Introduction:
Water is a basic natural resource required by all human beings. Man requires a minimum body intake of water that varies from 2.8 - 13 litres per head per day depending on the climate and the temperature. The water is normally taken in food and drink, and the intake must balance the water loss from the body through:
- Breathing
- Sweating
- Excretion of urine
- Excretion of faeces
If there is no intake of water into the body, death can ensue in 7-10 days. Water is also essential to man for maintaining personal hygiene and freedom from disease. Of the total volume of water 1,385 million km$^3$ on the planet earth, 96.5% is salt water (Oceans and seas), the fresh water is mostly ice (24 million Km$^3$). The fresh water available as annual stream flow is 46,768 Km$^3$, that is 0.00034% of the total global water. The world water consumption is estimated at 4,000 km$^3$, consisting of:
- 2680 Km$^3$ for Agriculture.
- 973 Km$^3$ for industry
- 300 Km$^3$ for Municipal supplies
- 170 Km$^3$ in reservoirs
These are a few drops compared to the total water.

Other Water Purposes
In addition to personal use, water is required for many other purposes namely:-
1. Public water supplies- Most of these supplies are used by domestic households for drinking, cooking, dishwashing, general cleaning, laundry, personal washing and bathing, lavatory flushing, car washing and garden watering. The lesser portion is utilized by industry, and commercial and trade premises.
2. Industrial water Supplies - Various industrial processes require large quantities of water for cooking purposes, steam raising, material processing and the disposal of waste.
3. Cooling water is used in large quantities for the generation of electricity. This water is usually obstructed from rivers, lakes and estuaries.
5. Water for amenity and recreational purposes. This water is not abstracted from the hydrological cycle. This includes streams, rivers, reservoirs, estuaries, canals, and coastal waters. This water is used for all types of water sports such as swimming, fishing, boating, sailing, skiing as a means of transport for pleasure or Commercial purposes.
Sources of water

The input to the hydrological cycle on land is precipitated water falling as rain, hail or snow.

When this water reaches the ground some of it is evaporated, or runs off into the sea, streams and rivers, and the remaining enters the ground water system.

Man obtains water from two chief sources of supply:

1. Surface water- this is drawn from streams, rivers, lakes and storage reservoirs eg. Household tanks.
2. Ground water – This is drawn from underground aquifers through boreholes and wells.

The quality of surface water, the degree of pollution present, and fluctuations in the volume of water available are crucial factors that determine the volume of water supplies available for all users.

Surface water, especially in rivers has three functions.

- Rivers provide a source of water for all users,
- They are also used for the removal of effluent discharges from industrial plants and sewage works (only after crucial treatment).
- Rivers also have a recreational and amenity role in providing facilities for fishing, swimming, boating and sailing in the countryside and towns. If the rivers ecosystem is polluted then, the recreational and amenity functions are diminished.

Aquifers or water bearing rock layers (ground water) can be used as an alternative to surface water. Aquifers provide a natural storage for ground water, and they exist in rock strata such as sandstone, some limestones, greensand and chalk, sited above impermeable rock. Water is abstracted by wells or bore-holes, and it is replenished by ground water infiltrating from around the water aquifer. Aquifers can be polluted in two ways:

(i) If they are sited in coastal areas where the porous rock is below sea level, there may be an intrusion of sea water, when the level of fresh water falls below a critical point in the aquifer.

(ii) Pollution can occur if an aquifer is supplied by ground water that has percolated through polluted ground or a land tip.

WATER POLLUTION

Definition:

-To the general public, pollution is evident in terms of the observed appearance of the water eg. A river is polluted if the water is turbid, has foam on the surface, has an objectionable smell, and does not support fish and other living organisms.
- Pollution may also be defined as a natural or induced change in the quality of water which renders it unusable or dangerous as regards food, human and animal health, industry, agriculture, fishing or leisure pursuits.
- Basically water pollution is induced by human activities which cause pollutants to enter natural waters.
Sources of water pollution

The main source of water pollution is the discharge of solid or liquid waste products containing pollutants on to the land surface, or into surface or coastal waters.

The wastes that contribute towards water pollution may be grouped into three types:

1. Sewage waste
2. Industrial waste
3. Agricultural waste

SEWAGE WASTE

Sewage is literally the contents of sewers. These contents comprise the sewerage system that carries water-borne wastes of a community.

Sewage originates from domestic and commercial premises, land drains, some industrial plants and agricultural sites. Other industrial waste is discharged directly into rivers, canals and the sea and not into the sewage systems.

The largest volume of discharged waste is in the form of an effluent. This is a broad term used to describe any solid, liquid or gaseous product, in a treated or untreated condition that is discharged from a process.

In relation to water pollution, effluents are usually liquids that vary considerably in composition. eg industrial effluent may contain water, organic solvents, oils, suspended solids, and dissolved chemical compounds.

The chemical content may be organic or inorganic and the effluent may vary in quality or strength from relatively harmless dirty water to highly toxic metallic and organic sludges.

TYPES OF EFFLUENTS

There are as many different types of effluents as there are industrial processes. Effluents may be broadly categorized according to their origin as follows:

1. Sewage works effluent – this comes from domestic and commercial premises and often contains some industrial waste. It is normally treated before discharge into water sources eg Ruai Nairobi, and other municipalities in Kenya – but treatment works are often overloaded. There is some discharge of untreated sewage into the sea, in some urban areas of the world.
2. Industrial plant effluent – This originates from all manufacturing and processing industrial plants. It may be treated by the producer or discharged into sewers and treated as sewage.
3. Agricultural Premises effluent – This originates from dairy milking parlous, cattle housing premises, and silage clamps, and it is usually untreated.
4. Waste tip seepage – This effluent moves from domestic and industrial waste tips, mining and quarrying waste spoil heaps etc into the ground and eventually into water courses. It is usually untreated.
5. Run-off from land – This is untreated natural drainage of ground water into water courses.
6. Accidental spillage of chemicals during loading and transit - This occurs sporadically and locally when chemical is washed away into rivers, drains, and sewers.
7. Accidental leakage from industrial storage tanks, oil refineries etc. sited beside rivers, estuaries or the sea coast.
8. Other sources such as river and canal craft toilets, overloaded toilets or camp sites and from pesticide stores.

Industrial effluents differ in their potential and strength in causing pollution of water. Paper pulp and pharmaceutical manufacture, coal carbonization, wool scouring and tanning produce effluent with a very high BOD value eg wool scouring BOD of 10,000 BOD mg/l, pharmaceutical manufacture and mixed chrome tanning, carbohydrate production 10,000 BOD mg/l, paper pulping 25,000 BOD mg/l. Others include silage with upto 50,000 mg/l BOD and some chemical effluent with 30,000 BOD mg/l. Each of these effluents contains a number of potentially polluting chemical substances for example:

**Organics:** These include; proteins, carbohydrates, fats and oils, dyestuffs, organic acids, phenols, detergents and organopesticides.

**Inorganic:** These include; Acids, alkalis, metals, metallic salts, phosphates, nitrates, other salts, bleaches, sulphides, cyanides, cyanates, chromates, minerals (china clay and soil).

The agricultural industry produces considerable quantities of very potent organic effluent. Houses for cattle, pigs and poultry produce large amounts of manure slurry. This consists of excreta, urine, bedding materials and pesticides derived from fodder and silage as well as phosphates and nitrates. Farmers have to dispose of this waste slurry, and method used may create water pollution. The slurry is usually stored and spread or sprayed on to arable and grassland. Surface drainage and underground leaching and seepage can cause organic pollution and increase in concentration of nitrates and phosphates in water courses.

This effect is observed where substantial quantities of nitrogenous and phosphatic fertilizers and pesticides are regularly applied to farm land and crops.

Marine water are being increasingly polluted by crude oil. This is caused by spillage or accidental discharge of oil effluents from various sources eg oil tankers – occasional accidents or when ships go aground. All oil tankers need to wash out their tanks between loadings, and some captains illegally discharge the wash effluents at sea causing localized pollution.

Apart from tankers, there are other accidental or intentional discharges of oil into surface waters eg. from storage tanks, pipe-lines, oil bunkering operations, oil refineries and road transport accidents, and private car owners. Some of this leaked or discarded oil effluent is discharged into sewers, or eventually drains into rivers and the sea. The development of off-shore drilling and oil-well operations also creates spills and accidents can occur eg. The North Sea oil well blow-out at the Ekofisk Field in 1978.

There is environmental concern about specific effluents that contain Radioactive pollutants eg. from nuclear reactors.
EFFLUENT TREATMENT

Ideally no effluent should be released into the environment before it has received adequate and satisfactory treatment.

**Treatment and disposal of Sewage**

Sewage is a turbid liquid, consisting of 99.9% water containing a complex of organic and inorganic matter, in the form of suspended solids, colloidal particles, dissolved compounds and microorganisms such as Protozoa, bacteria and viruses.

The objectionable odour and colour is largely caused by the 66% organic matter present, and the anaerobic bacteria action that takes place within it.

The organic matter is present as: paper, faeces, urine, soap, detergents, fats, oils, greases, and food materials.

The inorganic substances present include; sand, clay, ammonia and ammonium salts derived from the decomposition of urine, metallic salts, nitrates, phosphates etc.

The precise composition of sewage varies depending on its origin and its industrial effluent input, which may be upto 50% by volume.

Modern sewage treatments basically aim to remove the floating and suspended solids, and provide biological treatment of the organic matter present.

Sewage treatment can be divided into three stages:

1. **Preliminary stage**

2. **Primary stage**

3. **Secondary stage**

Some treatment plants provide a final tertiary stage to produce a higher quality effluent.

1. **Preliminary stage**

   The preliminary treatment removes large suspended debri and solid particles by screening.

2. **Primary Stage**

   In this stage Sedimentation takes place which results in the removal of some 55% of settleable solids as sludge, and 35% reduction in BOD value. The sewage at this point contains suspended colloids, finely divided solids and dissolved solutes.

3. **Secondary Stage**

   The activated sludge method is applied in the modern sewage treatment plants. The primary effluent is agitated and aerated in large tanks, in the presence of flocculent suspension of activated sludge containing microorganisms. In this biological treatment, microorganisms utilize the organic matter and break it down into non-pollutive inorganic compounds. The treatment has been called self purification, and it takes place naturally in streams and rivers. However, in sewage works, optimum conditions are provided to enable the bio-degradation of organic matter to take place more rapidly than in natural water.
Following the secondary biological treatment, there is a further sedimentation phase to allow more settlement of suspended solids. The effluent emerging from the secondary stage can be discharged into water courses. However, it is further recommended that a tertiary stage be incorporated where effluent from secondary stage is discharged into a wet-land for further purification and passed into a fish pond, before release into water courses.

**Flow diagram of a Sewage Treatment Plant**

Tertiary treatment has its limitations, for example it cannot completely compensate for poor secondary treatment and it does not remove all suspended solids, organic matter and dissolved solutes. Consequently the effluent cannot be used as drinking water without the normal chemical treatment given to natural waters.

The primary and secondary treatments do not completely remove all potentially polluting materials, especially metals, nitrites, phosphates, ammonium compounds and bacteria.

**BIOLOGICAL EFFECTS OF WATER POLLUTION**

Natural waters cannot be easily defined, but they can be described in terms of the physical, chemical and biological qualities/conditions present.

The physical condition should consist of clean water, with an ambient temperature, and freedom from suspended solids, colouration, surface scum or foam, abnoxious odour and taste. The chemical condition should ensure that there is adequate oxygen, a correct balance of dissolved chemical nutrients to support life, and an absence of excessive organic matter, and toxic substances.

Biologically, most natural waters contain a range of microorganisms, plants, and animals that exist in a balanced ecological state. All ponds, lakes, streams and rivers are ecosystems where the biological population exists within the physico-chemical environment.

The biological effects of water pollution may be grouped into the following:
1. **Dissolved oxygen content of water**

Oxygen is vital for the respiration of nearly all biological life, and it is essential that water should be well aerated for the continued survival of aquatic life. Aeration involves atmospheric oxygen diffusing or passing from the air, through the water surface into ponds, streams, rivers, canals and the sea.

The amount of oxygen available in any volume of water is expressed as parts per million by weight (ppm) or milligrams per litre (mg/l) or grams per cubic metre (g/m³).

When organic waste is discharged into a river, some of it is oxidized by the natural microorganisms present, and this creates a biological oxygen demand (BOD). Consequently the dissolved oxygen level falls and oxygen deficit is created. If the BOD and deoxidation rate exceed the reoxidation rate from the atmosphere, then the oxygen deficit persists. These are the conditions of water pollution and the disruption of the aquatic ecosystem. If no more organic matter enters the water, the existing pollution material is gradually completely oxidized and so reoxidation takes place and the river is said to recover from pollution.

2. **Oxygen Demand (the biological Oxygen Demand (BOD))**

This is a measure of the polluting organic matter present in a sample of water. BOD can be defined as the amount of dissolved oxygen consumed by chemical and microbiological action when a sample of water is incubated for 5 days at 20°C in the dark. BOD is expressed as mg/l or ppm of oxygen taken by the sample. There is a rapid decrease of dissolved oxygen near the pollution outfall, followed by a gradual increase with increasing time after discharge, to reach the dissolved oxygen level of the unpolluted water.

3. **Biodegradation**

Organic matter is described as biodegradable if it is readily decomposed by the action of microorganisms. The microorganisms exist as a mixture of bacteria, fungi and Protozoa. In heavily polluted water, they are visible as pink, yellow, brown slimy growths that are often called “sewage fungus”. The microorganisms utilize pollutive organic compounds for their growth and nutrition and produce simple products, thereby reducing the amount of pollution. There are two types of metabolism, aerobic and anaerobic.

**AEROBIC** microorganisms use oxygen to carry out oxidation reactions such as the following:-

1. Carbohydrates, phenols etc are converted to carbon dioxide and water.
2. Organic nitrogen compounds are converted to carbon dioxide, water, amines and ammonia.
3. Organic sulphur compounds are converted to sulphides.
4. Organic phosphorus compounds are converted to phosphates.

Biodegradation of these compounds rapidly decreases the dissolved oxygen, and creates a BOD in the polluted water. Heavily polluted water has little or no dissolved oxygen. Under these conditions only **anaerobic** microorganisms can exist. Under anaerobic conditions, the anerobic microorganisms cause the following reactions to occur:-
1. Carbohydrates are converted into methane
2. Organic sulphur compounds and sulphates are converted into sulphides.
3. Organic phosphorus compounds are converted to phosphine.
4. Organic nitrogen compounds are converted to nitrate, and then ammonia.

Ponds, streams and rivers that are heavily polluted often have an obnoxious smell caused by hydrogen sulphide, and may show a black deposit of Iron (II) sulphide and heavy growth of “sewage fungus”.

The type of biodegradation which occurs is also affected by the content of pollutive discharges. If the effluent contains biological toxins such as heavy metals, cyanides and sulphides the aerobic microorganisms will be killed, even if there is sufficient dissolved oxygen in the water.

A surface film of oil on water restricts reoxygenation and together with bacterial degradation of the oil hydrocarbons causes the dissolved oxygen content to fall quickly. Hard detergents are resistant to secondary sewage treatment, and frequently produce a layer of surface foam when the effluent is discharged into rivers. The foam also restricts surface reoxygenation and may cause anaerobic condition to arise. When pollutive waste enters a river, the balanced ecological conditions are changed. Downstream from the discharge point the rate of biodegradation increases, causing a fall in the dissolved oxygen content and an oxygen deficit results. The extent of these changes depends largely upon the total amount of organic material in the river.

WATER POLLUTANTS AND THEIR EFFECTS

The effects of water pollution can be considered under six (6) headings:

1. Physical effects, such as suspended particle solids.
2. Oxidation effects caused by bacterial action or chemical oxidation of inorganic and organic substances, both of which significantly reduce the dissolved oxygen content of water.
3. Toxic chemical effects caused by a range of substances that cause immediate or cumulative physiological changes in plants, animals and humans.
4. Chemical nutrients effects resulting from high concentration of nitrates and phosphates.
5. Pathogenic effects caused by microorganisms where bacteria, fungi and viruses are present in sufficient numbers to cause a health hazard.
6. Radionuclide effects caused by the accumulation of radioactive substances in food organisms, which produce human body changes.

1. PHYSICAL EFFECTS

Insoluble finely divided organic solids, undergo slow biodegradation and cause a reduction of the dissolved oxygen in the water.

Inert solids are of varying particle sizes and density, and they either settle out, or remain suspended according to their properties and the turbulence of the water.

Settled particles may slowly accumulate on vegetation foliage, and produce a deposit on the river bed. The effect of settlement layers is to reduce the solar energy absorption by
plants and so lower the rate of photosynthesis, and to produce low oxygen conditions in the river bed. This may prevent the growth of salmon and trout eggs and preclude the survival of bottom living invertebrate animals. Small suspended particles make water turbid, and this reduces light penetration, reduces photosynthesis, and restricts plant growth. Turbidity also reduces visibility in the water and limits the food gathering capacity of many animals. Fish and some invertebrates have their respiratory efficiency reduced because the gills surfaces become clogged with suspended matter.

All these physical effects cause a disturbance of the balanced ecosystem. Some animal species do not survive, others are reduced in numbers, and so food chains and nets are affected. Waste oils, fats and grease can enter rivers and estuaries from several sources. Oils and allied petrol-chemicals form a thin film on the water surface which prevents the exchange of oxygen with the atmosphere. This causes a reduction of the water oxygen saturation and deoxygenated pollution effects rise. At sea, oil slicks are responsible for the deaths of many birds, eg. Scoters, puffins, razorbills and diving ducks. In-shore oil is deposited on rocks and sand, and this prevents the beaches being used for recreation and enjoyment by the public, and affects marine life. Shore animals such as clubs, shrimps, nussels, winkles, limpets and barnacles ingest toxic hydrocarbon, they are unable to feed, and the respiratory system becomes clogged and ineffective. A badly oiled shore can be largely denuded of animal life, and sea weeds are also affected.

2. OXIDATION EFFECTS
There are two types of oxidation:
(i) Action of bacteria on organic pollutants
(ii) Chemical oxidation of other pollutants present in industrial waste.

Both types of oxidation involve the use of dissolved oxygen, and so produce an increased BOD and an oxygen deficit in the water sources.

Examples of bacteriological oxidation are:- conversion of sulphide to sulphate in the sulphur cycle, and ammonia to nitrite and then nitrate in the nitrogen cycle.

3. CHEMICAL TOXIC EFFECTS
Some organic and inorganic chemical substances are toxic or poisonous to plants, animals and humans.

Chemical toxins can be broadly considered under the following four headings:
(i) Metal and salt toxins
(ii) Pesticide toxins
(iii) Acid and alkali toxins
(iv) Other organic compounds toxins eg. Phenols and cyanides.
(i) **Toxic metals**
These are usually heavy metals eg Iron, Lead, Mercury, Cadmiumium, Zinc, Copper, Nickel and Arsenic.
Varying quantities of these metals may cause a deleterious effect, and plants and animals vary in this respect. For example:
0.3mg/l of Zinc, 0.02 mg/l of Copper and 0.33mg/l of lead are lethal to sicklebacks.
Plants growth is retarded by Zinc concentrations of 7mg/l or more, but 0.5mg/l of Copper or 0.01mg/l of Mercury will kill algae.
One of the most significant effects of metallic pollution is that aquatic organisms can absorb and accumulate concentrations of these metals in their tissues. Consequently increasing concentrations can build up in food chains and nets, and they are highest in species of the secondary and tertiary trophic levels eg there may be upto 15 times as much Mercury, present in fish as in algae. Human populations use the higher level consumers as food, and thereby ingest the metal toxins.

(ii) **Pesticides Toxins**
Pesticides are a cause of water pollution. The most hazardous pesticides are the organochloride compounds, because of their stability and persistence in the environment. Persistent organochlorides can accumulate in the food chains eg. Some shrimps and fish can concentrate some pesticides by a factor of 1000 to 10,000. Animals eg birdsseals and porpoises, may have upto 55g/m³ of DDT in their fatty tissues.

(iii) **Acid and Alkali Toxins**
Acids and alkalis may be regarded as hazardous because they lower or raise the pH value of water from its neutral value of pH 7. Most animals and plants will not survive in water with a pH value of below 5 (acid), or above pH value of 9 (alkaline).
Changes in pH can also affect the actions of other toxins eg cyanides and sulphides, are more toxic in acid conditions than they are in neutral or alkaline conditions.

(iv) **Other Organic Compound Toxins**
Polychlorinated biphenyls, or PCBS, are by-products of the plastic, lubricant, rubber and paper producing industries. PCBS have appeared in tissues of fish, predatory birds, pelagic feeding marine birds and shore mussels. PCBS are lethal to these animals even in very small quantities.
Cyanides are very toxic to all biological life. Chlorophenols are toxic to bacteria and fish (1mg/l) and even to man (over 40mg/l).

4. **CHEMICAL NUTRIENT EFFECTS**
Chemical nutrients are substances that are required by plants and animals for maintaining their growth and metabolism.
In water pollution, the two most important nutrients are Nitrogen and phosphorus, usually present in nitrates and phosphates.
Small amounts of nitrates and phosphates occur in all natural waters. In lakes, over a long period of time, the nutrient levels slowly rise as a result of the biodegradation of dead material. This rise in nutrients is called natural ageing or eutrophication.
Increased concentrations of nitrates and phosphates in water produce the overall effect of increased rate of growth of e.g. Unicellular green and blue algae and floating filamentous algae in entrophic conditions. A dense slimy layer develops on the surface of the water – referred to as “bloom” condition. This bloom reduces light penetration and restricts atmospheric reoxygenation of water. The effect is to cause adverse conditions for river and canal craft navigation, and for swimming, bathing and fishing. The dense algae growth eventually dies, and the subsequent biodegradation produces an oxygen deficit which can result to abnoxious anaerobic conditions. In relation to humans, there is concern about excessive nitrate concentration in drinking water abstracted from rivers, aquifers and boreholes. Nitrates are taken into the body in food and drink and can cause disease. Some bacteria in the intestines can reduce nitrates to nitrites, and when this enters the blood, the nitrite attaches to the hemoglobin to form a complex called methahaemoglobin. This causes a reduction in the oxygen carrying capacity of the blood, and a condition called anoxia, or methahaemoglobin anaemia, or blue baby disease. This is particularly severe in young babies and may be fatal. It has been suggested that nitrites can be further converted to amines and nitrosamines in the human body, and these organic chemicals are a possible cause of gastric cancer.

5. MICRO-ORGANISM EFFECTS
Wastes that are discharged into water contain pathogenic organisms that are capable of causing human diseases e.g. Some bacteria cause; cholera, typhoid fever, bacillary dysentery and gastroenteritis. Viruses are also found in water, including strains which cause poliomyelitis, infectious hepatitis etc. The infective egg and larval stages of some animal parasites also occur in water e.g. Ascaris lubricoides, (Round worm), the beef and pork tapeworm and Echinococcus Species (hydatid disease). All these types of organisms occur in faeces, and so are present in sewage and farm slurry.

6. RADIONUCLIDE EFFECTS
Development of nuclear energy is producing more radioactive waste to be disposed off into the environment, and it contains various radionuclides with long half-lives. Example of radionuclides are: - Ruthenium-106, Strontium- 90, Cerium – 144, Caesium – 137. These radionuclides can end up in the food chain, and so enter the bodies of humans and animals. It is known that Caesium -137 can become concentrated on bottom living fish such us plaice, dabs and skates. Man uses members of the higher trophic levels as food. For example fish, shellfish and Crustaceans such as crabs, lobsters and shrimps.