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ONLINE COURSE WARE

SUBJECT NAME: Environmental Engineering

SUBJECT CODE: CH(FT)301

CREDIT: 2

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Population Growth

Exponential & logistic growth

- In exponential growth, a population's *per capita* (per individual) growth rate stays the same regardless of population size, making the population grow faster and faster as it gets larger.
- In nature, populations may grow exponentially for some period, but they will ultimately be limited by resource availability.
- In logistic growth, a population's *per capita* growth rate gets smaller and smaller as population size approaches a maximum imposed by limited resources in the environment, known as the carrying capacity.
- Exponential growth produces a J-shaped curve, while logistic growth produces an S-shaped curve.

Exponential growth and decay: a differential equation

The general idea is that, instead of solving equations to find unknown numbers, we might solve equations to find unknown functions. There are many possibilities for what this might mean, but one is that we have an unknown function y of x and are given that y and its derivative y′ (with respect to x) satisfy a relation

$$y'=ky$$

where, k is some constant. Such a relation between an unknown function and its derivative (or derivatives) is what is called a differential equation. Many basic ‘physical principles’ can be written in such terms, using ‘time’ tt as the independent variable.

Having been taking derivatives of exponential functions, a person might remember that the function $f(t)=e^{kt}$ has exactly this property:

$$d/dt(e^{kt})=k\cdot e^{kt}$$

For that matter, any constant multiple of this function has the same property: $d/dt(c\cdot e^{kt})=k\cdot c\cdot e^{kt}$

And it turns out that these really are all the possible solutions to this differential equation.

There is a certain buzz-phrase which is supposed to alert a person to the occurrence of this little story: if a function f has exponential growth or exponential decay then that is taken to mean that ff can be written in the form

$$f(t)=c\cdot e^{kt}$$

If the constant k is positive it has exponential growth and if k is negative then it has exponential decay.

Carrying capacity and the Logistic model

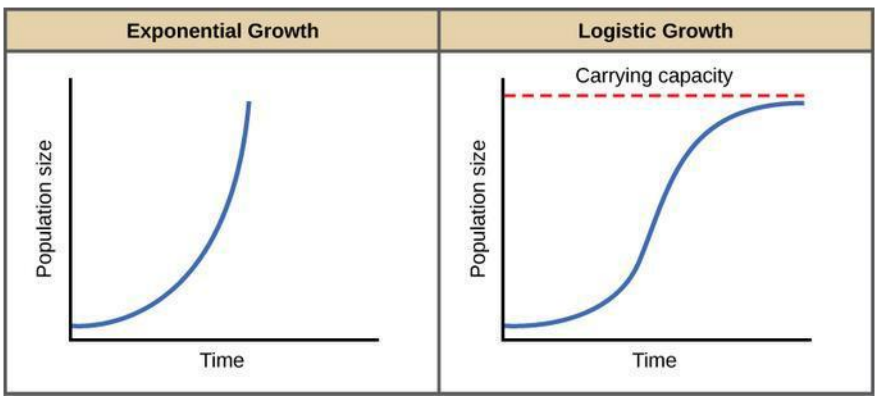
In the real world, with its limited resources, exponential growth cannot continue indefinitely. Exponential growth may occur in environments where there are few individuals and plentiful resources, but when the number of individuals becomes large enough, resources will be depleted, slowing the growth rate. Eventually, the growth rate will plateau or level off. This population size, which represents the maximum population size that a particular environment can support, is called the carrying capacity, or K.

The formula we use to calculate logistic growth adds the carrying capacity as a moderating force in the growth rate. The expression "K – N" is indicative of how many individuals may be added to a population at a given stage, and "K – N" divided by "K" is the fraction of the carrying capacity available for further growth. Thus, the exponential growth model is restricted by this factor to generate the logistic growth equation:

$$dN/dT= r_{max}\times(dN/dT)=r_{max}\times N\times((KN)/K)$$

Notice that when N is very small, (K-N)/K becomes close to K/K or 1; the right side of the equation reduces to $r_{max}N$, which means the population is growing exponentially and is not influenced by carrying capacity. On the other hand, when N is large, (K-N)/K come close to zero, which means that population growth will be slowed greatly or even stopped. Thus, population growth is greatly slowed in large populations by the carrying capacity K. This model also allows for negative population growth or a population decline. This occurs when the number of individuals in the population exceeds the carrying capacity (because the value of (K-N)/K is negative).

A graph of this equation yields an S-shaped curve; it is a more-realistic model of population growth than exponential growth. There are three different sections to an S-shaped curve. Initially, growth is exponential because there are few individuals and ample resources available. Then, as resources begin to become limited, the growth rate decreases. Finally, growth levels off at the carrying capacity of the environment, with little change in population size over time.



Material Balance

A mass balance, also called a material balance, is an application of conservation of mass to the analysis of physical systems. By accounting for material entering and leaving a system, mass flows can be identified which might have been unknown, or difficult to measure without this technique. The exact conservation law used in the analysis of the system depends on the context of the problem, but all revolve around mass conservation, i.e. that matter cannot disappear or be created spontaneously.

The general form quoted for a mass balance is *The mass that enters a system must, by conservation of mass, either leave the system or accumulate within the system*.

Mathematically the mass balance for a system without a chemical reaction is as follows: Input= output+ accumulation

Strictly speaking the above equation holds also for systems with chemical reactions if the terms in the balance equation are taken to refer to total mass, i.e. the sum of all the chemical species of the system. In the absence of a chemical reaction the amount of any chemical species flowing in and out will be the same; this gives rise to an equation for each species present in the system. However, if this is not the case then the mass balance equation must be amended to allow for the generation or depletion (consumption) of each chemical species. Some use one term in this equation to account for chemical reactions, which will be negative for depletion and positive for generation. However, the conventional form of this equation is written to account for both a positive generation term (i.e. product of reaction) and a negative consumption term (the reactants used to produce the products). Although overall one term will account for the total balance on the system, if this balance equation is to be applied to an individual species and then the entire process, both terms are necessary. This modified equation can be used not only for reactive systems, but for population balances such as arise in particle mechanics problems. The equation is given below; note that it simplifies to the earlier equation in the case that the generation term is zero.

Input+generation= output+ accumulation+consumption

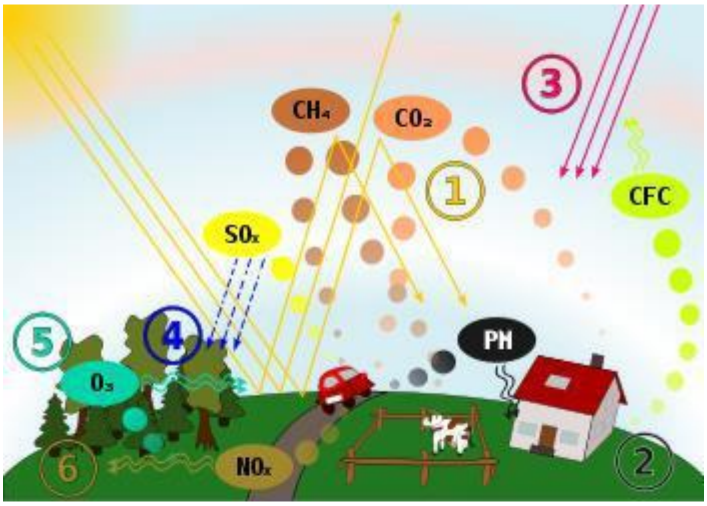
- In the absence of a nuclear reaction the number of atoms flowing in and out must remain the same, even in the presence of a chemical reaction.
- For a balance to be formed, the boundaries of the system must be clearly defined.
- Mass balances can be taken over physical systems at multiple scales.
- Mass balances can be simplified with the assumption of steady state, in which the accumulation term is zero.

Air Pollution

Introduction

Air is the ocean we breathe. Air supplies us with *oxygen* which is essential for our bodies to live. Air is 99.9% nitrogen, oxygen, water vapour and inert gases. Human activities can release substances into the air, some of which can cause problems for humans, plants, and animals. There are several main *types* of pollution and well-known *effects* of pollution which are commonly discussed. These include smog, acid rain, the greenhouse effect, and "holes" in the ozone layer. Each of these problems has serious implications for our health and well-being as well as for the whole environment. The atmosphere is a complex dynamic natural gaseous system that is essential to support life on planet Earth. Stratospheric ozone depletion due to air pollution has long been recognized as a threat to human health as well as to the Earth's ecosystems. Indoor air pollution and urban air quality are listed as two of the world's worst pollution problems in the 2008 Blacksmith Institute World's Worst Polluted Places report.

Pollutants



Schematic drawing, causes and effects of air pollution: (1) greenhouse effect, (2) particulate contamination, (3) increased UV radiation, (4) acid rain, (5) increased ground level ozone concentration, (6) increased levels of nitrogen oxides.

An air pollutant is known as a substance in the air that can cause harm to humans and the environment. Pollutants can be in the form of solid particles, liquid droplets, or gases. In addition, they may be natural or man-made.

Pollutants can be classified as primary or secondary. Usually, primary pollutants are directly emitted from a process, such as ash from a volcanic eruption, the carbon monoxide gas from a motor vehicle exhaust or sulphur dioxide released from factories. Secondary pollutants are not emitted directly. Rather, they form in the air when primary pollutants react or interact. An important example of a secondary pollutant is ground level ozone — one of the many secondary pollutants that make up photochemical smog. Some pollutants may be both primary and secondary: that is, they are both emitted directly and formed from other primary pollutants.

About 4 percent of deaths in the United States can be attributed to air pollution, according to the Environmental Science Engineering Program at the Harvard School of Public Health.

Major primary pollutants produced by human activity include:

- Sulphur oxides (SO_x) - especially sulphur dioxide, a chemical compound with the formula SO_2. SO_2 is produced by volcanoes and in various industrial processes. Since coal and petroleum often contain sulphur compounds, their combustion generates sulphur dioxide. Further oxidation of SO_2, usually in the presence of a catalyst such as NO_2, forms H_2SO_4, and thus acid rain.[2] This is one of the causes for concern over the environmental impact of the use of these fuels as power sources.
- Nitrogen oxides (NO_x) - especially nitrogen dioxide are emitted from high temperature combustion. Can be seen as the brown haze dome above or plume downwind of cities. Nitrogen dioxide is the chemical compound with the formula NO_2. It is one of the several nitrogen oxides. This reddish-brown toxic gas has a characteristic sharp, biting odor. NO_2 is one of the most prominent air pollutants.
- Carbon monoxide - is a colourless, odourless, non-irritating but very poisonous gas. It is a product by incomplete combustion of fuel such as natural gas, coal or wood. Vehicular exhaust is a major source of carbon monoxide.
- Carbon dioxide (CO_2) - a colourless, odourless, non-toxic greenhouse gas associated with ocean acidification, emitted from sources such as combustion, cement production, and respiration
- Volatile organic compounds - VOCs are an important outdoor air pollutant. In this field they are often divided into the separate categories of methane (CH_4) and non-methane (NMVOCs). Methane is an extremely efficient greenhouse gas which contributes to enhance global warming. Other hydrocarbon VOCs are also significant greenhouse gases via their role in creating ozone and in prolonging the life of methane in the atmosphere, although the effect varies depending on local air quality. Within the NMVOCs, the aromatic compounds benzene, toluene and xylene are suspected carcinogens and may lead to leukaemia through prolonged exposure. 1,3-butadiene is another dangerous compound which is often associated with industrial uses.
- Particulate matter - Particulates alternatively referred to as particulate matter (PM) or fine particles, are tiny particles of solid or liquid suspended in a gas. In contrast, aerosol refers to particles and the gas together. Sources of particulate matter can be manmade or natural. Some particulates occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels in vehicles, power plants and various industrial processes also generate significant amounts of aerosols. Averaged over the globe, anthropogenic aerosols—those made by human activities—currently account for about 10 percent of the total amount of aerosols in our atmosphere. Increased levels of fine particles in the air are linked to health hazards such as heart disease,[3] altered lung function and lung cancer.
- Persistent free radicals connected to airborne fine particles could cause cardiopulmonary disease.[4][5]

- Toxic metals, such as lead, cadmium and copper.
- Chlorofluorocarbons (CFCs) - harmful to the ozone layer emitted from products currently banned from use.
- Ammonia (NH_3) - emitted from agricultural processes. Ammonia is a compound with the formula NH_3. It is normally encountered as a gas with a characteristic pungent odour. Ammonia contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to foodstuffs and fertilizers. Ammonia, either directly or indirectly, is also a building block for the synthesis of many pharmaceuticals. Although in wide use, ammonia is both caustic and hazardous.
- Odours — such as from garbage, sewage, and industrial processes
- Radioactive pollutants - produced by nuclear explosions, war explosives, and natural processes such as the radioactive decay of radon.

Secondary pollutants include:

- Particulate matter formed from gaseous primary pollutants and compounds in photochemical smog. Smog is a kind of air pollution; the word "smog" is a portmanteau of smoke and fog. Classic smog results from large amounts of coal burning in an area caused by a mixture of smoke and sulphur dioxide. Modern smog does not usually come from coal but from vehicular and industrial emissions that are acted on in the atmosphere by ultraviolet light from the sun to form secondary pollutants that also combine with the primary emissions to form photochemical smog.
- Ground level ozone (O_3) formed from NO_x and VOCs. Ozone (O_3) is a key constituent of the troposphere. It is also an important constituent of certain regions of the stratosphere commonly known as the Ozone layer. Photochemical and chemical reactions involving it drive many of the chemical processes that occur in the atmosphere by day and by night. At abnormally high concentrations brought about by human activities (largely the combustion of fossil fuel), it is a pollutant, and a constituent of smog.
- Peroxyacetyl nitrate (PAN) - similarly formed from NO_x and VOCs.

Minor air pollutants include:

- A large number of minor hazardous air pollutants. Some of these are regulated in USA under the Clean Air Act and in Europe under the Air Framework Directive.
- A variety of persistent organic pollutants, which can attach to particulate matter.

Persistent organic pollutants (POPs) are organic compounds that are resistant to environmental degradation through chemical, biological, and photolytic processes. Because of this, they have been observed to persist in the environment, to be capable of long-range transport, bioaccumulation in human and animal tissue, biomagnified in food chains, and to have potential significant impacts on human health and the environment.

Sources of Pollutants

The two main sources of pollutants in urban areas are transportation (predominantly automobiles) and fuel combustion in stationary sources, including residential, commercial, and industrial heating and cooling and coal-burning power plants. Motor vehicles produce high levels of carbon monoxides (CO) and a major source of hydrocarbons (HC) and nitrogen oxides (NOx). Whereas, fuel combustion in stationary sources is the dominant source of sulfur dioxide (SO2).

Carbon Dioxide

Carbon dioxide (CO_2) is one of the major pollutants in the atmosphere. Major sources of CO_2 are fossil fuels burning and deforestation. "The concentrations of CO_2 in the air around 1860 before the effects of industrialization were felt, is assumed to have been about 290 parts per million (ppm). In the hundred years and more since then, the concentration has increased by about 30 to 35 ppm that is by 10 percent". (Breuer 67) Industrial countries account for 65% of CO_2 emissions with the United States and Soviet Union responsible for 50%. Less developed countries (LDCs), with 80% of the world's people, are responsible for 35% of CO_2 emissions but may contribute 50% by 2020. "Carbon dioxide emissions are increasing by 4% a year". (Miller 450)

In 1975, 18 thousand million tons of carbon dioxide (equivalent to 5 thousand million tons of carbon) was released into the atmosphere, but the atmosphere showed an increase of only 8 billion tons (equivalent to 2.2 billion tons of carbon". (Breuer 70) The ocean waters contain about sixty times more CO_2 than the atmosphere. If the equilibrium is disturbed by externally increasing the concentration of CO_2 in the air, then the oceans would absorb more and more CO_2. If the oceans can no longer keep pace, then more CO_2 will remain into the atmosphere. As water warms, its ability to absorb CO_2 is reduced.

CO_2 is a good transmitter of sunlight, but partially restricts infrared radiation going back from the earth into space. This produces the so-called greenhouse effect that prevents a drastic cooling of the Earth during the night. Increasing the amount of CO_2 in the atmosphere reinforces this effect and is expected to result in a warming of the Earth's surface. Currently carbon dioxide is responsible for 57% of the global warming trend. Nitrogen oxides contribute most of the atmospheric contaminants.

NO_X - nitric oxide (NO) and nitrogen dioxide (NO_2)

- Natural component of the Earth's atmosphere.
    - Important in the formation of both acid precipitation and photochemical smog (ozone), and causes nitrogen loading.
- Comes from the burning of biomass and fossil fuels.
    - 30 to 50 million tons per year from human activities, and natural 10 to 20 million tons per year.
    - Average residence time in the atmosphere is days. Has a role in reducing stratospheric ozone.

N_2O - nitrous oxide

- Natural component of the Earth's atmosphere.
- Important in the greenhouse effect and causes nitrogen loading.
    - Human inputs 6 million tons per year, and 19 million tons per year by nature. Residence time in the atmosphere about 170 years.
- 1700 (285 parts per billion), 1990 (310 parts per billion), 2030 (340 parts per billion).

Comes from nitrogen based fertilizers, deforestation, and biomass burning.

Sulphur and chlorofluorocarbons (CFCs)

Sulphur dioxide is produced by combustion of sulphur-containing fuels, such as coal and fuel oils. Also, in the process of producing sulphuric acid and in metallurgical process involving ores that contain sulphur. Sulphur oxides can injure man, plants and materials. At sufficiently high concentrations, sulphur dioxide irritates the upper respiratory tract of human beings because potential effect of sulphur dioxide is to make breathing more difficult by causing the finer air tubes of the lung to constrict. "Power plants and factories emit 90% to 95% of the sulphur dioxide and 57% of the nitrogen oxides in the United States. Almost 60% of the SO2 emissions are released by tall smoke stakes, enabling the emissions to travel long distances". (Miller 494) As emissions of sulphur dioxide and nitric oxide from stationary sources are transported long distances by winds, they form secondary pollutants such as nitrogen dioxide, nitric acid vapour, and droplets containing solutions of sulphuric acid, sulphate, and nitrate salts. These chemicals descend to the earth's surface in wet form as rain or snow and in dry form as a gases fog, dew, or solid particles. This is known as acid deposition or acid rain.

Chlorofluorocarbons (CFCs)

CFCs are lowering the average concentration of ozone in the stratosphere. "Since 1978 the use of CFCs in aerosol cans has been banned in the United States, Canada, and most Scandinavian countries. Aerosols are still the largest use, accounting for 25% of global CFC use". (Miller 448) Spray cans, discarded or leaking refrigeration and air conditioning equipment, and the burning plastic foam products release the CFCs into the atmosphere. Depending on the type, CFCs stay in the atmosphere from 22 to 111 years. Chlorofluorocarbons move up to the stratosphere gradually over several decades. Under high energy ultra violet (UV) radiation, they break down and release chlorine atoms, which speed up the breakdown of ozone (O3) into oxygen gas (O2).

Chlorofluorocarbons, also known as Freons, are greenhouse gases that contribute to global warming. Photochemical air pollution is commonly referred to as "smog". Smog, a contraction of the words smoke and fog, has been caused throughout recorded history by water condensing on smoke particles, usually from burning coal. With the introduction of petroleum to replace coal economies in countries, photochemical smog has become predominant in many cities, which are located in sunny, warm, and dry climates with many motor vehicles. The worst episodes of photochemical smog tend to occur in summer.

Smog

Photochemical smog is also appearing in regions of the tropics and subtropics where savanna grasses are periodically burned. Smog's unpleasant properties result from the irradiation by sunlight of hydrocarbons caused primarily by unburned gasoline emitted by automobiles and other combustion sources. The products of photochemical reactions include organic particles, ozone, aldehydes, ketones, peroxyacetyl nitrate, organic acids, and other oxidants. Ozone is a gas created by nitrogen dioxide or nitric oxide when exposed to sunlight. Ozone causes eye irritation, impaired lung function, and damage to trees and crops. Another form of smog is called industrial smog.

This smog is created by burning coal and heavy oil that contain sulphur impurities in power plants, industrial plants, etc... The smog consists mostly of a mixture of sulphur dioxide and fog. Suspended droplets of sulphuric acid are formed from some of the sulphur dioxide, and a variety of suspended solid particles. This smog is common during the winter in cities such as London, Chicago, and Pittsburgh. When these cities burned large amounts of coal and heavy oil without control of the output, large-scale problems were witnessed. In 1952 London, England, 4,000 people died as a result of this form of fog. Today coal and heavy oil are burned only in large boilers and with reasonably good control or tall smokestacks so that industrial smog is less of a problem. However, some countries such as China, Poland, Czechoslovakia, and some other eastern European countries, still burn large quantities of coal without using adequate controls.

Causes of Air Pollution

Increase in urban population

Between 1951 and 1991, the urban population has tripled, from 62.4 million to 217.6 million, and its proportion has increased from 17.3% to 25.7%. Nearly two-thirds of the urban population is concentrated in 317 class I cities (population of over 100 000), half of which lives in 23 metropolitan areas with populations exceeding 1 million. The number of urban agglomerations/cities with populations of over a million has increased from 5 in 1951 to 9 in 1971 and 23 in 1991 (Pachauri and Sridharan 1998). This rapid increase in urban population has resulted in unplanned urban development, increase in consumption patterns and higher demands for transport, energy, other infrastructure, thereby leading to pollution problems.

Increase in number of vehicles

The number of motor vehicles has increased from 0.3 million in 1951 to 37.2 million in 1997 (Most 2000). Out of these, 32% are concentrated in 23 metropolitan cities. Delhi itself accounts for about 8% of the total registered vehicles and has more registered vehicles than those in the other three metros (Mumbai, Calcutta, and Chennai) taken together. At the all-India level, the percentage of two-wheeled vehicles in the total number of motor vehicles increased from 9% in 1951 to 69% in 1997, and the share of buses declined from 11% to 1.3% during the same period (MoST 2000). This clearly points to a tremendous increase in the share of personal transport vehicles. In 1997, personal transport vehicles (two-wheeled vehicles and cars only) constituted 78.5% of the total number of registered vehicles. Road-based passenger transport has recorded very high growth in recent years especially since 1980-81. It is estimated that the roads accounted for 44.8 billion passenger kilometre (PKM) in 1951 which has since grown to 2,515 billion PKM in 1996. The freight traffic handled by road in 1996 was about 720 billion tonne kilometre (TKM) which has increased from 12.1 TKM in 1951 (Most 1996). In contrast, the total road network has increased only 8 times from 0.4 million kms in 1950-51 to 3.3 million kms in 1995-96. The slow growth of road infrastructure and high growth of transport performance and number of vehicles all imply that Indian roads are reaching a saturation point in utilising the existing capacities. The consumption of gasoline and HSD has grown more than 3 times during the period 1980-1997. While the consumption of gasoline and HSD were 1,522 and 9,050 thousand tonnes in

1980-81, it increased to 4,955 and 30,357 thousand tonnes in 1996-97, respectively (CMIE 2000).

Increase in industrial activity

India has made rapid strides in industrialisation, and it is one of the ten most industrialised nations of the world. But this status, has brought with it unwanted and unanticipated consequences such as unplanned urbanisation, pollution and the risk of accidents. The CPCB (Central Pollution Control Board) has identified seventeen categories of industries (large and medium scale) as significantly polluting and the list includes highly air polluting industries such as integrated iron and steel, thermal power plants, copper/zinc/aluminium smelters, cement, oil refineries, petrochemicals, pesticides and fertiliser units. The state-wise distribution of these pre- 1991 industries indicates that the states of Maharashtra, Uttar Pradesh, Gujarat, Andhra Pradesh and Tamil Nadu have a large number of industries in these sectors. The category wise distribution of these units reveals that sugar sector has the maximum number of industries, followed by pharmaceuticals, distillery, cement and fertiliser. It also indicates that agro-based and chemical industries have major shares of 47% and 37% of the total number of industries respectively. The status of pollution control as on 30 June 2000 is as follows: out of 1,551 industries, 1,324 have so far been provided the necessary pollution control facilities, 165 industries have been closed down and the remaining 62 industries are defaulters (CPCB 2000a). It may be noted that in some of the key sectors such as iron and steel, 6 out of 8 units belong to the defaulters' category in terms of having pollution control facilities to comply with the standards. On the other hand, cement, petrochemicals and oil refinery sectors do not have any defaulters. Small scale industries are a special feature of the Indian economy and play an important role in pollution. India has over 3 million small scale units accounting for over 40 percent of the total industrial output in the country (CII and SII 1996). In general, Indian small scale industries lack pollution control mechanisms. While the larger industries are better organised to adopt pollution control measures, the small scale sector is poorly equipped (both financially and technically) to handle this problem. They have a very high aggregate pollution potential. Also, in many urban centres, industrial units are located in densely populated areas, thereby affecting a large number of people.

Increase in power generation

Since 1950-51, the electricity generation capacity in India has multiplied 55 times from a meagre 1.7 thousand MW to 93.3 thousand MW (MoF 2000). The generating capacity in India comprises a mix of hydro, thermal, and nuclear plants. Since the early seventies, the hydro-thermal capacity mix has changed significantly with the share of hydro in total capacity declining from 43% in 1970-71 to 24% in 1998-99. Thermal power constitutes about 74% of the total installed power generation capacity. However, increasing reliance on this source of energy leads to many environmental problems. India's coal has a very high in ash content (24%–45%). The increased dependence of the power sector on an inferior quality coal has been associated with emissions from power plants in the form of particulate matter, toxic elements, fly ash, and oxides of nitrogen, sulphur and carbon besides ash, which required vast stretches of land for disposal. During 1998-99, the power stations consumed

208 million tonnes of coal, which in turn produced 80 million tonnes of ash posing a major problem disposal (CPCB 2000b). Thermal power plants belong to the 17 categories of highly polluting industries. As on 30 June 2000, out of the 97 pre-1991 TPP's, 20 plants had not yet provided the requisite pollution control facilities (CPCB 2000a).

Domestic pollution

Pollution from different types of cooking stoves using coal, fuel wood, and other biomass fuels contributes to some extent, to the overall pollution load in urban areas. For example, in Delhi, the share of the domestic sector is about 7%–8% of the total pollution load (MoEF 1997). The main concern is the use of inefficient and highly polluting fuels in the poorer households leading to deterioration in indoor air-quality and health. However, a positive development in the domestic energy consumption is that liquefied petroleum gas is fast becoming the most popular cooking fuel, especially in urban areas, as it is cleaner and more efficient than traditional cooking fuels.

Other sources

The problem of air pollution in urban areas is also aggravated due to inadequate power supply for industrial, commercial and residential activities due to, which consumers have to use diesel-based captive power generation units emitting high levels NO_X and SO_X. In addition, non-point sources such as waste burning, construction activities, and roadside air borne dust due to vehicular movement also contribute to the total emission load.

Ambient air quality

Under the National Ambient Air Quality Monitoring (NAAQM) network, three criteria air pollutants, namely, SPM, SO_2, and NO_2 have been identified for regular monitoring at all the 290 stations spread across the country. CPCB (2000c) analyses the status and trends of air quality at various cities in India for the period 1990-98. The most prevalent form of air pollution appears to be SPM although there are many stations at which SO2 and NO2 levels exceed permissible limits. The high influx of population to urban areas increase in consumption patterns, unplanned urban and industrial development and poor enforcement mechanism has led to the problem of air pollution. The government has taken a number of measures such as legislation, emission standards for industries, guidelines for siting of industries, environmental audit, EIA, vehicular pollution control measures, pollution prevention technologies, action plan for problem areas, development of environmental standards, and promotion of environmental awareness. However, despite all these measures, air pollution still remains one of the major environmental problems. At the same time, there have been success stories as well such as the reduction of ambient lead levels (due to introduction of unleaded petrol) and comparatively lower SO2 levels (due to progressive reduction of sulphur content in fuel).

SPM

Suspended particulate matter is one of the most critical air pollutants in most of the urban areas in the country and permissible standards are frequently violated several monitored locations. Its levels have been consistently high in various cities over the past several years. The annual average minimum and maximum SPM concentration in residential areas of various cities ranged from 60 µg/m3 (at Bangalore during 1991) to 521 µg/m3 (at Patna during 1995), while in industrial areas the annual average ranged between 53 μg/m3 (Chennai during 1992) and 640 μg/m3 (Calcutta during 1993). The mean of average values of SPM for nine years (1990 to 1998) ranged between 99 μg/m3 and 390 μg/m3 in residential areas and between 123 μg/m3 and 457 μg/m3 in industrial areas indicating that the annual average limit of suspended particulate matter for residential areas (140 μg/m3) and for industrial areas (360 μg/m3) had been frequently violated in most cities. The maximum suspended particulate matter (SPM) values were observed in Kanpur, Calcutta, and Delhi, while low values have been recorded in the south Indian cities of Chennai, Bangalore, and Hyderabad. The SPM non-attainment areas are dispersed throughout the country. The states with maximum SPM problems are Gujarat, Maharashtra, and Madhya Pradesh, where SPM problems are high to critical in a large number of cities. The widespread criticality of the SPM problem in the country is due to the synergistic effects of both anthropogenic and natural sources. Some of these are extensive urbanisation and construction activities, vehicular pollution increase, extensive use of fossil fuel in industrial activities, inadequacy of pollution control measures, biomass burning, presence of large acid and semi-acid area in north-west part of India, increasing desertification, and decreasing vegetation cover.

Health effects

The World Health Organization states that 2.4 million people die each year from causes directly attributable to air pollution, with 1.5 million of these deaths attributable to indoor air pollution. "Epidemiological studies suggest that more than 500,000 Americans die each year from cardiopulmonary disease linked to breathing fine particle air pollution. . ." A study by the University of Birmingham has shown a strong correlation between pneumonia related deaths and air pollution from motor vehicles. Worldwide more deaths per year are linked to air pollution than to automobile accidents. Published in 2005 suggests that 310,000 Europeans die from air pollution annually. Direct causes of air pollution related deaths include aggravated asthma, bronchitis, emphysema, lung and heart diseases, and respiratory allergies. The US EPA estimates that a proposed set of changes in diesel engine technology (*Tier 2*) could result in 12,000 fewer *premature mortalities*, 15,000 fewer heart attacks, 6,000 fewer emergency room visits by children with asthma, and 8,900 fewer respiratory-related hospital admissions each year in the United States.

The worst short term civilian pollution crisis in India was the 1984 Bhopal Disaster. Leaked industrial vapours from the Union Carbide factory, belonging to Union Carbide, Inc., U.S.A., killed more than 2,000 people outright and injured anywhere from 150,000 to 600,000 others, some 6,000 of whom would later die from their injuries. The United Kingdom suffered its worst air pollution event when the December 4 Great Smog of 1952 formed over London. In six days more than 4,000 died, and 8,000 more died within the following months. An accidental leak of anthrax spores from a biological warfare laboratory in the former USSR in 1979 near Sverdlovsk is believed to have been the cause of hundreds of civilian deaths. The worst single incident of air pollution to occur in the United States of America occurred in Donora, Pennsylvania in late October, 1948, when 20 people died and over 7,000 were injured.

The health effects caused by air pollutants may range from subtle biochemical and physiological changes to difficulty in breathing, wheezing, coughing and aggravation of existing respiratory and cardiac conditions. These effects can result in increased medication use, increased doctor or emergency room visits, more hospital admissions and premature death. 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, the individual's health status and genetics.

A new economic study of the health impacts and associated costs of air pollution in the Los Angeles Basin and San Joaquin Valley of Southern California shows that more than 3800 people die prematurely (approximately 14 years earlier than normal) each year because air pollution levels violate federal standards. The number of annual premature deaths is considerably higher than the fatalities related to auto collisions in the same area, which average fewer than 2,000 per year.

Diesel exhaust (DE) is a major contributor to combustion derived particulate matter air pollution. In several human experimental studies, using a well validated exposure chamber setup, DE has been linked to acute vascular dysfunction and increased thrombus formation. This serves as a plausible mechanistic link between the previously described association between particulate matter air pollution and increased cardiovascular morbidity and mortality.

Effects on cystic fibrosis

A study from 1999 to 2000 by the University of Washington showed that patients near and around particulate matter air pollution had an increased risk of pulmonary exacerbations and decrease in lung function. Patients were examined before the study for amounts of specific pollutants like *Pseudomonas aeruginosa* or *Burkholderia cenocepacia* as well as their socioeconomic standing. Participants involved in the study were located in the United States in close proximity to an Environmental Protection Agency. During the time of the study 117 deaths were associated with air pollution. A trend was noticed that patients living closer or in large metropolitan areas to be close to medical help also had higher level of pollutants found in their system because of more emissions in larger cities. With cystic fibrosis patients already being born with decreased lung function everyday pollutants such as smoke emissions from automobiles, tobacco smoke and improper use of indoor heating devices could add to the disintegration of lung function.

Effects on COPD

Chronic obstructive pulmonary disease (COPD) include diseases such as chronic bronchitis, emphysema, and some forms of asthma.

A study conducted in 1960-1961 in the wake of the Great Smog of 1952 compared 293 London residents with 477 residents of Gloucester, Peterborough, and Norwich, three towns with low reported death rates from chronic bronchitis. All subjects were male postal truck drivers aged 40 to 59. Compared to the subjects from the outlying towns, the London subjects exhibited more severe respiratory symptoms (including cough, phlegm, and dyspnoea), reduced lung function (FEV_1 and peak flow rate), and increased sputum production and purulence. The differences were more pronounced for subjects aged 50 to 59. The study controlled for age and smoking habits, so concluded that air pollution was the most likely cause of the observed differences.

It is believed that much like cystic fibrosis, by living in a more urban environment serious health hazards become more apparent. Studies have shown that in urban areas patients suffer mucus hyper secretion, lower levels of lung function, and more self diagnosis of chronic bronchitis and emphysema.

The Great Smog of 1952

Early in December 1952, a cold fog descended upon London. Because of the cold, Londoners began to burn more coal than usual. The resulting air pollution was trapped by the inversion layer formed by the dense mass of cold air. Concentrations of pollutants, coal smoke in particular, built up dramatically. The problem was made worse by use of low-quality, high-sulphur coal for home heating in London in order to permit export of higher-quality coal, because of the country's tenuous post-war economic situation. The "fog", or smog, was so thick that driving became difficult or impossible. The extreme reduction in visibility was accompanied by an increase in criminal activity as well as transportation delays and a virtual shut down of the city. During the 4 day period of fog, at least 4,000 people died as a direct result of the weather.

Effects on children

Cities around the world with high exposure to air pollutants have the possibility of children living within them to develop asthma, pneumonia and other lower respiratory infections as well as a low initial birth rate. Protective measures to ensure the youths' health are being taken in cities such as New Delhi, India where buses now use compressed natural gas to help eliminate the “pea-soup” smog. Research by the World Health Organization shows there is the greatest concentration of particulate matter particles in countries with low economic world power and high poverty and population rates. Examples of these countries include Egypt, Sudan, Mongolia, and Indonesia. The Clean Air Act was passed in 1970; however in 2002 at least 146 million Americans were living in areas that did not meet at least one of the “criteria pollutants” laid out in the 1997 National Ambient Air Quality Standards. Those pollutants included: ozone, particulate matter, sulphur dioxide, nitrogen dioxide, carbon monoxide, and lead. Because children are outdoors more and have higher minute ventilation they are more susceptible to the dangers of air pollution.

Health effects in relatively "clean" areas

Even in areas with relatively low levels of air pollution, public health effects can be substantial and costly. This is because effects can occur at very low levels and a large number of people can potentially breathe in such pollutants. A 2005 scientific study for the British Columbia Lung Association showed that a 1% improvement in ambient PM2.5 and ozone concentrations will produce a $29 million in annual savings in the region in 2010. This finding is based on health valuation of lethal (mortality) and sub-lethal (morbidity) effects.

Reduction efforts

There are various air pollution control technologies and land use planning strategies available to reduce air pollution. At its most basic level land use planning is likely to involve zoning and transport infrastructure planning. In most developed countries, land use planning is an important part of social policy, ensuring that land is used efficiently for the benefit of the wider economy and population as well as to protect the environment.

Efforts to reduce pollution from mobile sources includes primary regulation (many developing countries have permissive regulations), expanding regulation to new sources (such as cruise and transport ships, farm equipment, and small gas-powered equipment such as lawn trimmers, chainsaws, and snowmobiles), increased fuel efficiency (such as through the use of hybrid vehicles), conversion to cleaner fuels (such as bioethanol, biodiesel, or conversion to electric vehicles).

Control devices

The following items are commonly used as pollution control devices by industry or transportation devices. They can either destroy contaminants or remove them from an exhaust stream before it is emitted into the atmosphere.

Particulate control

- Mechanical collectors (dust cyclones, multicyclones)
- Electrostatic precipitators: An electrostatic precipitator (ESP), or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge. Electrostatic precipitators are highly efficient filtration devices that minimally impede the flow of gases through the device, and can easily remove fine particulate matter such as dust and smoke from the air stream.
- Baghouses: Designed to handle heavy dust loads, a dust collector consists of a blower, dust filter, a filter-cleaning system, and a dust receptacle or dust removal system (distinguished from air cleaners which utilize disposable filters to remove the dust).
- Particulate scrubbers: Wet scrubber is a form of pollution control technology. The term describes a variety of devices that use pollutants from a furnace flue gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, so as to remove the pollutants.

Scrubbers

- Baffle spray scrubber
- Cyclonic spray scrubber
- Ejector venture scrubber
- Mechanically aided scrubber
- Spray tower
- Wet scrubber

NOx control

- Low NOx burners
- Selective catalytic reduction (SCR)
- Selective non-catalytic reduction (SNCR)
- NOx scrubbers
- Exhaust gas recirculation
- Catalytic converter (also for VOC control)

VOC abatement

- Adsorption systems, such as activated carbon
- Flares
- Thermal oxidizers
- Catalytic oxidizers
- Biofilters
- Absorption (scrubbing)
- Cryogenic condensers
- Vapor recovery systems

Acid Gas/SO_2 control

- Wet scrubbers
- Dry scrubbers
- Flue gas desulfurization

Mercury control

- Sorbent Injection Technology
- Electro-Catalytic Oxidation (ECO)
- K-Fuel

Dioxin and furan control

Miscellaneous associated equipment

- Source capturing systems
- Continuous emissions monitoring systems (CEMS)

In general, there are two types of air quality standards. The first class of standards (such as the U.S. National Ambient Air Quality Standards) set maximum atmospheric concentrations for specific pollutants. Environmental agencies enact regulations which are intended to result in attainment of these target levels. The second class (such as the North American Air Quality Index) take the form of a scale with various thresholds, which is used to communicate to the public the relative risk of outdoor activity. The scale may or may not distinguish between different pollutants.

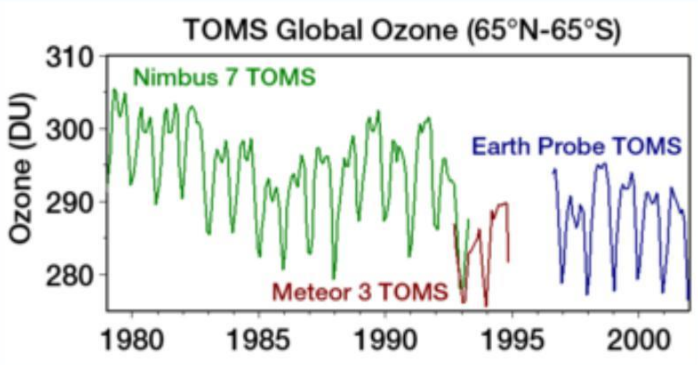
Ozone depletion

Ozone depletion describes two distinct, but related observations: a slow, steady decline of about 4% per decade in the total volume of ozone in Earth's stratosphere (ozone layer) since the late 1970s, and a much larger, but seasonal, decrease in stratospheric ozone over Earth's polar regions during the same period. The latter phenomenon is commonly referred to as the **ozone hole**. In addition to this well-known stratospheric ozone depletion, there are also tropospheric ozone depletion events, which occur near the surface in Polar Regions during spring.

The detailed mechanism by which the polar ozone holes form is different from that for the mid-latitude thinning, but the most important process in both trends is catalytic destruction of ozone by atomic chlorine and bromine. The main source of these halogen atoms in the stratosphere is photodissociation of chlorofluorocarbon (CFC) compounds, commonly called freons, and of bromofluorocarbon compounds known as halons. These compounds are transported into the stratosphere after being emitted at the surface. Both ozone depletion mechanisms strengthened as emissions of CFCs and halos increased.

CFCs and other contributory substances are commonly referred to as **ozone-depleting substances** (**ODS**). Since the ozone layer prevents most harmful UVB wavelengths (270–315 nm) of ultraviolet light (UV light) from passing through the Earth's atmosphere, observed and projected decreases in ozone have generated worldwide concern leading to adoption of the Montreal Protocol that bans the production of CFCs and halos as well as related ozone depleting chemicals such as carbon tetrachloride and trichloroethane. It is suspected that a variety of biological consequences such as increases in skin cancer, cataracts, damage to plants, and reduction of plankton populations in the ocean's photic zone may result from the increased UV exposure due to ozone depletion.

Three forms (or allotropes) of oxygen are involved in the ozone-oxygen cycle: oxygen atoms (O or atomic oxygen), oxygen gas (O_2 or diatomic oxygen), and ozone gas (O_3 or triatomic oxygen). Ozone is formed in the stratosphere when oxygen molecules photo dissociate after absorbing an ultraviolet photon whose wavelength is shorter than 240 nm. This produces two oxygen atoms. The atomic oxygen then combines with O_2 to create O_3. Ozone molecules absorb UV light between 310 and 200 nm, following which ozone splits into a molecule of O_2 and an oxygen atom. The oxygen atom then joins up with an oxygen molecule to regenerate ozone. This is a continuing process which terminates when an oxygen atom "recombines" with an ozone molecule to make two O_2 molecules: $O + O_3 \rightarrow 2\ O_2$



Global monthly average total ozone amount.

The **greenhouse effect** is the heating of the surface of a planet or moon due to the presence of an atmosphere containing gases that absorb and emit infrared radiation. Thus, greenhouse gases trap heat within the surface-troposphere system. This mechanism is fundamentally different from that of an actual greenhouse, which works by isolating warm air inside the structure so that heat is not lost by convection. The greenhouse effect was discovered by Joseph Fourier in 1824, first reliably experimented on by John Tyndall in 1858, and first reported quantitatively by Svante Arrhenius in 1896.

The black body temperature of the Earth is 5.5 °C. Since the Earth's surface reflects about 28% of incoming sunlight, the planet's mean temperature would be far lower - about -18 or -19 °C - in the absence of the effect. Because of the effect, it is instead much higher at about 14 °C.

Global warming, a recent warming of the Earth's surface and lower atmosphere, is believed to be the result of an "enhanced greenhouse effect" mostly due to human-produced increases in atmospheric greenhouse gases. This human induced part is referred to as *anthropogenic global warming* (AGW).

The Earth receives energy from the Sun mostly in the form of visible light and nearby wavelengths. About 50% of the sun's energy is absorbed at the Earth's surface. Like all bodies with a temperature above absolute zero the Earth's surface radiates energy in the infrared range. Greenhouse gases in the atmosphere absorb most of the infrared radiation emitted by the surface and pass the absorbed heat to other atmospheric gases through molecular collisions. The greenhouse gases also radiate in the infrared range. Radiation is emitted both upward, with part escaping to space, and downward toward Earth's surface. The surface and lower atmosphere are warmed by the part of the energy that is radiated downward, making our life on earth possible.

Greenhouse gases

In order of volume, Earth's most abundant greenhouse gases are:

- water vapour
- carbon dioxide
- methane
- nitrous oxide
- ozone
- CFCs

By their percentage contribution to the greenhouse effect the four major gases are:

- water vapour, 36–70%
- carbon dioxide, 9–26%
- methane, 4–9%
- ozone, 3–7%

The major non-gas contributor to the Earth's greenhouse effect, clouds, also absorb and emit infrared radiation and thus have an effect on radioactive properties of the atmosphere.

The overall amount of ozone in the stratosphere is determined by a balance between photochemical production and recombination.

Ozone can be destroyed by a number of free radical catalysts, the most important of which are the hydroxyl radical (OH·), the nitric oxide radical (NO·), atomic chlorine (Cl·) and bromine (Br·). All of these have both natural and manmade sources; at the present time, most of the OH· and NO· in the stratosphere is of natural origin, but human activity has dramatically increased the levels of chlorine and bromine. These elements are found in certain stable organic compounds, especially chlorofluorocarbons (CFCs), which may find their way to the stratosphere without being destroyed in the troposphere due to their low reactivity. Once in the stratosphere, the Cl and Br atoms are liberated from the parent compounds by the action of ultraviolet light, e.g. ('h' is Planck's constant, 'ν' is frequency of electromagnetic radiation)

$CFCl_3 + h\nu \rightarrow CFCl_2 + Cl$

The Cl and Br atoms can then destroy ozone molecules through a variety of catalytic cycles. In the simplest example of such a cycle, a chlorine atom reacts with an ozone molecule, taking an oxygen atom with it (forming ClO) and leaving a normal oxygen molecule. The chlorine monoxide (i.e., the ClO) can react with a second molecule of ozone (i.e., O_3) to yield another chlorine atom and two molecules of oxygen. The chemical shorthand for these gas-phase reactions is:

$Cl + O_3 \rightarrow ClO + O_2$

$ClO + O_3 \rightarrow Cl + 2\ O_2$

The overall effect is a decrease in the amount of ozone. More complicated mechanisms have been discovered that lead to ozone destruction in the lower stratosphere as well.

A single chlorine atom would keep on destroying ozone (thus a catalyst) for up to two years (the time scale for transport back down to the troposphere) were it not for reactions that remove them from this cycle by forming reservoir species such as hydrogen chloride (HCl) and chlorine nitrate ($ClONO_2$). On a per atom basis, bromine is even more efficient than chlorine at destroying ozone, but there is much less bromine in the atmosphere at present. As a result, both chlorine and bromine contribute significantly to the overall ozone depletion. Laboratory studies have shown that fluorine and iodine atoms participate in analogous catalytic cycles. However, in the Earth's stratosphere, fluorine atoms react rapidly with water and methane to form strongly-bound HF, while organic molecules which contain iodine react so rapidly in the lower atmosphere that they do not reach the stratosphere in significant quantities. Furthermore, a single chlorine atom is able to react with 100,000 ozone molecules. This fact plus the amount of chlorine released into the atmosphere by chlorofluorocarbons (CFCs) yearly demonstrates how dangerous CFCs are to the environment.

Water pollution

Over two thirds of Earth's surface is covered by water; less than a third is taken up by land. As Earth's population continues to grow, people are putting ever-increasing pressure on the planet's water resources. In a sense, our oceans, rivers, and other inland waters are being "squeezed" by human activities—not so they take up less room, but so their quality is reduced. Poorer water quality means **water pollution**.

We know that pollution is a *human problem* because it is a relatively recent development in the planet's history: before the 19th century Industrial Revolution, people lived more in harmony with their immediate environment. As industrialisation has spread around the globe, so the problem of pollution has spread with it. When Earth's population was much smaller, no one believed pollution would ever present a serious problem. It was once popularly believed that the oceans were far too big to pollute. Today, with over 8 billion people on the planet, it has become apparent that there are limits. Pollution is one of the signs that humans have exceeded those limits.

Water pollution is becoming a huge problem which is faced by all of the human existence and as well as by every wild life species. According to present scales for pollution of water, 10 to 15 billion pounds full of waste materials like garbage is threw in different seas and rivers of the entire world. Not only this, now, as per the latest records for water pollution in India; 20 billion gallons of drinking water pollution also dumped in running rivers and seas.

This serious problem of water pollution is not only serious for the present day but, it is also getting worst on a regular day by day basis. As the seas and rivers have a running current of movement; thus, pollution of water does get transported in to various cities and towns on an immense scale. Not only this but, pollution of water also travel to various locations and hence increase water pollution in India. One more reason for the increasing air and water pollution along with drinking water pollution is because of highly growing industrial sector. These industrial sectors not only results harmfully in increasing drinking water pollution but also increase the air and water pollution on the same time. Another major reason for pollution of water in our country is because of the huge population which is increasing day-by-day. Today, with such huge growing population also the ecosystem is getting effected and giving rise directly to the air and water pollution. Huge population means higher level of water pollution and higher level for pollution of water increases the diseases and death rate for human lives. Thus, rapidly growth in high population is also resulting in increased water pollution in India. Now, if seen clearly and closely on these told water pollution sources, then it can be said that both increasing population and industrialization are the major reason behind the drinking water pollution along with other air and water pollution. Today, water pollution is the greatest problem which can easily cause harmful effect to the entire ecosystem. Dead animals and wild life species is not a new headline coming from the reason of drinking water pollution along with air and water pollution. Just because of this reason of water pollution in India, many diseases namely: Hepatitis also get transferred by these dead animals. Thus, to stop such problems of water pollution in India, major steps and measures to control it must be taken quickly.

How serious is the problem? According to the environmental campaign organization WWF: *"Pollution from toxic chemicals threatens life on this planet. Every ocean and every continent, from the tropics to the once-pristine polar regions, is contaminated."*

What is water pollution?

Water pollution can be defined in many ways. Usually, it means one or more substances have built up in water to such an extent that they cause problems for animals or people. Oceans, lakes, rivers, and other inland waters can naturally clean up a certain amount of pollution by dispersing it harmlessly. If you poured a cup of black ink into a river, the ink would quickly disappear into the river's much larger volume of clean water. The ink would still be there in the river, but in such a low concentration that you would not be able to see it. At such low levels, the chemicals in the ink probably would not present any real problem. However, if you poured gallons of ink into a river every few seconds through a pipe, the river would quickly turn black. The chemicals in the ink could very quickly have an effect on the quality of the water. This, in turn, could affect the health of all the plants, animals, and humans whose lives depend on the river. Thus, water pollution is all about *quantities*: how much of a polluting substance is released and how big a volume of water it is released into. A small quantity of a toxic chemical may have little impact if it is spilled into the ocean from a ship. But the same amount of the same chemical can have a much bigger impact pumped into a lake or river, where there is less clean water to disperse it.

Water pollution almost always means that some damage has been done to an ocean, river, lake, or other water source. A 1971 United Nations report defined ocean pollution as:

"The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities, including fishing, impairment of quality for use of sea water and reduction of amenities."

What are the main types of water pollution?

When we think of Earth's water resources, we think of huge oceans, lakes, and rivers. Water resources like these are called **surface waters**. The most obvious type of water pollution affects surface waters. For example, a spill from an oil tanker creates an oil slick that can affect a vast area of the ocean.

Not all of Earth's water sits on its surface, however. A great deal of water is held in underground rock structures known as aquifers, which we cannot see and seldom think about. Water stored underground in aquifers is known as **groundwater**. Aquifers feed our rivers and supply much of our drinking water. They too can become polluted, for example, when weed killers used in people's gardens drain into the ground. Groundwater pollution is much less obvious than surface-water pollution, but is no less of a problem. In 1996, a study in Iowa in the United States found that over half the state's groundwater wells were contaminated with weed killers.

Surface waters and groundwater are the two types of water resources that pollution affects. There are also two different ways in which pollution can occur. If pollution comes from a single location, such as a discharge pipe attached to a factory, it is known as **point-source pollution**. Other examples of point source pollution include an oil spill from a tanker, a discharge from a smoke stack (factory chimney), or someone pouring oil from their car down a drain. A great deal of water pollution happens not from one single source but from many different scattered sources. This is called **nonpoint-source pollution**.

When point-source pollution enters the environment, the place most affected is usually the area immediately around the source. For example, when a tanker accident occurs, the oil slick is concentrated around the tanker itself and, in the right ocean conditions; the pollution disperses the further away from the tanker you go. This is less likely to happen with nonpoint source pollution which, by definition, enters the environment from many different places at once.

Sometimes pollution that enters the environment in one place has an effect hundreds or even thousands of miles away. This is known as **transboundary pollution**. One example is the way radioactive waste travels through the oceans from nuclear reprocessing plants in England and France to nearby countries such as Ireland and Norway.

How do we know when water is polluted?

Some forms of water pollution are very obvious: everyone has seen TV news footage of oil slicks filmed from helicopters flying overhead. Water pollution is usually less obvious and much harder to detect than this. But how can we measure water pollution when we cannot see it? How do we even know it's there?

There are two main ways of measuring the quality of water. One is to take samples of the water and measure the concentrations of different chemicals that it contains. If the chemicals are dangerous or the concentrations are too great, we can regard the water as polluted. Measurements like this are known as **chemical indicators** of water quality. Another way to measure water quality involves examining the fish, insects, and other invertebrates that the water will support. If many different types of creatures can live in a river, the quality is likely to be very good; if the river supports no fish life at all, the quality is obviously much poorer. Measurements like this are called **biological indicators** of water quality.

What are the causes of water pollution?

Most water pollution doesn't begin in the water itself. Take the oceans: around 80 percent of ocean pollution enters our seas from the land. Virtually any human activity can have an effect on the quality of our water environment. When farmers fertilise the fields, the chemicals they use are gradually washed by rain into the groundwater or surface waters nearby. Sometimes the causes of water pollution are quite surprising. Chemicals released by smokestacks (chimneys) can enter the atmosphere and then fall back to earth as rain, entering seas, rivers, and lakes and causing water pollution. Water pollution has many different causes and this is one of the reasons why it is such a difficult problem to solve.

Sewage

With over 8 billion people on the planet, disposing of sewage waste is a major problem. In developing countries, many people still lack clean water and basic sanitation (hygienic toilet facilities). Sewage disposal affects people's immediate environments and leads to water-related illnesses such as diarrhoea that kills 3-4 million children each year. (According to the World Health Organization, water-related diseases could kill 135 million people by 2020.) In developed countries, most people have flush toilets that take sewage waste quickly and hygienically away from their homes.

Yet the problem of sewage disposal does not end there. When you flush the toilet, the waste has to go somewhere and, even after it leaves the sewage treatment works, there is still waste to dispose of. Sometimes sewage waste is pumped untreated into the sea. Until the early 1990s, around 5 million tons of sewage was dumped by barge from New York City each year. The population of Britain produces around 300 million gallons of sewage every day, some of it still pumped untreated into the sea through long pipes. The New River that crosses the border from Mexico into California carries with it 20-25 million gallons (76-95 million litres) of raw sewage each day.

In theory, sewage is a completely natural substance that should be broken down harmlessly in the environment: 90 percent of sewage is water. In practice, sewage contains all kinds of other chemicals, from the pharmaceutical drugs people take to the paper, plastic, and other wastes they flush down their toilets. When people are sick with viruses, the sewage they produce carries those viruses into the environment. It is possible to catch illnesses such as hepatitis, typhoid, and cholera from river and sea water.

Nutrients

Suitably treated and used in moderate quantities, sewage can be a fertilizer: it returns important nutrients to the environment, such as nitrogen and phosphorus, which plants and animals need for growth. The trouble is, sewage is often released in much greater quantities than the natural environment can cope with. Chemical fertilizers used by farmers also add nutrients to the soil, which drain into rivers and seas and add to the fertilizing effect of the sewage. Together, sewage and fertilizers can cause a massive increase in the growth of algae or plankton that overwhelms huge areas of oceans, lakes, or rivers. This is known as a **harmful algal bloom** (also known as an HAB or red tide, because it can turn the water red). It is harmful because it removes oxygen from the water that kills other forms of life, leading to what is known as a**dead zone**. The Gulf of Mexico has one of the world's most spectacular dead zones. Each summer, it grows to an area of around 7000 square miles (18,000 square kilometres), which is about the same size as the state of New Jersey.

Waste water

A few statistics illustrate the scale of the problem that waste water (chemicals washed down drains and discharged from factories) can cause. Around half of all ocean pollution is caused by sewage and waste water. Each year, the world generates 400 billion tons of industrial waste, much of which is pumped untreated into rivers, oceans, and other waterways. In the United States alone, around 400,000 factories take clean water from rivers, and many pump polluted waters back in their place. However, there have been major improvements in waste water treatment recently. For example, in the United States over the last 30 years, the Environmental Protection Agency (EPA) has spent $70 billion improving treatment plants that now serve about 85 percent of the US population.

Factories are point sources of water pollution, but quite a lot of water is polluted by ordinary people from nonpoint sources; this is how ordinary water becomes waste water in the first place. Virtually everyone pours chemicals of one sort or another down their drains or toilets.

Even detergents used in washing machines and dishwashers eventually end up in our rivers and oceans. So do the pesticides we use on our gardens. A lot of toxic pollution also enters waste water from highway **runoff**. Highways are typically covered with a cocktail of toxic chemicals—everything from spilled fuel and brake fluids to bits of worn tyres (themselves made from chemical additives) and exhaust emissions. When it rains, these chemicals wash into drains and rivers. It is not unusual for heavy summer rainstorms to wash toxic chemicals into rivers in such concentrations that they kill large numbers of fish overnight. It has been estimated that, in one year, the highway runoff from a single large city leaks as much oil into our water environment as a typical tanker spill. Some highway runoff runs away into drains; others can pollute groundwater or accumulate in the land next to a road, making it increasingly toxic as the years go by.

Chemical waste

Detergents are relatively mild substances. At the opposite end of the spectrum are highly toxic chemicals such as **polychlorinated biphenyls (PCBs)**. They were once widely used to manufacture electronic circuit boards, but their harmful effects have now been recognized and their use is highly restricted in many countries. Nevertheless, an estimated half million tons of PCBs were discharged into the environment during the 20th century. In a classic example of trans boundary pollution, traces of PCBs have even been found in birds and fish in the Arctic. They were carried there through the oceans, thousands of miles from where they originally entered the environment. Although PCBs are widely banned, their effects will be felt for many decades because they last a long time in the environment without breaking down.

Another kind of toxic pollution comes from **heavy metals**, such as lead, cadmium, and mercury. Lead was once commonly used in gasoline (petrol), though its use is now restricted in some countries. Mercury and cadmium are still used in batteries (though some brands now use other metals instead). Until recently, a highly toxic chemical called tributyltin (TBT) was used in paints to protect boats from the ravaging effects of the oceans. Ironically, however, TBT was gradually recognized as a pollutant: boats painted with it were doing as much damage to the oceans as the oceans were doing to the boats.

The best known example of heavy metal pollution in the oceans took place in 1938 when a Japanese factory discharged a significant amount of mercury metal into **Minamata Bay**, contaminating the fish stocks there. It took a decade for the problem to come to light. By that time, many local people had eaten the fish and around 2000 were poisoned. Hundreds of people were left dead or disabled.

Radioactive waste

People view radioactive waste with great alarm—and for good reason. At high enough concentrations it can kill; in lower concentrations it can cause cancers and other illnesses. The biggest sources of radioactive pollution in Europe are two factories that reprocess waste fuel from nuclear power plants: Sellafield on the north-west coast of Britain and Cap La Hague on the north coast of France. Both discharge radioactive waste water into the sea, which ocean currents then carry around the world. Countries such as Norway, which lie downstream from Britain, receive significant doses of radioactive pollution from Sellafield. The Norwegian government has repeatedly complained that Sellafield has increased radiation levels along its coast by 6-10 times. Both the Irish and Norwegian governments continue to press for the plant's closure.

Oil pollution

When we think of ocean pollution, huge black oil slicks often spring to mind, yet these spectacular accidents represent only a tiny fraction of all the pollution entering our oceans. Even considering oil by itself, tanker spills are not as significant as they might seem: only 12% of the oil that enters the oceans comes from tanker accidents; over 70% of oil pollution at sea comes from routine shipping and from the oil people pour down drains on land. However, what makes tanker spills so destructive is the sheer quantity of oil they release at once — in other words, the concentration of oil they produce in one very localized part of the marine environment. The biggest oil spill in recent years (and the biggest ever spill in US waters) occurred when the tanker *Exxon Valdez* broke up in Prince William Sound in Alaska in 1989. Around 12 million gallons (44 million litres) of oil were released into the pristine wilderness—enough to fill your living room 800 times over! Estimates of the marine animals killed in the spill vary from approximately 1000 sea otters and 34,000 birds to as many as 2800 sea otters and 250,000 sea birds. Several billion salmon and herring eggs are also believed to have been destroyed.

Plastics

If you've ever taken part in a community beach clean, you'll know that plastic is far and away the most common substance that washes up with the waves. There are three reasons for this: plastic is one of the most common materials, used for making virtually every kind of manufactured object from clothing to automobile parts; plastic is light and floats easily so it can travel enormous distances across the oceans; most plastics are not biodegradable (they do not break down naturally in the environment), which means that things like plastic bottle tops can survive in the marine environment for a long time. (A plastic bottle can survive an estimated 450 years in the ocean and plastic fishing line can last up to 600 years.)

While plastics are not toxic in quite the same way as poisonous chemicals, they nevertheless present a major hazard to seabirds, fish, and other marine creatures. For example, plastic fishing lines and other debris can strangle or choke fish. (This is sometimes called **ghost fishing**.) One scientific study in the 1980s estimated that a quarter of all seabirds contain some sort of plastic residue. In another study about a decade later, a scientist collected debris from a 1.5 mile length of beach in the remote Pitcairn islands in the South Pacific. His study recorded approximately a thousand pieces of garbage including 268 pieces of plastic, 71 plastic bottles, and two dolls heads.

Alien species

Most people's idea of water pollution involves things like sewage, toxic metals, or oil slicks, but pollution can be biological as well as chemical. In some parts of the world, alien species are a major problem. Alien species (sometimes known as **invasive species**) are animals or plants from one region that have been introduced into a different ecosystem where they do not belong. Outside their normal environment, they have no natural predators, so they rapidly run wild, crowding out the usual animals or plants that thrive there. Common examples of alien species include zebra mussels in the Great Lakes of the USA, which were carried there from Europe by ballast water (waste water flushed from ships). The Mediterranean Sea has been invaded by a kind of alien algae called *Caulerpa taxifolia*. In the Black Sea, an alien jellyfish called *Mnemiopsis leidyi* reduced fish stocks by 90% after arriving in ballast water. In San Francisco Bay, Asian clams called *Potamocorbula amurensis*, also introduced by ballast water, have dramatically altered the ecosystem. In 1999, Cornell University's David Pimentel estimated that alien invaders like this cost the US economy $123 billion a year.

Other forms of pollution

These are the most common forms of pollution—but by no means the only ones. Heat or **thermal pollution** from factories and power plants also causes problems in rivers. By raising the temperature, it reduces the amount of oxygen dissolved in the water, thus also reducing the level of aquatic life that the river can support.

Another type of pollution involves the disruption of **sediments** (fine-grained powders) that flow from rivers into the sea. Dams built for hydroelectric power or water reservoirs can reduce the sediment flow. This reduces the formation of beaches, increases coastal erosion (the natural destruction of cliffs by the sea), and reduces the flow of nutrients from rivers into seas (potentially reducing coastal fish stocks).

Increased sediments can also present a problem. During construction work, soil, rock, and other fine powders sometimes enters nearby rivers in large quantities, causing it to become turbid (muddy or silted). The extra sediment can block the gills of fish, effectively suffocating them. Construction firms often now take precautions to prevent this kind of pollution from happening.

What are the effects of water pollution?

Some people believe pollution is an inescapable result of human activity: they argue that if we want to have factories, cities, ships, cars, oil, and coastal resorts, some degree of pollution is almost certain to result. In other words, pollution is a necessary evil that people must put up with if they want to make progress. Fortunately, not everyone agrees with this view. One reason people have woken up to the problem of pollution is that it brings costs of its own that undermine any economic benefits that come about by polluting.

Take oil spills, for example. They can happen if tankers are too poorly built to survive accidents at sea. But the economic benefit of compromising on tanker quality brings an economic cost when an oil spill occurs. The oil can wash up on nearby beaches, devastate the ecosystem, and severely affect tourism. The main problem is that the people who bear the cost of the spill (typically a small coastal community) are not the people who caused the problem in the first place (the people who operate the tanker). Yet, arguably, everyone who puts gasoline (petrol) into their car—or uses almost any kind of petroleum-fuelled transport—contributes to the problem in some way. So oil spills are a problem for everyone, not just people who live by the coast and tanker operates.

Sewage is another good example of how pollution can affect us all. Sewage discharged into coastal waters can wash up on beaches and cause a health hazard. People who bathe or surf in the water can fall ill if they swallow polluted water—yet sewage can have other harmful effects too: it can poison shellfish (such as cockles and mussels) that grow near the shore. People who eat poisoned shellfish risk suffering from an acute—and sometimes fatal—illness called paralytic shellfish poisoning. Shellfish is no longer caught along many shores because it is simply too polluted with sewage or toxic chemical wastes that have discharged from the land nearby.

Pollution matters because it harms the environment on which people depend. The environment is not something distant and separate from our lives. It's not a pretty shoreline hundreds of miles from our homes or a wilderness landscape that we see only on TV. The environment is everything that surrounds us that gives us life and health. Destroying the environment ultimately reduces the quality of our own lives—and that, most selfishly, is why pollution should matter to all of us.

Effect of water pollution is spread on immense area and does not only affect the outer environment, but existence of every living being also get worst. There are some major water pollution effects which in the current days is affecting every single organism of the ecosystem. In this description we are going to talk about the increasing effect of water pollution on the entire eco-balance and other additional harmful chemicals which increase it.

If we see closely, then the list of these effects of water pollution will not end up like this only. The list for water pollution effects is long and goes on and on when started. Firstly the thing which gets affected adversely with the effect of water pollution is the ecosystem's food chain. The entire food chain is connected upon the dependence of each other's lives which is hindered directly by numerous effects of water pollution. Sudden death due to any water pollution effects harms adversely to another species life span and also takes down the entire chain with it. A simple example of water to animal and animal to humans with the help of meat can be taken to understand the adversely effects of water pollution. Several diseases are also spread just because of the water pollution effects. Diseases like cholera and food poisoning are the beginning stages for the effect of water pollution which are easily caught by any person. Raining of Acidic liquid and chemicals is also one of another reasons and effects of water pollution. Destroying the purity level of the water also comes under the water pollution effects which in results for diseases and temperature problems.

Apart from these, destruction of sea food and the level along with the temperature of water also states guilty to the adversely effect of water pollution. Thus, it can be seen that, with these harmful steps and increased population with increased industrialization, the ecological balance of entire eco system is hindered. Not only on the environment but these effects also impact adversely on ours health. All these problems can be tackled easily with balanced steps taken by each and every person.

Water Pollution Solutions

Today, water pollution is one of the serious concerns for each and every country around the world. Thus, for this purpose there are numerous of laws and regulations for water pollution solutions are been imposed everywhere. But, then also drawbacks are faced by these solutions to water pollution. Reason behind the drawbacks for water pollution solutions in India is not by its imposition but in some regions enforcement of these rules are not that much strict in comparisons to others.

To get control and to impose these water pollution solutions literally in every place, government just have to again place the regulations and rules regarding it. Moreover some effective water pollution solutions in India involve the reduction in manures and chemical usages and promoting a bio-dynamic cultivation for farming purposes. Lesser deforestation and creating ponds to lower the level of flow which enters under the surface as underground water are also major water pollution solutions. In another possible solutions to water pollution is to lower the level of usage for chemicals and other pesticides for farming process. By utilizing lesser or stopping gradually the usage of fertilizers and such chemicals also can be considered as very effective water pollution solutions in India. Some other solutions to water pollution are like, re-establishment of wetlands and filtration of waste materials. Driving fewer vehicles also results as better water pollution solutions. Better sewage and reduction of other dumping waste materials in seas and oceans also acts as solutions to water pollution. Conservation of water and better techniques for the managing the storm water are also good water pollution solutions in India.

Changes for water pollution solutions in India not only can take place on the national level but, individuals can contribute a lot in it. Any single person can also help in solutions to water pollution. By purchasing green products like organic products and individual protections for usage of chemicals in our daily life can also results in better water pollution solutions. It is a duty of every citizen to properly place the garbage and dispose of it to a right place which can reduce the unwanted chemical flow in the atmosphere and also reduces the waste materials which are dumped in seas and oceans.

How can we stop water pollution?

There is no easy way to solve water pollution; if there were, it wouldn't be so much of a problem. Water pollution prevention in India is the most important work for the environment which includes the support from both government and as well as form people also. For this water pollution control various rules and regulations under various acts are imposed on several sectors. Mostly this prevention of water pollution acts are imposed on the industrial sector than any other. As increasing pollution is becoming a serious problem these days, thus, water pollution prevention procedure is been working with its full efficiency.

Major part of the country is affected and working on water pollution prevention in India with these sorts of water and air pollutions just because of the industrial sector. This heavy industrialization with bigger area of working chemical factories directly dumps tons of waste chemicals and materials in seas and oceans against water pollution control which causes such problems. Things which are needed for water pollution prevention in India are sudden change and gradual action should be taken toward it. Bann on dumping of waste materials and hazardous chemicals can also act as a good water pollution control. It can be understood that dumping is not the way to get rid of the waste materials and also make hurdles in the path for prevention of water pollution. Primary education and awareness is also a good measure for water pollution prevention. There have been many programs started similarly to this water pollution prevention in India. Water pollution control can also be done by lowering the usage of chemicals and fertilizers. Personal precautions like driving lesser vehicles can also prove to be a good prevention of water pollution. Above all, a better water pollution prevention needs a higher level of interest which must be given upon it.

Apart from above water pollution prevention steps, installation of filtration system is also a good step. It is the most effective and working prevention of water pollution. At homes clearing up drains also acts as water pollution control. Water conservation is also a step for water pollution prevention in India. Education and identification for such problems also helps in prevention of water pollution. Hence, it can be noticed that, a small effort from cleaning the waste before throwing in to garbage or drains can also contribute a lot in water pollution prevention. Broadly speaking, there are three different things that can help to tackle the problem—education, laws, and economics—and they work together as a team.

Education

Making people aware of the problem is the first step to solving it. In the early 1990s, when surfers in Britain grew tired of catching illnesses from water polluted with sewage, they formed a group called Surfers against Sewage to force governments and water companies to clean up their act. People who've grown tired of walking the world’s polluted beaches often band together to organize community beach-cleaning sessions. Anglers who no longer catch so many fish have campaigned for tougher penalties against factories that pour pollution into our rivers. Greater public awareness can make a positive difference.

Laws

One of the biggest problems with water pollution is its transboundary nature. Many rivers cross countries, while seas span whole continents. Pollution discharged by factories in one country with poor environmental standards can cause problems in neighbouring nations, even when they have tougher laws and higher standards. Environmental laws can make it tougher for people to pollute, but to be really effective they have to operate across national and international borders. This is why we have international laws governing the oceans, such as the 1982 UN Convention on the Law of the Sea (signed by over 120 nations), the 1972 London Dumping Convention, the 1978 MARPOL International Convention for the Prevention of Pollution from Ships, and the 1998 OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic. The European Union has water-protection laws (known as directives) that apply to all of its member states. They include the 1976 Bathing Water Directive, which seeks to ensure the quality of the waters that people use for recreation. Most countries also have their own water pollution laws. In the United States, for example, there is the 1972 Water Pollution Control Act and the 1974 Safe Drinking Water Act.

Economics

Most environmental experts agree that the best way to tackle pollution is through something called the **polluter pays principle**. This means that whoever causes pollution should have to pay to clean it up, one way or another. Polluter pays can operate in all kinds of ways. It could mean that tanker owners should have to take out insurance that covers the cost of oil spill cleanups, for example. It could also mean that shoppers should have to pay for their plastic grocery bags, as is now common in Ireland, to encourage recycling and minimize waste. Or it could mean that factories that use rivers must have their water inlet pipes downstream of their effluent outflow pipes, so if they cause pollution they themselves are the first people to suffer. Ultimately, the polluter pays principle is designed to deter people from polluting by making it less expensive for them to behave in an environmentally responsible way.

Our clean future

Life is ultimately about choices—and so is pollution. We can live with sewage-strewn beaches, dead rivers, and fish that are too poisonous to eat. Or we can work together to keep the environment clean so the plants, animals, and people who depend on it remain healthy. We can take individual action to help reduce water pollution, for example, by using environmentally friendly detergents, not pouring oil down drains, reducing pesticides, and so on. We can take community action too, by helping out on beach cleans or litter picks to keep our rivers and seas that little bit cleaner. And we can take action as countries and continents to pass laws that will make pollution harder and the world less polluted. Working together, we can make pollution less of a problem—and the world a better place.

What is eutrophication, what causes it and what are the dangers?

Eutrophication means natural nutrient enrichment of streams and lakes. The enrichment is often increased by human activities, such as agriculture (manure addition). Over time, lakes then become eutrophic due to an increase in nutrients.

Eutrophication is mainly caused by an increase in nitrate and phosphate levels and has a negative influence on water life. This is because, due to the enrichment, water plants such as algae will grow extensively. As a result the water will absorb less light and certain aerobic bacteria will become more active. These bacteria deplete oxygen levels even further, so that only anaerobic bacteria can be active. This makes life in the water impossible for fish and other organisms.

What is acid rain and how does it develop?

Typical rainwater has a pH of about 5 to 6. This means that it is naturally a neutral, slightly acidic liquid. During precipitation rainwater dissolves gasses such as carbon dioxide and oxygen. The industry now emits great amounts of acidifying gasses, such as sulphuric oxides and carbon monoxide. These gasses also dissolve in rainwater. This causes a change in pH of the precipitation – the pH of rain will fall to a value of or below 4. When a substance has a pH of below 6.5, it is acid. The lower the pH, the more acid the substance is. That is why rain with a lower pH, due to dissolved industrial emissions, is called acid rain.

Why does water sometimes smell like rotten eggs?

When water is enriched with nutrients, eventually anaerobic bacteria, which do not need oxygen to practice their functions, will become highly active. These bacteria produce certain gasses during their activities. One of these gases is hydrogen sulphide. This compounds smells like rotten eggs. When water smells like rotten eggs we can conclude that there is hydrogen present, due to a shortage of oxygen in the specific water.

What causes white deposit on showers and bathroom walls?

Water contains many compounds. A few of these compounds are calcium and carbonate. Carbonate works as a buffer in water and is thus a very important component. When calcium reacts with carbonate a solid substance is formed, that is called lime. This lime is what causes the white deposit on showers and bathroom walls and is commonly known as lime deposit. It can be removed by using a specially suited cleaning agent.

Biochemical oxygen demand

Biochemical oxygen demand or **BOD** is a chemical procedure for determining the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. It is not a precise quantitative test, although it is widely used as an indication of the organic quality of water. It is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water.

The BOD test

There are two commonly recognized methods for the measurement of BOD.

Dilution method

To ensure that all other conditions are equal, a very small amount of micro-organism seed is added to each sample being tested. This seed is typically generated by diluting activated sludge with de-ionized water. The BOD test is carried out by diluting the sample with oxygen saturated de-ionized water, inoculating it with a fixed aliquot of seed, measuring the dissolved oxygen (DO) and then sealing the sample to prevent further oxygen dissolving in. The sample is kept at 20 °C in the dark to prevent photosynthesis (and thereby the addition of oxygen) for five days, and the dissolved oxygen is measured again. The difference between the final DO and initial DO is the BOD.

The loss of dissolved oxygen in the sample, once corrections have been made for the degree of dilution, is called the BOD_5. For measurement of **carbonaceous BOD** (cBOD), a nitrification inhibitor is added after the dilution water has been added to the sample. The inhibitor hinders the oxidation of nitrogen.

BOD can be calculated by:

- Undiluted: Initial DO - Final DO = BOD
- Diluted: ((Initial DO - Final DO)- BOD of Seed) x Dilution

Factor Dilution factor= Volume of waste water / total volume of water

BOD is similar in function to chemical oxygen demand (COD), in that both measure the amount of organic compounds in water. However, COD is less specific, since it measures everything that can be chemically oxidised, rather than just levels of biologically active organic matter.

Manometric method

This method is limited to the measurement of the oxygen consumption due only to carbonaceous oxidation. Ammonia oxidation is inhibited.

The sample is kept in a sealed container fitted with a pressure sensor. A substance that absorbs carbon dioxide (typically lithium hydroxide) is added in the container above the sample level. The sample is stored in conditions identical to the dilution method. Oxygen is consumed and, as ammonia oxidation is inhibited, carbon dioxide is released. The total amount of gas, and thus the pressure, decreases because carbon dioxide is absorbed. From the drop of pressure, the sensor electronics computes and displays the consumed quantity of oxygen.

The main advantages of this method compared to the dilution method are:

- Simplicity: no dilution of sample required, no seeding, no blank sample.
- Direct reading of BOD value.
- Continuous display of BOD value at the current incubation time.

Test Limitations

The test method involves variables limiting reproducibility. Tests normally show observations varying plus or minus ten to twenty percent around the mean.

Toxicity

Some wastes contain chemicals capable of suppressing microbiological growth or activity. Potential sources include industrial wastes, antibiotics in pharmaceutical or medical wastes, sanitizers in food processing or commercial cleaning facilities, chlorination disinfection used following conventional sewage treatment, and odour-control formulations used in sanitary waste holding tanks in passenger vehicles or portable toilets. Suppression of the microbial community oxidizing the waste will lower the test result.

Appropriate Microbial Population

The test relies upon a microbial ecosystem with enzymes capable of oxidizing the available organic material. Some waste waters, such as those from biological secondary sewage treatment, will already contain a large population of microorganisms acclimated to the water being tested. An appreciable portion of the waste may be utilized during the holding period prior to commencement of the test procedure. On the other hand, organic wastes from industrial sources may require specialized enzymes. Microbial populations from standard seed sources may take some time to produce those enzymes. A specialized seed culture may be appropriate to reflect conditions of an evolved ecosystem in the receiving waters.

Chemical oxygen demand

In environmental chemistry, the **chemical oxygen demand** (**COD**) test is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers), making COD a useful measure of water quality. It is expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution. Older references may express the units as parts per million (ppm).

Overview

The basis for the COD test is that nearly all organic compounds can be fully oxidized to carbon dioxide with a strong oxidizing agent under acidic conditions. The amount of oxygen required to oxidize an organic compound to carbon dioxide, ammonia, and water is given by:

$$C_nH_aO_bN_c + \left(n + \frac{a}{4} - \frac{b}{2} - \frac{3}{4}c\right) O_2 \rightarrow nCO_2 + \left(\frac{a}{2} - \frac{3}{2}c\right) H_2O + cNH_3$$

This expression does not include the oxygen demand caused by the oxidation of ammonia into nitrate. The process of ammonia being converted into nitrate is referred to as *nitrification.* The following is the correct equation for the oxidation of ammonia into nitrate.

$$NH_3 + 2O_2 \rightarrow NO_3^- + H_3O^+$$

It is applied after the oxidation due to nitrification if the oxygen demand from nitrification must be known. Dichromate does not oxidize ammonia into nitrate, so this nitrification can be safely ignored in the standard chemical oxygen demand test.

Using potassium dichromate

Potassium dichromate is a strong oxidizing agent under acidic conditions. (Acidity is usually achieved by the addition of sulfuric acid.) The reaction of potassium dichromate with organic compounds is given by:

$$C_nH_aO_bN_c + dCr_2O_7^{2-} + (8d + c)H^+ \rightarrow nCO_2 + \frac{a + 8d - 3c}{2}H_2O + cNH_4^+ + 2dCr^{3+}$$

where *d = 2n/3 + a/6 - b/3 - c/2*. Most commonly, a 0.25 N solution of potassium dichromate is used for COD determination, although for samples with COD below 50 mg/L, a lower concentration of potassium dichromate is preferred.

In the process of oxidizing the organic substances found in the water sample, potassium dichromate is reduced (since in all redox reactions, one reagent is oxidized and the other is reduced), forming Cr^{3+}. The amount of Cr^{3+} is determined after oxidization is complete, and is used as an indirect measure of the organic contents of the water sample.

Blanks

Because COD measures the oxygen demand of organic compounds in a sample of water, it is important that no outside organic material be accidentally added to the sample to be measured. To control for this, a so-called blank sample is required in the determination of COD (and BOD -biochemical oxygen demand - for that matter). A blank sample is created by adding all reagents (e.g. acid and oxidizing agent) to a volume of distilled water. COD is measured for both the water and blank samples, and the two are compared. The oxygen demand in the blank sample is subtracted from the COD for the original sample to ensure a true measurement of organic matter.

Measurement of excess

For all organic matter to be completely oxidized, an excess amount of potassium dichromate (or any oxidizing agent) must be present. Once oxidation is complete, the amount of excess potassium dichromate must be measured to ensure that the amount of Cr^{3+} can be determined with accuracy. To do so, the excess potassium dichromate is titrated with ferrous ammonium sulphate (FAS) until all of the excess oxidizing agent has been reduced to Cr^{3+}. Typically, the oxidation-reduction indicator Ferroin is added during this titration step as well. Once all the excess dichromate has been reduced, the Ferroin indicator changes from blue-green to reddish-brown. The amount of ferrous ammonium sulphate added is equivalent to the amount of excess potassium dichromate added to the original sample. And also we can determine COD by boiling the water sample and we can determine CO2 ratio by the infra-red analyzer

Preparation Ferroin Indicator reagent

A solution of 1.485 g 1,10-phenanthroline monohydrate is added to a solution of 695 mg $FeSO_4 \cdot 7H_2O$ in water, and the resulting red solution is diluted to 100 mL.

Calculations

The following formula is used to calculate COD:

$$COD = \frac{8000(b-s)n}{sample\ volume}$$

where *b* is the volume of FAS used in the blank sample, *s* is the volume of FAS in the original sample, and *n* is the normality of FAS. If milliliters are used consistently for volume measurements, the result of the COD calculation is given in mg/L.

The COD can also be estimated from the concentration of oxidizable compound in the sample, based on its stoichiometric reaction with oxygen to yield CO_2 (assume all C goes to CO_2), H_2O (assume all H goes to H_2O), and NH_3 (assume all N goes to NH_3), using the following formula:

COD = (C/FW)(RMO)(32)

Where C = Concentration of oxidizable compound in the sample,

FW = Formula weight of the oxidizable compound in the sample,

RMO = Ratio of the # of moles of oxygen to # of moles of oxidizable compound in their reaction to CO_2, water, and ammonia

For example, if a sample has 500 wppm of phenol:

$C_6H_5OH + 7O_2 \rightarrow 6CO_2 + 3H_2O$

COD = (500/94)(7)(32) = 1191 wppm

Aquifer

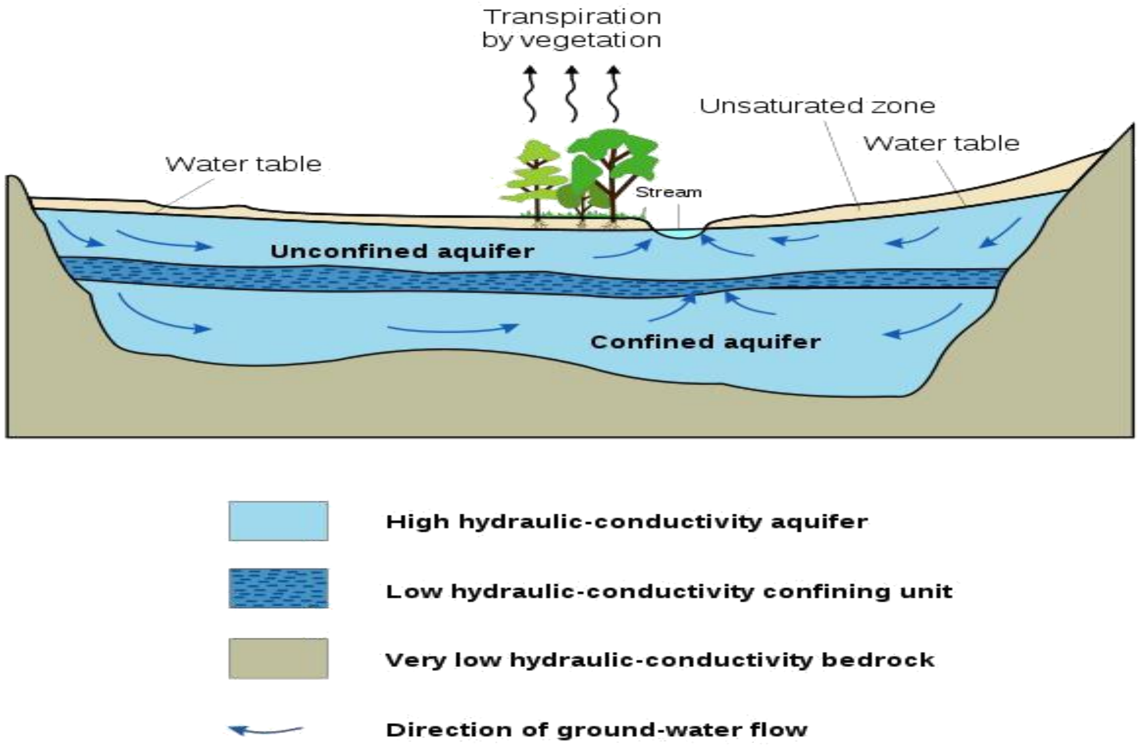
An **aquifer** is a wet underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, or silt) from which groundwater can be usefully extracted using a water well. The study of water flow in aquifers and the characterization of aquifers is called hydrogeology. Related terms include **aquitard**, which is a bed of low permeability along an aquifer, and**aquiclude** (or *aquifuge*), which is a solid, impermeable area underlying or overlying an aquifer. If the impermeable area overlies the aquifer pressure could cause it to become a confined aquifer.

Aquifer Depth

Aquifers may occur at various depths. Those closer to the surface are not only more likely to be used for water supply and irrigation, but are also more likely to be topped up by the local rainfall. Many desert areas have limestone hills or mountains within them or close to them that can be exploited as groundwater resources. Parts of the Atlas Mountains in North Africa, the Lebanon and Anti-Lebanonranges of Syria, Israel and Lebanon, the Jebel Akhdar (Oman) in Oman, parts of the Sierra Nevada and neighboring ranges in the United States' Southwest, have shallow aquifers that are exploited for their water. Over-exploitation can lead to the exceeding of the practical sustained yield; i.e., more water is taken out than can be replenished. Along the coastlines of certain countries, such as Libyaand Israel, population growth has led to over-population, which has caused the lowering of water table and the subsequent contamination of the groundwater with saltwater from the sea (saline intrusions). The beach provides a model to help visualize an aquifer. If a hole is dug into the sand, very wet or saturated sand will be located at a shallow depth. This hole is a crude well, the wet sand represents an aquifer, and the level to which the water rises in this hole represents the water table.

Classification

This diagram indicates typical flow directions in a cross-sectional view of a simple confined/unconfined aquifer system. The system shows two aquifers with one aquitard (a confining or impermeable layer), between them, surrounded by the bedrock *aquiclude*, which is in contact with a gaining stream (typical in humid regions). The water table and unsaturated zone are also illustrated. An *aquitard* is a zone within the earth that restricts the flow of groundwater from one aquifer to another. An aquitard can sometimes, if completely impermeable, be called an *aquiclude* or *aquifuge*. Aquitards are composed of layers of either clay or non-porous rock with low hydraulic conductivity.



Saturated versus unsaturated

Groundwater can be found at nearly every point in the Earth's shallow subsurface, to some degree; although aquifers do not necessarily contain fresh water. The Earth's crust can be divided into two regions: the *saturated* zone or *phreatic* zone (e.g., aquifers, aquitards, etc.), where all available spaces are filled with water, and the *unsaturated zone* (also called the vadose zone), where there are still pockets of air with some water, but can be filled with more water.

Saturated means the pressure head of the water is greater than atmospheric pressure (it has a gauge pressure > 0). The definition of the water table is surface where the pressure head is equal to atmospheric pressure (where gauge pressure = 0).

Unsaturated conditions occur above the water table where the pressure head is negative (absolute pressure can never be negative, but gauge pressure can) and the water that incompletely fills the pores of the aquifer material is under suction. The water content Unsaturated means the zone is held in place by surface adhesive forces and it rises above the water table (the zero gauge pressure isobar) by capillary action to saturate a small zone above the phreatic surface (the capillary fringe) at less than atmospheric pressure. This is termed tension saturation and is not the same as saturation on a water content basis. Water content in a capillary fringe decreases with increasing distance from the phreatic surface. The capillary head depends on soil pore size. In sandy soils with larger pores, the head will be less than in clay soils with very small pores. The normal capillary rise in a clayey soil is less than 1.80 m (six feet) but can range between 0.3 and 10 m (1 and 30 ft). The capillary rise of water in a small diameter tube is this same physical process. The water table is the level to which water will rise in a large-diameter pipe (e.g., a well) that goes down into the aquifer and is open to the atmosphere.

Aquifers versus aquitards

Aquifers are typically saturated regions of the subsurface that produce an economically feasible quantity of water to a well or spring (e.g., sand and gravel or fractured bedrock often make good aquifer materials).

An **aquitard** is a zone within the earth that restricts the flow of groundwater from one aquifer to another. An aquitard can sometimes, if completely impermeable, be called an **aquiclude** or **aquifuge**. Aquitards comprise layers of either clay or non-porous rock with low hydraulic conductivity.

In mountainous areas (or near rivers in mountainous areas), the main aquifers are typically unconsolidated alluvium, composed of mostly horizontal layers of materials deposited by water processes (rivers and streams), which in cross-section (looking at a two-dimensional slice of the aquifer) appear to be layers of alternating coarse and fine materials. Coarse materials, because of the high energy needed to move them, tend to be found nearer the source (mountain fronts or rivers), whereas the fine-grained material will make it farther from the source (to the flatter parts of the basin or overbank areas - sometimes called the pressure area). Since there are less fine-grained deposits near the source, this is a place where aquifers are often unconfined (sometimes called the forebay area), or in hydraulic communication with the land surface.

Confined versus unconfined

There are two end members in the spectrum of types of aquifers; *confined* and *unconfined* (with semi-confined being in between). **Unconfined** aquifers are sometimes also called *water table* or *phreatic* aquifers, because their upper boundary is the water table or phreatic surface. (See Biscayne Aquifer.) Typically (but not always) the shallowest aquifer at a given location is unconfined, meaning it does not have a confining layer (an aquitard or aquiclude) between it and the surface. The term "perched" refers to ground water accumulating above a low-permeability unit or strata, such as a clay layer. This term is generally used to refer to a small local area of ground water that occurs at an elevation higher than a regionally-extensive aquifer. The difference between perched and unconfined aquifers is their size (perched is smaller). If the distinction between confined and unconfined is not clear geologically (i.e., if it is not known if a clear confining layer exists, or if the geology is more complex, e.g., a fractured bedrock aquifer), the value of storativity or specific storage (**The specific storage is the amount of water that a portion of an aquifer releases from storage, per unit mass or volume of aquifer, per unit change in hydraulic head, while remaining fully saturated**) returned from an aquifer test can be used to determine it (although aquifer tests in unconfined aquifers should be interpreted differently than confined ones). Confined aquifers have very low storativity values (much less than 0.01, and as little as 10^{-5}), which means that the aquifer is storing water using the mechanisms of aquifer matrix expansion and the compressibility of water, which typically are both quite small quantities. Unconfined aquifers have storativities (typically then called specific yield) greater than 0.01 (1% of bulk volume); they release water from storage by the mechanism of actually draining the pores of the aquifer, releasing relatively large amounts of water (up to the drainable porosity of the aquifer material, or the minimum volumetric water content).

Surface water treatment

The processes below are the ones commonly used in water purification plants. Some or most may not be used depending on the scale of the plant and quality of the water.

Pre-treatment

1. Pumping and containment – The majority of water must be pumped from its source or directed into pipes or holding tanks. To avoid adding contaminants to the water, this physical infrastructure must be made from appropriate materials and constructed so that accidental contamination does not occur.

2. Screening (*see also screen filter) – The first step in purifying surface water is to remove large debris such as sticks, leaves, rubbish and other large particles which may interfere with subsequent purification steps. Most deep groundwater does not need screening before other purification steps.*

3. Storage – Water from rivers may also be stored in bankside reservoirs for periods between a few days and many months to allow natural biological purification to take place. This is especially important if treatment is by slow sand filters. Storage reservoirs also provide a buffer against short periods of drought or to allow water supply to be maintained during transitory pollution incidents in the source river.

4. Pre-conditioning – Water rich in hardness salts is treated with soda-ash (sodium carbonate) to precipitate calcium carbonate out utilizing the common-ion effect.

5. Pre-chlorination – In many plants the incoming water was chlorinated to minimize the growth of fouling organisms on the pipe-work and tanks. Because of the potential adverse quality effects (see chlorine below), this has largely been discontinued.

Widely varied techniques are available to remove the fine solids, micro-organisms and some dissolved inorganic and organic materials. The choice of method will depend on the quality of the water being treated, the cost of the treatment process and the quality standards expected of the processed water.

pH adjustment

Distilled water has a pH of 7 (neither alkaline nor acidic) and sea water has an average pH of 8.3 (slightly alkaline). If the water is acidic (lower than 7), lime, soda ash, or sodium hydroxide is added to raise the pH. For somewhat acidic waters (lower than 6.5), forced draft degasifiers are the cheapest way to raise the pH, as the process raises the pH by stripping dissolved carbon dioxide (carbonic acid) from the water. Lime is commonly used for pH adjustment for municipal water, or at the start of a treatment plant for process water, as it is cheap, but it also increases the ionic load by raising the water hardness. Making the water slightly alkaline ensures that coagulation and flocculation processes work effectively and also helps to minimize the risk of lead being dissolved from lead pipes and lead solder in pipe fittings. Acid (HCl or H_2SO_4) may be added to alkaline waters in some circumstances to lower the pH. Having alkaline water does not necessarily mean that lead or copper from the plumbing system will not be dissolved into the water but as a generality, water with a pH above 7 is much less likely to dissolve heavy metals than water with a pH below 7.

Flocculation

Flocculation is a process which clarifies the water. Clarifying means removing any turbidity or colour so that the water is clear and colourless. Clarification is done by causing a precipitate to form in the water which can be removed using simple physical methods. Initially the precipitate forms as very small particles but as the water is gently stirred, these particles stick together to form bigger particles. Many of the small particles that were originally present in the raw water adsorb onto the surface of these small precipitate particles and so get incorporated into the larger particles that coagulation produces. In this way the coagulated precipitate takes most of the suspended matter out of the water and is then filtered off, generally by passing the mixture through a coarse sand filter or sometimes through a mixture of sand and granulated anthracite (high carbon and low volatiles coal). Coagulants / flocculating agents that may be used include:

1. Iron(III) hydroxide. This is formed by adding a solution of an iron (III) compound such as iron(III) chloride to pre-treated water with a pH of 7 or greater. Iron (III) hydroxide is extremely insoluble and forms even at a pH as low as 7. Commercial formulations of iron salts were traditionally marketed in the UK under the name Cuprus.

2. Aluminium hydroxide is also widely used as the flocculating precipitate although there have been concerns about possible health impacts and mis-handling led to a severe poisoning incident in 1988 at Camelford in south-west UK when the coagulant was introduced directly into the holding reservoir of final treated water.

3. Poly DADMAC is an artificially produced polymer and is one of a class of synthetic polymers that are now widely used. These polymers have a high molecular weight and form very stable and readily removed flocs, but tend to be more expensive in use compared to inorganic materials. The materials can also be biodegradable.

Sedimentation

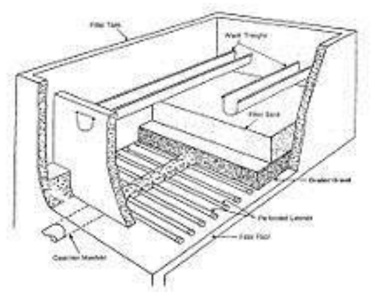
Waters exiting the flocculation basin may enter the sedimentation basin, also called a clarifier or settling basin. It is a large tank with slow flow, allowing floc to settle to the bottom. The sedimentation basin is best located close to the flocculation basin so the transit between does not permit settlement or floc break up. Sedimentation basins may be rectangular, where water flows from end to end, or circular where flow is from the centre outward. Sedimentation basin outflow is typically over a weir so only a thin top layer—that furthest from the sediment—exits. The amount of floc that settles out of the water is dependent on basin retention time and on basin depth. The retention time of the water must therefore be balanced against the cost of a larger basin. The minimum clarifier retention time is normally 4 hours. A deep basin will allow more floc to settle out than a shallow basin. This is because large particles settle faster than smaller ones, so large particles collide with and integrate smaller particles as they settle. In effect, large particles sweep vertically through the basin and clean out smaller particles on their way to the bottom.

As particles settle to the bottom of the basin, a layer of sludge is formed on the floor of the tank. This layer of sludge must be removed and treated. The amount of sludge that is generated is significant, often 3 to 5 percent of the total volume of water that is treated. The cost of treating and disposing of the sludge can be a significant part of the operating cost of a water treatment plant. The tank may be equipped with mechanical cleaning devices that continually clean the bottom of the tank or the tank can be taken out of service when the bottom needs to be cleaned.

Filtration

After separating most floc, the water is filtered as the final step to remove remaining suspended particles and unsettled floc.

Rapid sand filters



Cutaway view of a typical rapid sand filter

The most common type of filter is a rapid sand filter. Water moves vertically through sand which often has a layer of activated carbon or anthracite coal above the sand. The top layer removes organic compounds, which contribute to taste and odour. The space between sand particles is larger than the smallest suspended particles, so simple filtration is not enough. Most particles pass through surface layers but are trapped in pore spaces or adhere to sand particles. Effective filtration extends into the depth of the filter. This property of the filter is key to its operation: if the top layer of sand were to block all the particles, the filter would quickly clog.

To clean the filter, water is passed quickly upward through the filter, opposite the normal direction (called *backflushing* or *backwashing*) to remove embedded particles. Prior to this, compressed air may be blown up through the bottom of the filter to break up the compacted filter media to aid the backwashing process; this is known as *air scouring*. This contaminated water can be disposed of, along with the sludge from the sedimentation basin, or it can be recycled by mixing with the raw water entering the plant although this is often considered poor practice since it re-introduces an elevated concentration of bacteria into the raw water

Some water treatment plants employ pressure filters. This work on the same principle as rapid gravity filters, differing in that the filter medium is enclosed in a steel vessel and the water is forced through it under pressure.

Advantages:

- Filters out much smaller particles than paper and sand filters can.
- Filters out virtually all particles larger than their specified pore sizes.
- They are quite thin and so liquids flow through them fairly rapidly.
- They are reasonably strong and so can withstand pressure differences across them of typically 2–5 atmospheres.
- They can be cleaned (back flushed) and reused.

Membrane filtration

Membrane filters are widely used for filtering both drinking water and sewage. For drinking water, membrane filters can remove virtually all particles larger than 0.2 um—including *giardia* and *cryptosporidium.* Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water). However no filtration can remove substances that are actually dissolved in the water such as phosphorus, nitrates and heavy metal ions.

Slow sand filters

Slow "artificial" filtration (a variation of bank filtration) to the ground, Water purification plant Káraný, Czech Republic

Slow sand filters may be used where there is sufficient land and space as the water must be passed very slowly through the filters. These filters rely on biological treatment processes for their action rather than physical filtration. The filters are carefully constructed using graded layers of sand with the coarsest sand, along with some gravel, at the bottom and finest sand at the top. Drains at the base convey treated water away for disinfection. Filtration depends on the development of a thin biological layer, called the zoogleal layer or Schmutzdecke, on the surface of the filter. An effective slow sand filter may remain in service for many weeks or even months if the pre-treatment is well designed and produces water with a very low available nutrient level which physical methods of treatment rarely achieve. Very low nutrient levels allow water to be safely sent through distribution system with very low disinfectant levels thereby reducing consumer irritation over offensive levels of chlorine and chlorine by-products. Slow sand filters are not backwashed; they are maintained by having the top layer of sand scraped off when flow is eventually obstructed by biological growth.

A specific 'large-scale' form of slow sand filter is the process of bank filtration, in which natural sediments in a riverbank are used to provide a first stage of contaminant filtration. While typically not clean enough to be used directly for drinking water, the water gained from the associated extraction wells is much less problematic than river water taken directly from the major streams where bank filtration is often used.

Removal of ions and other dissolved substances

Ultrafiltration membranes use polymer membranes with chemically formed microscopic pores that can be used to filter out dissolved substances avoiding the use of coagulants. The type of membrane media determines how much pressure is needed to drive the water through and what sizes of micro-organisms can be filtered out.

Ion exchange: Ion exchange systems use ion exchange resin- or zeolite-packed columns to replace unwanted ions. The most common case is water softening consisting of removal of Ca^{2+} and Mg^{2+}ions replacing them with benign (soap friendly) Na^{+} or K^{+} ions. Ion exchange resins are also used to remove toxic ions such as nitrate, nitrite, lead, mercury, arsenic and many others.

Electrode ionization: Water is passed between a positive electrode and a negative electrode. Ion exchange membranes allow only positive ions to migrate from the treated water toward the negative electrode and only negative ions toward the positive electrode. High purity deionized water is produced with a little worse degree of purification in comparison with ion exchange treatment. Complete removal of ions from water is regarded as electrodialysis. The water is often pre-treated with a reverse osmosis unit to remove non-ionic organic contaminants.

Disinfection

Disinfection is accomplished both by filtering out harmful micro-organisms and also by adding disinfectant chemicals. Water is disinfected to kill any pathogens which pass through the filters and to provide a residual dose of disinfectant to kill or inactivate potentially harmful micro-organisms in the storage and distribution systems. Possible pathogens include viruses, bacteria, including*Salmonella*, *Cholera*, *Campylobacter* and *Shigella*, and protozoa, including *Giardia lamblia* and other *cryptosporidia*. Following the introduction of any chemical disinfecting agent, the water is usually held in temporary storage – often called a contact tank or clear well to allow the disinfecting action to complete.

Chlorine disinfection

The most common disinfection method involves some form of chlorine or its compounds such as chloramine or chlorine dioxide. Chlorine is a strong oxidant that rapidly kills many harmful micro-organisms. Because chlorine is a toxic gas, there is a danger of a release associated with its use. This problem is avoided by the use of sodium hypochlorite, which is a relatively inexpensive solution that releases free chlorine when dissolved in water. Chlorine solutions can be generated on site by electrolyzing common salt solutions. A solid form, calcium hypochlorite exists that releases chlorine on contact with water. Handling the solid, however, requires greater routine human contact through opening bags and pouring than the use of gas cylinders or bleach which are more easily automated. The generation of liquid sodium hypochlorite is both inexpensive and safer than the use of gas or solid chlorine. All forms of chlorine are widely used despite their respective drawbacks. One drawback is that chlorine from any source reacts with natural organic compounds in the water to form potentially harmful chemical by-products trihalomethanes (THMs) and haloacetic acids (HAAs), both of which are carcinogenic in large quantities and regulated by the United States Environmental Protection Agency (EPA) and the Drinking Water Inspectorate in the UK. The formation of THMs and haloacetic acids may be minimized by effective removal of as many organics from the water as possible prior to chlorine addition. Although chlorine is effective in killing bacteria, it has limited effectiveness against protozoa that form cysts in water (*Giardia lamblia* and *Cryptosporidium*, both of which are pathogenic).

$Cl_2 + H_2O \rightarrow HOCl$ (hypochlorous acid) $+ H^+ + Cl^-$

$HOCl \rightarrow HCl + [O]$ nascent oxygen

The strong oxidizing power, present due to liberation of nascent oxygen, destroys enzymatic processes in the pathogenic cell and thus kills them.

Chlorine dioxide disinfection

Chlorine dioxide is a faster-acting disinfectant than elemental chlorine, however it is relatively rarely used, because in some circumstances it may create excessive amounts of chlorite, which is a by-product regulated to low allowable levels in the United States. Chlorine dioxide is supplied as an aqueous solution and added to water to avoid gas handling problems; chlorine dioxide gas accumulations may spontaneously detonate.

Chloramine disinfection

The use of chloramine is becoming more common as a disinfectant. Although chloramine is not as strong an oxidant, it does provide a longer-lasting residual than free chlorine and it won't form THMs or haloacetic acids. It is possible to convert chlorine to chloramine by adding ammonia to the water after addition of chlorine. The chlorine and ammonia react to form chloramine. Water distribution systems disinfected with chloramines may experience nitrification, as ammonia is a nutrient for bacterial growth, with nitrates being generated as a by-product.

Ozone disinfection

O_3 is an unstable molecule which readily gives up one atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne organisms. It is a very strong, broad spectrum disinfectant that is widely used in Europe. It is an effective method to inactivate harmful protozoa that form cysts. It also works well against almost all other pathogens. Ozone is made by passing oxygen through ultraviolet light or a "cold" electrical discharge. To use ozone as a disinfectant, it must be created on-site and added to the water by bubble contact. Some of the advantages of ozone include the production of fewer dangerous by-products (in comparison to chlorination) and the lack of taste and odour produced by ozonisation. Although fewer by-products are formed by ozonation, it has been discovered that the use of ozone produces a small amount of the suspected carcinogen bromate, although little bromine should be present in treated water. Another of the main disadvantages of ozone is that it leaves no disinfectant residual in the water. Ozone has been used in drinking water plants since 1906 where the first industrial ozonation plant was built in Nice, France. The U.S. Food and Drug Administration has accepted ozone as being safe; and it is applied as an anti-microbiological agent for the treatment, storage, and processing of foods.

Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth (algae, periphyton attached algae, and nuisance plants weeds). This enhanced plant growth, often called an algal bloom, reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die. Nutrients can come from many sources, such as fertilizers applied to agricultural fields, golf courses, and suburban lawns; deposition of nitrogen from the atmosphere; erosion of soil containing nutrients; and sewage treatment plant discharges. Water with a low concentration of dissolved oxygen is called hypoxic. Eutrophication is caused by the decrease of an ecosystem with chemical nutrients, typically compounds containing nitrogen or phosphorus. It may occur on land or in the water. Eutrophication is frequently a result of nutrient pollution such as the release of sewage effluent into natural waters (rivers or coasts) although it may occur naturally in situations where nutrients accumulate (e.g. depositional environments) or where they flow into systems on an ephemeral basis (e.g. intermittent upwelling in coastal systems). Eutrophication generally promotes excessive plant growth and decay, favors certain weedy species over others, and is likely to cause severe reductions in water quality. In aquatic environments, enhanced growth of choking aquatic vegetation or phytoplankton (that is, an algal bloom) disrupts normal functioning of the ecosystem, causing a variety of problems. Human society is impacted as well: eutrophication decreases the resource value of rivers, lakes, and estuaries such that recreation, fishing, hunting, and aesthetic enjoyment are hindered. Health-related problems can occur where eutrophic conditions interfere with drinking water treatment. Although traditionally thought of as enrichment of aquatic systems by addition of fertilizers into lakes, bays, or other semi-enclosed waters (even slow-moving rivers), terrestrial ecosystems are subject to similarly adverse impacts. Increased content of nitrates in soil frequently leads to undesirable changes in vegetation composition and many plant species are endangered as a result of eutrophication in terrestric ecosystems, e.g. majority of orchid species in Europe. Ecosystems (like some meadows, forests and bogs that are characterized by low nutrient content and species-rich, slowly growing vegetation adapted to lower nutrient levels) are overgrown by faster growing and more competitive species-poor vegetation, like tall grasses, that can take advantage of unnaturally elevated nitrogen level and the area may be changed beyond recognition and vulnerable species may be lost. Eg. species-rich fens are overtaken by reed or reedgrass species, spectacular forest undergrowth affected by run-off from nearby fertilized field is turned into a thick nettle

and bramble shrub. Eutrophication was recognized as a pollution problem in European and North American lakes and reservoirs in the mid-20th century. Since then, it has become more widespread. Surveys showed that 54% of lakes in Asia are eutrophic; in Europe, 53%; in North America, 48%; in South America, 41%; and in Africa, 28%.

Concept of eutrophication

Eutrophication is apparent as increased turbidity in the northern part of the Caspian Sea, imaged from orbit. Eutrophication can be a natural process in lakes, as they fill in through geological time, though other lakes are known to demonstrate the reverse process, becoming less nutrient rich with time. Estuaries also tend to be naturally eutrophic because land-derived nutrients are concentrated where run-off enters the marine environment in a confined channel and mixing of relatively high nutrient fresh water with low nutrient marine water occurs. Phosphorus is often regarded as the main culprit in cases of eutrophication in lakes subjected to point source pollution from sewage. The concentration of algae and the tropic state of lakes correspond well to phosphorus levels in water. Studies conducted in the Experimental Lakes Area in Ontario have shown a relationship between the addition of phosphorus and the rate of eutrophication. Humankind has increased the rate of phosphorus cycling on Earth by four times, mainly due to agricultural fertilizer production and application. Between 1950 and 1995, 600,000,000 tonnes of phosphorus were applied to Earth's surface, primarily on croplands. Control of point sources of phosphorus have resulted in rapid control of eutrophication, mainly due to policy changes. Human activities can accelerate the rate at which nutrients enter ecosystems. Runoff from agriculture and development, pollution from septic systems and sewers, and other human-related activities increase the flux of both inorganic nutrients and organic substances into terrestrial, aquatic, and coastal marine ecosystems (including coral reefs). Elevated atmospheric compounds of nitrogen can increase soil nitrogen availability. Chemical forms of nitrogen are most often of concern with regard to eutrophication because plants have high nitrogen requirements so that additions of nitrogen compounds stimulate plant growth (primary production). Nitrogen is not readily available in soil because N_2, a gaseous form of nitrogen, is very stable and unavailable directly to higher plants. Terrestrial ecosystems rely on microbial nitrogen fixation to convert N2 into other physical forms (such as nitrates). However, there is a limit to how much nitrogen can be utilized. Ecosystems receiving more nitrogen than the plants require are called nitrogen-saturated. Saturated terrestrial ecosystems contribute both inorganic and organic nitrogen to freshwater, coastal, and marine eutrophication, where nitrogen is also typically a limiting nutrient. However, in marine environments, phosphorus may be limiting because it is leached from the soil at a much slower rate than nitrogen, which are highly insoluble.

Ecological effects

Adverse effects of eutrophication on lakes, reservoirs, rivers and coastal marine waters

• Increased biomass of phytoplankton

• Toxic or inedible phytoplankton species

• Increases in blooms of gelatinous zooplankton

• Increased biomass of benthic and epiphytic algae

• Changes in macrophyte species composition and biomass

• Decreases in water transparency

• Taste, odor, and water treatment problems

• Dissolved oxygen depletion

• Increased incidences of fish kills

• Loss of desirable fish species

• Reductions in harvestable fish and shellfish

• Decreases in perceived aesthetic value of the water body

Many ecological effects can arise from stimulating primary production, but there are three particularly troubling ecological impacts: decreased biodiversity, changes in species composition and dominance, and toxicity effects.

Decreased biodiversity

When an ecosystem experiences an increase in nutrients, primary producers reap the benefits first. In aquatic ecosystems, species such as algae experience a population increase (called an algal bloom). Algal blooms limit the sunlight available to bottom-dwelling organisms and cause wide swings in the amount of dissolved oxygen in the water. Oxygen is required by all respiring plants and animals and it is replenished in daylight by photosynthesizing plants and algae. Under eutrophic conditions, dissolved oxygen greatly increases during the day, but is greatly reduced after dark by the respiring algae and by microorganisms that feed on the increasing mass of dead algae. When dissolved oxygen levels decline to hypoxic levels, fish and other marine animals suffocate. As a result, creatures such as fish, shrimp, and especially immobile bottom dwellers die off. In extreme cases, anaerobic conditions ensue, promoting growth of bacteria such as Clostridium botulinum that produces toxins deadly to birds and mammals. Zones where this occurs are known as dead zones.

Sources of high nutrient runoff

Characteristics of point and nonpoint sources of chemical inputs

Point sources

• Wastewater effluent (municipal and industrial)

• Runoff and leachate from waste disposal systems

• Runoff and infiltration from animal feedlots

• Runoff from mines, oil fields, unsewered industrial sites

• Overflows of combined storm and sanitary sewers

• Runoff from construction sites >20,000 m^2

Nonpoint Sources

• Runoff from agriculture/irrigation

• Runoff from pasture and range

• Urban runoff from unsewered areas

• Septic tank leachate

• Runoff from construction sites <20,000 m^2

• Runoff from abandoned mines

• Atmospheric deposition over a water surface

• Other land activities generating contaminants

Point sources

Point sources are directly attributable to one influence. In point sources the nutrient waste travels directly from source to water. For example, factories that have waste discharge pipes directly leading into a water body would be classified as a point source. Point sources are relatively easy to regulate.

Nonpoint sources

Nonpoint source pollution (also known as 'diffuse' or 'runoff' pollution) is that which comes from ill-defined and diffuse sources. Nonpoint sources are difficult to regulate and usually vary spatially and temporally (with season, precipitation, and other irregular events). It has been shown that nitrogen transport is correlated with various indices of human activity in watersheds, including the amount of development. Agriculture and development are activities that contribute most to nutrient loading.

There are three reasons that nonpoint sources are especially troublesome:

• Soil retention

• Runoff to surface water and leaching to groundwater

• Atmospheric deposition

Prevention and reversal

Eutrophication poses a problem not only to ecosystems, but to humans as well. Reducing eutrophication should be a key concern when considering future policy, and a sustainable solution for everyone, including farmers and ranchers, seems feasible. While eutrophication does pose problems, humans should be aware that natural runoff (which causes algal blooms in the wild) is common in ecosystems and should thus not reverse nutrient concentrations beyond normal levels.

Effectiveness

Cleanup measures have been mostly, but not completely, successful. Finnish phosphorus removal measures started in the mid-1970s and have targeted rivers and lakes polluted by industrial and municipal discharges. These efforts have had a 90% removal efficiency. Still, some targeted point sources did not show a decrease in runoff despite reduction efforts. what can the economy do?

Impact of farming

Farming is what makes possible the production of food surpluses and settled living. It also brings about big changes in the relationships between living things and in their habitats. Farming - especially modern, intensive farming can damage the environment in many different ways.

Effect of fertilizers

Fertilisers containing plant nutrients are sprayed onto fields to make plants grow faster and boost crop yields. When it rains the nutrients may get washed down from the fields and into rivers and lakes (this is called run-off). The result is eutrophication - which can kill almost everything living in the aquatic environment. It works like this:

Effect of pesticides

Pesticides are chemicals used to kill insects, weeds and microorganisms that might damage crops. However, pesticides damage other organisms apart from those they are intended to kill - for example, depriving insect-eating birds of food. Pesticides can also enter local food chains. Organisms that ingest them cannot break them down, so they persist in their bodies. (Substances that cannot be broken down are called persistent substances: the pesticide DDT is an example.) The pesticides may then build up at ever-higher levels until they become toxic to much larger organisms.

Here's how it works: Other impacts of farming

Agriculture can impact on the environment in many other ways. For example:

• farming takes up land, reducing habitats and wildlife

• monocultures (large amounts of one type of food) provide lots of food for pests as well as humans

• irrigation (watering of crops) may take too much water from rivers, depriving downstream habitats of water

• clearing land for farming may result in soil erosion, damaging ecosystemsand leaving land barren

• Intensive livestock farming produces huge amount of faeces, which may pollute waterways

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Land Pollution

Increased mechanization

The increase in the concentration of population in cities, along with the internal combustion engine, led to the increased number of roads and all the infra structure that goes with them. Roads cause visual, noise, light, air and water pollution, in addition to land pollution. The visual and noise areas are obvious, however light pollution is becoming more widely recognized as a problem. From outer space, large cities can be picked out at night by the glow of their lighting, so city dwellers seldom experience total darkness.

As the demand for food has grown very high, there is an increase in field size and mechanization. The increase in field size makes it economically viable for the farmer but results in loss of habitat and shelter for wildlife, as hedgerows and copses disappear. When crops are harvested, the naked soil is left open to wind after the heavy machinery has compacted it. Another consequence of more intensive agriculture is the move to monoculture. This is unnatural, it depletes the soil of nutrients, allows diseases and pests to spread and, in short, brings into play the use of chemical substances foreign to the environment.

A pesticide is a substance or mixture of substances used to kill a pest. A pesticide may be a chemical substance, biological agent (such as a virus or bacteria), antimicrobial, disinfectant or device used against any pest. Pests include insects, plant pathogens, weeds, mollusks, birds, mammals, fish, nematodes (roundworms) and microbes that compete with humans for food, destroy property, spread or are a vector for disease or cause a nuisance. Although there are benefits to the use of pesticides, there are also drawbacks, such as potential toxicity to humans and other Pesticides are used to control organisms which are considered harmful. For example, they are used to kill mosquitoes that can transmit potentially deadly diseases like west Nile virus, yellow fever, and malaria disease. They can also kill bees, wasps or ants that can cause allergic reactions. Insecticides can protect animals from illnesses that can be caused by parasites such as fleas, Pesticides can prevent sickness in humans that could be caused by moldy food or diseased produce.

Herbicides

Herbicides are used to kill weeds, especially on pavements and railways. They are similar to auxins and most are biodegradable by soil bacteria. However one group derived from trinitrotoluene (2:4 D and 2:4:5 T) have the impurity dioxin, which is very toxic and causes fatality even in low concentrations. It also causes spontaneous abortions, hemorrhaging and cancer Agent Orange(50% 2:4:5 T) was used as a defoliant in Vietnam. Eleven million gallons were used and children born since then to American soldiers who served in this conflict, have shown increased physical and mental disabilities compared to the rest of the population. It affects the head of the sperm and the chromosomes inside it. Another herbicide, much loved by murder story writers, is Parquet. It is highly toxic but it rapidly degrades in soil due to the action of bacteria and does not kill soil fauna.

Insecticides are used to rid farms of pests which damage crops. The insects damage not only standing crops but also stored ones and in the tropics it is reckoned that one third of the total production is lost during food storage. As with fungicides, the first insecticides used in the nineteenth century were inorganic e.g. Paris Green and other compounds of arsenic, Nicotine has also been used since the late eighteenth century.

There are now two main groups of synthetic insecticides - Organochlorines include DDT, Aldrin, Dieldrin and BHC. They are cheap to produce, potent and persistent. DDT was used on a massive scale from the 1930s, with a peak of 72,000 tonnes used 1970. Then usage fell as the harmful environmental effects were realized. It was found worldwide in fish and birds and was even discovered in the snow in the Antarctic. It is only slightly soluble in water but is very soluble in the bloodstream. It affects the nervous and endocrine systems and causes the eggshells of birds to lack calcium causing them to be easily breakable. It is thought to be responsible for the decline of the numbers of birds of prey like ospreys and peregrine falcons in the 1950s - they are now recovering. As well as increased concentration via the food chain, it is known to enter via permeable membranes, so fish get it through their gills. As it has low water solubility, it tends to stay at the water surface, so organisms that live there are most affected. DDT found in fish that formed part of the human food chain caused concern, but the levels found in the liver, kidney and brain tissues was less than 1 ppm and in fat was 10 ppm which was below the level likely to cause harm. However, DDT was banned in Britain and America to stop the further build up of it in the food chain. The USA exploited this ban and sold DDT to developing countries, who could not afford the expensive replacement chemicals and who did not have such stringent regulations governing the use of pesticides.

Organophosphate]]s, e.g. parathion, methyl parathion and about 40 other insecticides are available nationally. Parathion is highly toxic, methyl-parathion is less so and Malathion is generally considered safe as it has low toxicity and is rapidly broken down in the mammalian liver. This group works by preventing normal nerve transmission as cholinesterase is prevented from breaking down the transmitter substance acetylcholine, resulting in uncontrolled muscle movements.

Entry of a variety of pesticides into our water supplies causes concern to environmental groups, as in many cases the long term effects of these specific chemicals is not known.

Mining

Modern mining projects leave behind disrupted communities, damages landscapes, and polluted water. Mining also affects ground and surface waters, the aquatic life, vegetation, soils, animals, and the human health. Acid mine drainage can cause damage to streams which in return can kill aquatic life. The vast variety of toxic chemicals released by mining activities can harm animals and aquatic life as well as their habitat. The average mine disturbs over a thousand acres of land.

Burial

Burial is the technique used by Jews, Christians and other religions with Abrahamic influence, to dispose of the corpse of dead humans and animals. This process leads to regular soil erosion due to loosening of soil. Also, the decomposing fluids act as poisonous herbicides, pesticides and may even lead to epidemics in surrounding areas. It leads to soil pollution, soil erosion and even water pollution.

Construction

Construction often puts sediments in rivers and bodies of water. By doing this, natural water filters are damaged. Natural water filters help break down many pollutants before they reach other water bodies. Some harmful chemicals that may run off with water and sediments from construction sites are oils, debris, and paint. This can cause damage to soil, aquatic life, and promote hazardous chemicals to get into drinking water.

Increased waste disposal

In Scotland in 1993, 14 million tons of waste was produced. 100,000 tons was special waste and 260,000 tons was controlled waste from other parts of Britain and abroad. 45% of the special waste was in liquid form and 18% was asbestos - radioactive waste was not included. Of the controlled waste, 48% came from the demolition of buildings, 22% from industry, 17% from households and 13% from business - only 3% were recycled. 90% of controlled waste was buried in landfill sites and produced 2 million tons of methane gas. 1.5% was burned in incinerators and 1.5% were exported to be disposed of or recycled. There are 748 disposal sites in Scotland. There are very few vacant or derelict land sites in the north east of Scotland, as there are few traditional heavy industries or coal/mineral extraction sites. However some areas are contaminated by aromatic hydrocarbons (500 cubic meters).

The Urban Waste Water Treatment Directive allows sewage sludge to be sprayed onto land and the volume is expected to double to 185,000 tons of dry solids in 2005. This has good agricultural properties due to the high nitrogen and phosphate content. In 1990/1991, 13% wet weight was sprayed onto 0.13% of the land, however this is expected to rise 15 fold by 2005. There is a need to control this so that pathogenic microorganisms do not get into water courses and to ensure that there is no accumulation of heavy metals in the top soil

Disposal methods

Landfill operation in Hawaii.

Disposing of waste in a landfill involves burying the waste, and this remains a common practice in most countries. Landfills were often established in abandoned or unused quarries, mining voids or borrow pits. A properly-designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials. Older, poorly-designed or poorly-managed landfills can create a number of adverse environmental impacts such as wind-blown litter, attraction of vermin, and generation of liquid leachate. Another common byproduct of landfills is gas (mostly composed of methane and carbon dioxide), which is produced as organic waste breaks down anaerobically. This gas can create odor problems, kill surface vegetation, and is a greenhouse gas.

A landfill compaction vehicle in action.

Design characteristics of a modern landfill include methods to contain leachate such as clay or plastic lining material. Deposited waste is normally compacted to increase its density and stability, and covered to prevent attracting vermin (such as mice or rats). Many landfills also have landfill gas extraction systems installed to extract the landfill gas. Gas is pumped out of the landfill using perforated pipes and flared off or burnt in a gas engine to generate electricity.

Spittelau incineration plant in Vienna.

Incineration is a disposal method that involves combustion of waste material. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". Incinerators convert waste materials into heat, gas, steam, and ash.

Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical waste). Incineration is a controversial method of waste disposal, due to issues such as emission of gaseous pollutants.

Incineration is common in countries such as Japan where land is more scarce, as these facilities generally do not require as much area as landfills. Waste-to-energy (WtE) or energy-from-waste (EfW) are broad terms for facilities that burn waste in a furnace or boiler to generate heat, steam and/or electricity. Combustion in an incinerator is not always perfect and there have been concerns about micro-pollutants in gaseous emissions from incinerator stacks. Particular concern has focused on some very persistent organics such as dioxins which may be created within the incinerator and which may have serious environmental consequences in the area immediately around the incinerator. On the other hand this method produces heat that can be used as energy.

Recycling methods

PVC, LDPE, PP, and PS (see resin identification code) are also recyclable, although these are not commonly collected. These items are usually composed of a single type of material, making them relatively easy to recycle into new products. The recycling of complex products (such as computers and electronic equipment) is more difficult, due to the additional dismantling and separation required.

Sustainability

Waste Management is a key player in maintaining a business's ISO14001 accreditations.

Companies are encouraged to improve their environmental efficiencies each year. One way to do this is **by improving a company's waste management with a new recycling service. (such** as recycling: glass, food waste, paper and cardboard, plastic bottles etc)

Biological reprocessing

An active compost heap.

Waste materials that are organic in nature, such as plant material, food scraps, and paper products, can be recycled using biological composting and digestion processes to decompose the organic matter. The resulting organic material is then recycled as mulch or compost for agricultural or landscaping purposes. In addition, waste gas from the process (such as methane) can be captured and used for generating electricity. The intention of biological processing in waste management is to control and accelerate the natural process of decomposition of organic matter.

There is a large variety of composting and digestion methods and technologies varying in complexity from simple home compost heaps, to industrial-scale enclosed-vessel digestion of mixed domestic waste (see Mechanical biological treatment). Methods of biological decomposition are differentiated as being aerobic or anaerobic methods, though hybrids of the two methods also exist.

An example of waste management through composting is the Green Bin Program in Toronto, Canada, where household organic waste (such as kitchen scraps and plant cuttings) are collected in a dedicated container and then composted.

Anaerobic digestion component of Lübeck mechanical biological treatment plant in Germany, 2007

The energy content of waste products can be harnessed directly by using them as a direct combustion fuel, or indirectly by processing them into another type of fuel. Recycling through thermal treatment ranges from using waste as a fuel source for cooking or heating, to fuel for boilers to generate steam and electricity in a turbine. Pyrolysis and gasification are two related forms of thermal treatment where waste materials are heated to high temperatures with limited oxygen availability. The process typically occurs in a sealed vessel under high pressure. Pyrolysis of solid waste converts the material into solid, liquid and gas products. The liquid and gas can be burnt to produce energy or refined into other products. The solid residue (char) can be further refined into products such as activated carbon. Gasification and advanced Plasma arc gasification are used to convert organic materials directly into a synthetic gas (syngas) composed of carbon monoxide and hydrogen. The gas is then burnt to produce electricity and steam.

An important method of waste management is the prevention of waste material being created, also known as waste reduction. Methods of avoidance include reuse of second-hand products, repairing broken items instead of buying new, designing products to be refillable or reusable (such as cotton instead of plastic shopping bags), encouraging consumers to avoid using disposable products (such as disposable cutlery), removing any food/liquid remains from cans, packaging, and designing products that use less material to achieve the same purpose (for example, light weighting of beverage cans).

Noise Pollution

Sound is a mechanical wave that is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing and of alevel sufficiently strong to be heard, or the sensation stimulated in organs of hearing by such vibrations.

Sound is a sequence of waves of pressure that propagates through compressible media such as air or water. (Sound can propagate through solids as well, but there are additional modes of propagation). During propagation, waves can be reflected, refracted, or attenuated by the medium.

The behavior of sound propagation is generally affected by three things:

- A relationship between density and pressure. This relationship, affected by temperature, determines the speed of sound within the medium.
- The propagation is also affected by the motion of the medium itself. For example, sound moving through wind. Independent of the motion of sound through the medium, if the medium is moving, the sound is further transported.
- The viscosity of the medium also affects the motion of sound waves. It determines the rate at which sound is attenuated. For many media, such as air or water, attenuation due to viscosity is negligible.

When sound is moving through a medium that does not have constant physical properties, it may be refracted (either dispersed or focused).

The perception of sound in any organism is limited to a certain range of frequencies. For humans, hearing is normally limited to frequencies between about 20 Hz and 20,000 Hz (20 kHz), although these limits are not definite. The upper limit generally decreases with age. Other species have a different range of hearing. For example, dogs can perceive vibrations higher than 20 kHz, but are deaf to anything below 40 Hz. As a signal perceived by one of the major senses, sound is used by many species for detecting danger, navigation, predation, and communication. Earth's atmosphere, water, and virtually any physical phenomenon, such as fire, rain, wind, surf, or earthquake, produces (and is characterized by) its unique sounds. Many species, such as frogs, birds, marine and terrestrial mammals, have also developed special organs to produce sound. In some species, these produce song and speech. Furthermore, humans have developed culture and technology (such as music, telephone and radio) that allows them to generate record, transmit, and broadcast sound. The scientific study of human sound perception is known as psychoacoustics.

Sound is transmitted through gases, plasma, and liquids as longitudinal waves, also called compression waves. Through solids, however, it can be transmitted as both longitudinal waves and transverse waves. Longitudinal sound waves are waves of alternating pressure deviations from the equilibrium pressure, causing local regions of compression and rarefaction, while transverse waves (in solids) are waves of alternating shear stress at right angle to the direction of propagation.

Matter in the medium is periodically displaced by a sound wave, and thus oscillates. The energy carried by the sound wave converts back and forth between the potential energy of the extra compression (in case of longitudinal waves) or lateral displacement strain (in case of transverse waves) of the matter and the kinetic energy of the oscillations of the medium.

The speed of sound depends on the medium the waves pass through, and is a fundamental property of the material. In general, the speed of sound is proportional to the square root of the ratio of the elastic modulus (stiffness) of the medium to its density. Those physical properties and the speed of sound change with ambient conditions. For example, the speed of sound in gases depends on temperature. In 20 °C (68 °F) air at the sea level, the speed of sound is approximately 343 m/s (1,230 km/h; 767 mph) using the formula "v = (331 + 0.6 T) m/s". In fresh water, also at 20 °C, the speed of sound is approximately 1,482 m/s (5,335 km/h; 3,315 mph). In steel, the speed of sound is about 5,960 m/s (21,460 km/h; 13,330 mph). The speed of sound is also slightly sensitive (a second-order anharmonic effect) to the sound amplitude, which means that there are nonlinear propagation effects, such as the production of harmonics and mixed tones not present in the original sound (see parametric array).

Sound pressure is the difference, in a given medium, between average local pressure and the pressure in the sound wave. A square of this difference (i.e., a square of the deviation from the equilibrium pressure) is usually averaged over time and/or space, and a square root of this average provides a root mean square (RMS) value. For example, 1 Pa RMS sound pressure (94 dBSPL) in atmospheric air implies that the actual pressure in the sound wave oscillates between (1 atm $-\sqrt{2}$ Pa) and (1 atm $+\sqrt{2}$ Pa), that is between 101323.6 and 101326.4 Pa. Such a tiny (relative to atmospheric) variation in air pressure at an audio frequency is perceived as a deafening sound, and can cause hearing damage, according to the table below.

As the human ear can detect sounds with a wide range of amplitudes, sound pressure is often measured as a level on a logarithmic decibel scale. The **sound pressure level**(SPL) or L_p is defined as

$$L_\mathrm{p} = 10\,\log_{10}\left(\frac{p^2}{{p_\mathrm{ref}}^2}\right) = 20\,\log_{10}\left(\frac{p}{p_\mathrm{ref}}\right)\ \mathrm{dB}$$

where p is the root-mean-square sound pressure and p_{ref} is a reference sound pressure. Commonly used reference sound pressures, defined in the standard ANSI S1.1-1994, are 20 µPa in air and 1 µPa in water. Without a specified reference sound pressure, a value expressed in decibels cannot represent a sound pressure level.

Since the human ear does not have a flat spectral response, sound pressures are often frequency weighted so that the measured level matches perceived levels more closely. The International Electrotechnical Commission (IEC) has defined several weighting schemes. A-weighting attempts to match the response of the human ear to noise and A-weighted sound pressure levels are labeled dBA. C-weighting is used to measure peak levels.

Sound Intensity is the amount of sound energy that flows normally through unit area of the medium in unit time. Time is generally measured in second. The unit of intensity is watt/meter^2. Energy per second per square meter = Joule s^{-1} m^{-2} = Wm^{-2}.

Sound intensity level or acoustic intensity level is a logarithmic measure of the sound intensity (measured in W/m^2), in comparison to a reference level.

The measure of a ratio of two sound intensities is

$$L_\mathrm{I} = 10\,\log_{10}\left(\frac{I_1}{I_0}\right)\ \mathrm{dB}$$

where I_1 and I_0 are the intensities.

The sound intensity level is given the letter "L_I" and is measured in "dB". The decibel is a dimensionless quantity.

If I_0 is the standard reference sound intensity

$$I_0 = 10^{-12}\,\mathrm{W/m^2}$$

(W = watt), then instead of "dB SPL" we use "dB SIL". (SIL = sound intensity level).

Musical Sound consists of a series of harmonic waves following each other at regular interval of time, without sudden changes in their amplitude.

The three characteristics which differentiate musical sounds from one another are:

- Loudness
- Pitch
- Quality or timbre

Loudness

It is that characteristic of a musical sound that determines the degree of sensation that the sound can produce in the ear. It depends on the intensity of the sound which is objective in nature and the sensitivity of the ear which is subjective in nature. The factors on which loudness depends and the unit of measurement have been described earlier in this section.

Pitch

It is that characteristic of a musical sound by which a shrill sound can be distinguished from a grave one, even though the two sounds may be of the same intensity. It is also defined as that characteristic of sound by which the ear assigns it a place on a musical scale. When a stretched string is plucked, a sound of a certain pitch sensation is produced. If the tension in the string is increased, the pitch (the shrillness) becomes higher. Increasing the tension also increases the frequency of vibration. Therefore, pitch is intimately related to frequency. But frequency alone does not determine the pitch. Below 1000Hz, the pitch is slightly higher than the frequency and above 1000Hz the position is reversed. The loudness of sound also affects the pitch up to 1000Hz. An increase in loudness causes a decrease in pitch. From about 1000 to 3000Hz, the pitch is independent of loudness, while above 3000Hz an increase in loudness causes an increase in pitch.

The voice of a woman or a child is shrill but that of a man is hoarse (i.e., flat or grave). The sound emitted by a cuckoo is shrill while that by a crow or a lion is hoarse. The buzzing of a mosquito, though low in intensity has a high pitch. The pitch of the sound changes when the source or the observer or both are in relative motion.

Quality or timber

It is that characteristic of a musical sound which enables us to distinguish between the sounds produced by two different musical instruments or two different persons although their pitch and loudness may be same. It is because of this characteristic that we are able to recognize the voice of a known person over the telephone or to distinguish between the sounds produced by different musical instruments in an orchestra.

The quality depends primarily on the waveform of the sound. The waveform of the sound emitted by a tuning fork is a simple sine curve. But most bodies vibrate in a very complex manner. Besides the fundamental frequency f, they consist of additional frequencies of 2f, 3f, 4f, etc. These additional tones are called overtones or harmonics. According to Helmholtz, the quality of a musical note is determined by the number, relative frequency and intensities of the component simple tones of which a complex vibration is composed of.

One can produce the same tone with the same frequency and intensity as one's favorite singer, but the singer's voice has a better quality because of a different combination of the overtones in it.

What is noise?

The word noise is derived from the Latin term **nausea**. It has been defined as unwanted sound, a potential hazard to health and communication dumped into the environment with regard to the adverse effect it may have on unwilling ears. In simple terms, noise is unwanted sound. Sound is a form of energy which is emitted by a vibrating body and on reaching the ear causes the sensation of hearing through nerves. Sounds produced by all vibrating bodies are not audible. The frequency limits of audibility are from 20 HZ to 20,000 HZ. A noise problem generally consists of three inter-related elements- the source, the receiver and the transmission path. This transmission path is usually the atmosphere through which the sound is propagated, but can include the structural materials of any building containing the receiver

Noise may be continuous or intermittent. Noise may be of high frequency or of low frequency which is undesired for a normal hearing. For example, the typical cry of a child produces sound, which is mostly unfavourable to normal hearing. Since it is unwanted sound, we call it noise. The discrimination and differentiation between sound and noise also depends upon the habit and interest of the person/species receiving it, the ambient conditions and impact of the sound generated during that particular duration of time. There could be instances that, excellently rendered musical concert for example, may be felt as noise and exceptional music as well during the course of the concert! Sounds of frequencies less than 20 HZ are called infrasonic and greater than 20, 0000 HZ are called ultrasonic. Since noise is also a sound, the terms noise and sound are synonymously used and are followed in this module.

Sources of Noise Pollution: - Noise pollution like other pollutants is also a by- product of industrialization, urbanizations and modern civilization.

Broadly speaking, the noise pollution has two sources, i.e. industrial and non- industrial. The industrial source includes the noise from various industries and big machines working at a very high speed and high noise intensity. Non- industrial source of noise includes the noise created by transport/vehicular traffic and the neighbourhood noise generated by various noise pollution can also be divided in the categories, namely, natural and manmade. Most leading noise sources will fall into the following categories: roads traffic, aircraft, railroads, construction, industry, noise in buildings, and consumer products

1. Road Traffic Noise

In the city, the main sources of traffic noise are the motors and exhaust system of autos, smaller trucks, buses, and motorcycles. This type of noise can be augmented by narrow streets and tall buildings, which produce a canyon in which traffic noise reverberates.

2. Air Craft Noise

Now-a-days , the problem of low flying military aircraft has added a new dimension to community annoyance, as the nation seeks to improve its nap-of the- earth aircraft operations over national parks, wilderness areas , and other areas previously unaffected by aircraft noise has claimed national attention over recent years.

3. Noise from railroads

The noise from locomotive engines, horns and whistles, and switching and shunting operation in rail yards can impact neighbouring communities and railroad workers. For example, rail car retarders can produce a high frequency, high level screech that can reach peak levels of 120 dB at a distance of 100 feet, which translates to levels as high as 138, or 140 dB at the railroad worker's ear.

4. Construction Noise

The noise from the construction of highways, city streets, and buildings is a major contributor to the urban scene. Construction noise sources include pneumatic hammers, air compressors, bulldozers, loaders, dump trucks (and their back-up signals), and pavement breakers.

5. Noise in Industry

Although industrial noise is one of the less prevalent community noise problems, neighbours of noisy manufacturing plants can be disturbed by sources such as fans, motors, and compressors mounted on the outside of buildings Interior noise can also be transmitted to the community through open windows and doors, and even through building walls. These interior noise sources have significant impacts on industrial workers, among whom noise-induced hearing loss is unfortunately common.

6. Noise in building

Apartment dwellers are often annoyed by noise in their homes, especially when the building is not well designed and constructed. In this case, internal building noise from plumbing, boilers, generators, air conditioners, and fans, can be audible and annoying. Improperly insulated walls and ceilings can reveal the sound of amplified music, voices, footfalls and noisy activities from neighbouring units. External noise from emergency vehicles, traffic, refuse collection, and other city noises can be a problem for urban residents, especially when windows are open or insufficiently glazed.

7. Noise from Consumer products

Certain household equipment, such as vacuum cleaners and some kitchen appliances have been and continue to be noisemakers, although their contribution to the daily noise dose is usually not very large

Harmful Effects

On Human Being, Animal and Property: Noise has always been with the human civilization but it was never so obvious, so intense, so varied & so pervasive as it is seen in the last of this century. Noise pollution makes men more irritable. The effect of noise pollution is multifaceted & inter related. The effects of Noise Pollution on Human Being, Animal and property are as follows:

I It decreases the efficiency of a man:- Regarding the impact of noise on human efficiency there are number of experiments which print out the fact that human efficiency increases with noise reduction. A study by *Sinha & Sinha* in India suggested that reducing industrial booths could improve the quality of their work. Thus human efficiency is related with noise.

II Lack of concentration: - For better quality of work there should be concentration, Noise causes lack of concentration. In big cities, mostly all the offices are on main road. The noise of traffic or the loud speakers of different types of horns divert the attention of the people working in offices.

III Fatigue: - Because of Noise Pollution, people cannot concentrate on their work. Thus they have to give their more time for completing the work and they feel tiring

IV Abortion is caused: - There should be cool and calm atmosphere during the pregnancy. Unpleasant sounds make a lady of irrigative nature. Sudden Noise causes abortion in females.

V It causes Blood Pressure: - Noise Pollution causes certain diseases in human. It attacks on the person's peace of mind. The noises are recognized as major contributing factors in accelerating the already existing tensions of modern living. These tensions result in certain disease like blood pressure or mental illness etc.

VI Temporary or permanent Deafness: - The effect of nose on audition is well recognized. Mechanics, locomotive drivers, telephone operators etc. All have their hearing. Impairment as a result of noise at the place of work. Physicist, physicians & psychologists are of the view that continued exposure to noise level above. 80 to 100 db is unsafe, loud noise causes temporary or permanent deafness.

VII EFFECT ON VEGETATION: - Poor quality of Crops: - Now is well known to all that plants are similar to human being. They are also as sensitive as man. There should be cool & peaceful environment for their better growth. Noise pollution causes poor quality of crops in a pleasant atmosphere.

VIII EFFECT ON ANIMAL: - Noise pollution damages the nervous system of animal. Animal looses the control of its mind. They become dangerous.

IX EFFECT ON PROPERTY: - Loud noise is very dangerous to buildings, bridges and monuments. It creates waves which struck the walls and put the building in danger condition. It weakens the edifice of buildings.

Noise Control:

The noise pollution can be controlled at the source of generation itself by employing techniques like-

Reducing the noise levels from domestic sectors: The domestic noise coming from radio, tape recorders, television sets, mixers, washing machines, cooking operations can be minimised by their selective and judicious operation. By usage of carpets or any absorbing material, the noise generated from felling of items in house can be minimised.

Maintenance of automobiles: Regular servicing and tuning of vehicles will reduce the noise levels. Fixing of silencers to automobiles, two wheelers etc., will reduce the noise levels.

Control over vibrations: The vibrations of materials may be controlled using proper foundations, rubber padding etc. to reduce the noise levels caused by vibrations.

Low voice speaking: Speaking at low voices enough for communication reduces the excess noise levels.

Prohibition on usage of loud speakers: By not permitting the usage of loudspeakers in the habitant zones except for important meetings / functions. Now-a-days, the urban Administration of the metro cities in India is becoming stringent on usage of loudspeakers.

Selection of machinery: Optimum selection of machinery tools or equipment reduces excess noise levels. For example selection of chairs or selection of certain machinery/equipment which generate less noise (Sound) due to its superior technology etc. is also an important factor in noise minimisation strategy.

Maintenance of machines: Proper lubrication and maintenance of machines, vehicles etc. will reduce noise levels. For example, it is a common experience that, many parts of a vehicle will become loose while on a rugged path of journey. If these loose parts are not properly fitted, they will generate noise and cause annoyance to the driver/passenger. Similarly is the case of machines. Proper handling and regular maintenance is essential not only for noise control but also to improve the life of machine.

Measurement of noise levels

A-Weighted Decibels, dBA

The threshold of human hearing varies with frequency, being most sensitive to sound mid frequencies (500 Hz to 4000 Hz), and less sensitive at lower and higher frequencies. The pressure amplitude of a sound therefore does not directly relate to its perceived loudness and both frequency and amplitude need to be taken into account. For low level sounds, filter having a frequency response corresponding to that of human hearing (in level range about 40 dBA), is incorporated in sound level meters. Sound level measurements made using this filter (A-weighting) are described as A-weighted decibels, dBA. The level of a sound expressed in dBA is a reasonable measure of the loudness of that sound. Different sounds having the same dBA level generally sound about equally as loud, although the character of the noise also plays a part in its perceived loudness. A change of 1dBA or less in the level of a sound is difficult for most people to detect, whilst a 3 dBA to 5dBA change corresponds to small but noticeable change in loudness. A 10 dBA change is generally accepted to correspond to an approximate doubling or halving in loudness.