Environmental Microbiology

Lecture Objectives: Define Environmental Microbiology and articulate its relevance to the human race.

Environmental microbiology is the study of the composition and physiology of microbial communities in the environment. The environment in this case means the soil, water, air and sediments covering the planet and can also include the animals and plants that inhabit these areas. Environmental microbiology also includes the study of microorganisms that exist in artificial environments such as bioreactors. An average gram of soil contains approximately one billion (1,000,000,000) microbes representing probably several thousand species. Microorganisms have special impact on the whole biosphere. They are the backbone of ecosystems of the zones where light cannot approach. In such zones, chemosynthetic bacteria are present which provide energy and carbon to the other organisms there. Some microbes are decomposers which have ability to recycle the nutrients. Microbes have a special role in biogeochemical cycles. Microbes, especially bacteria, are of great importance because their symbiotic relationship (either positive, neutral, or negative) have special effects on the ecosystem.

Environmental Microbiology – anther definition : The study of microbial fate and activity in air, water and soil, and the resulting impact on human health and welfare.

Compare with: Microbial Ecology – definition: The science that explores interrelationships between organisms and their living and abiotic environment.

Driving force behind Environmental Microbiology: How can we harness the understanding of environmental microbes to benefit society?

Important Events Leading to Environmental Microbiology A Historical Perspective.

A) Ancient History

1676 Antonie van Leeuwenhoek - 1st microscope "animalcules"
1830-1900 Louis Pasteur-rejected theory of spontaneous generation-demonstrated presence of microbes in air
1856-1953 Sergei Winogradski - "Father" of Soil Microbiology - nitrification, autotrophy.
1843-1910 Robert Koch – Nobel Prize- pure culture technique - Koch's postulates: a specific organism causes a specific process (e.g., disease)

B) 20th Century

1928 Griffith - bacterial genetics - transformation
1952 Selman Waksman - Principles of Soil Microbiology - Discovery of streptomycin (Nobel Prize)
1953 Watson and Crick - Structure of DNA (Nobel Prize)
1985 Kary Mullis - Polymerase Chain Reaction (Nobel Prize)

C) The Next Millenium (الألفية التالية) "Bioinformatics"

Modern Environmental Microbiology

- **Soil microbiology**
- **Aquatic microbiology**
- **Hazardous waste/bioremediation**
- **Water quality**
- **Food safety**
- **Aeromicrobiology**
- **Occupational health/infection control**

What do Microbes do? How can we use this to our advantage?
Microbes have small genomes but:-

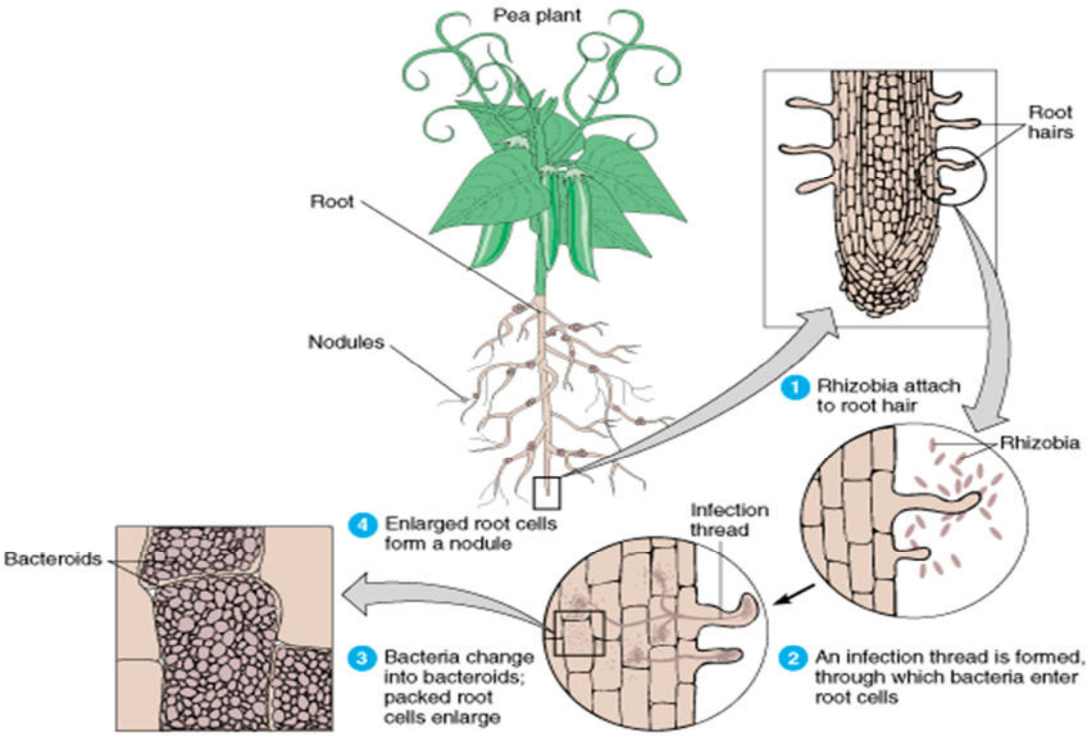
- Not do a lot, but what do, do well
- Extremophiles: Microbes live in extreme conditions of
    - Temperature
    - Acidity
    - Alkalinity
    - Salinity
- Eubacteria vs Archaebacteria

Biological definition of organismal interactions: **Symbiosis:** a relationship between two different species

- Parasitism: one organism gets nutrients from another
- Mutualism: both partners benefit
- Commensalisms: one benefits more

examples

Mycorrhizae *Endomycorrhizae* or *vesicular arbuscular mycorrhizae*(Endo within) And *ectomycorrhizae*, on the outside oaks. (This symbiosis is a highly evolved mutualistic relationship found between fungi and plants, the most prevalent plant symbiosis known, and **arbuscular mycorrhizal fungus** is found in 80% of vascular plant families in existence today. help plants to capture nutrients such as phosphorus, sulfur, nitrogen and micronutrients from the soil)



Other examples? Biogeochemical cycles

- Matter can neither be created or destroyed
- A constant amount of matter in the environment must be recycled
- Microbes are essential in the conversion of nutrients into organic and usable formats
- Microbes are essential in the conversion of nutrients into the inorganic form

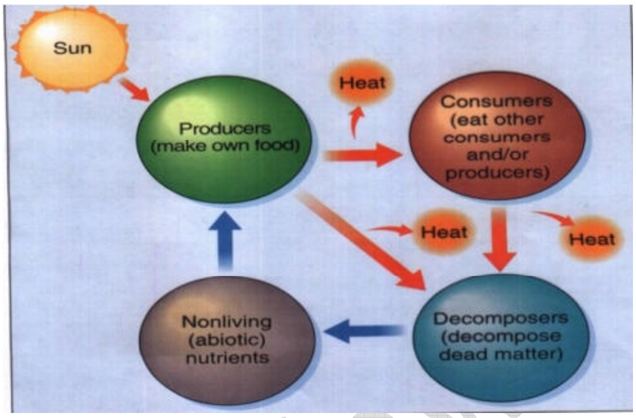
1-The carbon cycle

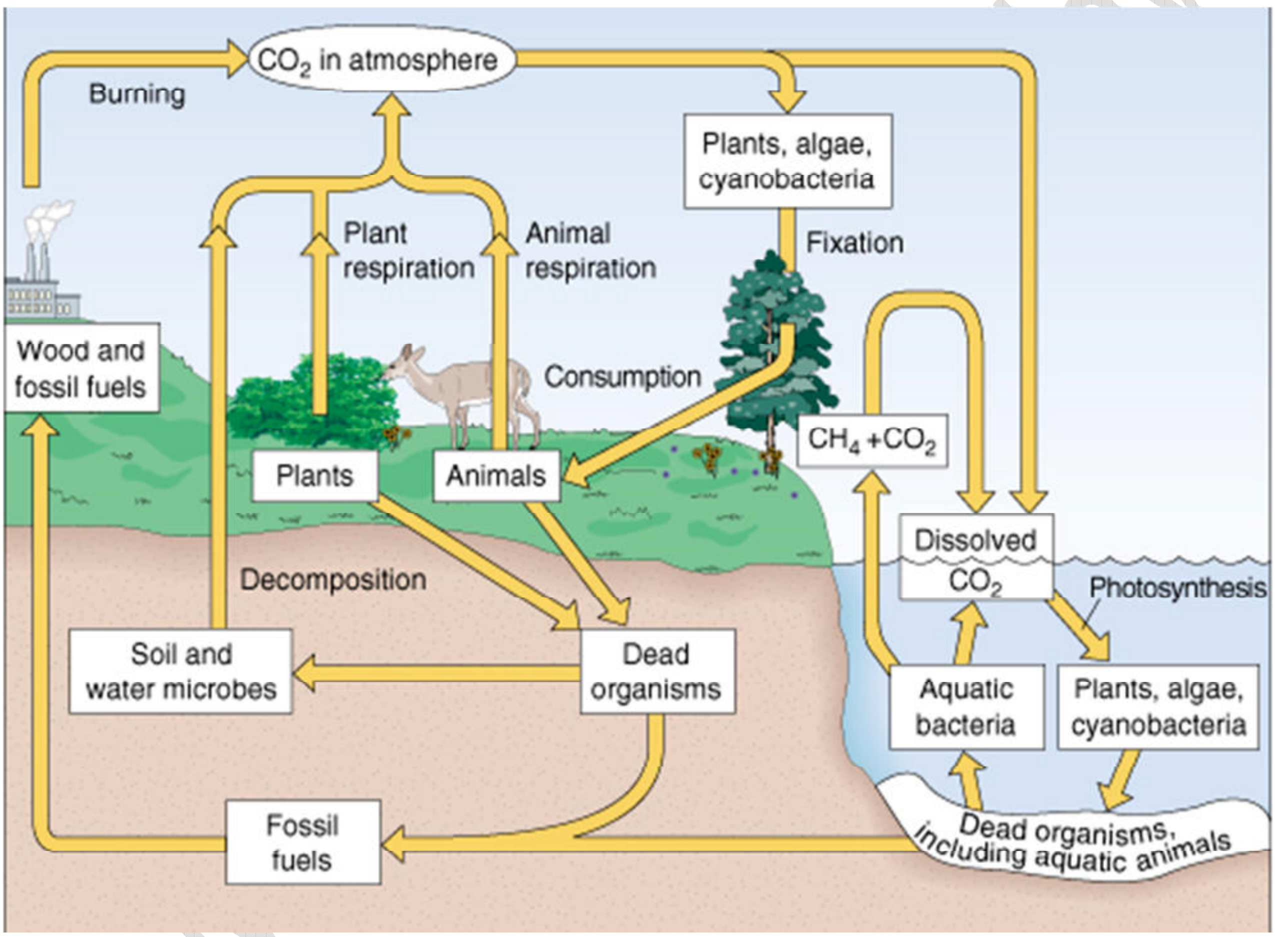
- **Photoautotrophs**
- **Chemoautorophs**

  Both convert inorganic forms of carbon into organic forms using external sources of energy.

- **Chemoheterotrophs**

  Release Inorganic form of carbon (CO_2) to complete the cycle.
  Non-living sinks include $CaCO_3$ and fossil fuels



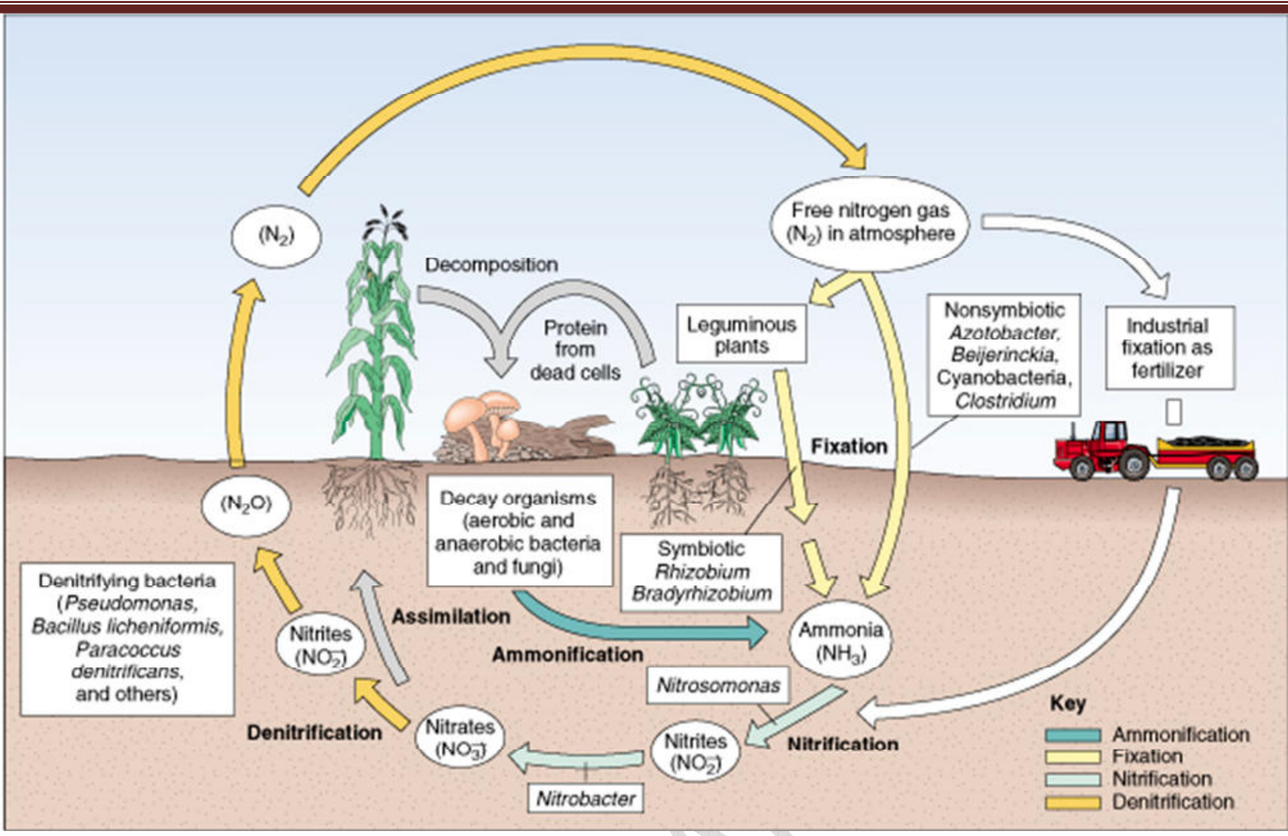


2- The nitrogen cycle

- Local shortages because of Nitrogen stuff
- Microbes decompose proteins form dead cells and release amino acids
- Ammonia is liberated by microbial ammonificaiton of amino acids
- Ammonia is oxidized to produce nitrates for energy by nitrifying bacteria

More nitrogen stuff

- Denitrifying bacteria reduce nitrogen in nitrates to molecular nitrogen
- N_2 is converted into ammonia by nitrogen fixing bacteria
- Ammonium and nitrate are used by bacteria and plants to synthesize amino acids
- Fertilization and microbes
- Cyanobacteria for a symbiosis with small floating fern Azolla (السرخس العائمة الأزولا) in rice paddy waters.



3- Sulfur cycle

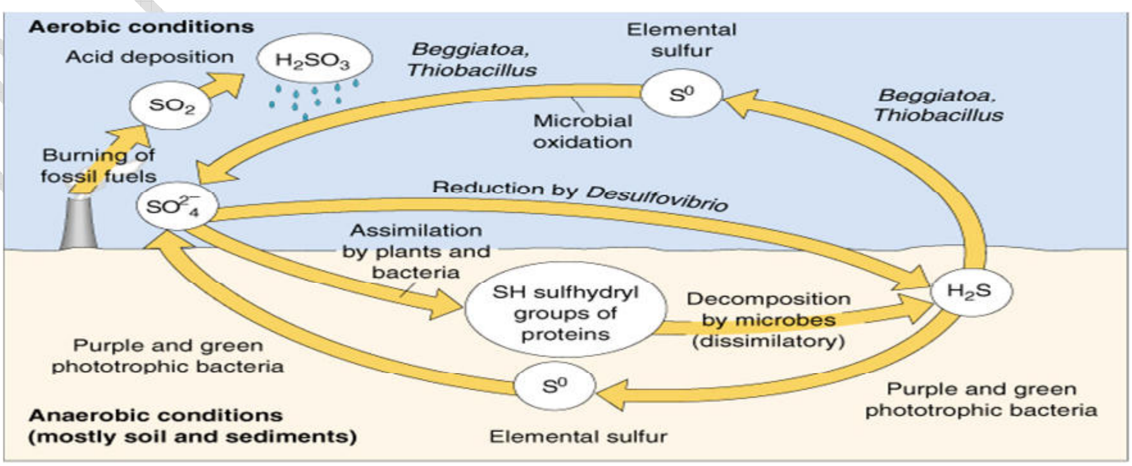
- Plants and certain microbes can use SO_4^{2-} to make amino acids
- H_2S is oxidized to form SO_4^{2-}

$$\text{Proteins and waste products} \xrightarrow[\text{decomposition}]{\text{Microbial}} \text{Amino acids}$$

$$\text{Amino acids (–SH)} \xrightarrow{\text{Microbial dissimilation}} H_2S$$

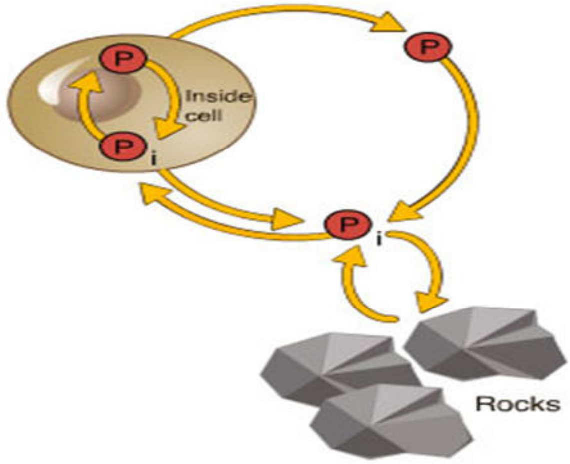
$$H_2S \xrightarrow{\textit{Thiobacillus}} SO_4^{2-} \text{ (for energy, by respiration)}$$

$$SO_4^{2-} \xrightarrow{\text{Microbial \& plant assimilation}} \text{Amino acids}$$



4- The Phosphorus Cycle

- Inorganic phosphorus is solubilized by microbial acids
- Made available to plants and other microbes
- Is soluble in water
- Combines with calcium in calcium phosphate deposits of ancient seas.



Life without Sunshine

- Primary producers in most ecosystems are photoautotrophs.
- Primary producers in deep ocean and endolithic communities are chemoautotrophic bacteria.

$H_2S \longrightarrow SO_4^{2-}$ Provides energy for bacteria which may be used to fix CO_2

$CO_2 \xrightarrow{\text{Calvin Cycle}} \text{Sugars}$ Provides carbon for cell growth

Biodegradation of pollutants

Microorganisms are used for *in-situ* microbial biodegradation or bioremediation of domestic, agricultural and industrial wastes and subsurface pollution in soils, sediments and marine environments. The ability of each microorganism to degrade toxic waste depends on the nature of each contaminant. Since most sites typically have multiple pollutant types, the most effective approach to microbial biodegradation is to use a mixture of bacterial species and strains, each specific to the biodegradation of one or more types of contaminants. It is vital to monitor the composition of the indigenous and added bacteria in order to evaluate the activity level and to permit modifications of the nutrients and other conditions for optimizing the bioremediation process.

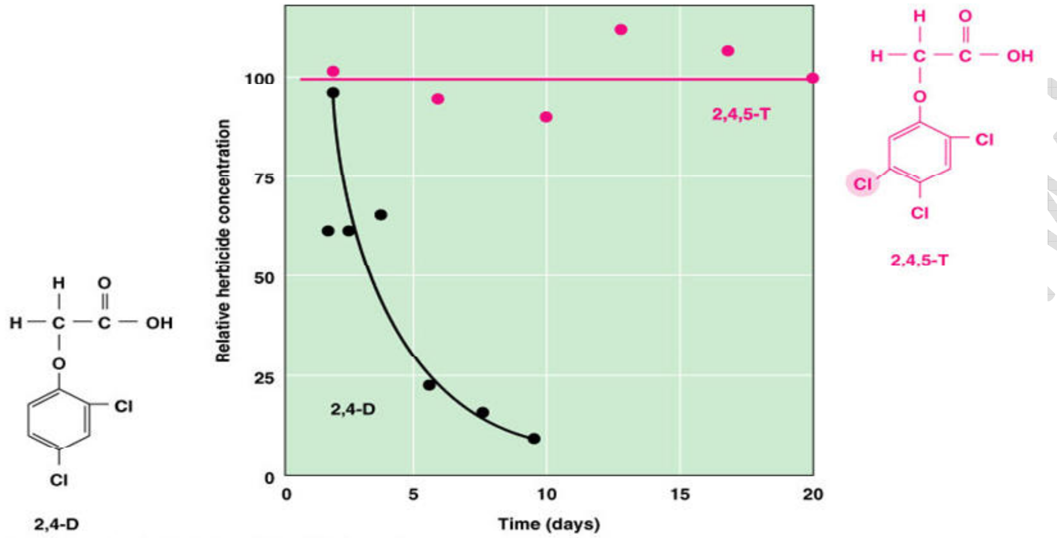
Biodegradation of pollutants: Microbial biodegradation of pollutants plays a pivotal role in the bioremediation of contaminated soil and groundwater sites. Such pollutants include chloroethenes, steroids, organophosphorus compounds**.**

Oil biodegradation: Petroleum oil is toxic, and pollution of the environment by oil causes major ecological concern. Oil spills of coastal regions and the open sea are poorly containable and mitigation is difficult; much of the oil can, however, be eliminated by the hydrocarbon-degrading activities of microbial communities, in particular the hydrocarbonoclastic bacteria (HCB). These organisms can help remedy the ecological damage caused by oil pollution of marine habitats.

Use of chemicals in soil and water

- Many man-made chemicals do not biodegrade because they are not made by living organisms; Why?

Decomposition by Microbes (Components of agent orange)



Components of agent orange

Bioremediation

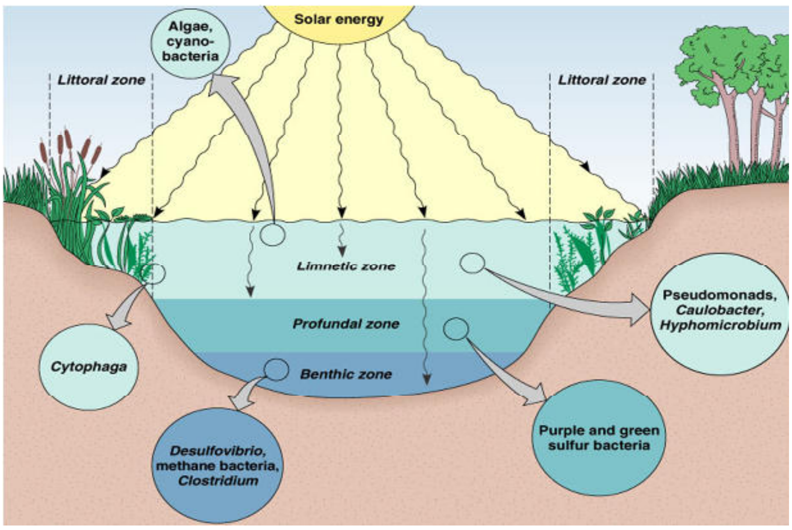
- Use of microorganism to remove pollution
- Cheaper
- Can use natural organism
- Is helped by preventing limited nutrients

Solid Municipal Waste piles (أكوام النفايات البلدية الصلبة)

- Many municipal waste piles are inefficiently run because they are dry and anaerobic

Aquatic conditions

- Biofilms (الأغشية الحيوية) are composed of whole communities of microbes that are metabolically diverse
- Bodies of water (المسطحات المائية) are naturally set up to process waste
- Tend to grow in presence of oxygen and light
- Use is best when oxygen content is increased
- Phytoplankton in oceans are primary producers in the open ocean
- Freshwater Donation



Water microbiology

An adequate supply of safe drinking water is one of the major prerequisites for a healthy life, but waterborne diseases are still a major cause of death in many parts of the world, particularly in young children, the elderly, or those with compromised immune systems. As the epidemiology of waterborne diseases is changing, there is a growing global public health concern about new and reemerging infectious diseases that are occurring through a complex interaction of social, economic, evolutionary, and ecological factors. An important challenge is therefore the rapid, specific and sensitive detection of waterborne pathogens. Presently, microbial tests are based essentially on time-consuming culture methods. However, newer enzymatic, immunological and genetic methods are being developed to replace and/or support classical approaches to microbial detection. Moreover, innovations in nanotechnology and nanosciences are having a significant impact in biodiagnostics, where a number of nanoparticle-based assays and nanodevices have been introduced for biomolecular detection. Molecular techniques based on genomics, proteomics and transcriptomics are rapidly growing as complete microbial genome sequences are becoming available, and advances are made in sequencing technology, analytical biochemistry, microfluidics and data analysis. While the clinical and food industries are increasingly adapting these techniques, there appear to be major challenges in detecting health-related microbes in source and treated drinking waters. This is due in part to the low density of pathogens in water, necessitating significant processing of large volume samples. From the vast panorama of available molecular techniques, some are finding a place in the water industry: Quantitative PCR, protein detection and immunological approaches, loop-mediated isothermal amplification (LAMP), microarrays.

Roll of microorganism in water quality

- Bio magnifications(التكبير الحيوي: تركيز السموم في الكائن الحي نتيجة لتناول كائنات أخرى تحتوي السموم على نطاق أوسع.)
- Indicators of fecal contamination
- Blooms (الازدهار)
- Eutrophication (الإثراء الغذائي)

Waterborne Diseases

Water quality tests

- Coliforms are aerobic or facultatively anaerobic, gram negative non endospore forming rods that ferment lactose with the production of acid and gas within 48 hours of been placed in a medium at 35°C
- Fecal Coliforms predominantly *E. coli* are used to indicate the presence of human feces
- Indicator organisms: Used to detect fecal contamination
- MPN: Most probable number/100 ml of water

Waterborne Disease Outbreaks Associated with Drinking Water

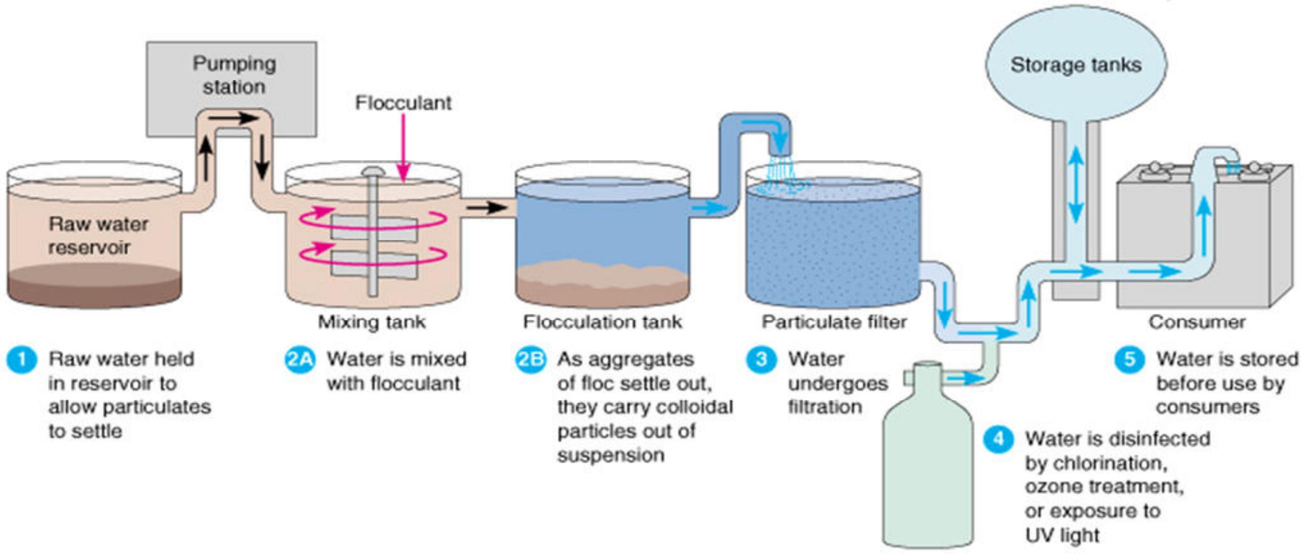
Cause of Outbreak	Percentage
Parasitic (*Cryptosporidium, Giardia*)	35.3
Unidentified	29.4
Bacterial (*Salmonella, Campylobacter,* etc.)	23.5
Chemical (pesticides, nitrates, excess fluorides)	11.8

Waterborne Disease Outbreaks Associated with Recreational Water

Cause of Outbreak	Percentage
Cryptosporidium	50.0
E. coli O157:H7	16.7
Unknown	16.7
Norwalk-like viruses	11.1
Shigella	5.6

Water Treatment

- Water held in a holding reservoir long enough that suspended matter settles
- Flocculation treatment (علاج التلبد) uses a chemical such as alum(الشب) to coalesce (الالتئام) and settle colloidal material (ترسب المواد الغروية)
- Filtration removes protozoan cyst and other microbes
- Drinking water is disinfected with chlorine to kill remaining pathogenic bacteria



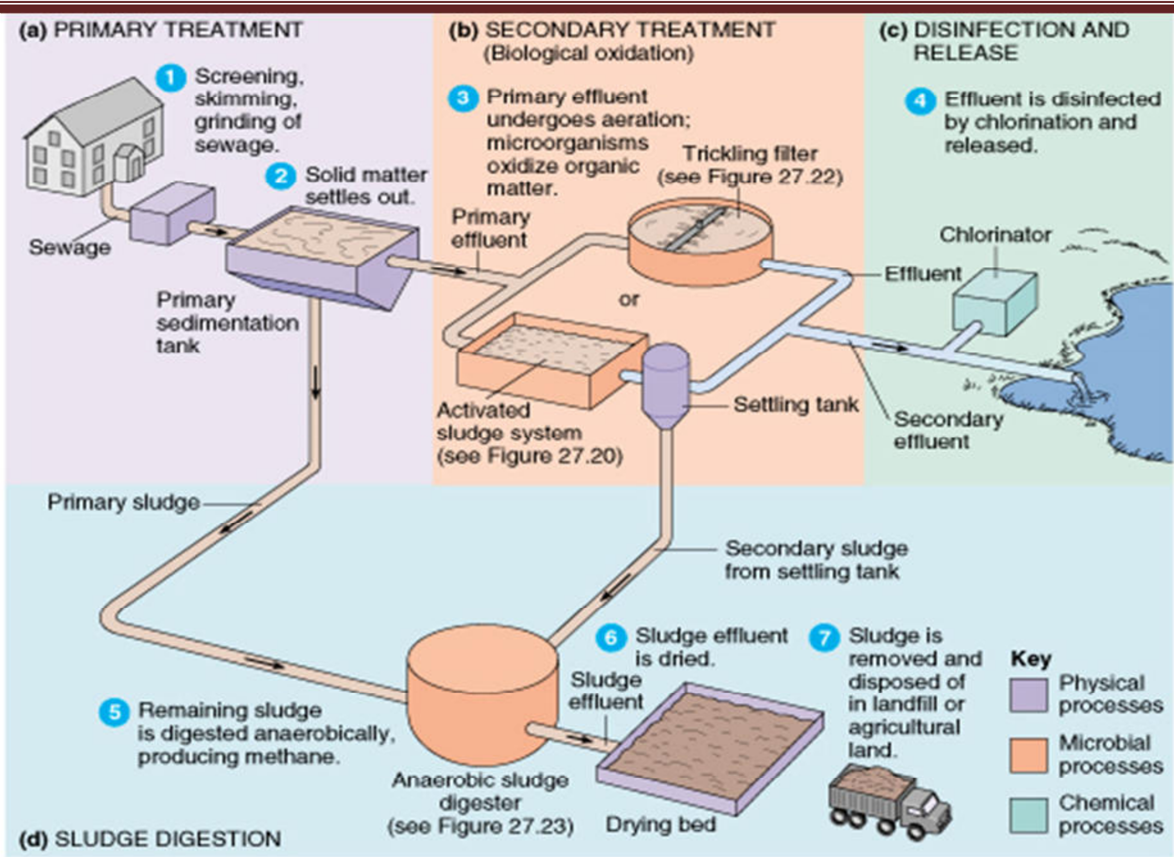
Waste biotreatment

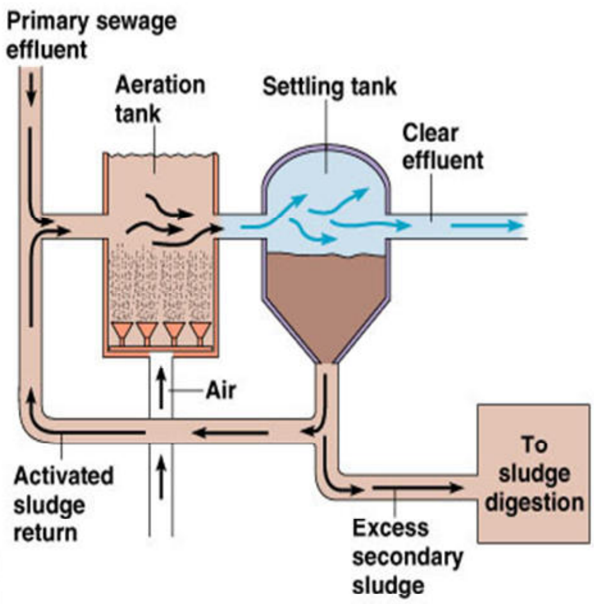
Bio-treatment, the processing of wastes using living organisms, is an environmentally friendly alternative to other options for treating waste material. Bioreactors have been designed to overcome the various limiting factors of bio-treatment processes in highly controlled systems. This versatility in the design of bioreactors allows the treatment of a wide range of wastes under optimized conditions. It is vital to consider various microorganisms and a great number of analyses are often required.

Wastewater treatment: Wastewater treatment processes are geared towards one purpose: cleaning up water. Recent application of molecular techniques is unveiling the microbial composition and architecture of the complex communities involved in the treatment processes. It is now recognized that wastewater processes harbor a vast variety of microorganisms most of which are yet-to-be cultured, hence uncharacterized.

Sewage Treatment

- The quality of life that we see in first world countries is due to our treatment of sewage
- Primary treatment: removal of solid materials (35% BOD).
- Secondary treatment: Reduction of BOD (95%BOD) by the metabolic degradation of organic matter.
- BOD biochemical oxygen demand
- Tertiary treatment: provides essentially drinkable water is much more expensive to do



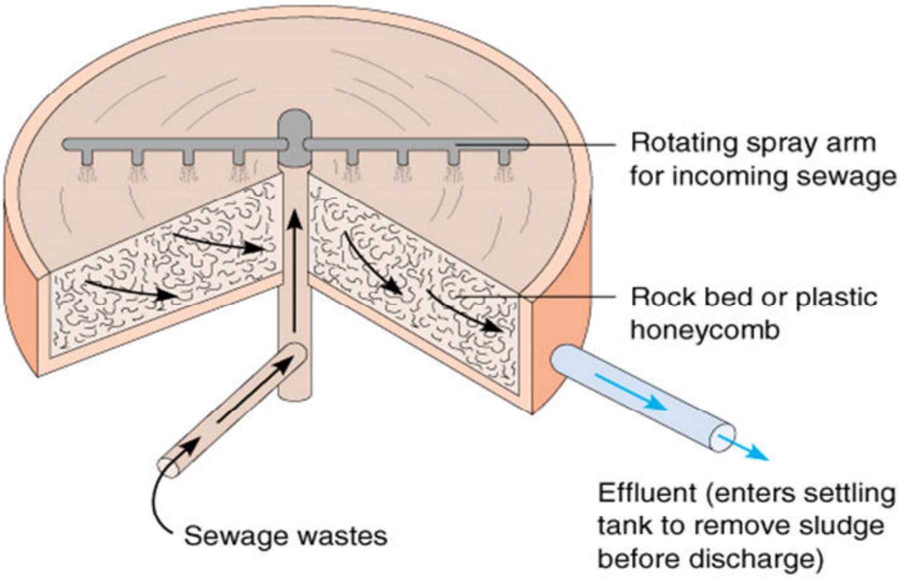


(a) Diagram of an activated sludge system


(b) An aeration tank. Note surface is frothing from aeration.

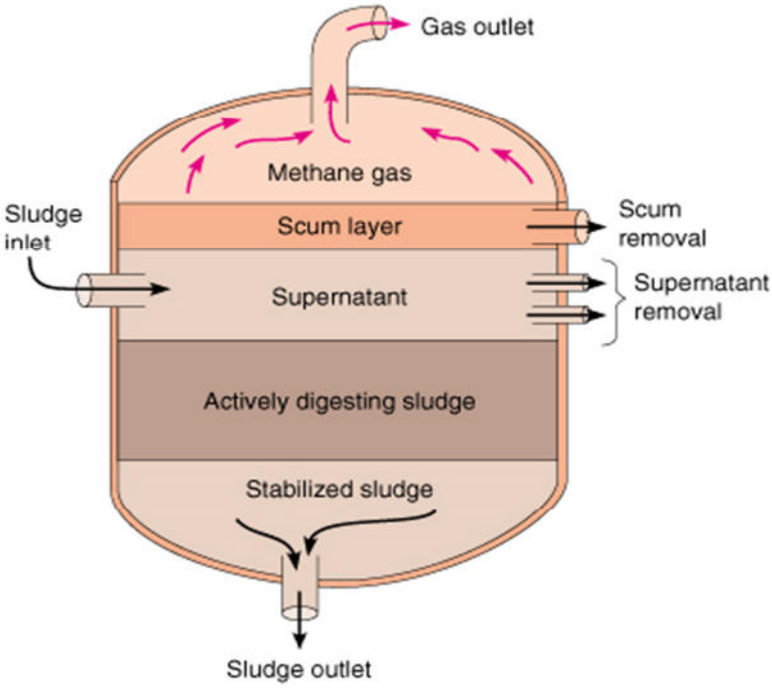
Alternative treatments of sewage

- Septic tanks
- Oxidation ponds



(b) A cutaway view of a trickling filter system

Sludge produced by sewage treatment plants

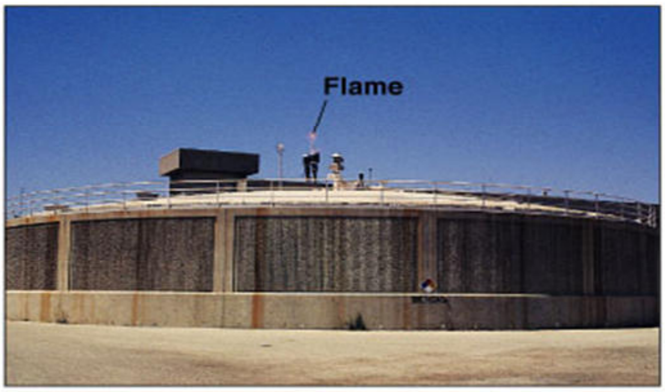


Section of a sludge digester. The scum and supernatant layers are low in solids and are recirculated through secondary treatment.

Anaerobic Sludge Digester:

Most methane is derived from reduciton of carbon dioxide by hydrogen gas. Other methane producing microbe split acetic acid to yield methane and carbon dioxide.

- $CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$
- $CH_3COOH \rightarrow CH_4 + CO_2$



Examples of Microorganisms in Environments

Legionella

Legionella is common in many environments, with at least 50 species and 70 serogroups identified. *Legionella* is commonly found in aquatic habitats where its ability to survive and to multiply within different protozoa equips the bacterium to be transmissible and pathogenic to humans.

Lactobacillus

Lactobacillus species are found in the environment mainly associated with plant material. They are also found in the gastrointestinal tract of humans, where they are symbiotic and make up a portion of the gut flora.

Aspergillus

Aspergillus spores are common components of aerosols where they drift on air currents, dispersing themselves both short and long distances depending on environmental conditions. When the spores come in contact with a solid or liquid surface, they are deposited and if conditions of moisture are right, they germinate. The ability to disperse globally in air currents and to grow almost anywhere when appropriate food and water are available means that ubiquitous is among the most common adjectives used to describe these molds.

Microbial nitrogen cycling

Microorganisms that convert gaseous nitrogen (N_2) to a form suitable for use by living organisms are pivotal for life on earth. This process is called nitrogen fixation. Another set of microbial reactions utilise the bioavailable nitrogen creating N_2 and completing the cycle in a process called denitrification. This crucial nutrient cycle has long been the subject of extensive research.

Rhizobia

Symbiotic nitrogen fixation is a mutualistic process in which bacteria reside inside plants and reduce atmospheric nitrogen to ammonia. This ammonia can then be used by the plant for the synthesis of proteins and other nitrogen-containing compounds such as nucleic acids. The Gram-negative soil bacteria that carry out this process are collectively referred to as rhizobia (from the Greek words Riza = Root and Bios = Life).

Microalgae

Algae are a highly diverse group of protists, ranging from simple, unicellular organisms to complex, multicellular entities with a range of differentiated tissues and distinct organs. They are found among diverse aquatic ecosystems and play important roles by supplying carbon and energy as well as providing habitat to other members of the biological communities. Some algae cause significant environmental and health problems.

Anaerobic protozoa

Diplomonads are a group of mitochondrion-lacking, binucleated flagellates found in anaerobic or micro-aerophilic environments. Most research on diplomonads has focused on *Giardia*, which is a major cause of water-borne enteric disease in humans and other animals.

Soil microbiology

Soil microbiology is the study of organisms in soil, their functions, and how they affect soil properties. It is believed that between two to four billion years ago, the first ancient bacteria and microorganisms came about in Earth's primitive seas. These bacteria could fix nitrogen, in time multiplied and as a result released oxygen into the atmosphere. This release of oxygen led to more advanced microorganisms. Microorganisms in soil are important because they affect the structure and fertility of different soils. Soil microorganisms can be classified as bacteria, actinomycetes, fungi, algae, and protozoa. Each of these groups has different characteristics that define the organisms and different functions in the soil it lives in.

Bacteria

Bacteria are the smallest organisms in the soil and are the only soil microorganisms that are prokaryotic. All of the other microorganisms are eukaryotic, which means they have a more advanced cell structure with internal organelles and the advanced ability to reproduce sexually. A prokaryote has a very simple cell structure with no internal organelles. Bacteria are the most abundant microorganisms in the soil, and serve many important purposes, one of those being nitrogen fixation among other biochemical processes.

Biochemical processes

One of the most distinguished features of bacteria as a whole is their biochemical versatility. A species called *Pseudomonas* can metabolize a wide range of chemicals and fertilizers. In contrast, another species known as *Nitrobacters* can only derive its energy by turning nitrite into nitrate, which results in a gain of oxygen and is known also as oxidation. Furthermore, the species *Clostridium* is also an example of bacteria’s versatility because it, unlike most species, can actually grow in the absence of oxygen.

Nitrogen fixation

Bacteria are responsible for the process of nitrogen fixation, which is the conversion of atmospheric nitrogen into nitrogen which can be used by plants to uptake. Autotrophic bacteria, or bacteria that derives its energy making its own food by oxidation, like the *Nitrobacters* species, rather than feeding on plants or other organisms. The bacteria that are autotrophic are responsible for nitrogen fixation.

Actinomycetes

Actinomycetes are soil microorganisms. They are a type of bacteria. They are similar to both bacteria and fungi, and have characteristics linking them to both groups. Actinomycetes are often believed to be the missing evolutionary link between bacteria and fungi, but they have many more characteristics in common with bacteria than they do fungi. One of the most notable characteristics of the actinomycetes is their ability to produce antibiotics. Streptomycin, neomycin, erythromycin and tetracycline are only a few examples of the antibiotics derived from actinomycetes. Streptomycin is used to treat tuberculosis and infections caused by certain bacteria and neomycin is used to reduce the risk of bacterial infection during surgery. Erythromycin is a very important antibiotic that is used to treat certain infections caused by bacteria, such as bronchitis; pertussis (whooping cough); pneumonia; and ear, intestine, lung, urinary tract, and skin infections. This ability to produce these useful antibiotics is the basis of our entire pharmaceutical industry and has saved human lives.

Fungi

Next to bacteria, fungi are abundant in soil population compared to other microorganisms. Fungi are important in the soil as food sources for other, larger organisms, pathogens, beneficial symbiotic relationships with plants or other organisms and help to reduce crop residues and biochemically process nutrients to improve the soil they inhabit. Fungi can be split into different species based on primarily on the size, shape and color of their spores, which are used to reproduce.

Algae

Algae can make its own nutrients through a process known as photosynthesis. Photosynthesis is when light energy is converted to chemical energy that can be stored as nutrients. For algae to grow, it must be exposed to areas of light because photosynthesis requires light, so algae is typically distributed evenly wherever sunlight and moderate moisture is available. Algae, however, do not have to be on the soil surface or directly exposed to sun rays, but it can live below the soil surface as long as the algae has uniform temperature and moisture conditions. Bacteria are not the only organism that can fix nitrogen, because algae are capable of performing nitrogen fixation as well.

Protozoa

Protozoa are eukaryotic organisms which are some of the first microorganisms to develop a means of sexual reproduction, which is a huge evolutionary step from duplication of spores, like many of the other soil microorganisms depend on. Protozoa can be split up into three categories: flagellates, amoebae, and ciliates. Flagellates are the smallest members of the protozoa group, and can be divided further based on whether they can participate in photosynthesis. Amoebae are larger than flagellates and move in a different way. Ciliates are the largest of the protozoa group

It is important to understand the many different groups and species of microorganisms in different soils because they affect so much of the soil. Microorganisms contribute to nutrient availability in soil, manage soil stability by means of different biochemical processes such as nitrogen fixation, and they contribute to the growth and success of the plants and overall ecosystem of a soil environment.