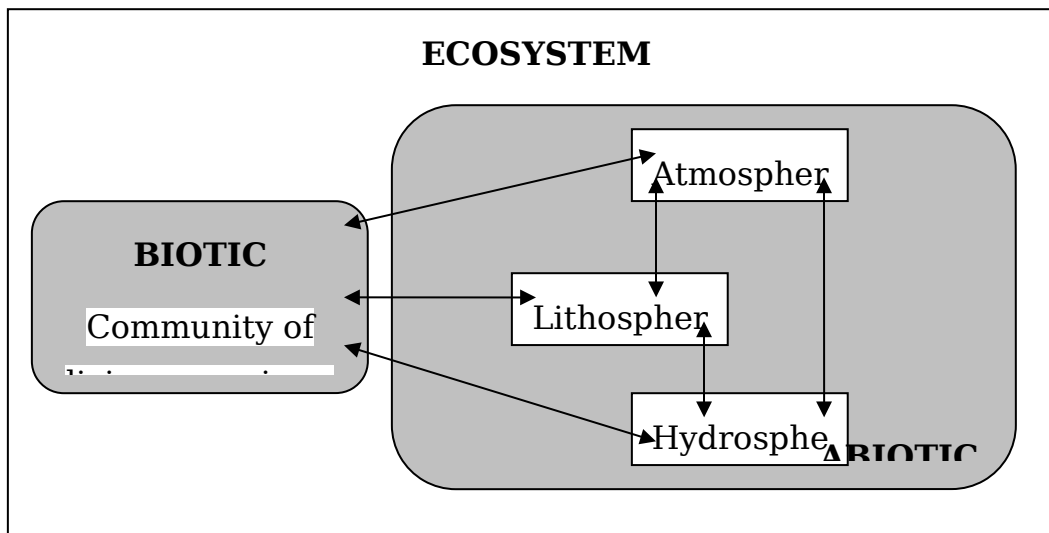


Fig 1.1 Ecosystem interactions

Ecological systems can broadly be classified into two classes: *Aquatic and Terrestrial* ecosystems.

Aquatic ecosystems. Three broad categories of aquatic ecosystems can be distinguished on the basis of major chemical difference- freshwater (river, lake and pond), marine (ocean and sea), and estuarine (coastal, bay, tidal).

Freshwater ecosystems: encompasses all inland bodies of flowing and still water. Flowing water or *lotic* habitats include the different parts of a river: the headwater streams and brooks, mid-valley streams with pools and riffles, the floodplain zone, and the estuaries where rivers flow into the sea. The amount, variability, and reliability of water flow in rivers has enormous significance for plants, animals, and people living along the course of the river. Rivers and their flood plains possess diverse and valuable ecosystems. Hence, great care must be exercised when altering this regime through basin and river management, as careless handling or over-exploitation of water resources has catastrophic impacts on riparian ecosystems.

Still water or *lentic* habitats (ponds and freshwater lakes) comprise a shallow-water zone or wetlands along the shore; an upper open-water zone that extends to the depth at which light is insufficient for photosynthesis; a deep-water zone on which the warmer, less dense water floats; and a bottom zone of soft mud and silt, where decomposition takes place.

Wetlands are unique transient ecosystems, falling between true aquatic systems on one hand and terrestrial systems on the other. The water table is usually at or near surface, or the land is covered by shallow water. About 6% of the total surface area of the world is covered by wetlands. Wetlands are among the earth's most productive ecosystems.

Box 1.1 Aquatic ecosystems of Ethiopia

Lotic:

- 7000 km total river length
- 12 major river basins

Terrestrial ecosystems: are usually named after the dominant vegetation type of an area. Hence, there can be forest (different types), grassland, and

desert ecosystems. Soil and climate are the major factors that determine the distribution of terrestrial ecosystems.

Box 1.2 Major terrestrial ecosystems of Ethiopia:

- Afroalpine and sub-Afroalpine ecosystem (found in > 3200 m.a.s.l)
- Mountain grassland ecosystem (1500 – 3000 m.a.s.l)
- Combertum-Terminalia woodland ecosystem (generally found on rocky sand soils; 500-1900 m.a.s.l)
- Mountain moist forest ecosystem (major forest area in the country; mainly south west)
- Acacia-commiphora woodland ecosystem (900-1900

1.2 Ecological processes and natural cycles

Ecological processes

Ecosystems function through two ecological processes- energy flowing in one direction from the Sun, and through nutrients, which are continuously recycled. These two processes are essential for the survival and maintenance of the biotic environment. Light energy is used by plants, which, by the process of photosynthesis, convert it to chemical energy in the form of carbohydrates and other carbon compounds. This energy is then transferred through the ecosystem by a series of steps called a food web. A simplified model for energy and nutrient movement is shown in Fig. 1.2.

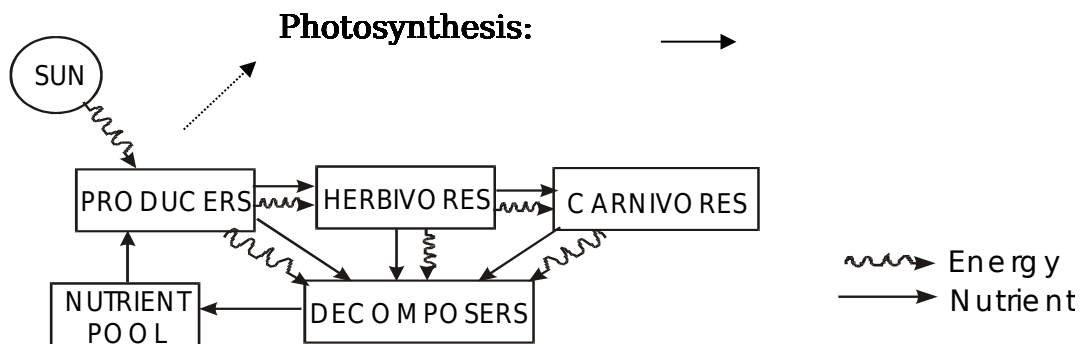


Fig. 1.2 The food web

Energy flow fuels the biogeochemical cycles, or nutrient cycles. The cycling of nutrients begins with their release from organic matter by weathering and decomposition in a form that can be picked up by plants. Plants incorporate nutrients available in soil and water and store them in their tissues. The nutrients are transferred from one trophic level to another through the food web. Because most plants and animals go uneaten, nutrients contained in their tissues, after passing through the decomposer food web, are ultimately released by bacterial and fungal decomposition, a process that reduces complex organic compounds into simple inorganic compounds available for re-use by plants.

Within an ecosystem nutrients are cycled internally. But there are leakages or outputs, and these must be balanced by inputs, or the ecosystem will fail to function. Nutrient inputs to the system come from weathering of rocks, from windblown dust, and from precipitation, which can carry material great distances. Varying quantities of nutrients are carried from terrestrial ecosystems by the movement of water and deposited in aquatic ecosystems and associated lowlands. Erosion and the harvesting of timber and crops remove considerable quantities of nutrients that must be replaced. The failure to do so results in an impoverishment of the ecosystem. This is why agricultural lands must be fertilized.

Natural cycles of the environment

The natural cycles and ecosystems operate in a balanced manner which stabilizes the entire biosphere and sustains the life processes on earth. Some major natural cycles are discussed below.

The hydrologic cycle: is a continuous natural process which helps in exchange of water between the atmosphere, the land, the sea, living plants and animals (See Fig. 1.4). The solar radiation drives the hydrologic cycle.

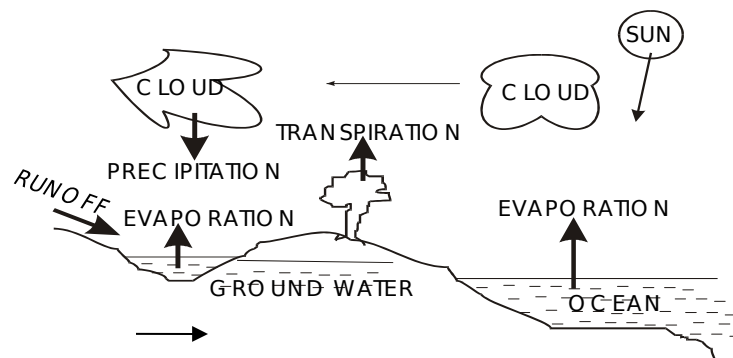


Fig. 1.4 The hydrologic cycle

The Nitrogen cycle: Nitrogen and its compounds are essential for the maintenance of life processes in the biosphere. There is a continuous exchange of nitrogen within ecosystems, operating the nitrogen cycle (See Fig. 1.5).

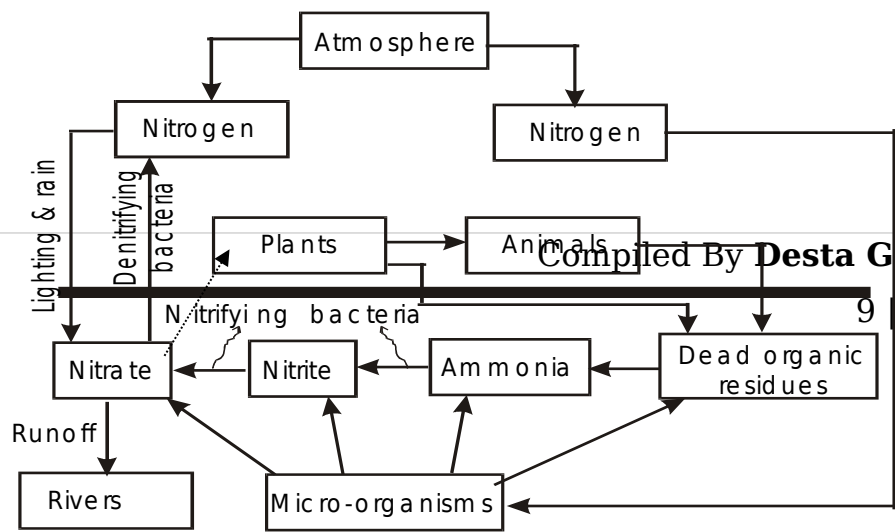


Fig. 1.5 The Nitrogen Cycle

The activities of humans have severely altered the nitrogen cycle. Some of the major processes involved in this alteration include:

- o The application of nitrogen fertilizers to crops has caused increased rates of denitrification and leaching of nitrate into groundwater. The additional nitrogen entering the groundwater system eventually flows into streams, rivers, lakes, and estuaries. In these systems, the added nitrogen can lead to eutrophication.
- o Increased deposition of nitrogen from atmospheric sources because of fossil fuel combustion and forest burning. Both of these processes release a variety of solid forms of nitrogen through combustion.
- o Livestock ranching: Livestock release large amounts of ammonia into the environment from their wastes. This nitrogen enters the soil system and then the hydrologic system through leaching, groundwater flow, and runoff.
- o Sewage waste and septic tank leaching.

The Phosphate cycle

Phosphates are important to metabolism in both plants and animals. Phosphorus cycle occurs both in terrestrial and aquatic ecosystems. The natural phosphorus cycle has been affected by pollution, mainly from agricultural runoff containing super-phosphate and also from domestic

sewage containing phosphates derived from excreta and detergents. Phosphate pollution of rivers and lakes is the cause of algal bloom (eutrophication), which reduces the dissolved oxygen in water and disrupts the natural food chain.

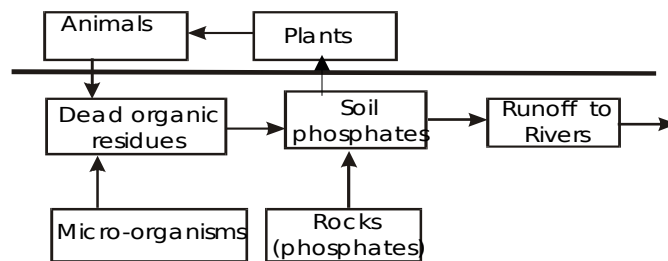


Fig. 1.6 The Phosphate cycle on land

The carbon cycle

Carbon, used by all living organisms, continuously circulates in the earth's ecosystem. In the atmosphere, it exists as the gas carbon dioxide, which is used by plants in the process of photosynthesis. Animals acquire the carbon stored in plant tissue when they eat and exhale carbon dioxide as a by-product of metabolism. Although some carbon is removed from circulation temporarily as fossil fuels and limestone deposits, respiration and photosynthesis balance to keep the amount of atmospheric carbon relatively stable. Industrialization, however, has contributed additional carbon dioxide to the environment. Figure 1.7 depicts the natural carbon cycle and the increase in atmospheric CO₂ due to combustion of fossil fuel.

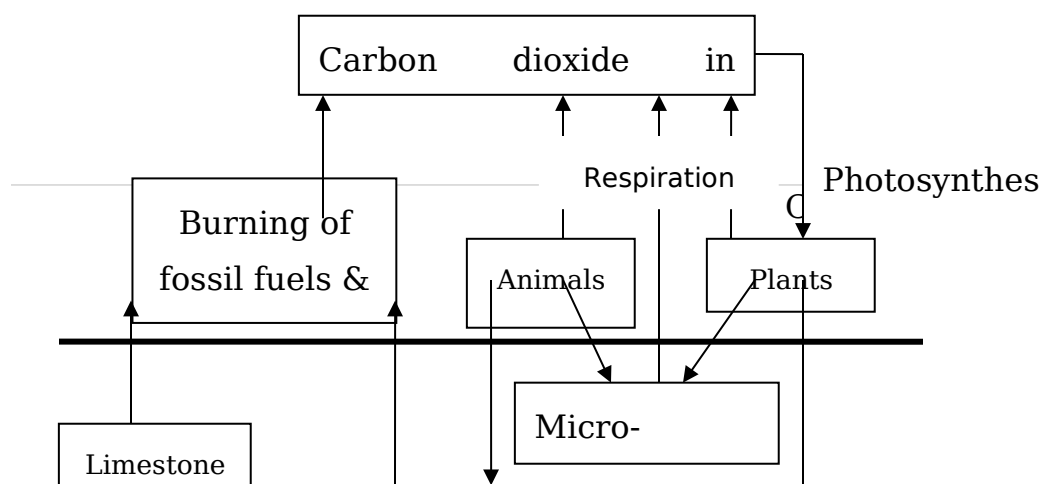


Fig. 1.7 The Carbon Cycle

1.3 The Value of the Environment

Environmental Functions

Many societies today have technological capabilities undreamed of in centuries past. Their citizens have such a global command of resources that even foods flown in fresh from all over the planet are taken for granted, and daily menus are decoupled from the limitations of regional growing seasons and soils. These developments have focused so much attention upon human-engineered and exotic sources of fulfillment that they divert attention from the local biological underpinnings that remain essential to economic prosperity and other aspects of our well-being.

These biological underpinnings are encompassed in the phrase ecosystem functions, which refer to a wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life. Ecosystems provide human beings with different goods and life support services. Four categories of ecosystem functions can be identified.

Regulation function: this group of functions relates to the capacity of natural and semi-natural ecosystems to regulate essential ecological

processes and life support systems which, in turn, contributes to the maintenance of a healthy environment by **providing clean air**, water, and soil. Major regulation functions of the natural environment are listed below.

- **Protection against** harmful cosmic influences
- **Regulation of the** local and global climate
- **Regulation of the** local and global energy balance
- Regulation of the chemical composition of the atmosphere
- Regulation of runoff and flood prevention
- Water catchment and ground water recharge
- Prevention of soil erosion and sediment control
- Formation of topsoil and maintenance of soil fertility
- Fixation of solar energy and biomass production
- Storage and recycling of organic matter
- Storage and recycling of nutrients
- Storage and recycling of human waste
- Regulation of biological control mechanisms
- Maintenance of migration and nursery habitats
- Maintenance of biological (and genetic) diversity

Carrier function: **natural and semi-natural** ecosystems provide space and suitable substrate or **medium for many human** activities such as habitation, cultivation and recreation. The major ones include:

- Human habitation and (indigenous) settlements
- Cultivation (crop growing, animal husbandry, aquaculture)

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- Energy conversion
- Recreation and tourism
- Nature protection

Production function: nature provides many resources, ranging from food and raw materials for industrial use to energy resources and genetic material. They include

- Oxygen
- Water (for drinking, irrigation, industry, etc)
- Food
- Genetic resources
- Medicinal resources
- Raw materials for building, construction, and industrial use
- Biochemicals (other than fuels and medicines)
- Fuel and energy
- Fodder and fertilizer

Information function: natural ecosystems contribute to the maintenance of mental health by providing opportunities for reflection, spiritual enrichment, cognitive development, and aesthetic experience. Specific functions include

- Aesthetic information
- Spiritual and religious information
- Historic information

- Cultural and artistic inspiration
- Scientific and educational information

Valuing the Environment

Different socio-economic values could be attributed to the above environmental functions. These values can be categorized into three major types- Ecological, Social and Economic values.

Ecological values: this is often expressed in qualitative terms; quantification will usually only be possible in “natural” dimensions (e.g. number of species, amount of runoff prevented). Two kinds of ecological values can be distinguished- conservative and existence values. (Assignment)

Conservation value. Many environmental functions do not provide direct benefits but are, nevertheless, quite essential to human welfare. Conservation (non-use) values are mainly provided by the services of natural and semi-natural environments, such as the regulation and information functions. The regulation functions maintain and conserve the environmental conditions necessary for most of the other functions that provide more direct economic benefits. Because of the problems involved in quantifying the economic and monetary value of these non-use benefits, they are usually not reflected in national accounts.

Existence value. This type of value which, stemmed from feelings of stewardship on behalf of future generations and non-human populations, relates to the intangible, intrinsic, and ethical values attributed to nature. The responsibility people feel towards future generations is also called the *bequest value*; even if we do not benefit ourselves directly, we do have a responsibility to our children and grandchildren to conserve natural

ecosystems and enhance the evolution of biological diversity as much as possible. .

Social values can be quantified by setting acceptable minimum limits for different functions (e.g. acceptable limits of water quality indicators). The values can be seen in two ways:

Health value. Many environmental functions contribute directly or indirectly, to human health. Oxygen, drinking water, and food are essential resources to maintain human life. Natural regulation processes contribute to the maintenance of clear air water and soils. Nature provides a large array of medicinal resources and contributes to mental health by providing a multitude of opportunities for recreation and cognitive development. The socioeconomic importance of this value is evident and the specific contribution of a given ecosystem or function may be expressed in terms of human lives “saved” or in monetary indicators, such as the costs of medical treatment required in the absence of a given function (or the actual loss of life and/or economic damage suffered after a given function is disturbed), for example, the disturbance of the protective function of the stratospheric ozone layer.

Option value. The option value of nature ecosystem and environmental function relates to the importance people place on a safe future (i.e., the future availability of a given amenity, good or service) either within their own lifetime, or for future generations. This value is therefore sometimes also referred to as *bequest value*, or *serendipity value*. Since the future is uncertain, all types of option value can be seen as a value to risk aversion in the face of uncertainty. It is a type life insurance for access to future benefits from natural ecosystems.

Economic values can be measured by the economic benefits they render to human beings. Three such values can be identified:

Consumptive use value. The consumptive use value of environmental functions relates to the use of natural products, which are harvested directly from the natural ecosystem. This value, therefore, mainly relates to natural resources in the narrow sense, which are included in the category of production functions. Because these natural products are consumed directly, without passing through a market, consumptive use values seldom appear in national income accounts such as Gross National Product (GNP) or Gross domestic product (GDP), although their economic value is often considerable.

Productive use value. The most important part of the traditional economic value of a given good or service is probably still its contribution to the production process which consists of many different sectors, such as agriculture, energy conversion, transportation, and industry. Since this

Box 3.1 Some Values of Wetlands

Wetlands have immense values from ecological, economic, biological and aesthetic viewpoints.

- They support extensive freshwater and marine fisheries.
- They are natural sewage treatment plants. An 8-ha marsh or pond can clean 4.54 million liters of raw

value can relatively easily be expressed in monetary units, the productive use value of natural resources is usually the only economic value of environmental functions, which is reflected in national income accounts.

Employment value. In many economic sectors, employment depends directly on environmental functions, such as peoples who are employed in the management of protected areas and the guiding of recreational activities in nature. In addition jobs held by fishermen and farmers depend on a healthy natural environment and many jobs in industry are in one way or another dependent on environmental functions.

Monetary valuation of environmental functions

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It is possible to calculate monetary values for many of the environmental functions and values, especially for those of direct economic importance. Some of the methods available for this purpose are shown in Table 1.1.

Table 1.1 Monetary valuation methods for environmental values

Value	Monetary valuation method						
	Market price	Shadow price					
		Cost of environmental damage	Maintenance costs	Mitigation costs	Willingness to pay /accept	Property pricing	Travel cost
Conservation		X	X	X	X		
Existence			X		X		
Health			X		X		
Option			X		X		
Consumptive	X						
Productive	X					X	X
Employment	X						

It should be stressed that socio-economic valuation of environmental functions does not necessarily mean that the importance of nature and its

biological resources is entirely reduced to monetary values. It should be regarded as an addition, and not a replacement of, their many intrinsic and intangible values.

The function valuation system presented above can be helpful in many ways, notably in Environmental Impact Assessment and Cost Benefit analysis. An important application area is the use in providing ecological baseline information for development projects. Especially for drafting environmental profiles, country reviews and formulating carrying capacity limits, information on environmental functions and values is essential.

Information on environmental functions and values may also be used to provide more general guidelines for development assistance or national government policies. In order to obtain a clear insight into the environmental trade-offs involved in alternative development projects, environmental impact assessment studies should assess both the direct environmental effects of certain human activities or interventions in a given area, and the environmental functions and hazards affected by the activity.

1.4 Environmental problems

Environmental problems range from “Brown” to “Green” issues. The “Brown” issues include environmental health problems and pollution. They are primarily local and urban in nature. Issues related to resource depletion and degradation are termed as “Green” problems and can be global or transnational in spatial extent. Specific environmental problems include:

- Lack of access to environmental infrastructures such as water supply, wastewater and drainage systems, solid waste management, etc.)
- Pollution (water, indoor air, outdoor air, soil, noise, light)

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- Resource depletion and degradation (deforestation, land degradation, soil erosion, over fishing, depletion of non-renewable resources, etc.)
- Conservation (biodiversity, habitat loss and fragmentation, endangered species, etc.)
- Climate change
- Natural hazards (flooding, earthquake, volcanic eruption, landslide, etc.)

Environmental problems may have adverse impacts on ecological, social and economic values. It is of great importance to assess/predict the magnitude of environmental impacts on these values. It is also necessary to identify the underlying causes and factors that are responsible for environmental problems. Table 1.2 represents diverse biophysical and socio-economic factors that result in ecosystem degradation.

Table 1.2 Major factors that involve in ecosystem degradation

Factor	Sub-factors	Specific factors
Biophysical	Climatic	Rainfall, temperature, wind direction, etc.
	Physiographic	Topography, altitude, slope
	Edaphic	Soil-water, soil types & conditions
	Landuse change	Settlement, agriculture, etc.
Socio-economic	Demographic	Population density, age/education structure, migration, settlement pattern
	Economic	Income level, occupational structure, tenure status, market/credit facilities
	Cultural	Beliefs, values, attitudes and perceptions, indigenous technologies
	Political	Decision-making system, developmental policy priorities, trade practices & policy

CHAPTER 2

WATER QUALITY ENGINEERING

Water quality is a term that implies some value judgment of the water with respect to a particular use. There are a variety of uses for water each requiring their own set of specific quality requirements. These can be categorized into simple groups, such as:

1. Those requiring water of highest quality and free of pathogens; uses include: drinking water supply, salmonid fishery, swimming and certain industrial processes such as food processing;
2. Those requiring water of lesser quality but still free from toxins and pathogens; uses include: amenity and recreation such as boating, irrigation and certain industries;
3. Where quality is unimportant; use include: cooling water and navigation.

Water quality degradation interferes with vital and legitimate water uses at scales from local to regional to international levels. Water quality parameters and standards are therefore necessary to ensure that the appropriate quality of resource is available to a particular use.

2.1 Water quality parameters and standards

Parameters that define a water quality may be classified into three broad categories: physical, chemical, and biological parameters (Table 3.1).

Table 2.1(a) Physical parameters

Parameter	Significance
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Temperat ure	Temperature of water is a very important factor for aquatic life. It controls the rate of metabolic and reproductive activities, and determines which fish species can survive. Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria and toxic chemicals in water.
Conductivi ty	Conductivity is a measure of how well water can conduct an electrical current . Therefore, conductivity is an indirect measure of the presence of dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron, and can be used as an indicator of water pollution.
Total Suspende d Solids (sand, silt, clay, in colloidal suspensio n)	Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. High concentrations of suspended solids can cause many problems for stream health and aquatic life. TSS may destroy fish habitat through blanketing of fish spawning and feeding areas and elimination of certain food organisms; directly affect fish through gill abrasion and fin rot; reduces sunlight penetration, thereby impairing photosynthesis of aquatic plants. Suspended sediment decreases recreational values, reduces fish habitat, adds to the mechanical wear of water supply pumps and distribution systems, and adds treatment costs for water supplies. Nutrients and toxic substance attached to sediment particles are transported to water bodies and may enter aquatic food chains, cause fish toxicity problems, impair recreational

	uses, or degrade the water as a drinking water source.
Total dissolved solids	Total Dissolved Solids (TDS) are solids in water that can pass through a filter (usually with a pore size of 0.45 micrometers). TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. If TDS concentrations are too high or too low, the growth of many aquatic lives can be limited, and death may occur. TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect.
Turbidity	Turbidity is a measure of the cloudiness of water. Turbidity in water is caused by suspended matter such as clay, silt, and organic matter and by plankton and other microscopic organisms that interfere with the passage of light through the water. Turbidity is closely related to total suspended solids (TSS), but also includes plankton and other organisms. Turbidity itself is not a major health concern, but high turbidity can interfere with disinfection and provide a medium for microbial growth. It also may indicate the presence of microbes.

Table 2.1(b) Chemical parameters

Dissolved	Dissolved Oxygen (DO) is found in microscopic bubbles of
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Oxygen (DO)	oxygen that are mixed in the water and occur between water molecules. DO is a very important indicator of a water body's ability to support aquatic life.
Oxygen demanding organics: BOD, COD, TOC, etc.	Organic materials may enter surface waters dissolved or suspended in runoff; natural decomposition of these materials may deplete dissolved oxygen supplies in the surface waters. Dissolved oxygen may be reduced to below the threshold necessary to maintain aquatic life, harming or killing fish and other aquatic plants and animals.
Nutrients (phosphorus and nitrogen- Total nitrogen, Kjeldahl N)	Nutrient enrichment of surface waters may cause excessive algae and aquatic plant growth, choking open waters consuming oxygen (mainly through plant die-off); fish and aquatic organisms, fishing and boating, and the use of the resources of water supply are thereby affected. Nitrogen contaminants in drinking water significantly above the drinking water standard may cause methoglobinemia (a blood disease) in infants, and have forced closure of several water supplies.
Principal inorganic cations and anions: Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Fe^+ , Mn^{2+} , HCO_3^- , CO_3^{2-} , Cl^- , SO_4^{2-} , NO_3^- , PO_4^{3-} , F^-	See next page
Toxic	These substances become toxic in excess. Toxic chemicals

substances: e.g. Arsenic, Asbestos, Lead, Zinc, Mercury, synthetic organics like cyanide, phenols, pesticides, etc.	may enter surface waters either dissolved in runoff or attached to sediment or organic materials, and may enter groundwater through soil infiltration. The principal concerns in surface water are their entry into the food chain, bioaccumulation, toxic effects on fish, wildlife, and micro-organisms, habitat degradation, and potential degradation of public water supply sources; the groundwater impacts are primarily related to water supply sources.
pH	pH represents the effective concentration of hydrogen ions (H^+) in water. The pH of most mineral waters is 6 to 9. Most ecological life is sensitive to pH changes. It is also important to maintain appropriate pH level in water and wastewater treatment processes.
Hardness	Hardness is measure of polyvalent cations (ions with a charge greater than +1) in water. Hardness generally represents the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, because these are the most common polyvalent cations. Other ions, such as iron (Fe^{2+}) and manganese (Mn^{2+}), may also contribute to the hardness of water, but are generally present in much lower concentrations. Waters with high hardness values are referred to as "hard," while those with low hardness values are "soft". Hardness affects the amount of soap that is needed to produce foam or lather. Hard water requires more soap, because the calcium and magnesium ions form complexes

	with soap, preventing the soap from sudsing. Hard water can also leave a film on hair, fabrics, and glassware. Hardness of the water is very important in industrial uses, because it forms scale in heat exchange equipment, boilers, and pipe lines. Some hardness is needed in plumbing systems to prevent corrosion of pipes. Hardness mitigates metals toxicity, because Ca^{2+} and Mg^{2+} help keep fish from absorbing metals such as lead, arsenic, and cadmium into their bloodstream through their gills. The greater the hardness, the harder it is for toxic metals to be absorbed through the gills.
Alkalinity	Alkalinity is a measure of the buffering capacity of water, or the capacity of bases to neutralize acids. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. Alkalinity does not refer to pH, but instead refers to the ability of water to resist change in pH. The presence of buffering materials helps neutralize acids as they are added to the water. These buffering materials are primarily the bases bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}), and occasionally hydroxide (OH^-), borates, silicates, phosphates, ammonium, sulfides, and organic ligands. Waters with low alkalinity are very susceptible to changes in pH. Waters with high alkalinity are able to resist major shifts in pH. Alkalinity not only helps regulate the pH of a water body, but also the metal content. Bicarbonate and carbonate ions in water can remove toxic metals (such as lead, arsenic, and cadmium) by precipitating the metals out of solution.

Table 2.1(c) Biological parameters

Indicator microorganisms (Coliforms): Fecal coliform (E.coli), Fecal streptococci, total coliforms, etc.	Used to determine the presence of pathogenic organisms in natural and treated water.
Aquatic plants and animals	Presence/absence of certain species may reveal the health of the aquatic ecosystem

Water quality standards are developed as rules by which to measure the quality of water. They normally state the amount of a particular pollutant which is viewed as not likely to cause some kind of harm to users. They can be used for several purposes. First, they are used as a basis for assessing water quality data. If the degree of pollution is at or below the standard, it is good, and if it above the standard, it is bad. Second, they are used as a regulatory or educational tool. They can be used as a “trigger” for initiating some kind of action, or as an “end point” for terminating action. This allows them to be viewed by different people in totally different ways. As a trigger, they in effect set an upper limit on the degree of pollution which will be allowed by society before something must be done to control it. As an end point they, in effect set a lower limit on the degree of pollution which is not acceptable by the society. Control measures which get the pollution level down to the standard are considered adequate, and further efforts to control the pollution are not required. Thus environmentalists see standards

as preventing further water quality improvement, and economists see standards as requiring costly control measures.

Types of water quality standards include *ambient water quality standard* (e.g. surface water quality standard), *water abstraction standard* (e.g. drinking water quality standard, irrigation water standard) and *effluent standard* (Fig. 3.1).

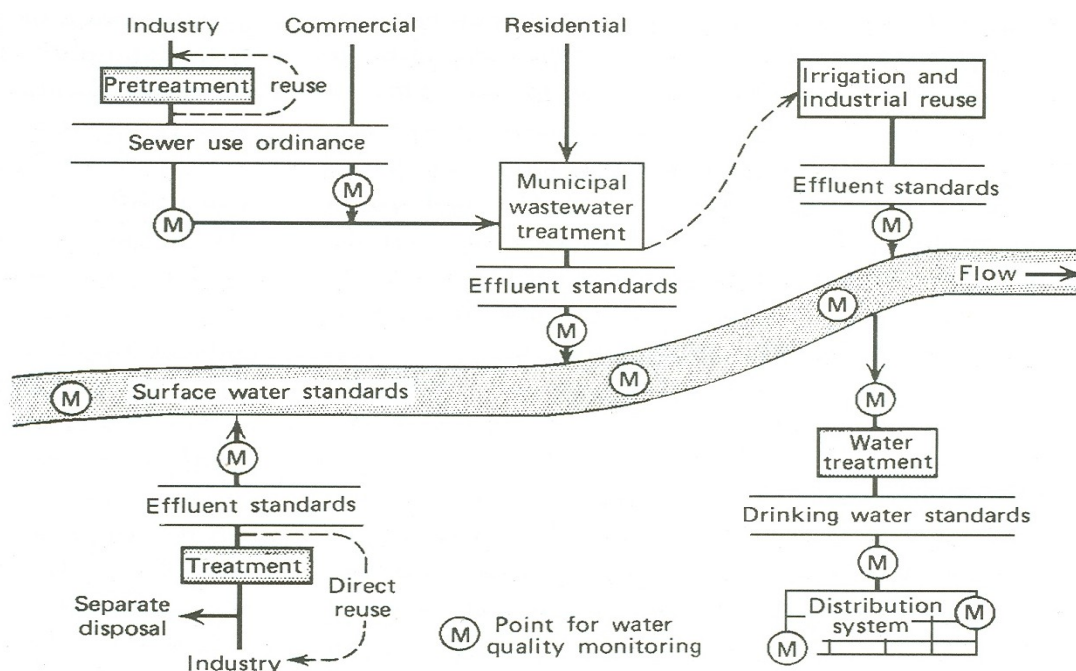


Fig. 2.1 Types of water quality standards

2.2 Water quality assessment

Water quality assessment is critical for pollution control and protection of the surface and ground waters. The selection of parameters for water quality assessment is dependent on the type of receiving water, the nature of the discharges into the receiving water, water use and any legal

designation relating to the system. Some of the key parameters of to be used for water quality assessment may include the following:

- River: BOD, DO, Temperature, NH₃, Cl, PO₄, NO₃, etc.
- Lake: DO, Temperature, PO₄, NO₃, SiO₂, Fe, Mn, Na, K, etc.
- Drinking water: Coliforms, Fe, Mn, Toxic metals, Pesticides, etc.
- Biodegradable effluents: BOD, COD, TSS, NH₃, PO₄, etc.
- Toxic effluents: BOD, COD, TSS, NH₃, Metals and/or other toxic compounds
- Water source quality appraisal: hardness, alkalinity, pH, Color, Conductivity, Iron, Chloride, Na, K, Silica, SO₄, Temperature, etc.

Water quality assessment requires a number of specific activities that include definition of objectives, sample collection, laboratory analysis, data analysis and interpretation Fig. 3.2)

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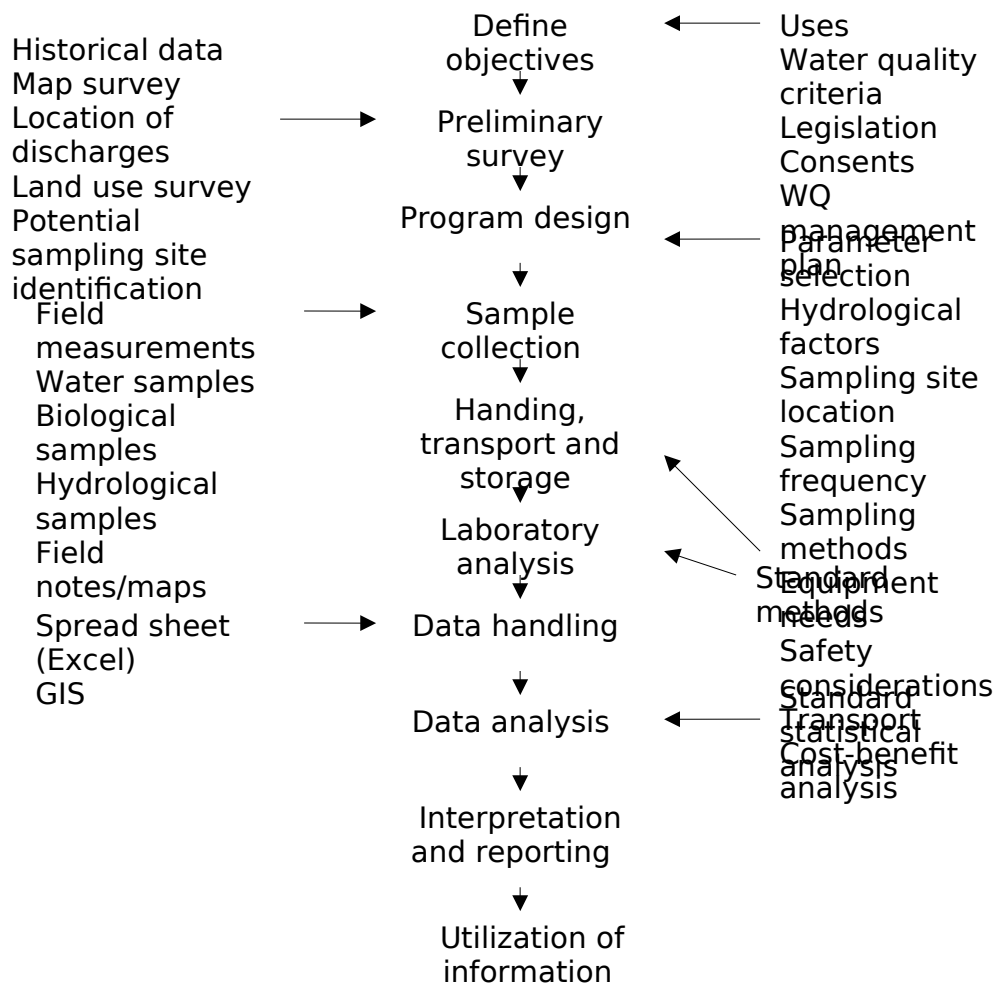


Fig. 2.2 Main components of a water quality assessment program

2.3 Water pollution and control

2.2.1 Water pollution

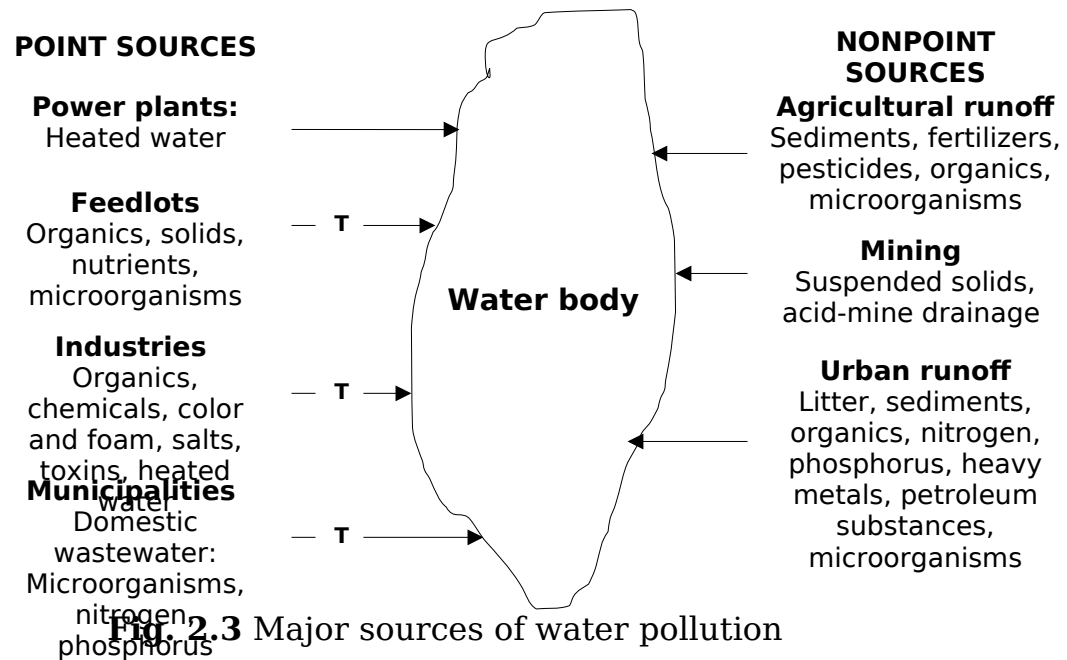
Water pollution may be defined as man-made or man-induced alteration of the chemical, physical, biological, or radiological integrity of water. Pollution of water may adversely affect human and ecological health as well as impair the use of water for other activities. The sources of water pollution can be point or nonpoint sources (Fig. 3.3).

Point sources of pollution include municipal and industrial wastewaters for which specific points of entry to a receiving water body can be identified. Key characteristics of point sources of pollution include:

- Single or multi-point location
- Discharge contains pollutants
- Volume of discharge generally unaffected by weather
- National Pollution Discharge Elimination System (NPDES) permit required to discharge; EPA authorizes state agency (e.g., WV DEP) to issue permits
- Controls required (usually through water treatment)

Nonpoint sources of pollution include general land runoff from urban and agricultural areas and other diffuse sources that do not have specific discharge points. The major characteristics of nonpoint source pollution are:

- Diffuse, source not easily located
- Highly variable in time and correlated with weather
- Prevention more effective (more difficult to treat)
- Largely unregulated, hence, voluntary



Major types of water pollution

- ◆ Pathogenic organisms which have a direct health impact on human beings (e.g. Typhoid, Cholera, etc.). This type of pollution is expressed in terms of the number of coliform bacteria per 100 ml of water sample (MPN/100 ml).
- ◆ *Organic pollution.* Biodegradation of oxygen demanding wastes deplete the dissolved oxygen content of the water body. The decrease in the DO content has in turn an adverse effect on the various aquatic species such as fish. The strength of the oxygen demanding waste is often expressed by BOD (Biochemical Oxygen Demand).
- ◆ *Eutrophication (Cultural).* This is due to the enrichment of water bodies by nutrients (Nitrogen and Phosphorus). Eutrophication results in abundant plant growth which in turn accelerates ageing of aquatic bodies. This problem occurs mainly in lakes, reservoirs and in slow-flowing rivers. Based on the level of nutrient level lakes can be classified into different types as shown Table 3.2. Phosphorus is typically the limiting nutrient in lakes, and algae growth is linked to phosphorus

inputs. Nitrogen is often the limiting nutrient in ocean waters and some streams

Table 3.2 Lake classification

Lake Classification		Chlorophyll <i>a</i> Concentration ($\mu\text{g} \cdot \text{L}^{-1}$)	Secchi Depth (m)	Total Phosphorus Concentration ($\mu\text{g} \cdot \text{L}^{-1}$)
Oligotrophic	Average	1.7	9.9	8
	Range	0.3–4.5	5.4–28.3	3.0–17.7
Mesotrophic	Average	4.7	4.2	26.7
	Range	3–11	1.5–8.1	10.9–95.6
Eutrophic	Average	14.3	2.5	84.4
	Range	3–78	0.8–7.0	15–386
Hypereutrophic		> 50	< 0.5	Often > 100

- ◆ *Toxic and hazardous substances.* The pollutants of concern are heavy metals (e.g. lead, mercury, zinc, etc.) and non-metallic salts (e.g., arsenic, selenium), synthetic organics (e.g. pesticides), etc. These pollutants are harmful even at lower concentrations.

- ◆ *Sediments* Runoff from urban construction sites is the major source of sediments. Loading water bodies with excessive sediment reduces their volume. This disrupts the normal functions of such systems as hydro-electric power plants, water supply systems, etc.

- ◆ *Thermal pollution* Runoff from heated urban surfaces and industrial cooling water are the major sources of thermal pollution. The increase in temperature of the natural water body can adversely affect different aquatic species.



2.3.2 Water quality modeling

Water quality modeling is used to analyze and predict the level of specific constituents- conservative or non-conservative constituents. It may also be used to compare various water quality management alternatives.

Commonly used non-conservative (those that change or react) substances include:

- Biochemical oxygen demand (BOD)
- Dissolved oxygen (DO)
- Temperature
- Algae as chlorophyll-a
- Organic nitrogen
- Ammonia nitrogen (NH₃-N)
- Nitrite nitrogen (NO₂-N)
- Nitrate nitrogen (NO₃-N)
- Organic phosphorus
- Dissolved phosphorus
- Coliforms

Conservative constituents of main interest include:

- Sediment
- Dissolved solids or salts
- Metals (Pb, Cu, Hg, Cr, Cd)

A simple modeling process is indicated in Fig. 2.4.

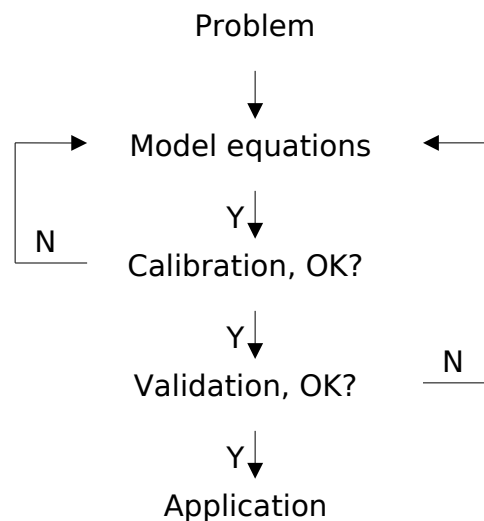


Fig. 2.4

Water quality control

The ultimate goal of water quality control is to maintain quality characteristics that protect specified beneficial uses of an aquatic system. Policy instruments for implementing water pollution control measures can be of two types:

- Regulatory instruments (Command and control), examples include
 - o Effluent standards
 - o Land use controls

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- o Permits and licenses
- Economic instruments- examples include
 - o Effluent charges
 - o Incentives

There different approaches and methods that can be used for water quality control as indicated in Table 2.4.

Table 2.4 Methods to control surface water pollution

Approach	Method
Pollution prevention	Source reduction: input changes, processes changes, product changes Recycling/reuse, water conservation Minimizing illicit wastewater discharge Improving solid waste management, etc.
Reducing waste after generation	Waste treatment • Conventional • Alternative treatment methods (e.g. septic tank, land treatment, constructed wetlands)
Increasing assimilative capacity of a watercourse	Low flow augmentation by using river control structures such as reservoirs. Artificial reaeration using aerators or

	weirs constructed across the water course
Making better use of the assimilative capacity of a watercourse	Regulated discharge, i.e., to temporarily store water during low flow period and to release it later when flow is high. To collect individual effluents to a common treatment plant and discharge it at a point where impact on quality is minimized.
Land use planning	Zoning Restrictions on population density and settlement on sensitive areas Erosion control Reducing impervious surfaces Reducing directly connected impervious surfaces Low impact land development

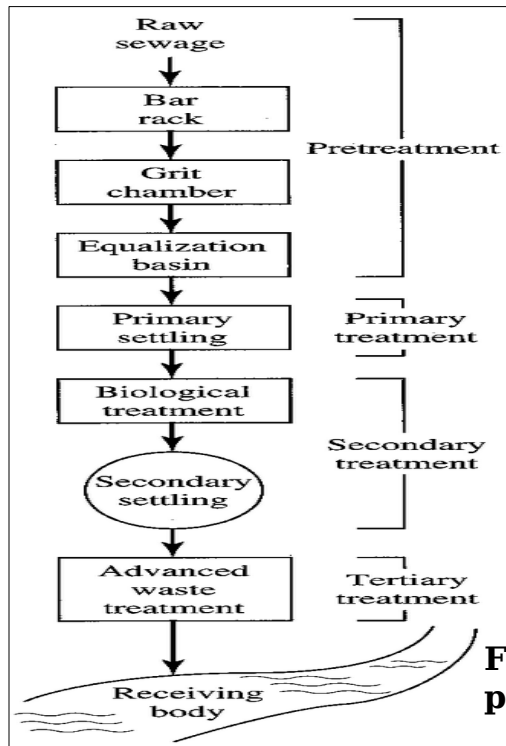
Wastewater treatment

Parameters that commonly characterize untreated domestic wastewater are presented in Table 2.5.

Table 2.5 Typical characteristics of domestic wastewater

Constituent	Weak (all mg/L except settleable solids)	Medium	Strong
Alkalinity (as CaCO ₃)	50	100	200
BOD ₅	100	200	300
Chloride	30	50	100
COD (as O ₂)	250	500	1000
Suspended Solids	100	200	350
Settleable solids	5	10	20
Total Dissolved Solids	200	500	1000
Total Kjeldahl nitrogen (as N)	20	40	80
Total organic carbon (as C)	75	50	300
Total phosphorus (as P)	5	10	20

The methods of sewage treatment include conventional treatment, waste stabilization ponds, onsite treatment methods and advanced treatment technologies. The processes that are involved in wastewater treatment are physical and biological processes. The common physical processes are screening, and removal of grit and suspended organic solids. Biological processes involve the agency of bacteria and algae and constitute by far the most important methods of sewage treatment, particularly in hot climates. Conventional wastewater treatment unit processes (Fig. 2.7)



Pretreatment - removes materials that can cause operational problems, equalization optional

Primary treatment - remove ~60% of solids and ~35% of BOD

Secondary treatment - remove ~85% of BOD and solids

Advanced treatment - varies: 95+ % of BOD and solids, N, P

Fig. 2.7 Wastewater treatment unit processes

Biological treatment systems can broadly be classified into three groups as

- *Suspended growth*: aerobic processes that achieve a high microorganism concentration through the recycle of biological solids (e.g. activated sludge unit).
- *Attached growth (fixed film reactors)*: allow a microbial layer to grow on the surface of a media (stone, plastic) while exposed to the atmosphere for oxygen supply (e.g. trickling filters).
- *Dual biological treatment*: uses two stage arrangements of attached growth and suspended growth processes to achieve a high quality effluent.

There are a number of alternative treatment processes under each of the above groups as indicated in Fig. 2.8.

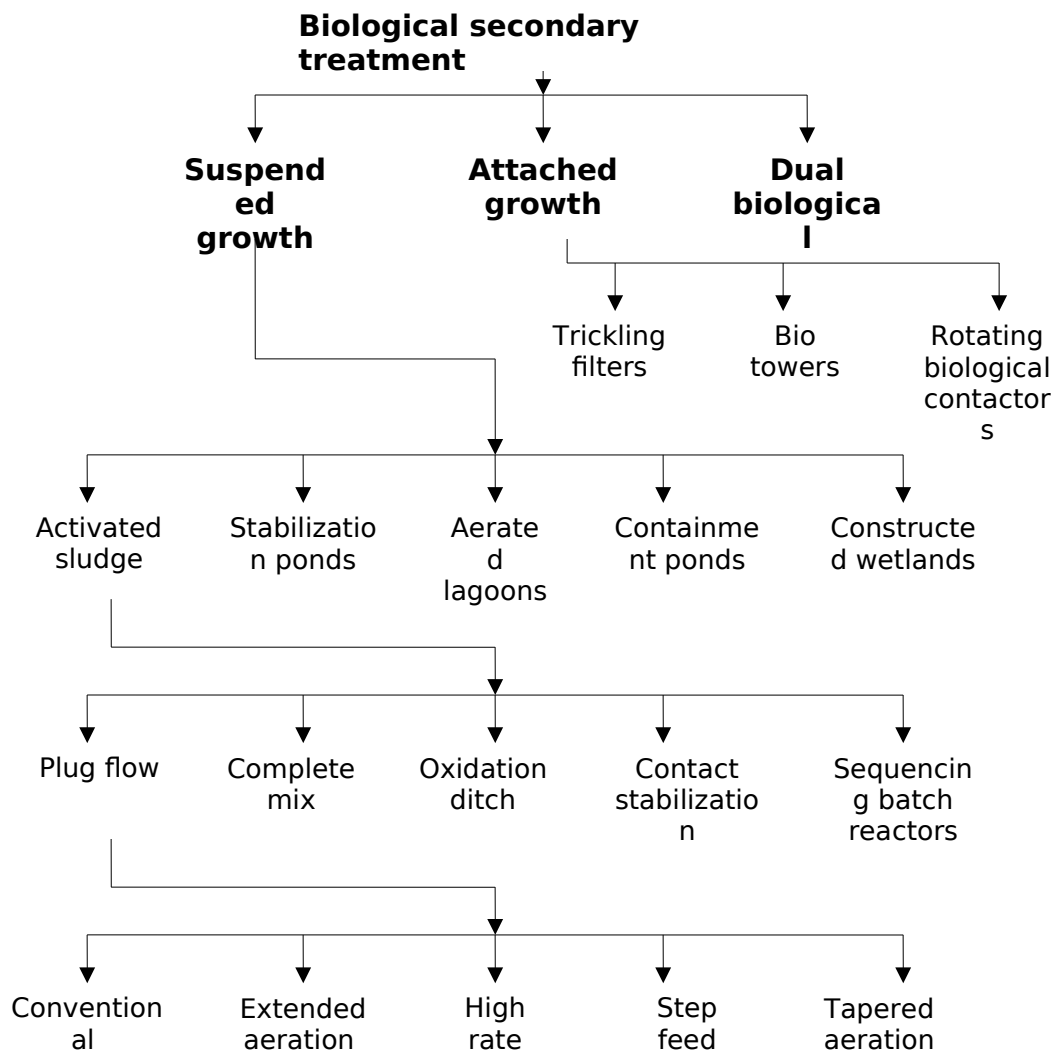


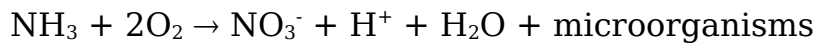
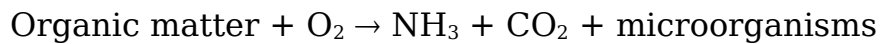
Fig. 2.8 Biological treatment systems

Biological nutrient removal systems

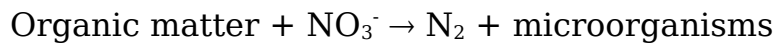
Nitrogen removal

Biological nitrogen removal is a two-step process

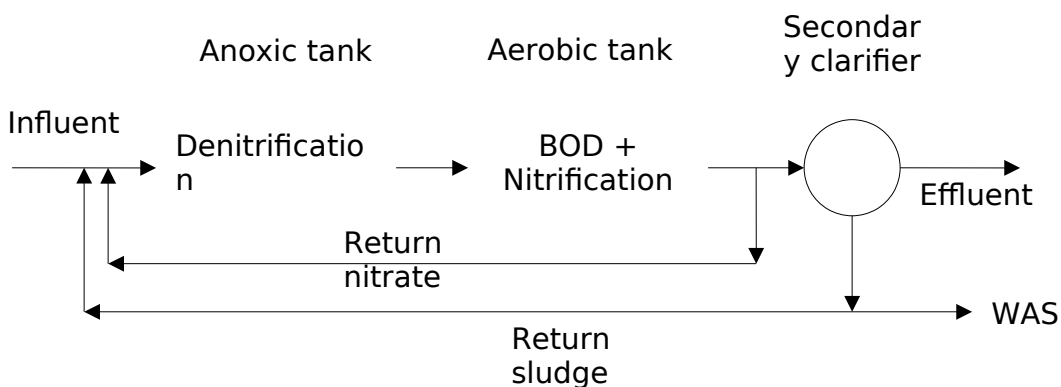
- Nitrification in aerobic environment



- Denitrification in an anoxic environment (no free oxygen)



There can be different arrangement that allow the nitrification-denitrification processes to take place (Fig. 2.9).



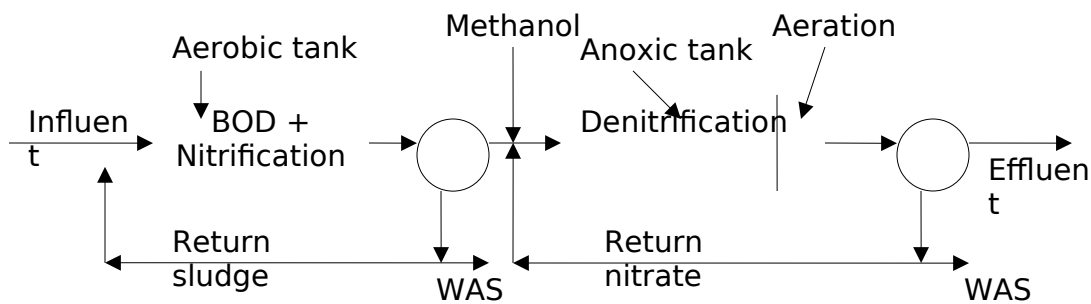


Fig. 2.9 Biological nitrogen removal

Phosphorus removal

Biological phosphorus removal is based on the idea of forcing the microorganisms to accumulate more phosphorus than is required for cell growth. This can be achieved by a system with anaerobic zone followed by an aerobic zone (Fig 2.10). The mechanism of phosphorus removal is via the bacteria *Acinobacter sp.* in the anaerobic tank where the phosphorus in the wastewater is released as soluble phosphates and then taken up by the biomass in the aerobic zone. This arrangement can reduce the level of phosphorus by 70-80%.

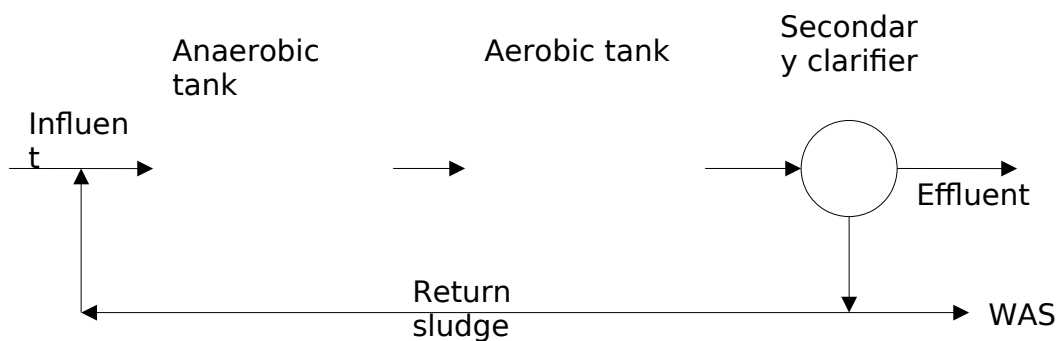


Fig. 2.10 Two-stage biological P removal

Waste stabilization ponds

Waste stabilization ponds (WSP) are shallow man-made basins into which wastewater flows and from which, after a retention time of several days a well-treated effluent is discharged. WSP systems comprise a series of ponds – ***anaerobic, facultative*** and several ***maturation ponds***. WSP are the most important method of sewage treatment in hot climates where sufficient land is normally available and where temperature is most favourable for their operation. Advantages of WSP include:

- They can achieve any required degree of treatment at the lowest cost and with minimum of maintenance by unskilled operators
- The removal of pathogens is considerably greater than that in other methods of sewage treatment
- They are well able to withstand both organic and hydraulic shock loads
- They can effectively treat a wide variety of industrial and agricultural wastes
- They can easily be designed so that the degree of treatment is readily altered
- The method of construction is such that, should at some future time the land be required for some other purpose, it is easily reclaimed
- The algae produced in the pond are potential sources of high-protein food which can be conveniently exploited by fish farming

Anaerobic ponds

These units are the smallest of the series. Commonly they are 2-4 m deep and receive high organic loads equivalent to 100 g BOD₅/m³-d. These high organic loads produce strict anaerobic conditions throughout the pond. In general terms, anaerobic ponds function much like open septic tanks and

work extremely well in warm climates. The optimum retention time is 5 days with a BOD₅ reduction of 70%.

Successful operation of anaerobic ponds require temperature $> 15^{\circ}\text{C}$ and pH > 6 . under these circumstances sludge accumulation is minimal resulting in a desludging frequency of once in 3-5 years.

Facultative ponds

Facultative ponds are the most common form of wastewater stabilization ponds. They are usually 1 to 1.5 meters in depth, with an aerobic layer which overlies an anaerobic layer that usually contains sludge deposits. Desludging is required rarely, only once every 10-15 years. These ponds require large land areas to maintain suitable BOD loadings. If structural failure occurs, a large area of an aquifer and soil are at risk of being contaminated.

Facultative ponds are designed for BOD₅ removal on the basis of a low organic surface load to permit the development of an active algal population. This way, algae generate the oxygen needed to remove soluble BOD₅. Wind has an important effect on the behavior of facultative ponds, as it induces vertical mixing of the pond liquid. Good mixing within the upper aerobic layer ensures a more uniform distribution of BOD, dissolved oxygen, bacteria and algae and hence a better degree of waste stabilization. The depth to which wind-induced mixing is felt is largely determined by the distance the wind is in contact with the water; an unobstructed contact length of about 100 m is required for maximum mixing by wind action.

There exists a *mutualistic* relationship between the pond algae and the pond bacteria: the algae provide the bacteria with oxygen and the bacteria provide the algae with carbon dioxide (Figure 2.11). Some oxygen and

carbon dioxide comes from the atmosphere by mass transfer, but the bulk is supplied by algal-bacterial mutualism.

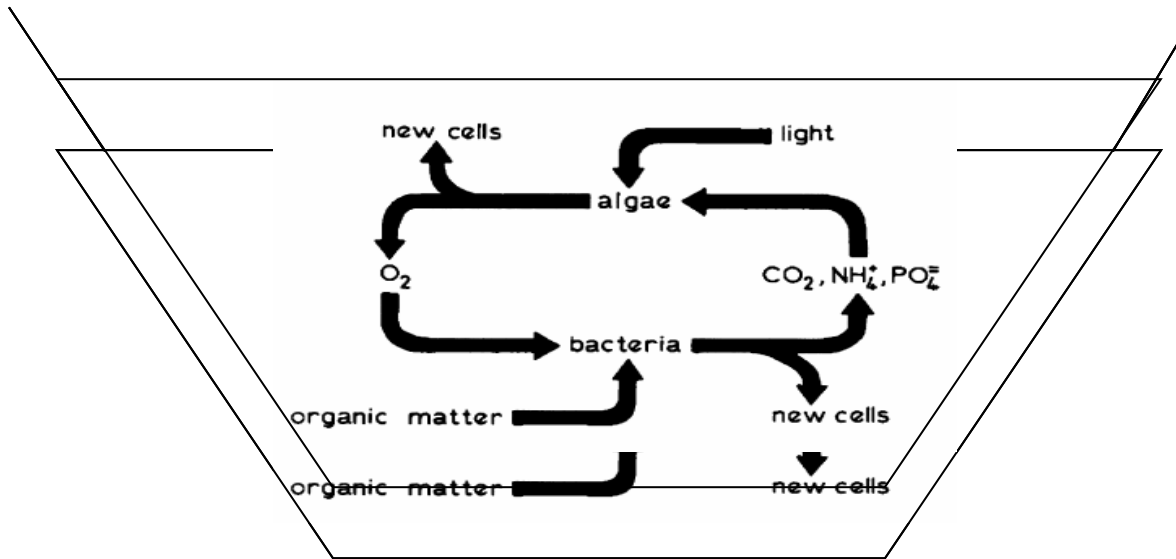


Fig 2.11

Maturation ponds

These ponds receive the effluent from a facultative pond and their size and number depend on the required bacteriological quality of the final effluent. Maturation ponds are shallow (1.0-1.5 m) and show less vertical stratification, and their entire volume is well oxygenated throughout the day. Maturation ponds only achieve a small removal of BOD₅, but their contribution to nitrogen and phosphorus removal is more significant.

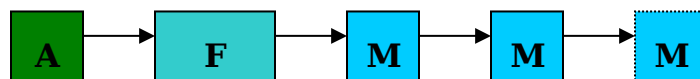
The primary function of maturation ponds is the removal of faecal coliforms, and this is extremely efficient in a properly designed series of ponds. With proper design removals > 99.99 per cent can be achieved.

Pond layout

In hot climates two pond layouts are acceptable as shown in Fig. 2.12. A multi-pond system comprising anaerobic, a facultative and three or more maturation ponds, each with a retention time of 5d is recommended as a minimum treatment if the final effluent is to be used for unrestricted irrigation.



(a)



(b)

Fig.2.12 Pond layouts (a) Weak-medium strength wastes

Onsite treatment methods

Septic systems: consist of (Fig. 3.13):

- a septic tank, where the sewage collects and is treated by anaerobic action,
- a vent-pipe, through which gases escape from the septic tank,
- a distribution box, where the supernatant collects,
- Septic or drain field (with perforated drain lines), where the supernatant is evenly distributed into the ground.

The first step in installing a septic system is to test the permeability of the soil. Then the relevant authority issues a permit. The septic tank is chosen and installed, then the septic field is put in place

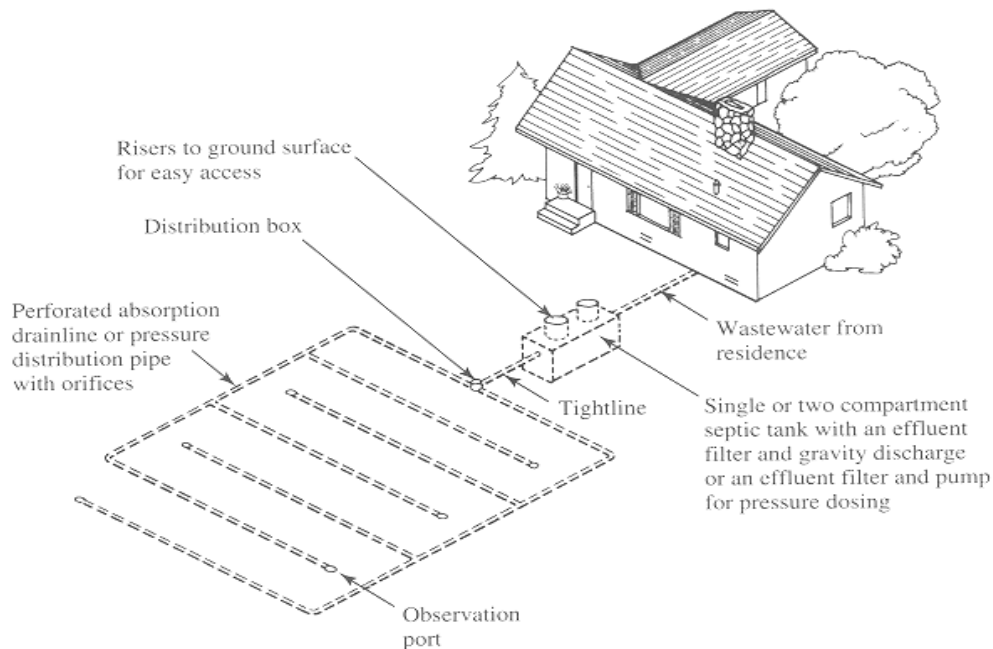


Fig. 2.13 Septic system

Septic tank (Fig. 3.14)

Untreated wastewater from a property flows into the septic tank, where the solids separate from the liquids. Some solids, such as soap scum or fat, will float to the top of the tank to form a scum layer. Heavier solids, such as human and kitchen wastes, settle to the bottom of the tank as sludge. Self-forming bacteria in the tank help the system "digest" these solids or sludge. The remaining liquids flow out of the tank to a drain field. Baffles built into the tank hold back the floating scum from moving past the outlet of the tank. The effluent from a septic tank, still contains about **70%** of the

polluted matter in the sewage, and hence there is a need for further treatment of the liquid from the tank.

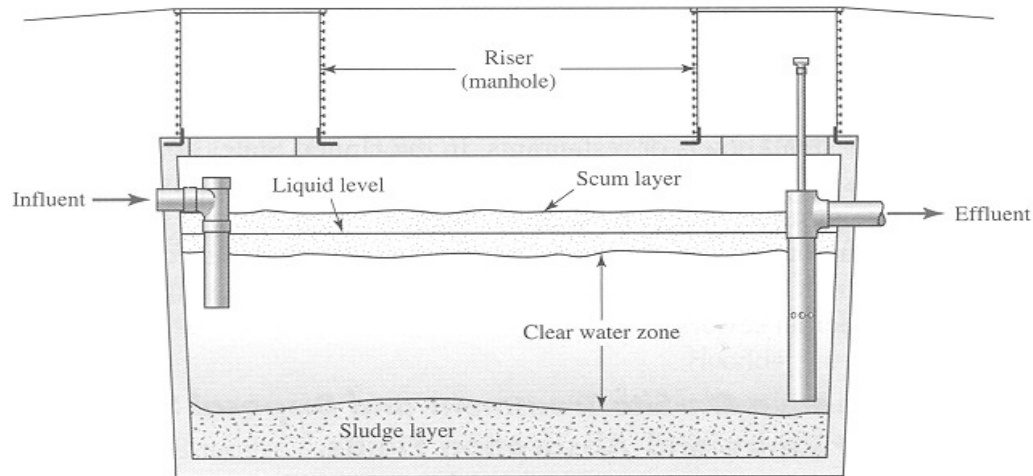


Fig. 2.14

Septic or Drain field (Fig. 2.15)

This part is perhaps the most important part of the septic system. The drain field is an underground soil treatment system, and it receives partially treated sewage from the septic tank. The soil on a site must be suitable for a drain field to work properly.

Percolation tests are required on the ground strata to ascertain the suitability of the soil for drain fields.

Connected to the septic tank by an underground pipe, the drain field may consist of trenches or a seepage bed. The bottom of the trenches of the drain field should generally be 900mm above the seasonally high water table, or bedrock. In a land drain or drain field, wastewater moves from the septic tank into perforated pipes, bedded on and surrounded in, gravel-filled

trenches. These pipes should be laid fairly flat, at a gradient of about 1 in 200, so that the effluent is dispersed along the whole length of the pipe run. The perforations in the pipe should preferably be larger than 6mm to avoid the effluent forming a biomass, which will soon result in blocking the holes. From the pipeline the pathogens, nutrients, and organic material are dispersed into the gravel where they are removed or neutralized as the liquid moves through into the soil.

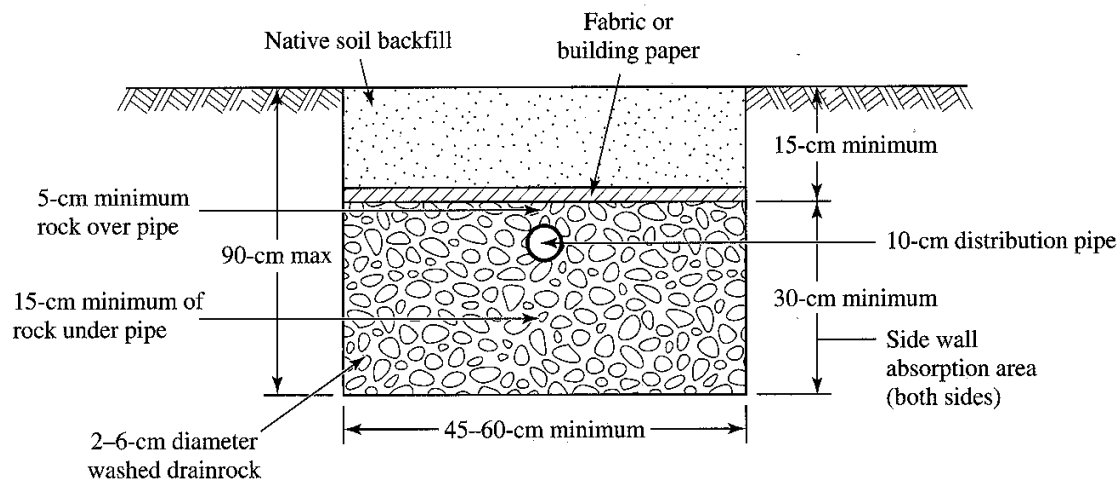


Fig. 2.15

Disadvantages of septic systems include:

- Maintenance-intensive- sludge must be pumped out every 1-2 years
- Leach field is vulnerable to clogging with oil and grease
- BOD and nitrates are not treated effectively

- Can cause groundwater contamination

Land treatment of wastewater

Land treatment of wastewater is a viable option when land availability is not a problem. This system regards wastewater as a resource rather than as a problem to be rectified. Three types of land application systems can be identified: Slow rate (SR), Rapid infiltration (RI) and Overland flow (OF) systems.

Slow rate systems rely on plants and soil percolation to provide treatment. These systems have also been referred to as irrigation systems.

In RI systems wastewater is applied to relatively permeable soil within a basin at a much higher rate than in the slow-rate system. Plants may be present in the basin, but play only a minor role in wastewater renovation. Treatment is accomplished by natural processes in the soil. It requires much smaller land areas and recharges groundwater table.

The overland flow treatment is used when surface soil permeability's are low. Vegetation is used in OF systems and the effluent is collected as runoff and conveyed to the receiving water. Treatment is provided by the plants and the microbial biomass at the soil surface as the wastewater flows down a sloping field.

Table. 2.6 Characteristics of land treatment systems

Feature	Slow-rate irrigation	Rapid infiltration	Overland flow
Hydraulic loading rate (cm/d)	0.2-1.5	1.5-3.0	0.6-3.6

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Land required for 1000 m ³ /d (1000 x m ²)	63.4-396	3.2-63.4	26.4-159
Soil type	Loamy sand to clay	Sand	Clay to clay loam
Soil permeability	Moderately slow to moderately rapid	Rapid	slow

Wetlands for wastewater treatment

Wetlands are natural/artificial wet ecosystems with diverse and complex roles in nature. Wetlands may support aquatic plants (emergent or floating plants). Wetlands are designed to remove conventional pollutants like BOD, SS, and nutrients. Heavy metals can also be removed to a great extent. The artificial wetland systems are called constructed wetlands.

Wetlands incorporate physical, biological, and chemical processes to treat wastewater. The water flows in and slows down as it spreads across the wetland surface. This slowing of the flow allows soil and sediment particles to filter or physically settle out. This process also removes nutrients such as phosphorous and chemicals that are attached to the sediments. Biological and chemical treatment processes transform materials rather than just physically remove them.

Constructed wetlands treatment systems are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. Constructed wetlands treatment systems generally fall into one of two general categories: **Subsurface Flow Systems** and **Free Water Surface Systems**. Subsurface Flow Systems are designed to create subsurface flow through a permeable medium, keeping the water being treated below the surface, thereby helping to avoid the development of odors and other nuisance problems.

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Such systems have also been referred to as "root-zone systems," "rock-reed-filters," and "vegetated submerged bed systems." The media used (typically soil, sand, gravel or crushed rock) greatly affect the hydraulics of the system. Free Water Surface Systems, on the other hand, are designed to simulate natural wetlands, with the water flowing over the soil surface at shallow depths. Both types of wetlands treatment systems typically are constructed in basins or channels with a natural or constructed subsurface barrier to limit seepage. Treatment is generally better in subsurface flow systems and these systems do not have mosquito problems.

Constructed wetlands maximize treatment by ensuring slow flow rates, and plants provide lots of surface area. Plant stems and roots provide surface areas that support communities of microorganisms, which use some of the nutrients and organic matter carried in the runoff water. For example, microbe communities on plant stems convert organic nitrogen to the inorganic ammonium nitrogen form. Other biological treatments involve plant uptake of nutrients such as nitrates and phosphates. Chemical treatment occurs when incoming compounds react with oxygen or soil minerals in the wetland. The rate and extent of these reactions is influenced by the wetland acidity and other environmental factors.

Constructed wetlands are usually provided after primary or secondary treatment systems (Fig. 2.16). The purpose of the wetland after the secondary treatment is to polish the effluent and achieve a superior quality.

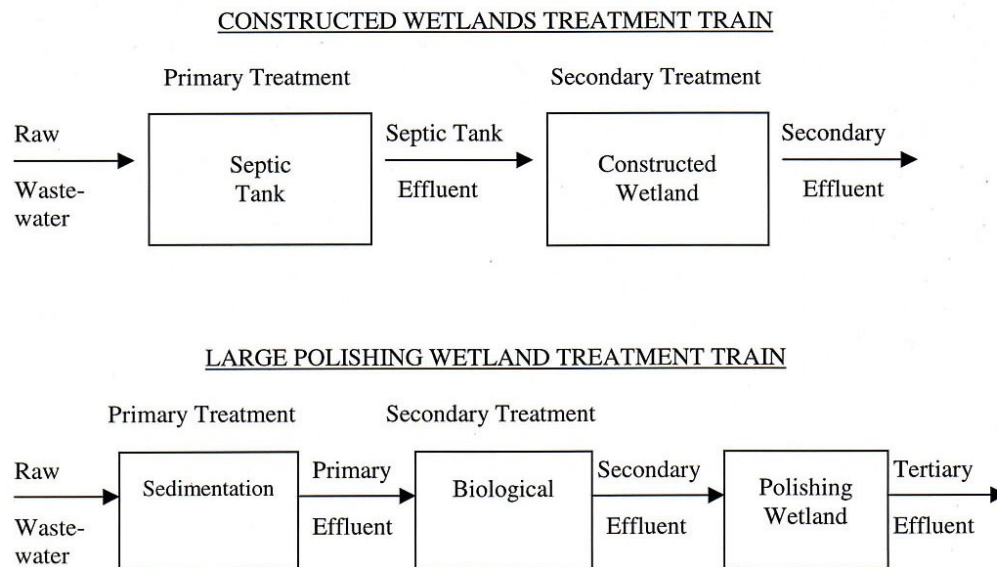


Fig. 2.16

CHAPTER THREE

AIR QUALITY ENGINEERING

Air pollution occurs when harmful or excessive quantities of substances are introduced into Earth's atmosphere. Air pollution is a significant risk factor for a number of pollution-related diseases, including respiratory infections, heart disease, COPD, stroke and lung cancer. The human health effects of poor air quality are far reaching, but principally affect the body's respiratory system and the cardiovascular system. Individual reactions to air pollutants depend on the type of pollutant a person is exposed to, the degree of exposure, and the individual's health status and genetics.] Indoor air pollution and poor urban air quality are listed as two of the world's worst toxic pollution problems in the 2008 Blacksmith Institute World's Worst Polluted Places report. Outdoor air pollution alone causes 2.1 to 4.21 million deaths annually. Overall, air pollution causes the deaths of around 7 million people worldwide each year, and is the world's largest single environmental health risk.

Air pollution may be defined as the presence in air of any abnormal material or property that reduces the usefulness of the air resource. A typical comparison of clean and polluted air is represented in Table 3.1.

Table 3.1 Comparison of Clean and Polluted Air

Component	Clean air	Polluted air
SO ₂	0.01-0.01 ppm	0.02-2 ppm
CO ₂	310-330 ppm	350-700 ppm
CO	< 1 ppm	5-200 ppm

NO _x	0.01-0.01 ppm	0.01-0.5 ppm
Hydrocarbons	0.01-0.02 1 ppm	1-20 ppm
Particulate matter	0.01-0.03 10-20 mg/m ³	70-700 /m ³

3.1 Sources and Types of Air Pollutants

The sources of air pollutants can be natural or anthropogenic.

- Natural
 - o Primarily, anaerobic oxidation of methane (CH₄)
- Anthropogenic combustion
 - o motor vehicles
 - o burning fossil fuels
 - o solid waste disposal
 - o industrial processes
 - o Burning leaves, brush, etc.

Air pollutants of major concern are divided into two groups: primary pollutants and secondary pollutants. Primary pollutants are those emitted by an identifiable source. The list includes CO, NO_x, Sox, particulates (PM-10), hydrocarbons, and lead. Secondary pollutants are those formed in the atmosphere by chemical reactions and include: O₃, other photochemical oxidants (peroxyacetyl nitrate), and oxidized hydrocarbons.

Carbon monoxide (CO)

- Most abundant air pollutant

- Produced by incomplete combustion (insufficient O₂, low temperature, short residence time, poor mixing)
- Major source (~ 77%) is motor vehicle exhaust
- Colorless and odorless
- When inhaled, binds to hemoglobin in blood to form carboxyhemoglobin, reducing the oxygen carrying capacity
- brain function reduced, heart rate increased at lower levels
- asphyxiation occurs at higher levels

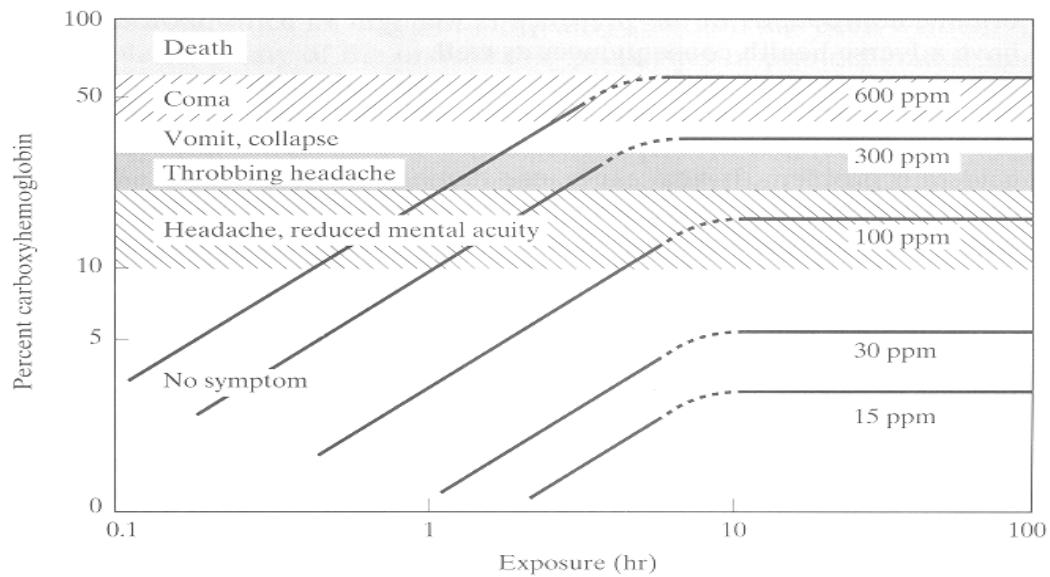


Fig. 3.1 Health effects of CO

Oxides of Nitrogen (NO_x)

- Primarily NO and NO₂
- NO₃, N₂O, N₂O₅ are also known to occur

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- Thermal NO_x created by oxidation of atmospheric N₂ when $T > 1000\text{ K}$
- Fuel NO_x from oxidation of N in fuel
- NO has few health effects, but is oxidized to NO₂
- NO₂ irritates lungs and promotes respiratory infections
- NO₂ reacts with hydrocarbons in presence of sunlight to produce smog
- NO₂ reacts with hydroxyl radicals to produce nitric acid - acid precipitation
- Acids of nitrogen: HNO₂ and HNO₃

Sulfur Oxides (SO_x)

- Source
 - o As *primary pollutants* (SO₂ or SO₃): from power plants, industry, volcanoes
 - o As *secondary pollutants*: from industrial and biological processes emitting H₂S
- Fate
 - o Converted to sulfate or sulfuric acid and settle or wash out
 - o Major contributor to acid rain

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- Health effects of sulfur dioxide:
 - o High concentrations of SO₂ can result in temporary breathing impairment.
 - o Longer-term exposures to high concentrations of SO₂, in conjunction with high levels of PM, include respiratory illness, alterations in the lungs' defenses, and aggravation of existing cardiovascular disease
 - o Short-term exposures of asthmatic individuals to elevated SO₂ levels may result in reduced lung function.
- Environmental effects of sulfur dioxide:
 - o Acid rain
 - o Decreased visibility

Particulate Matter

- Solid or liquid particles with sizes from 0.005 – 100 µm and are termed as ***aerosols***.
- Primary sources are
 - o Natural: Sea salt, soil dust, volcanoes, smoke from forest fires
 - o Anthropogenic : Fossil fuel burning and industrial processes
- Secondary sources: When H₂S, SO₂, NO_x, etc. converted to particulates
- Fate - settle out or are washed out

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- Health effects of particulate matter:
 - o Impact depends on particle size, shape and composition
 - o Large particles trapped in nose
 - o Particles $>10\text{ }\mu\text{m}$ removed in tracheobronchial system
 - o Particles $<0.5\text{ }\mu\text{m}$ reach lungs but are exhaled with air
 - o Particles $2 - 4\text{ }\mu\text{m}$ most effectively deposited in lungs
 - o Inhalable PM includes both fine and coarse particles.
 - o Coarse particles
 - o Aggravation of respiratory conditions, such as asthma.
 - o Fine particles
 - o increased hospital admissions and emergency room visits for heart and lung disease
 - o increased respiratory symptoms and disease
 - o decreased lung function
 - o premature death
- Environmental effects of particulate matters:
 - o Decreased visibility
 - o Damage to paints and building materials

Lead

- Sources
 - o Natural: Volcanic activity and airborne soil
 - o Anthropogenic

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- Smelters and refineries
- Incineration of lead-containing wastes
- Leaded gasoline - no longer used in many countries
- Fate: P_b particles attach to other particles and settle out or wash out
- Health effects of lead:
 - Accumulates in the blood, bones, and soft tissues.
 - Adversely affects the kidneys, liver, nervous system, and other organs.
 - Excessive exposure to P_b may cause neurological impairments, such as seizures, mental retardation, and behavioral disorders.
 - May be a factor in high blood pressure and subsequent heart disease.

Volatile organic compounds (VOC)

Comprise hydrocarbons and other substances (Hydrocarbons: CH_4 , ethylene, and benzene; others: formaldehyde, phenol, phosgene, carbon tetrachloride, CFCs and PCBs)

- Sources are mainly anthropogenic:
 - o Road transport, landfilling, mining, oil refineries, solvent evaporation, etc.
- Many of the VOCs are precursors for photochemical oxidants
- Health effects: Irritate eye, throat and lung; suspected carcinogens
- Environmental effects: Global warming, Damage ozone layer, Inhibit plant growth

Photochemical Smog

- Primary oxidants produced:

- o Ozone (O_3)
- o Formaldehyde
- o Peroxyacetyl nitrate (PAN)

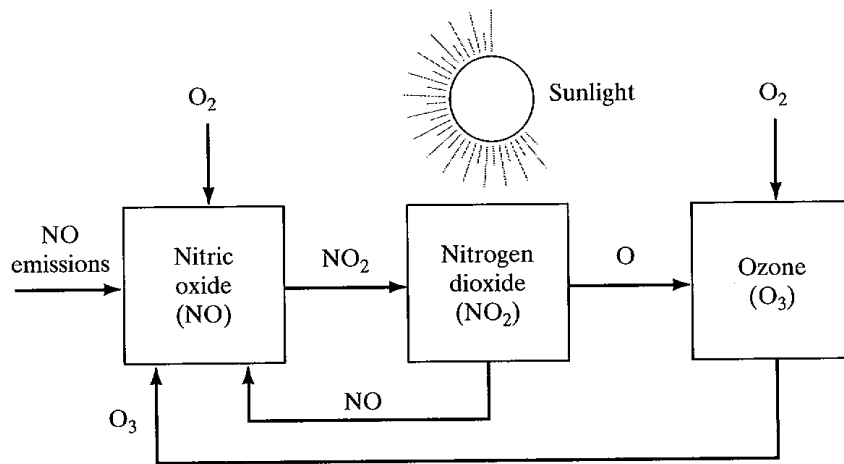


Fig. 3.2 Photochemical smog formation

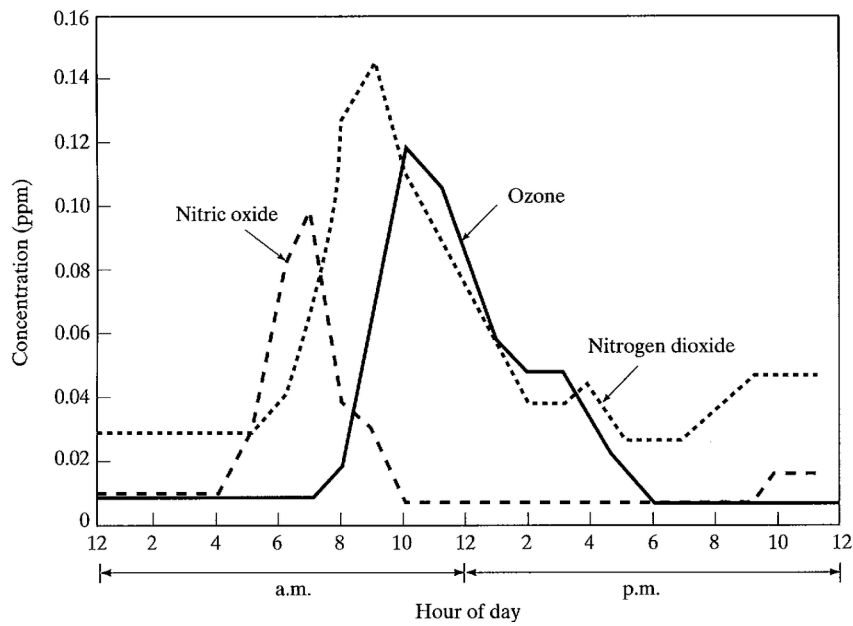


Fig. 3.3 Photochemical smog variation in a day

Health effects of ozone:

- Increased incidents of respiratory distress.
- Repeated exposures to ozone:
 - o Increased susceptibility to respiratory infection
 - o Lung inflammation
 - o Aggravation of pre-existing respiratory diseases such as asthma.
 - o Decreases in lung function and increased respiratory symptoms such as chest pain and cough.
- Environmental effects of ozone:
 - o reductions in agricultural and commercial forest yields
 - o Reduced growth and survivability of tree seedlings
 - o Increased plant susceptibility to diseases, pests, and other environmental stresses (e.g., harsh weather).

Summaries of the health and environmental effects of air pollutants are given in Tables 3.2 and 3.3.

Table 3.2 Effects on human health

Pollutant	Warning levels	Emergency levels	Significant harm levels
Photochemical oxidant	800 mg/m ³ , 1-hr av	1200 mg/m ³ , 1-hr av	800 mg/m ³ , 4-hr av 1200 mg/m ³ , 2-hr av 1400 mg/m ³ , 1-hr av

Carbon monoxide	34mg/m ³ , 8-hr av	46 mg/m ³ , 8-hr av	57.5 mg/m ³ , 8-hr av 86.3 mg/m ³ , 4-hr av 144 mg/m ³ , 1-hr av
Nitrogen dioxide	2260 mg/m ³ , 1-hr av 565 mg/m ³ , 24-hr av	740 mg/m ³ , 24-hr av	3750 mg/m ³ , 1-hr av 938 mg/m ³ , 24-hr av
Sulfur dioxide (SO ₂)	1600 mg/m ³ , 24-hr av	2100 mg/m ³ , 24-hr av	2620 mg/m ³ , 24-hr av
Particulate matter	625 mg/m ³ , 24-hr av	875 mg/m ³ , 24-hr av	1000 mg/m ³ , 24-hr av
SO ₂ and particulate matter combined	Product of mg/m ³ for both is equal to 261×10^3 , 24-hr av	Product of mg/m ³ for both is equal to 393×10^3 24-hr av	Product of mg/m ³ for both is equal to 490×10^3 , 24-hr av

Table 3.3 Effects on vegetation

Pollutant	Symptom	ppm	Sustained exposure time
Ozone (O ₃)	Fleck, bleaching, bleached spotting, growth suppression.	0.03	4 hr

	Tips of conifer needles become brown and necrotic.		
SO ₂	Bleached spots, bleached areas between veins, chlorosis, growth suppression, reduction in yield.	0.03	8 hr
Peroxyacetyl nitrate (PAN)	Glazing, silvering or bronzing on lower surface of leaves.	0.01	6 hr
HF	Tip and margin burn, chlorosis, dwarfing leaf abscission, lower yield.	0.000 1	5 weeks
C ₁₂	Bleaching between veins, tip and leaf abscission.	0.10	2 hr
Ethylene(C ₂ H ₄)	Withering, leaf abnormalities, flower dropping, and failure of flower to open.	0.05	6 hr

3.2 Global air pollution problems

Serious global air pollution problems include *acid rain*, *ozone layer depletion* and *global warming*.

Acid rain

Processes that cause acid rain are represented in Fig. 4.4. Major sources include vehicular emission and emission from factories.

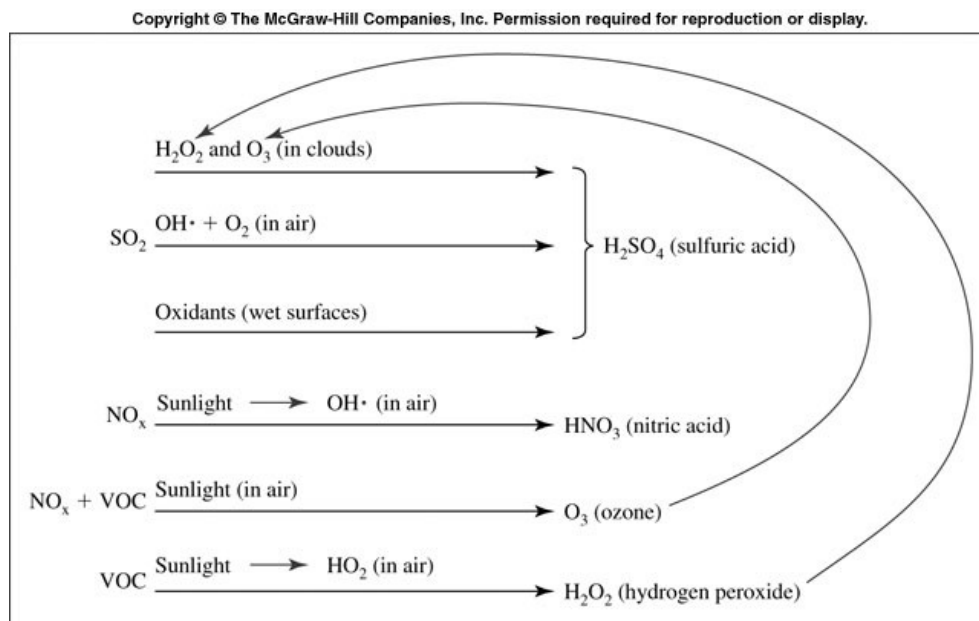


Fig 4.4 Atmospheric processes that cause acid rain

- Effects of acid rain
 - Affects fish
 - lower pH affects reproductive cycle
 - releases otherwise insoluble Al which is toxic to fish
 - has effects on vegetation
 - depletes soil nutrients
 - Degrades buildings & monuments

Ozone layer depletion

- Ozone in stratosphere is barrier to UV rays
- Chlorine in chlorofluorocarbons (CF_2Cl_2 & $CFCl_3$) reacts with ozone.

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- Chlorine recycles and continues to destroy ozone
- Some CFCs have 110-year lifetime in atmosphere
- Removed after Cl reacts with CH₄
- Source of the CFCs was aerosol propellant & refrigerants
- A 5% reduction in the ozone layer means 10% increase in skin cancer

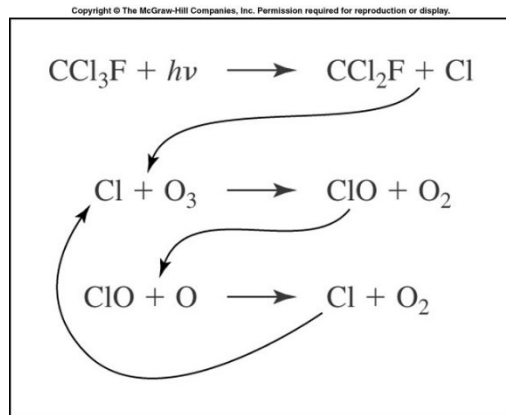


Fig. 4.5 Processes that deplete ozone

Conferences on Ozone Depletion

1987 Montreal Protocol

- freezes CFC production
- signers agree to reduce CFC production to 50% by 1998

1989 Helsinki Declaration

- phase out CFC production by 2000
- Phase out other chemicals (contain Br or Cl) as soon as feasible

1990 & 1992 - Strengthen Montreal Protocol

- ban production of CFCs, CCl₄, and methyl chloroform by January 1996

Global warming

It is caused by atmospheric buildup of greenhouse gases such as carbon dioxide, methane, water vapor, CFCs, etc. The major contributor to global warming is CO₂. It is an artificial disturbance in the environment resulting from:

- Burning of Fossil Fuels
- Cutting of Forests

This disturbance likely results in a warming of the earth's climate. The mechanisms for this phenomenon to occur are:

- CO₂ emits and absorbs radiation at wavelengths typical of the earth and the atmosphere.
- As the CO₂ concentration increases, the atmosphere has increased resistance to the necessary escape of radiation to space.
- Incoming solar radiation is not greatly affected by the change in CO₂ concentration.

Sources

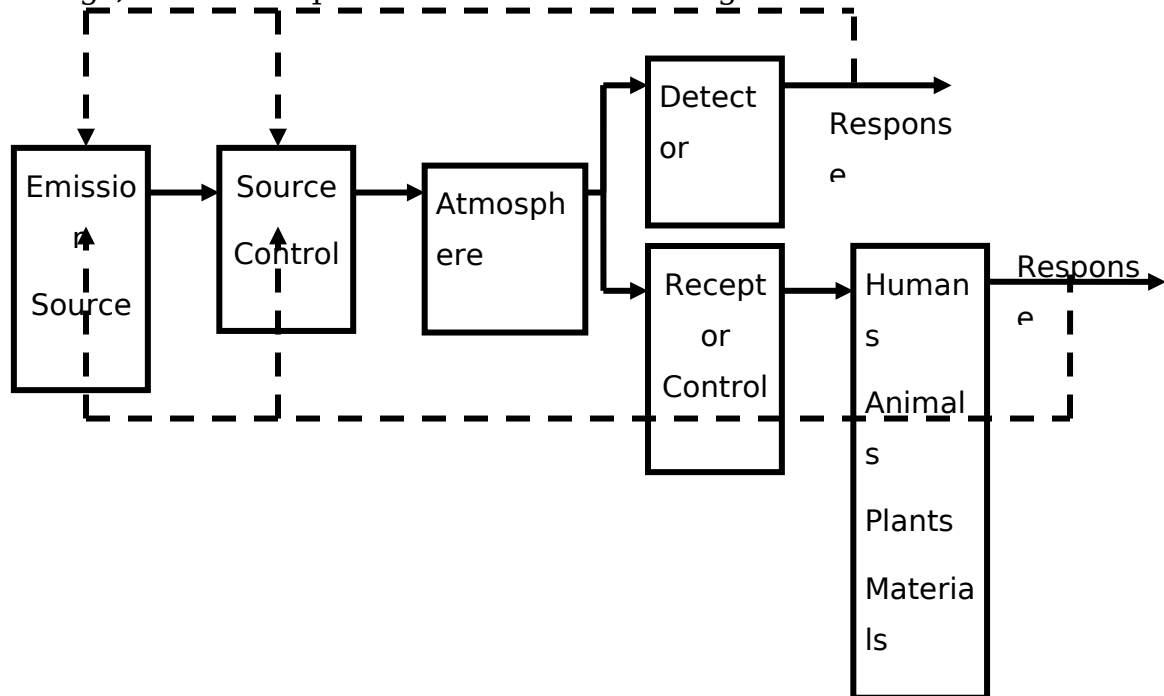
- Fossil fuel combustion
- Burning forests
- Decreasing CO₂ sinks by burning forests
 - growing rain forest 1-2 kg C/m²/yr
 - crops 0.2 - 0.4 kg C/m²/yr
- Other gasses contribute - methane, nitrous oxide and CFCs

3.3 Air pollution control

The driving forces for air pollution control include

- Environmental protection
- Occupational health consideration in workplace
- Social considerations
- Legal limitation imposed by government

The existence of air pollution problem can be identified by checking the ambient air quality or investigating the effects on receptors like humans, buildings, etc. Air pollution control strategies can focus on emission



minimization and source control technologies.

Fig. 3.6 Air pollution control system

The strategies may comprise long-term and short-term pollution control options (Fig. 3.7).

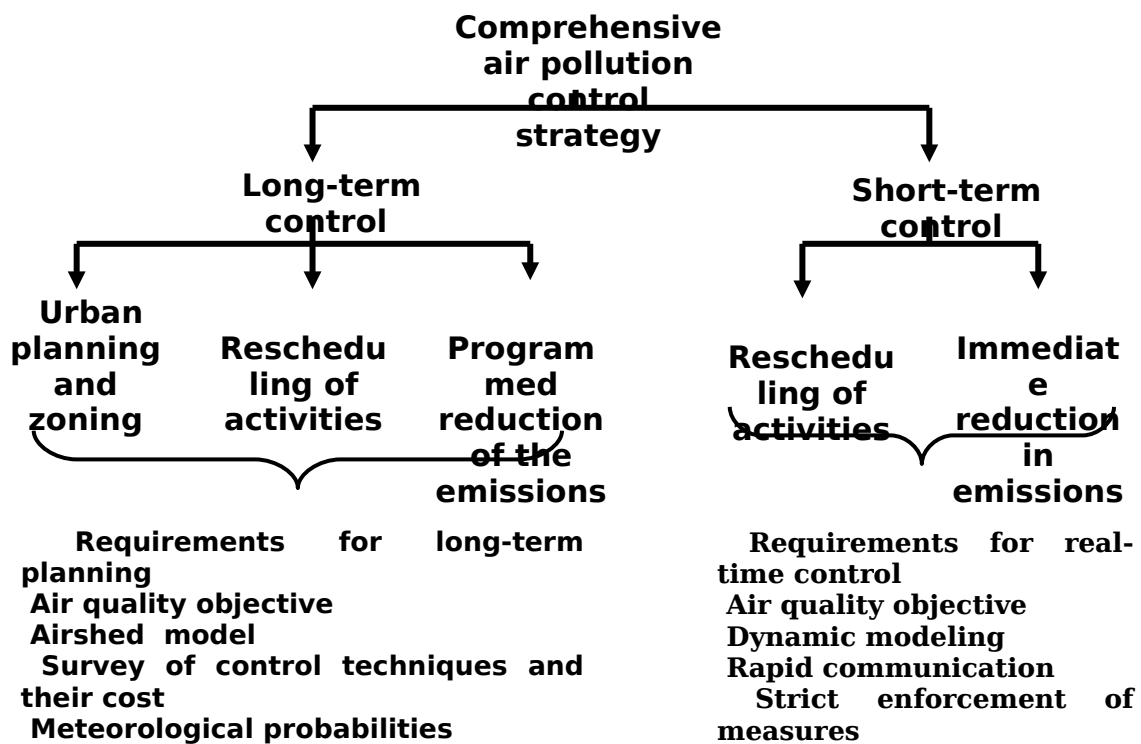


Fig. 3.7 Air pollution control options

Costs of air pollution may be expressed in terms of mitigation (control) costs or the damage costs (costs for medical treatment, costs to maintain degraded buildings, etc). Decision on pollution control investment should ensure a minimum total cost (Fig 3.8).

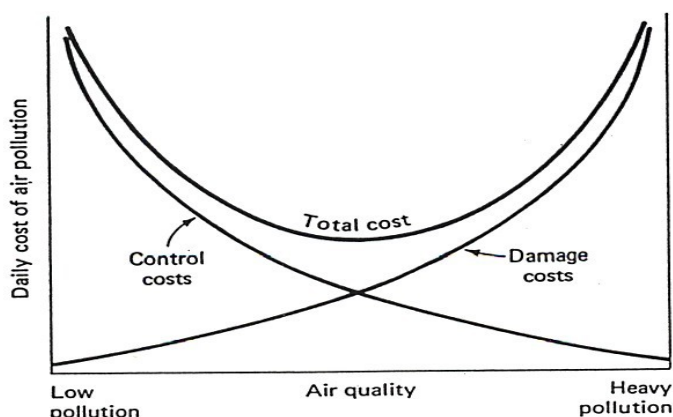


Fig. 3.8

Air pollution minimization strategies may include the following:

- Use clean fuels by vehicles (electric, fuel cell, ethanol, methanol, biodiesel, hydrogen, LPG, LNG, and CNG)
- Promoting the use of public transport by making it efficient, accessible, and cost effective
- Encouraging bicycling and walking by providing separate and attractive lanes
- Developing mixed land-use settlements that minimize the need for travel
- Discouraging private automobile dependence through fiscal measures
- Conducting timely and proper maintenance of roads
- Banning the use of leaded gasoline
- Good maintenance of vehicles
- Good driving practice (e.g. stop engine while waiting, avoid abrupt acceleration & deceleration)

CHAPTER FOUR

SOIL POLLUTION AND REMEDIATION

4.1 Types and sources of soil pollutants

4.1.1 Major Types of Soil Pollutants

A, Heavy Metals and Their Salts

Natural concentrations of heavy metals in soils depend primarily on the type and chemistry of the parent materials from which the soils are derived. Lead is one of the oldest metallic pollutants introduced by man into the environment. It was called plumbum nigrum by the Romans to differentiate it from plumbum - candidum_tin.

B, Other Inorganic Pollutants

Elements like aluminium, beryllium, and fluorine are considered environmental pollutants if they occur in excessive quantities in soils. Attention was drawn to aluminium, when in July 1988, 20 tons of aluminium sulphate were accidentally introduced into the water supply of the Camelford District of Cornwall.

C, Radionuclides

Since 1954 there has been an increasing pollution of soils with radioactive nuclides. These are natural or technically produced elements with unstable nuclei that spontaneously alter their compositions through radioactive decay in a series of successive nuclear reactions, ultimately leading to a stable configuration.

D, Nuclear Debris from Weapon Tests and Belligerent Activities

The distribution of nuclear debris has increased on a worldwide scale since thermonuclear devices first contaminated the Earth's atmosphere, following

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the nuclear bombardment of Hiroshima and Nagasaki by the United States Air Force at the end of the Second World War.

E, **Nuclear Debris from Major Nuclear Accidents**

Between the years 1957 and 1993, major nuclear accidents have occurred, contributing to the pollution of soil and atmosphere with nuclear debris. Some of these accidents are listed in **Table 6.4** (Alloway and Ayres 1997), together with their level of risk, as given by the scale of the International Atomic Energy Agency. The scale is from 1 to 7 in increasing order of risk.

Table 6.4 Some nuclear accidents as placed on the IAEA scale of risk (after Alloway and Ayres 1997)

Level	Nuclear accident
7	Chernobyl, 1986
6	Ural mountains, waste explosion, 1958
5	Fire at Windscale (Sellafield), 1957 and Three Mile Island, USA, 1979
4	Fatal accidents at Los Alamos, Wood River, and Idaho Falls (1945–1964)
3	Unauthorised release at Vandellos, Spain, 1989; Tomsk-7, Russia, 1993
2	Incidents at UK Magnox stations, 1968, 1983, 1989
1	Management deficiencies in waste reprocessing, Windscale, 1986

4.2 **Fate of pollutants in soil**

The transport and fate of pollutants in soils are governed by different biotic or abiotic processes and depend of several factors. These factors include soil properties (e.g., mineralogy, organic matter content, pH, moisture); chemical compounds properties (e.g., hydrophobicity, vapor pressure, and chemical stability); biota activity; sequestration; and environmental factors (e.g., temperature and precipitation). The most important mechanisms of transport of contaminants through soil are volatilization, leaching, and

erosion or suspension of soil particles. Mechanisms that control transport may be the same that control availability to organisms, and thus contaminant fate. Therefore, these concepts are closely related. Any study on the fate of pollutants in the environment is indeed a complex issue, since it involves movements from and to different compartments (soils, water, and air), and transfer along the food chain.

Although physical and chemical factors affect the fate of pollutants in soil and water, it is apparent that these are not the only factors governing the fate of pollutants. If they were, the large-scale accumulation of contaminants, including environmental and natural organic substances would dominate the earth, rendering our current pollution problems minuscule by comparison.

Soil contamination occurs through either point source or diffuse pollution; the main difference between the two types of contamination lies in how the contaminants are transferred to the soil. Landfills, incinerators, use soil as a support and are linked to the activities that necessarily transfer pollutants into the soil. Diffuse sources are associated with natural phenomena (long range transport, atmospheric deposition, sedimentation by surface water), with agricultural practices, with recycling and inadequate waste treatments.

4.3 Remediation techniques

Public concern about environmental pollution has increased substantially since the beginning of the twentieth century with growing awareness of the stresses being placed on the environment due to activities arising from both industrial activity and intensive agriculture, and as a consequence of high-profile incidents that have highlighted the risks of pollution for human health.

Once a need for soil remediation is recognized, the best available technology is selected according to the nature, toxicity, and origin of the contaminant, the present and potential hazard related to the degree of contamination, the chemical and physical characteristics of the soil, the land use, the time available for remediation, the community acceptance, and a cost-benefit analysis.

Bio-piles are a biological method of soil remediation that fall under the heading biodegradation. In this method, stacks or piles of soil containing concentrations of petroleum are separated. The separated heaps are aerated with microbes for biodegradation at an optimum temperature and pH. This is an effective method for removing petroleum, volatile organic compounds and pesticide chemicals, and is also easy to design. However, it is a short-term technology that may last only weeks or months. To achieve 100% efficacy it should be used in combination with the aforementioned techniques (Filler et al., 2001).

CHAPTER FIVE

SOLID AND HAZARDOUS WASTE MANAGEMENT

5.1 Solid waste characterization

Solid waste characterization involves determination of source, composition, and generation rates as well as their properties of wastes.

Four methods for estimating waste quantities and composition can be identified: direct sampling (also referred to as waste stream analysis and waste audits), material flow, surveying waste generators, and literature sources.

Direct sampling. Direct sampling involves sampling, sorting, and weighing materials from the waste stream of a specific generator. This method has been used to estimate the composition of municipal waste streams. Representative sampling methods must be employed to achieve accurate results. When using the direct sampling method, the following questions must be addressed: How will representative samples of waste be obtained; how large should each sample be; and how many samples should be selected to achieve the desired level of accuracy in the results? The responses to these questions will influence the cost of conducting the study as well as the usefulness of the data.

Waste stream analysis. Waste stream analysis is another method used for characterizing the waste stream of a specific operation for a designated time period. Waste stream analysis is defined as a method for collecting, sorting, and measuring the amount and type of wastes generated by an operation. Results of a waste stream analysis provide data about the amount and type of wastes/residues in the waste stream. Data should be collected for a minimum of one week; the length of time depends on how the data are to be used and the accuracy required. The results are averaged to estimate the amount of wastes that the facility generates for a period of time. The ten steps in conducting a waste stream analysis are:

Waste audit. The basic objectives of a waste audit are similar to a waste stream analysis. A waste audit involves a more detailed assessment of wastes. The waste audit assesses not only the output (waste), but also the input, such as food products, packaging materials, office supplies, mail, or any process that results in materials that must be discarded. The detailed and complicated analysis of material flow through an institution will enable the facility to find the amount purchased, used, recycled, and disposed of

for different materials. A waste audit can involve all materials or focus on a specific material, such as cardboard or office paper that is generated by a facility or department.

Material flow. The material flow method applies the concept of conservation of mass to track quantities of materials as they move through a defined system or region. The material flow methodology in this instance is based on the production weight data for materials and products. Generation data are the result of making specific adjustments for imports, exports, and diversions to the production data by each material and product category. The method also considers the useful life of products. One of the problems with the material flow approach is that it is difficult to quantify product residues, such as food left in the container and detergent remaining in the package.

Surveying waste. Surveying industrial generators, such as food processors, can provide useful data in quantifying waste generation. More accurate data can be obtained if the wastes/residues are measured at the disposal site.

Literature sources. Data on wastes/residues quantities and composition are available from a variety of sources including public agency documents, engineering reports, trade publications, and professional journals. These data may be helpful in assisting managers in identifying the type of residues/wastes generated by a specific industry or activity. However, caution should be used when making operational decisions on data reported in the above sources. For example, specific conditions are not described, such as types of waste reduction strategies or diversion programs. Waste

characterization studies are recommended rather than relying on published data since each industry site or foodservice operation is unique.

Source, composition, and generation of wastes

Identifying the source and composition of waste helps to devise appropriate handling, collection, treatment, and disposal mechanisms. Sources and types of solid wastes are presented in Table 5.1.

Table 5.1 Sources of solid wastes within a community

Source	Typical facilities, activities or locations	Types of solid wastes
Residential	homes, flats, apartment blocks etc	food wastes, paper, cardboard, plastics, textiles, yard wastes, wood, glass, metals, special wastes (eg bulky items such as white goods, batteries, oil tyres), household hazardous wastes
Commercial	Shops, restaurants, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops etc	Paper, cardboard, plastics, wood, metals, food wastes, glass, special wastes (as above), hazardous wastes
Institutional	Schools, hospitals, universities, prisons, government centers etc	As above in commercial
Construction	New construction sites,	Wood, steel, concrete, dirt etc

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and demolition	road repairs, building demolition	
Municipal services (excluding treatment works)	Street cleaning, landscaping, parks and beaches, creek bed cleaning, litter bins	Special wastes, rubbish, litter, sweepings, debris, general wastes
Treatment plant sites	Water, wastewater, industrial treatment processes etc	Effluent plus residual sludges
Municipal solid waste (MSW)	All of the above	All of the above
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power stations, demolition etc	Industrial process wastes, scrap materials etc. Non-industrial wastes including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazardous wastes
Agricultural	Crops, orchards, dairies, feedlots, piggeries, farms etc	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes

Source: Tchobanoglous (1993)

Sources and types of wastes in some urban centers of Ethiopia are indicated in Table 5.2

Table 5.2 Source and types of wastes in major urban centers of Ethiopia

Town	Source of waste	Types of waste
Hawassa	Domestic, factories, institutions, animals	Organic waste, plastic (festal), metal scraps and animal manure.
Adama	Industries, institutions, commercial, domestic, street sweepings and construction derbies	Paper, food leftover, fruits and vegetables, plastic, fine (dust) pieces of woods and animal dung.
Dire Dawa	Commercial, domestic, hospital, street sweeping	Paper, leaves, dust, festal hospital waste, broken glasses and metals
Harar	Domestic, factories, commercial	Food leftover, dust, leaves festal, plastic
Bahirdar	Domestic, commercial, agriculture	Food leftover, plastic, fertilizers, chemical residues, street sweepings, fine.
Addis Ababa	Industries, institutions, commercial, domestic, street sweepings and construction derbies	Bone Vegetable, Paper Wood Glass Rubber Plastics Textile Fine scrap metal, street sweepings

Proportion of different types of wastes for some countries and cities are presented in Tables 5.3.

Table 5.3 Composition of municipal solid waste

Compiled By **Desta Gemed**

Composition (% of wet weight)	Countries		
	Low income	Middle income	Industrialized
Vegetables and other putrescible materials	40-85	20-65	20-50
Paper and cardboard	1-10	15-40	15-40
Plastics	1-5	2-6	2-10
Metals	1-5	1-5	3-13
Glass	1-10	1-10	4-10
Rubber and leather	1-5	1-5	2-10
Inert material (ash, soil, and sand)	1-40	1-30	1-20

Waste generation rates are affected by degree of industrialization, climate and socio economic development. As economic prosperity increases, the amount of solid waste produced consists mostly of luxury waste such as paper, cardboard, plastic and heavier organic materials. In cities of

developing countries, on the other hand, waste densities and moisture contents are much higher. Generally the greater the economic prosperity and higher percentage of urban population, the greater the amount of solid waste produced. Knowledge of the amount of solid waste generation is necessary to design management strategies to effectively handle (reduce, reuse, recycle etc) those wastes.

Table 5.4 Typical generation rate of municipal solid waste

Country	Generation rate (kg/capita/day)
Industrial countries (UK, USA)	0.8-1.4
Middle income countries (Egypt, Nigeria, Singapore, Tunisia)	0.6- 0.8
Low income countries (Bangladesh, India, Indonesia, Pakistan, Thailand, Tanzania)	0.3-0.5

The per capita waste generation rates for Addis Ababa, Mekele and Bahirdar are estimated to be 0.252 kg/day, 0.203 kg/day and 0.223 kg/day, respectively.

Physical, chemical and biological properties of wastes

Knowledge of the various physical, chemical and biological properties of wastes is important for assessment of recycling impact, calculation of physical properties, investigation of combustion characteristics, and landfill requirements. Waste characterization study needs to be performed

seasonally to define equipment needs, management programs, and trends for future planning.

Physical properties

The important physical properties of MSW include *density* (sometimes referred to as specific weight), *moisture content*, *particle size and distribution*, *field capacity*, and *porosity*.

Density

This is the weight per unit volume and is expressed as kg/m³. Density varies because of the large variety of waste constituents, the degree of compaction, the state of decomposition, and in landfills because of the amount of daily cover and the total depth of waste. Inert wastes such as construction and demolition materials may have higher densities, and density can change as in landfills where the formation of landfill gas and decomposition may bring about significant mass loss. Density is important because it is needed to assess the total mass and volume of waste which must be managed.

The density of MSW is often referred to as loose, as found in containers, uncompacted, compacted etc. so it is important to specify what sort of waste is being referred to. Density varies not only because of the type of treatment it gets (collection vs compaction etc) but also because of geographic location, season, and length of time in storage. Some typical density values are presented in the Table 5.5.

Table 5.5 Typical solid waste densities of different countries

Country	Waste density (kg/m ³)
---------	------------------------------------

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Industrial countries	
UK	150
USA	100
Middle income countries	
Egypt	330
Nigeria	250
Singapore	175
Tunisia	175
Low income countries	
Bangladesh	600
India	400-570
Indonesia	400
Pakistan	500
Thailand	250
Tanzania	330

For Addis Ababa the solid waste density is assumed to vary from 205 to 370 kg/m³, with the average being 333 kg/m³.

Moisture Content

The most commonly used method of expressing moisture content is as a percentage of the wet weight of material. Moisture content is important in

regards to density, compaction, the role moisture plays in decomposition processes, the flushing of inorganic components, and the use of MSW in incinerators. Pre-treatment of waste to ensure uniform moisture content can be carried out prior to landfill disposal. The wet weight moisture content can be determined using the following equation:

$$M = \left(\frac{w - d}{w} \right) 100$$

Where M = moisture content (%)

w = initial weight of sample (kg)

d = weight of sample after drying at 105°C (kg)

Some typical moisture contents are shown in Table 5.6.

Table 5.6: Typical Moisture Contents of Wastes

Type of Waste	Moisture Content Range (%)	Moisture Content Typical (%)
RESIDENTIAL		
Food wastes (mixed)	50 - 80	70
Paper	4 - 10	6
Plastics	1 - 4	2
Yard Wastes	30 - 80	60
Glass	1 - 4	2

COMMERCIAL		
Food wastes	50 - 80	70
Rubbish (mixed)	10 - 25	15
CONSTRUCTION & DEMOLITION		
Mixed demolition combustibles	4 - 15	8
Mixed construction combustibles	4 - 15	8
INDUSTRIAL		
Chemical sludge (wet)	75 - 99	80
Sawdust	10 - 40	20
Wood (mixed)	30 - 60	35
AGRICULTURAL		
Mixed Agricultural waste	40 - 80	50
Manure (wet)	75 - 96	94

Source: Tchobanoglous et al. (1993)

Particle Size and Distribution

The size and distribution of the components of wastes are important for the recovery of materials, especially when mechanical means are used, such as

trommel screens and magnetic separators. For example, ferrous items which are of a large size may be too heavy to be separated by a magnetic belt or drum system. The size of the waste component can be computed using length, height, or width

Field Capacity

The field capacity of MSW is the total amount of moisture which can be retained in a waste sample subject to gravitational pull. It is a critical measure because water in excess of field capacity will form leachate, and leachate can be a major problem in landfills. Field capacity varies with the degree of applied pressure and the state of decomposition of the wastes, but typical values for uncompacted-compacted wastes from residential and commercial sources are in the range of 50 - 60%.

Permeability of compacted wastes

The hydraulic conductivity of compacted wastes is an important physical property because it governs the movement of liquids and gases in a landfill. Permeability depends on the other properties of the solid material include pore size distribution, surface area and porosity.

Chemical properties of waste

Knowledge of the chemical composition of waste is important to help evaluate alternative processing and recovery options. This is especially important where wastes are burned for energy recovery, in which case the most important properties are proximate analysis, elemental analysis, and energy content. Elemental analysis is also important in determining nutrient availability.

Proximate Analysis

Proximate analysis includes four tests - loss of moisture when heated to 105°C for 1 hour; volatile combustible matter (loss on ignition); fixed carbon; and ash (weight of residue after combustion). Some typical values are shown in Table 3.

Table 5.7: Typical Proximate Analysis Values (% by weight)

TYPE OF WASTE	MOISTURE	VOLATILE S	CARBON	ASH
Mixed food	70.0	21.4	3.6	5.0
Mixed paper	10.2	75.9	8.4	5.4
Mixed plastics	0.2	95.8	2.0	2.0
Yard wastes	60.0	30.0	9.5	0.5
Glass	2.0	-	-	96-99
Residential MSW	21.0	52.0	7.0	20.0

Source: Tchobanoglous et al. (1993)

Elemental Analysis

This is also known as ultimate analysis and involves the determination of carbon, hydrogen, oxygen, nitrogen, sulphur, and ash. Because of concern about halogens these are also often determined as well. The results of this analysis are used to characterize the composition of the organic matter in wastes. This is important for C/N ratios for biological decomposition. Typical values are shown in Table 3.4.

Table5.8: Typical data in Elemental Analysis (% by weight)

TYPE	C	H	O	N	S	AS H
Mixed food	73. 0	11. 5	14.8	0.4	0.1	0.2
Mixed paper	43. 3	5.8	44.3	0.3	0.2	6.0
Mixed plastic	60. 0	7.2	22.8	-	-	10. 0
Yard waste	46. 0	6.0	38.0	3.4	0.3	6.3
Refuse Derived Fuel	44. 7	6.2	38.4	0.7	<0. 1	9.9

Source: Tchobanoglous et al. (1993)

Energy Content

The energy content of the components of waste can be determined using a boiler system, laboratory bomb calorimeter, or by calculation using elemental composition. The SI unit of measurement is kJ/kg. The nomenclatures for energy contents are as follows:

H_u = lower heat value, i.e. from waste as collected

H_{wf} = normal heat value, i.e. from water-free waste (dry)

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H_{awf} = higher heat value, i.e. from ash- and water-free waste

$$H_u = H_{awf} \times B - 2.445 \times W \quad [\text{MJ/kg}]$$

Where, B = flammable fraction (volatile matter + fixed carbon)

W = moisture content fraction by weight

Empirical equations for estimating energy content include

- o Dulong formula

$$H_u = 337C + 1419(H_2 - 0.125O_2) + 93S + 23N \quad [\text{J/kg}]$$

Where C, H, O, S, and N = percent by weight of each component

- o Khan's equation (works well if there is little or no yard or garden waste)

$$E = 0.051[F + 3.6(CP)] + 0.352(PLR)$$

Where: E = energy content, MJ/kg

F = % of food by weight

CP = % of cardboard and paper by weight

PLR = % of plastic and rubber by weight

Table 5.9 Typical proximate analysis and energy content in MSW

<i>Proximate analysis (% by weight)</i>					<i>Energy content (MJ/kg)</i>		
Waste type	Moisture	Volatiles	Fixed carbon	Non-combustible (ash)	As collected lower heat value,	Dry normal, water free H_{wf}	Dry ash and water-free higher

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					H _u		heat value H _{awf}
Food mixed	70	21	3.6	5.0	4.2	13.9	16.7
Fats	2	95	2.5	0.2	37.4	38.2	39.1
Fruit	79	16	4.0	0.7	4.0	18.6	19.2
Meat	39	56	1.8	3.1	17.6	28.9	30.4
Paper mixed	10.2	76	8.4	5.4	15.7	17.6	18.7
Newspaper	6	81	11.5	1.4	18.5	19.7	20.0
Cardboard	5.2	77	12.3	5.0	26.2	27.1	27.4
Plastics mixed	0.2	96	2	2	32.7	33.4	37.1
Polyethylene	0.2	98	<0.1	1.2	43.4	43.4	43.9
Polystyrene	0.2	99	0.7	0.5	38.0	38.1	38.1
Polyurethane	0.2	87	8.3	4.4	26.0	26.0	27.1
PVC	0.2	87	10.8	2.1	22.5	22.5	22.7
Textiles	10	66	17.5	6.5	18.3	20.4	22.7
Yard wastes	60	30	9.5	0.5	6.0	15.1	15.1
Wood mixed	20	68	11.3	0.6	15.4	19.3	19.3
Glass	2			96-99	0.2	0.2	0.15
Metals	2.5			94-99	0.7	0.7	0.7

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Domestic MSW	15-40	40-60	4-15	10-30	11.6	14.5	19.3
Commercial MSW	10-30				12.8	15.0	
MSW	10-30				10.7	13.4	

Adapted from Tchobanoglous et al., 1993; Robinson, 1986; Mortensen, 1993

Examples

1. If $H_{awf} = 20$ MJ/kg, compute the lower heating value of MSW if:

W, water content = 21%

B, flammable = 59%

A, Ash = 20%.

Solution

$$\begin{aligned}
 H_u &= H_{awf} * B - 2.445 * W \\
 &= 20.0 * 0.59 - 2.445 * 0.21 \\
 &= 11.29 \text{ MJ/kg}
 \end{aligned}$$

2. Compute the lower heat value (H_u) of the domestic MSW shown below, using each waste component and its associated MJ/kg

<i>Component</i>	<i>% by weight</i>	<i>Component weight (tonnes)</i>	<i>Lower heat value, H_u (MJ/kg)</i>	<i>Total energy (GJ)</i>
Food waste	46	5129	4.2	21541
Paper and cardboard	11	1226	16.5	20229
Plastics	9	1003	32.7	32798

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Glass	7	780	0.2	156
Metals	5	558	0.7	390
Clothing/textiles	1	111	18.3	2031
Ashes, dust	19	2118	6.9	14614
Unclassified	2	223	-	-
Total	100	11150		91759

Solution

Total lower heat value (H_u) = 91759 GJ = **8.23 MJ/kg**

3. Using Khan's equation, compute the energy value of the waste in the above example.

Solution

$$E = 0.051[F + 3.6(CP)] + 0.352(PLR)$$

$$F = 46\%$$

$$P = 11\%$$

$$PLR = 9\%$$

Therefore,

$$E = 0.051[46 + 3.6(57)] + 0.352(9)$$

$$= \mathbf{7.53 \text{ MJ/kg}}$$

Biological properties of waste

Biological properties of MSW are relevant because of the technology of aerobic/anaerobic digestion to transform waste into energy and beneficial end products. Biodegradation can be aerobic or anaerobic. Some organic

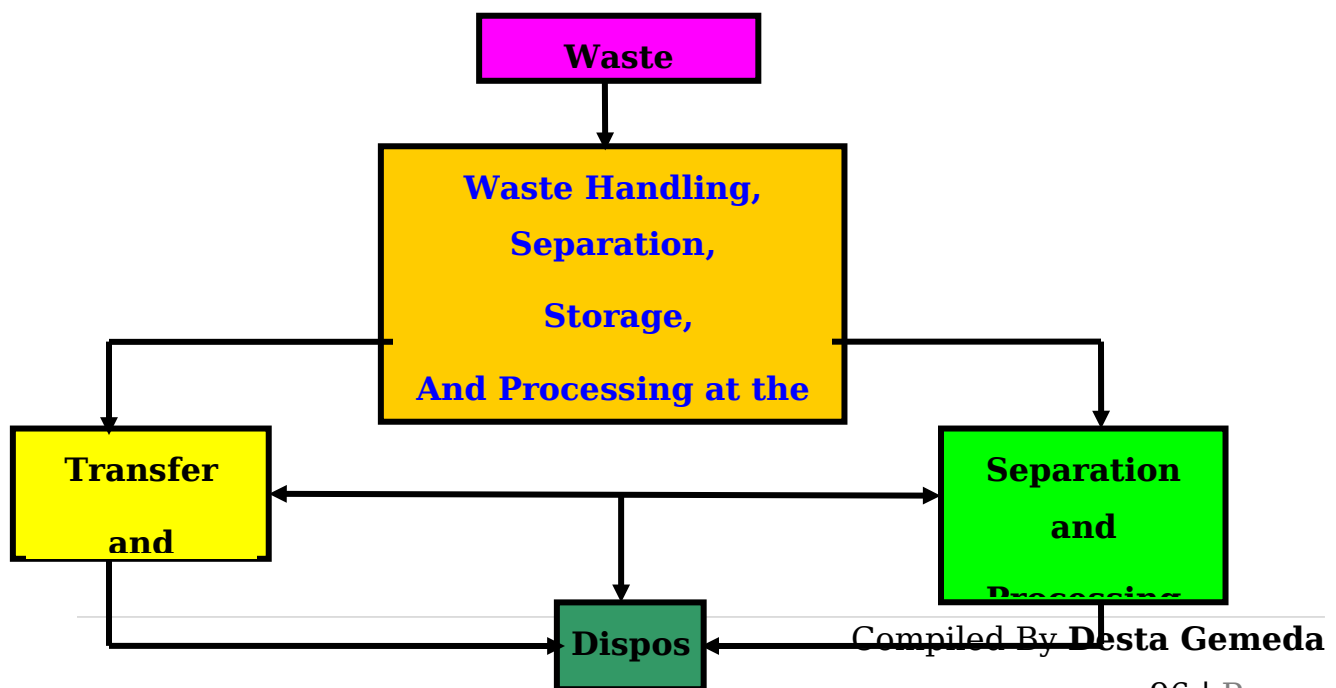
MSW components are undesirable for biological conversion that is plastic, rubber, leather, and wood. The relevant fractions for biological transformation include

- o Cellulose - a product of 6-carbon sugar glucose
- o Fats, oils and waxes - esters of alcohols and long-chain fatty acids
- o Lignin - present in some paper products
- o Lignocellulose - combination of lignin and cellulose
- o Proteins - amino acid chains

These organic components of MSW can be converted biologically to gases and relatively inert organic and inorganic solids. The production of odors and the generation of flies are also related to the putrescible nature of the organic materials.

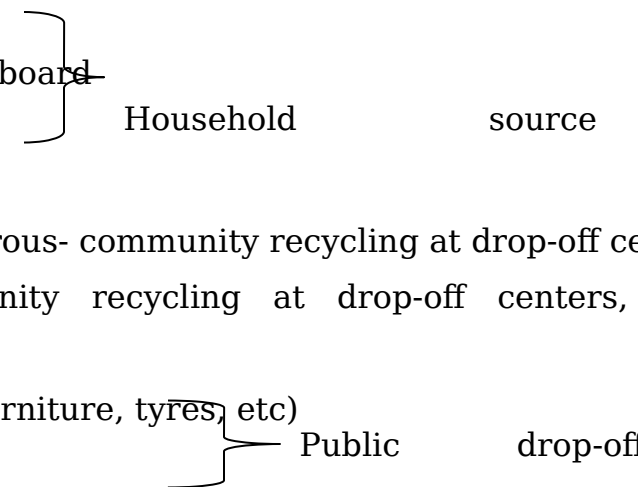
5.2 Elements of solid waste management

Functional elements of a solid waste management system are shown in Fig. 5.2.



Separation

Separation solid waste into its different components is essential to realize environmentally sound solid waste management options. Waste separation can be either at source where it is generated, or at the transfer station or at final destination. Municipal solid wastes may be separated as follows:

- Food wastes
 - Paper and cardboard
 - Plastic
 - Metals ferrous
 - Metals non-ferrous- community recycling at drop-off centers
 - Glass- community recycling at drop-off centers, household source separation
 - Bulky waste (furniture, tyres, etc)
 - Yard waste
 - Hazardous household waste
- 

For source separation to work, drop-off centers for accepting recyclable wastes and public awareness raising efforts are required.

Storage

The size of premises, nature (type) and generation rate of solid waste determines the type of storage to be used. Storage facilities must be animal and insect proof washable and robust enough to meet the exigencies if normal use. There is a limit to the duration that solid waste can be stored at source (in the premises) based on the type and source of solid waste.

Solid waste should be collected and disposed of from temporary stores to final disposal site before breeding various disease carrying vectors.

Uncovered container of waste ate exposed to human and animal scavengers that litter waste around and create community health problems.

Collection

Collection refers to the art of removing accumulated waste, be it containerized or not, from generating sources. Collection may occur at a centralized location where generators deliver their solid waste or by going from individual generator to another, which increases the expense of collection. Transfer or transportation, as the name indicates, refers to the transportation or/and haul of solid waste from a central point to one or more distant final management facility.

Methods of collection include communal collection, block collection, and door-to-door collection.

Transformation processes

Transformations of waste can occur through the intervention of people or by natural phenomena. Solid wastes can be transformed by physical, chemical and biological means as shown in Table 5.10. Typically waste transformations are used:

- to improve the efficiency of solid waste management systems
- to recover reusable and recyclable materials
- to recover conversion products and energy

Table 5.10: Transformation processes in solid waste management

Process	Method	Principal conversion products
Physical		
separation	manual and/or mechanical	individual components found in commingled MSW
volume reduction	Force or pressure	original waste reduced in volume
size reduction	Shredding, grinding, or milling	altered in form and reduced in size
Chemical		
combustion	thermal oxidation	CO ₂ , SO ₂ , oxidation products, ash
pyrolysis	destructive distillation	a variety of gases, tar and/or oil
gasification	starved air combustion	gases and inerts
Biological		
aerobic compost	aerobic biological conversion	compost
anaerobic digestion	anaerobic biological	methane, CO ₂ , trace gases, humus

	conversion	
anaerobic composting (in landfills)	anaerobic biological conversion	methane, CO ₂ , digested waste

Source: Tchobanoglous et al. (1993)

Disposal

A sanitary landfill is an engineered facility that requires detailed planning and specifications, careful construction, and efficient operation. In a landfill, solid wastes are disposed of by spreading in thin layers, compacting to smallest practical volume, and covering each day, or periodically, with soil or suitable substitute material in a way that minimises environmental problems. Care must be exercised to ensure that an environmental problem does not develop during operation or after closure. Careful design, construction, and operation can minimise the potential for problems arising at a landfill.

The three common configurations of sanitary landfills are the trench (excavated cell) method, the area method, and the canyon or depression method.

The excavated cell/trench method of land filling is ideally suited to areas where an adequate depth of cover material is available at the site and where the water table is not near the surface. Typically, cells are excavated to depths of 1 to 3 m, with side slope of 2:1 or 3:1 (3 horizontal). Trenches vary from 60 to 300m in length, 1 to 3m in depth, and 3 to 15m in width. (See Fig. 5.3)

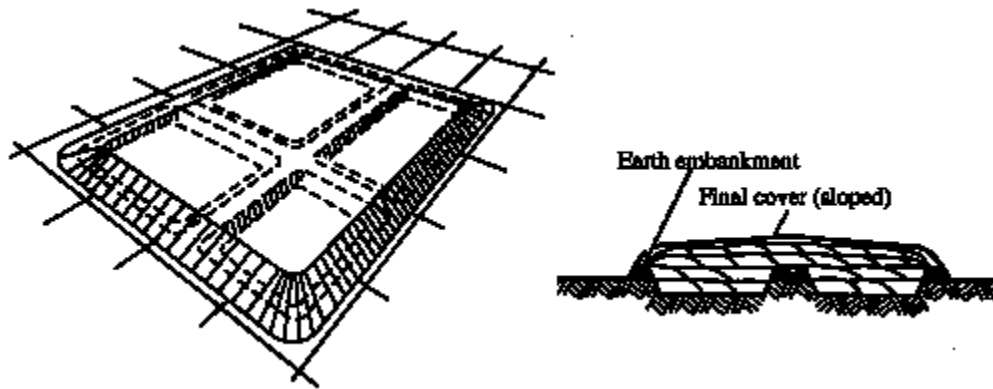


Fig. 5.3 The Trench Method of Landfill

The area method shown in Fig. 5.4 is used when the terrain is unsuitable for the excavation of cells or trenches in which to place the solid wastes. High groundwater conditions, necessitates the use of area-type landfills. Site preparations include the installation of a liner and leachate control system. Cover material must be hauled in by truck or earthmoving equipment from adjacent land or from borrow pit areas.

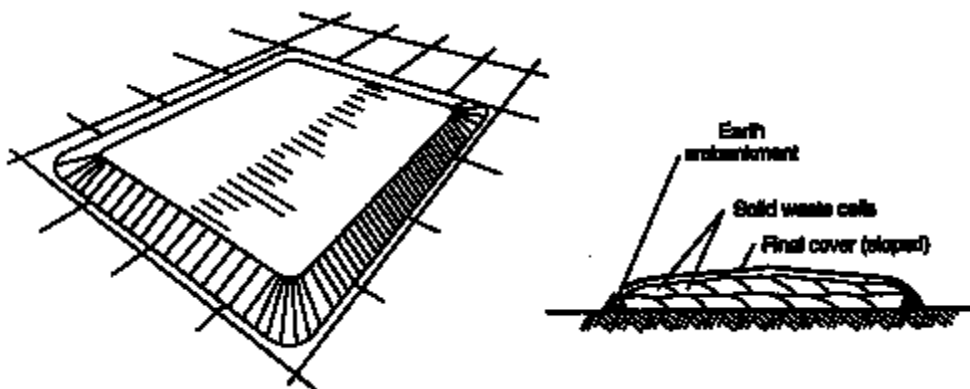


Fig. 5.4 The Area Method of Landfill

The canyon method is similar to the trench method except natural depressions or canyons are used rather than digging trenches. Canyons,

ravines, dry borrow pits and quarries have been used for landfills. The techniques to place and compact solid wastes in canyon/depression landfills vary with the geometry of the site, the characteristics of the available cover material, the hydrology and geology of the site, the type of leachate and gas control facilities to be used and the access to the site. (See Fig. 5.5)

Control of surface drainage often is a critical factor in development of canyon/depression sites. Typically, filling for each lift starts at the head end of the canyon and ends at the mouth, so as to prevent the accumulation of water behind the landfill canyon/depression sites; and the method of operation is essentially the same as the area method.

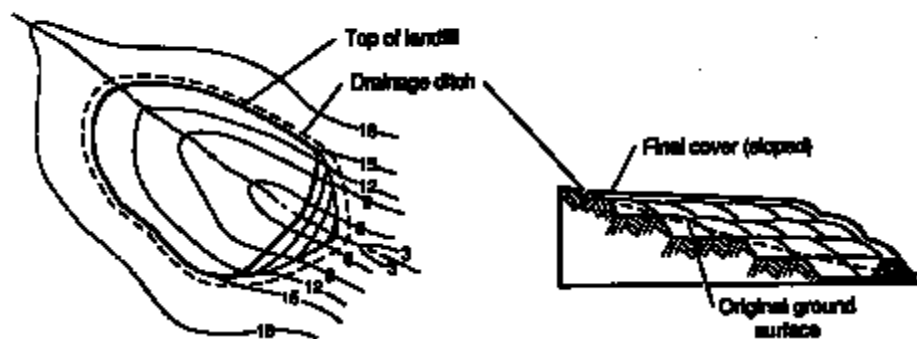


Fig. 5.5 The Canyon Method of Landfill

Landfill operations and processes may include the following:

- Landfill design
 - o Foundation design
 - o Liner design
 - o Leachate collection and gas collection
 - o Drainage design
- Landfill gas management
 - o Monitoring
 - o Collection
 - o Flaring or using
 - o Quantity and quality

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- o Filling design
- o Runoff collection
- o Closure design
- Landfill operations
 - o Waste inventory
 - o Cell layout
 - o Cells for hazardous waste
 - o Cells for non-hazardous waste
- Leachate management
 - o Collection
 - o Treatment
 - o Monitoring
 - o Reuse
- Environmental monitoring
 - o Air quality and odor monitoring
 - o CH₄, H₂S, VOCs, etc
 - o Groundwater monitoring
 - o Pests and litter
 - o Traffic
- Biochemical reactions in a landfill
 - o Biological decay rates
 - o Slowly biodegradable
 - o Rapidly biodegradable
 - o Non-biodegradable

Design of landfills should incorporate the following:

- Location of the landfill should consider
 - o Ecological and biological conditions
 - o Geological and hydrogeological conditions
 - o Existing and potential water supply sources
 - Groundwater
 - Surface water
 - o Historical and archeological sites
 - o Recreational areas

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- o Other planning issues, e.g. town and industrial development, agriculture, etc.
 - o Infrastructure requirements
 - Access possibilities
 - Transport distance
 - Treatment possibilities of the leachate
- Receiving area facilities
 - o Weightbridge for recording incoming waste according to type and origin
 - o Office and staff buildings
 - o Garage for machinery maintenance
 - o Containers where waste from individuals can be received so that they do not have to go to the deposit area
- Internal roads all the way to the deposit are that can carry the heavy loads from the heavy trucks and compactors
- Deposit area
 - o Size considering the amount of waste and other practical factors
 - o Fence to protect wind-blown litter
- Control and monitoring
 - o Controlling system has to ensure prohibition of banned wastes from disposal
 - o Monitoring system should cover: leachate, surface runoff, recipients, groundwater and noise
- Operation manual

Example: landfill area requirement

Determine the area required for a new landfill site with a projected life of 20 years for a population of 150000 generating 2.5 kg per household per

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day. Assume the density of waste is 400 kg/m³ and 5 persons per household. A planning restriction limits the height of the landfill to 10 m.

Solution:

Total waste generated = $2.5/5 \times (150000) = 75000 \text{ kg/day} = 27.375 \times 10^6 \text{ kg/year}$

Volume of landfill space required = $(27.375 \times 10^6)/400 = 68437.5 \text{ m}^3/\text{year}$

Required land area = $68437.5/10 = 6843.75 \text{ m}^2/\text{year}$

Increasing this are by 50% to allow for roads, receiving areas, fencing, etc, required area for 20 years becomes

$$A = 6843.75 \times 20 \times 1.5 = 205312.5 \text{ m}^2 = 21 \text{ ha}$$

5.3 Sources and types of hazardous wastes

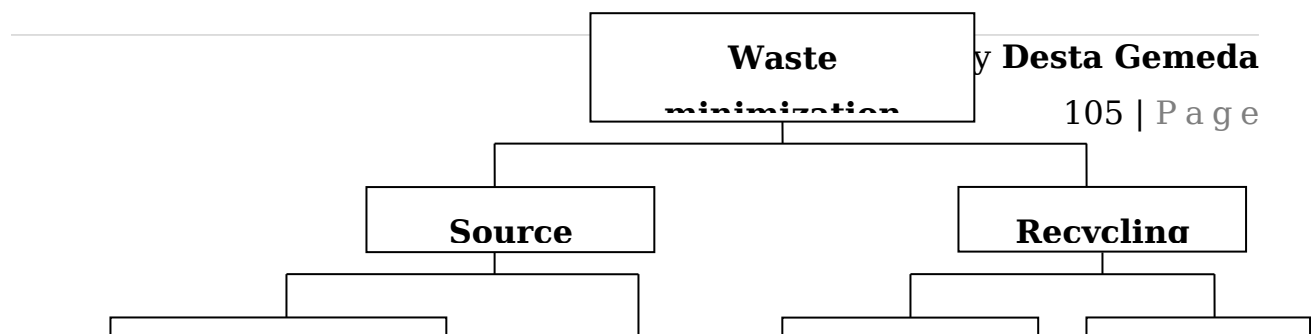
The term “hazardous waste” means a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical or infectious characteristics may:

- (a) cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or
- (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

5.3.1 Management options for hazardous wastes

Hazardous waste management options include waste minimization practices, and treatment and disposal facilities.

Waste minimization techniques



Treatment and disposal

- Thermal treatment- e.g. incineration
- Chemical treatment- e.g. neutralization
- Physical treatment- e.g. filtration
- Landfill

5.4 Handling of hazardous wastes

Necessary procedure to handle hazardous waste

1, Use Proper Storage Materials

In order to properly store hazardous materials, make sure to use appropriate hazardous waste storage containers. Use sealable containers that prevent the release of harmful chemical substances. Make sure that containers are compatible with the waste being stored and are manufactured with weather and corrosion resistant materials.

Ensure that all drums and storage containers have hazardous waste labels and are properly labeled with weather resistant labels.

2, Maintain Appropriate Storage Areas

Hazardous waste should be stored in a designated storage area that is inaccessible to unauthorized individuals. The area should be clearly identified as a hazardous waste storage area and should be designed to prevent secondary containment.

As part of your company procedures one of the most important practices is establish, perform and document weekly inspections of hazardous waste storage areas. A regular and thorough inspection will quickly reveal small problems that are easy to fix and prevent them from turning into large costly issues down the road.

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To help you with your procedures, we have created a handy weekly checklist for you to develop your procedures. You can download a free copy below.

3, Understand Your Requirements

What type of hazardous waste generator are you?

The Environmental Protection Agency (EPA) defines a hazardous waste generator as “any person or site whose processes and actions create hazardous waste.” Most businesses create waste in one form or another, therefore it is crucial for organizations to understand your hazardous waste generator status.

The EPA defines three separate classifications, including: Large Quantity Generators (LQG’s), Small Quantity Generators (SQG’s) and Conditionally Exempt Small Quantity Generators (CESQG’s).

Each classification must comply with its own set of regulations and processes with requirements being more stringent and costly the more waste produced. Complicating this process is the fact that waste generator status is measured on a monthly basis, and companies can change category from month to month based upon work flow and changes in production.

4, Train Your Employees

A well trained workforce is crucial to maintain a safe working environment. At a minimum, companies must ensure that all employees are thoroughly familiar with proper waste handling and emergency procedures, relevant to their responsibilities during normal facility operations and emergencies.

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For Large Quantity Generators, the training requirements are more stringent and include classroom instruction by a certified instructor or person trained in hazardous waste management procedures.

5, Keep and up-to-date contingency plan

Every hazardous waste generator is required to have an emergency contingency plan. A written Hazardous Waste Contingency Plan is a program designed to minimize hazards to human health and the environment from fires, explosions or an unplanned sudden release of a hazardous waste.

A proper contingency plan is developed by each facility owner or operator and establishes actions that must be immediately implemented during an emergency situation.

Your plan should lay out an organized, planned and coordinated response to an emergency. The type of contingency plan required for a facility depends on your hazardous waste generator status.

Follow these five tips and keep your facilities and employees protected. If you need help a qualified hazardous waste disposal company can help you establish proper protocols and handle your waste to keep you ahead of the regulators.

CHAPTER SIX

ENVIRONMENTAL IMPACT ASSESSMENT

6.1 Definition and purpose of EIA

Development policies, plans, programs and projects have effects on the local, regional and national environments. Sustainable development requires the assessment of these developmental activities against sustainability criteria. The assessment methods can conveniently be classified hierarchically as shown in Fig. 6.1.

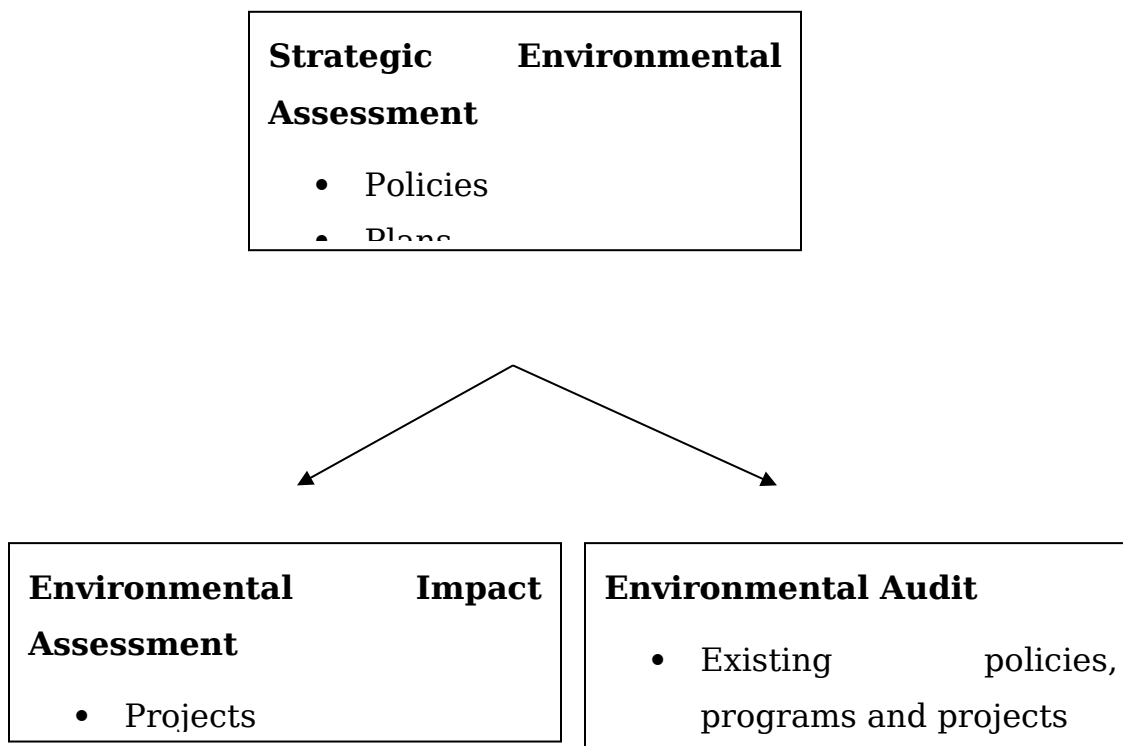


Fig. 6.1 Environmental assessment methods

Strategic Environmental Assessment (SEA)

SEA is applied to assess the environmental implications of policies, plans and programs. SEA is used to evaluate various policies such as land

policy, energy policy, industrial policy, etc. against sustainability requirements. It can also be used to investigate the interdependence, complementarity, and contradiction of various policies, plans and programs (PPPs) with respect to sustainable development.

6.2 The EIA process

6.2.1 Overview of the stages of the EIA process

This section very briefly presents an overview of the stages of EIA to help place them in the context of the whole process. More detail about each stage is provided later.

6.2.1.1 Screening

The EIA process begins from the very start of a project. Once a developer has identified a need and assessed all the possible alternatives of project design and sites to select a **preferred alternative**, two important questions must be asked: 'What will be the effects of this development on the environment? Are those effects significant?' If the answer to the second question is 'yes', an EIA may be required. Answering this question is a process known as **screening** and can be an essential first step into a formal EIA.

The EIA process is, it must be stressed, iterative. This is demonstrated at this early stage of screening where the requirement for a formal EIA and its associated cost implications can lead the developer to reassess the project design with a view to reducing the significant impacts to a level where an EIA is not legally required (Nielsen *et al* 2005).

6.2.1.2 Scoping

Where it is decided that a formal EIA is required, the next stage is to define the issues that need to be addressed, that is, those impacts that have a significant effect on the environment. This is known as **scoping** and is essential for focusing the available resources on the relevant issues.

6.2.1.3 Baseline study

Following on from scoping, it is essential to collect all relevant information on the current status of the environment. This study is referred to as a **baseline study** as it provides a baseline against which change due to a development can be measured.

6.2.1.4 Impact prediction

Once the baseline study information is available, the important task of **impact prediction** can begin. Impact prediction involves forecasting the likely changes in the environment that will occur as a result of the development.

6.2.1.5 Impact assessment

The next phase involves the assessment of the identified impacts - **impact assessment**. This requires interpretation of the importance or **significance** of the impacts to provide a conclusion, which can ultimately be used by decision-makers in determining the fate of the project application.

6.2.1.6 Mitigation

Frequently, the assessment of impacts will reveal damaging effects upon the environment. These may be alleviated by **mitigation** measures. Mitigation involves taking measures to reduce or remove environmental impacts and it can be seen that the iterative nature

of the EIA process is well demonstrated here. For example, successful design of mitigation measures could possibly result in the removal of all significant impacts; hence a new screening exercise would reveal that there might have been no need to carry out a formal EIA had the mitigation measures been included from the start.

6.2.1.7 Producing the environmental impact statement

The outcome of an EIA is usually a formal document, known as an **environmental impact statement (EIS)**, which sets out factual information relating to the development, and all the information gathered relating to screening, scoping, baseline study, impact prediction and assessment, mitigation, and monitoring measures. It is quite common that a requirement of an EIS is that it also produces a non-technical summary. This is a summary of the information contained within the EIS, presented in a concise non-technical format, for those who do not wish to read the detailed documents. This is very important, as EISs are public documents intended to inform the public of the nature and likely consequences of a development in time to comment and/or participate in the final project design.

6.2.1.8 EIS review

Once the EIA is complete, the EIS is submitted to the **competent authority**. This is the body with the authority to permit or refuse development applications. The competent authorities are often in a position of having very little time to make a decision and have a detailed and lengthy EIS to read through which may contain errors, omissions, and developer bias. It is essential, therefore, that they **review** the document. Review can take a number of forms: it may be purely an ad hoc process whereby the document is read and commented on by decision-makers; it can be more

formalised and expert opinion is sought; or it can be through the use of formal review methods designed specifically for the purpose. Basically, the review process should enable the decision-maker to decide whether the EIS is adequate (eg whether it is legally compliant), whether the information is correct, and whether it is unbiased. If it is, they are then in a position to use the EIS as information to be considered in determining whether the project should receive consent. This issue of review is discussed in more detail elsewhere in this module.

The competent authority is now in possession of the information they require about the possible effects of the development on the environment. They will use this information, in combination with all of the other details and representations they have received, to help them come to a decision.

CHAPTER SEVEN

ISSUES OF ENVIRONMENTAL POLICIES AND LEGISLATION

7.1 Definition

Environmental policy is the commitment of an organization or government to the laws, regulations, and other policy mechanisms concerning environmental issues. These issues generally include air and water pollution, waste management, ecosystem management, maintenance of biodiversity, the management of natural resources, wildlife and endangered species.

One way to describe environmental policy is that it comprises two major terms: environment and policy. Environment refers to the physical ecosystems, but can also take into consideration the social dimension (quality of life, health) and an economic dimension (resource management, biodiversity). Policy can be defined as a "course of action or principle adopted or proposed by a government, party, business or individual". Thus, environmental policy tends to focus on problems arising from human impact on the environment, which is important to human society by having a (negative) impact on human values. Such human values are often labelled as good health or the 'clean and green' environment.

7.2 Instruments, problems, and issues

Environmental policy instruments are tools used by governments and other organizations to implement their environmental policies. Governments, for example, may use a number of different types of instruments. For example, economic incentives and market-based instruments such as taxes and tax exemptions, tradable permits, and fees can be very effective to encourage compliance with environmental policy. The assumption is that corporations

and other organizations who engage in efficient environmental management and are transparent about their environmental data and reporting presumably benefit from improved business and organizational performance.

Bilateral agreements between the government and private firms and commitments made by firms independent of government requirement are examples of voluntary environmental measures. Another instrument is the implementation of greener public purchasing programs.

Several instruments are sometimes combined in a policy mix to address a particular environmental problem. Since environmental issues have many aspects, several policy instruments may be required to adequately address each one. Furthermore, a combination of different policies may give firms greater flexibility in policy compliance and reduce uncertainty as to the cost of such compliance.

Ideally, government policies are be carefully formulated so that the individual measures do not undermine one another, or create a rigid and cost-ineffective framework. Overlapping policies result in unnecessary administrative costs, increasing the cost of implementation. To help governments realize their policy goals, the OECD Environment Directorate, for example, collects data on the efficiency and consequences of environmental policies implemented by the national governments. The website, www.economicinstruments.com, provides database detailing countries' experiences with their environmental policies. The United Nations Economic Commission for Europe, through UNECE Environmental Performance Reviews, evaluates progress made by its member countries in improving their environmental policies.

The current reliance on a market-based framework has supporters and detractors. Among the detractors for example, some environmentalists contend that a more radical, overarching approach is needed than a set of specific initiatives, to deal with climate change. For example, energy efficiency measures may actually increase energy consumption in the absence of a cap on fossil fuel use, as people might drive more fuel-efficient cars. To combat this result, Aubrey Meyer calls for a 'framework-based market' of contraction and convergence. The Cap and Share and the Sky Trust are proposals based on the idea.

Environmental impact assessments (EIA) are conducted to compare impacts of various policy alternatives. Moreover, although it is often assumed that policymakers make rational decisions based on the merits of the project, Ecclestone and March argue that although policymakers normally have access to reasonably accurate environmental information, political and economic factors are important and often lead to policy decisions that rank environmental priorities of secondary importance.

The decision-making theory casts doubt on this premise. Irrational decisions are reached based on unconscious biases, illogical assumptions, and the desire to avoid ambiguity and uncertainty.

Ecclestone identifies and describes four of the most critical environmental policy issues facing humanity: water scarcity, food scarcity, climate change, and the population paradox.

7.3 Environmental policy integration

The concept of environmental policy integration (EPI) refers to the process of integrating environmental objectives into non-environmental policy areas, such as energy, agriculture and transport, rather than leaving them to be

pursued solely through purely environmental policy practices. This is oftentimes particularly challenging because of the need to reconcile global objectives and international rules with domestic needs and laws. EPI is widely recognised as one of the key elements of sustainable development. More recently, the notion of 'climate policy integration', also denoted as 'mainstreaming', has been applied to indicate the integration of climate considerations (both mitigation and adaptation) into the normal (often economically focused) activity of government.