



**MINISTRY OF HIGHER EDUCATION & SCIENTIFIC RESEARCH  
KRG, IRAQ**

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**ENVIRONMENTAL REMEDIATION  
PART II: PHYTOREMEDIATION**

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**2017-2018**

## PHYTOREMEDIATION

### Preamble

Water is a vital resource, necessary for all aspects of human and ecosystem survival and health. Water is needed for agricultural production, industrial and a variety of other purposes. The scarcity of water supply in many arid regions, combined with the need for disposal of large volumes of wastewater, has led to an increased use of treated wastewater for irrigation. Being low-cost and low-technology systems, eco-technological systems like “Constructed Wetlands” (CWs) are now standing as the potential alternative or supplementary systems for the treatment of municipal, industrial, agricultural wastewater, as well as storm water.

### Wastewater Characteristics

#### - Wastewater production or Sources of Wastewater

According to USEP, a wastewater is referred to as the water which leaves the consumer, having been contaminated by domestic, industrial, commercial operations and storm water inflows with products such as organic matter, chemicals and other particulate matter. The origin of wastewater is domestic, industrial, commercial and urban stormwater.

- 1) Domestic wastewater derives from number of sources, wastewater generated from toilet is termed as black water and it has high content of solids and contributes a significant amount of nutrients (nitrogen and phosphorous). Black water can be further separated as feces and urine, where urine is called yellow water and feces with water is known as brown water. Grey water consists of water from bathing/showering and from the kitchen. Domestic wastewater is contaminated with organic material, nitrogen, and phosphorus mainly.
- 2) Industrial wastewater includes industrial process water and water from service facilities for staff in the industrial plant usually. Contamination of industrial wastewater varies very much depending on type of the industry and pre-treatment facilities for wastewater in the industrial plant. Discharges from food industry consist of oxygen consuming substances (BOD or COD), nitrogen, phosphorus and suspended solids. Surface coating and plating industries, tanneries discharge dissolved metals, such as copper, chromium, zinc, as well as oxygen consuming substances, detergents.
- 3) Commercial wastewater is water coming from service sector, i.e. schools, restaurants, hospitals and other non-industrial institutions. The quality of commercial wastewater is similar to domestic wastewater.
- 4) Urban stormwater consists of precipitation on the urban territory that has percolated through the ground or streamed down directly to the drainage system. Rain washes away contaminants from the surface and thus urban stormwater contains more pollutants than rain water.

The average daily wastewater flow from a typical residential dwelling has been found as 185-265 L/cap/day (USEPA, 2002).

#### Composition of Wastewater:

In generally, municipal wastewater is characterized by its: Physically, wastewater is usually characterized by a gray color, musty odor, and a solids content of about 0.1%. From a physical point of view the suspended solids can lead to the development of

sludge deposits and anaerobic conditions when discharged into the receiving environment.

Chemically, wastewater is composed of organic and inorganic compounds as well as various gases. Organic components may consist of carbohydrates, proteins, fats, greases, surfactants, oils, pesticides, phenols, etc., Inorganic components may consist of heavy metals, nitrogen, phosphorus, sulfur, chlorides etc. Gases commonly dissolved in wastewater are hydrogen sulfide, methane, ammonia, oxygen, carbon dioxide, and nitrogen. The first three gases result from the decomposition of organic matter present in the wastewater.

Biologically, wastewater contains various microorganisms but the ones that are of concern are those classified as protista, plants, and animals. The category of protista includes bacteria, fungi, protozoa, and algae. Toxic compounds generated by the protista and found in wastewater pass through wastewater treatment facilities that have not been designed to remove them and can interfere with their operation.

### **Wastewater Pollutants and Water Pollution:**

Excessive nutrients, toxic compounds, and pathogenic agents are among the potential impacts on the environment from onsite wastewater systems (UAEPA, 2002). Domestic wastewater contains several pollutants that could cause significant human health or environmental risks if not treated effectively before being released to the receiving environment.

Surface waters can be polluted by industrial and municipal discharges as well as alterations to the natural environment, which may cause runoff of pollutants. Surface water pollution is classified into two major categories: point source pollution and non-point source pollution.

#### **- Point Source Pollution**

point source pollution comes from a defined outlet (EPA, 2005a), such as pipe discharges, industrial outflows, tributaries, or wastewater treatment plant outflows, are relatively easy to define and regulate. This includes industrial and municipal dischargers, or any other facility that discharges wastewater to receiving water.

Point source contaminants include dredged spoil, solid waste, incinerator residue, filter backwash, sewage, sewage sludge, garbage, munitions, chemical wastes, biological materials, some radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste.

#### **- Non-point Source Pollution**

Non-point source (NPS) pollution is typically caused by rainfall or snowmelt moving over or through the ground, picking up natural and human pollutants, and carrying those pollutants into surface waters. Pollutants include but are not limited to excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas; oil, grease, and toxic chemicals from urban runoff and energy production; sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks; salt from irrigation practices and acid drainage from abandoned mines; and bacteria and nutrients from livestock, pet wastes, and faulty septic systems (EPA,

2005b). NPS pollution presents great challenges because sources are ubiquitous yet highly variable. Non-point source pollution is a major problem for surface waters because it is often times difficult to identify the source of the pollution. Therefore, control of nonpoint sources of pollution is problematic. Often times, land use surveys and groundwater or surface water quality samples are the only ways of identifying where possible nonpoint sources may be located.

### **Wastewater pollutants of concern:**

Domestic and industrial wastewater contains several pollutants that could cause significant human health or environmental risks such as:

#### **1. Nitrogen pollution:**

The typical concentration of nitrogen in domestic effluent is greater than 80 mgN/L. Much of this results from toilet wastes. Faeces consist of unabsorbed food material, which include particulate organic nitrogen, and urine includes urea  $[\text{CO}(\text{NH}_2)_2]$ , which contributes to the concentration of both particulate and soluble nitrogen. Kitchen wastes (from food preparation) and bathroom wash-water (contaminated with perspiration and some cleaning agents) also contribute to the nitrogen load.

Nitrogen is becoming increasingly important in wastewater management because nitrogen can have many effects on the environment. Un-ionized ammonia ( $\text{NH}_3$ ), found in certain types of wastewater effluent, is potentially toxic to fish and many other aquatic organisms and it is also an oxygen-consuming compound, which can deplete the dissolved oxygen in water. The Depletion of dissolved oxygen in water is a problem in aquatic ecosystem since maintenance of a high oxygen concentration is crucial for survival of the higher life forms in aquatic ecosystem. Another ecological impact is eutrophication. All forms of nitrogen are taken up as a nutrient by photosynthetic blue-green bacterial and algae. The excessive growth of bacteria and algae due to the increase of the amount of nitrogen discharged into water, contributes to the reduction of the oxygen level in water. Although nitrate itself is not toxic, its conversion to nitrite is a concern to public health. Nitrite is a potential public health hazard in water consumed by infants. In the body, nitrite can oxidize the iron (II) and form methemoglobin, or "blue baby" syndrome, which binds oxygen less effectively than normal hemoglobin. The resulting decrease in oxygen levels in young children leads to shortness of breath, diarrhea, vomiting, and in extreme cases even death. These occurrences are generally associated with disposal of municipal sewage and fertilizer application to agricultural crops. Excessive nitrates in groundwater (50 mg/l), when drunk, may be toxic to people and animals. The maximum nitrate-nitrogen concentration in drinking water recommended by World Health Organization (WHO) is  $3 \text{ mg NO}_3^{-1} \text{ L}^{-1}$ .

#### **2. Phosphorus pollution:**

Phosphorus pollution in aquatic environments can be attributed to three major sources: industry, agriculture and wastewater treatment works. The use of phosphates in food processing, detergents and agriculture has resulted in the depletion of this essential plant nutrient, yet its presence in industrial wastes and its persistence in wastewater treatment plant effluents have led to increased concentrations of it in water bodies and have led therefore to widespread concern over its environmental impact. Phosphorus is present in urban sewage at levels between 6 and 10 mg/l, while

an even lower than  $10 \text{ mg L}^{-1}$  concentration in inland waters may stimulate algal growth. According to (EPA, 1976), phosphate concentration that exceeded  $0.025 \text{ mg L}^{-1}$  may stimulate excessive growth of algae and other aquatic plants which can be a nuisance. Excessive growth of these aquatic plants, or 'eutrophication', can seriously interfere with desirable water use; it results in large diurnal variation in dissolved oxygen levels, fish kills and changes in ecosystem function and diversity. Eutrophication has been a serious environmental concern in the developed world over the last 30 years or so and is now a major global concern.

Release of phosphorus has significantly increased over the years through agricultural practices, industrialization, and urbanization. Nutrient enrichment, or eutrophication of aquatic ecosystems from nitrogen and especially phosphorus, can cause an increase in algae and aquatic plants, loss of natural component species, and eventually a loss of the natural ecosystem. Carpenter refers to eutrophication as the largest water quality problem in the world.

### **3. Heavy metals Contamination:**

Heavy metals are metals with a density of over  $5 \text{ g.cm}^{-3}$ . Some metals are important as micronutrients to living cells (Fe, Mo, Mn). Even some that are useful to living cells can be toxic above trace levels (Zn, Ni, Cu, V, Co, W, Cr). Metals that are essential to plant function can become toxic at high enough levels. Conversely, some metals have no use as nutrients and are simply toxic to living organisms (As, Hg, Ag, Sb, Cd, Pb and U).

Metals can be present in raw household wastewater because many commonly used household products contain metals such as pharmaceuticals, paint, battery, transportation etc. Other sources of metals include vegetable matter and human excreta. The average concentration (mg/l) of heavy metals in wastewater ranged from 0.00 to 7.5 for Pb, 0.21 to 4.3 for Zn, 0.00 to 0.06 for Cd, 0.00 to 0.81 for Cr, 0.07 to 6.3 for Cu and 0.00 to 4.2 for Ni.

Metals like lead, mercury, cadmium, copper, and chromium can cause physical and mental developmental delays, kidney disease, gastrointestinal illnesses, and neurological problems (USEPA, 2002).

Health problems associated with lead poisoning which include: neurological damages leading to secondary condition characterized by low intelligence, loss of short memory, poor coordination and learning disabilities. In a prenatal exposure, the condition may include low birth weight, poor immune responses or otherwise. In adult, lead is suggested to have a linked to behavioural inhibition and even tooth decay.

Mercury is also a significant health issue. High concentrations may cause nervous system damage, leading to deformities in early child exposure, partial blindness, muscles wasting, and loss of reflex. It is also associated with low: learning abilities, coordination, and fertilities in males. Heavy metal like arsenic is said to cause cardiovascular disorder, skin-cancer and skin related diseases, kidney damage and peripheral neuropathy (WHO, 1997).

Copper, could cause anaemia, liver and kidney damages, stomach and intestinal problems when in excess concentration in the body Cadmium, is closely associated with renal dysfunction, lungs cancer, bone abnormalities such as osteomalacia and osteoporosis on long-term exposure in humans and animals. It bio-accumulates in the liver and kidney and it could lead to kidney and liver failure. Although iron is a non-toxic nutrient at reasonable levels, high concentrations in drinking water result in an unpleasant taste. Arsenic is a naturally occurring element that is highly toxic to humans. It is a known carcinogen and causes damage to the liver, skin, lungs and lymphatic system.

Typical municipal sludge in the United States contained, on the dry weight basis, 160-400, 80-320, 930-1,860 and up to 1400 mg kg<sup>-1</sup> dry weight of Cu, Zn, Pb, and Cr, respectively When industrial waste contributes significantly to the wastewater flow, sludge containing 41,000, 12,000, 26,000, 62,000, and 1,500 mg kg<sup>-1</sup> dry weight of Cr, Cu, Pb, Zn, and Cd, respectively have been reported. In the non-industrial communities, the trace metal contents of sewage sludge are significantly lower. The average concentration of Cd, Cu, Ni, Pb and Zn in the 12 month old sewage sludge in Bahrain were 9.2, 380, 53, 186, and 729 mg kg<sup>-1</sup> dry weight, respectively.

#### **4. Fats, Oils and Greases:**

Oil wastes either of petroleum or vegetable origin are considered as serious types of hazardous pollutants when they find their way into aquatic environments, since they are highly toxic to the aquatic organisms and can completely damage the ecology of beach areas.

Over the past 10 years there has been a distinct increase in the amount of fats, oils and greases (FOG) disposed via the wastewater system. According to the Water Research Council (WRC) FOG is a major cause of operational problems concerning wastewater treatment and associated expenditure to sewer system operators. FOG is an indirect cause of sewer blockages; it builds up in sewer pipes, encourages further build up of sediment, and therefore reduces the capacity of the wastewater treatment system to function correctly. Although the extent of FOG sources has not yet been identified, the main sources include: industry, catering establishments and domestic households. Sewer blockage incidents mainly originate from fast food outlets and restaurants; however in contrast to domestic sources these are now regulated. Under the Environmental Protection (Duty of Care) Regulations 1991 it is mandatory that waste cooking oil from catering premises is collected by an authorised collector and taken to an authorised site for recovery or disposal

#### **5. Biochemical oxygen demand and total suspended solids**

Biodegradable organic material creates biochemical oxygen demand (BOD), which can cause low dissolved oxygen concentrations in surface water, create taste and odor problems in well water, and cause leaching of metals from soil and rock into ground water and surface waters.

The amount of organic material that can rot in the sewage is measured by the biochemical oxygen demand. BOD is the amount of oxygen required by microorganisms to decompose the organic substances in sewage. Therefore, the

more organic material there is in the sewage, the higher the BOD. BOD levels of industrial sewage may be many times that of domestic sewage.

Total suspended solids (TSS) in system effluent can clog the infiltrative surface or soil interstices, while colloidal solids cause cloudiness in surface waters. TSS in direct discharges to surface waters can result in the development of sludge layers that can harm aquatic organisms (e.g., benthic macro invertebrates). Systems that fail to remove BOD and TSS and are located near surface waters or drinking water wells may present additional problems in the form of pathogens, toxic pollutants, and other pollutants (USEPA, 2002). Majority (about 80%) of the pollution load of wastewater is due to human excreta as it has high BOD (Bio-chemical Oxygen Demand) content (USEPA, 2002). In Europe, effluent BOD<sub>5</sub> and SS standards for discharge into surface waters range from 250 mg BOD<sub>5</sub> L<sup>-1</sup> in The Netherlands to 25 mg BOD<sub>5</sub> L<sup>-1</sup> in Austria and 70 mg SS L<sup>-1</sup> in The Netherlands to 35 mg SS L<sup>-1</sup> in the Czech Republic, respectively.

### **Wastewater reclamation processes:**

Treatments for health and some environmental problems are done at the wastewater treatment facility and include:

- a) biodegradable organics, macroorganic matter which can lead to depletion of dissolved oxygen as the organics decompose, are measured as BOD (biological oxygen demand) and COD (chemical oxygen demand);
- b) stable or refractory organics, specific organic compounds that are resistant to decomposition and may be potential toxicity problems if leached into groundwater;
- c) pathogens, pathogenic microorganisms such as total or feral coliform bacteria;
- d) trace elements that may accumulate in the environment and cause toxicity problems to plants, animals, or humans;
- e) nutrients such as N and P that may present pollution problems and act as a fertilizer to plants; and,
- f) salinity aspects, especially total salts and levels of specific salts (Na, Cl, B).

These process are decreased by combinations of physical, chemical and biological action via a range of preliminary, primary, secondary and tertiary treatment processes. Many of these processes have been used extensively since the late 1970s to overcome socio-technical and economic barriers in reuse schemes. Resent many contry used natural wastewater treatment such as phtoremediation by using constructed wetland.

### **Phytoremediation:**

Phytoremediation, an emerging cleanup technology for contaminated soils, groundwater, and wastewater, is both low-tech and low-cost. Phytoremediation can be defined as the engineered use of green plants, including grasses, forbs, and woody species, to remove, contain, extract or render harmless such environmental contaminants as heavy metals, trace elements, organic compounds, and radioactive compounds in solid substrates (e.g. soil), liquid substrates (e.g. water), and even the atmosphere. This definition includes all plant-influenced biological, chemical, and physical processes that aid in the uptake, sequestration, degradation, and metabolism

of contaminants, either by plants or by the free-living organisms that constitute the plant's rhizosphere.

For treating contaminated wastewater, the phytoremediation plants are grown in a bed of inert granular substrate, such as sand or pea gravel, using hydroponic or aeroponic techniques. The wastewater, supplemented with nutrients if necessary, trickles through this bed, which is ramified with plant roots that function as a biological filter and a contaminant uptake system. An added advantage of phytoremediation of wastewater is the considerable volume reduction attained through evapotranspiration. Phytoremediation considered as a environment-friendly technology to clean up the contaminated environment.

### **History of phytoremediation:**

The term phytoremediation ("phyto" meaning plant, and the Latin suffix "remedium" meaning to clean or restore) refers to a diverse collection of plant based technologies that use either naturally occurring, or genetically engineered, plants to clean contaminated environments. Phytoremediation is a term coined in 1991 (EPA, 2000b). Basic information for what is now called phytoremediation comes from a variety of research areas including constructed wetlands, oil spills, and agricultural plant accumulation of heavy metals.

The basic idea that plants can be used for environmental remediation is quite old or not new. Some plants which grow on metalliferous soils have developed the ability to accumulate massive amounts of indigenous metals in their tissues without symptoms of toxicity. But the concept has actually been implemented for the past 300 years on wastewater discharges.

Over time, this use of plants has evolved to the construction of treatment wetlands or even the planting of trees to counteract air pollution. In more recent years, as recognition grew of the damage resulting in the United States and around the world from decades of an industrial economy and extensive use of chemicals, so did interest in finding technologies that could address the residual contamination, among them phytoremediation.

### **Benefits and Limitations of Phytoremediation:**

#### **1. Benefits of Phytoremediation:**

Phytoremediation is an in situ, solar driven technique, which limits environmental disturbance and reduces costs. Moreover, it is particularly well-suited to the treatment of large areas of surface contamination. Phytoremediation also is considered to be more aesthetically pleasing than other remediation techniques.

Some wetland plants can transport oxygen to the rhizosphere under conditions that may otherwise limit the amount of oxygen available to soil microorganisms, as is the case in soils and sediments saturated with water or contaminated with oil. Microbial communities in the rhizosphere may be able to biodegrade a wide variety of organic contaminants. Phytoremediation does not require expensive equipment or highly-specialized personnel, and it is relatively easy to implement. Implementing phytoremediation may result in a cost savings of 50 to 80 percent over traditional technologies.

Phytoremediation also helps eliminate secondary air- or water-borne wastes. For example, some plants accumulate PAHs from the atmosphere. Likewise, phytoremediation has the potential to help reduce greenhouse gas emissions because it does not require the use of pumps or motors that give off greenhouse gases and plants used in phytoremediation may serve as sinks for the greenhouse gas carbon dioxide. Trees used in phytoremediation may reduce noise levels from industrial sites. Likewise, phytoremediation itself is less noisy than other reclamation alternatives. Phytoremediation may provide habitat to animals, promote biodiversity, and help speed the restoration of ecosystems that were previously disrupted by human activity at a site.

## **2. Limitations of Phytoremediation:**

For remediation to be successful, contamination must generally be shallow enough that plant roots can reach the contaminants, or contamination must be brought to the plant (EPA, 2000b). Root density general decreases with depth. Immobile contaminants – those that cannot migrate to the plant roots during water uptake – are increasingly unlikely to be affected by phytoremediation.

The time required to achieve the remedial goals may be longer with phytoremediation than with other treatment technologies. Phytoremediation can require several growing seasons for a tree stand to be established and for contaminant concentrations to be reduced.

Environmental conditions, such as soil texture, pH, salinity, oxygen availability, temperature and level of non-hydrocarbon contaminants (e.g., metals) must all be within the limits tolerated by plants. In addition, plants will not grow if concentrations of the target contaminant are too high. Thus, phytoremediation of the target contaminant will not proceed unless the soil is pretreated to reduce phytotoxicity or a resistant plant species is selected.

Phytoextraction techniques can cause contaminants to accumulate in plant tissues, which could cause ecological exposure issues or require harvesting (EPA, 2000b). The consumption of contaminated plants by wildlife is also of concern. Phytovolatilization may remove contaminants from the subsurface into the air, but might then cause increased airborne exposure (EPA, 2000b). Finally, Biological methods are not capable of 100% reduction of contaminants.

## **3. Phytoremediation Mechanisms:**

Depending on the contaminants, the site conditions, the level of clean-up required, and the types of plants, phytoremediation technology may lead to several different acceptable outcomes and has several distinct modes of action. These are phytostabilization, immobilization, accumulation, volatilization, phytodegradation, and rhizodegradation.

### **1. Phytoextraction of metals (Inorganics):**

Phytoextraction, also called phytoaccumulation (USEPA, 2000b), is the use of pollutant-accumulating plants "hyperaccumulators" to remove inorganic contaminants (includes heavy metals, metalloids, radionuclides, and salts) from soil, , without

destroying the soil structure and fertility. by concentrating them in the harvestable parts (shoots, leaves, etc.).

Discovery of metal hyperaccumulator species demonstrates that plants have the potential to remove metals from contaminated soils. A hyperaccumulator is a plant species capable of accumulating 100 times more metal than a common non-accumulating plant. Hyperaccumulators should have a metal accumulation exceeding a threshold value of shoot metal concentration of 1% (Zn, Mn), 0.1% (Ni, Co, Cr, Cu, Pb and Al), 0.01% (Cd and Se) or 0.001% (Hg) of the dry weight shoot biomass. Over 400 hyperaccumulator plants have been reported, including members of the Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Cunouniaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae, Violaceae, and Euphobiaceae.

Phytoextraction should be viewed as a long-term remediation effort, requiring many cropping cycles to reduce metal concentrations. However, crops such as ***Brassica junica* L.** can possess great potential for phytoextraction of metals from soil. In addition, many other investigators have shown metal uptake by cultivars such as lettuce, corn, and mushrooms. Alfalfa (***Medicago sativa***) has also shown to be extremely resistant to high levels of contaminants as well as a bio-accumulator.

The main advantage of this technique is the ability to concentrate the pollutant into a small volume and preventing the pollutant from extended interaction with the ecosystem. phytoextraction is suitable for remediating large areas of land contaminated at shallow depths with low to moderate levels of metal-contaminants. The cost of phytoextraction is fairly inexpensive when compared to conventional methods (USEPA, 2000b). Another benefit is that the contaminant is permanently removed from the soil. In addition, the amount of waste material that must be disposed of is substantially decreased ( up to 95 % ) (USEPA, 2000b) and in some cases, the contaminant can be recycled from the contaminated plant biomass. Disadvantages are that the contaminant is not destroyed, and a suitable disposal method and location must be found for the contaminated plant tissue. The use of hyperaccumulator species is limited by slow growth, shallow root system, and small biomass production.

## 2. Phytostabilization:

Phytostabilization, also known as phytorestoration, is the use of plant roots to reduce the mobility or bioavailability of pollutants in the environment (soil or groundwater), and can be divided into three mechanisms: “absorption and accumulation by roots, adsorption onto root surfaces, and incorporation into humic materials in the rhizosphere”.

The plants used for phytostabilization should have efficient root-accumulation of metals, low translocation of metals to the shoots, and large root system.

Phytostabilization, also referred to as in-place inactivation, is primarily used for the remediation of soil, sediment, and sludges (USEPA, 2000b). The plants primary purposes are to (1) decrease the amount of water percolating through the soil matrix, which may result in the formation of a hazardous leachate, (2) act as a barrier to prevent direct contact with the contaminated soil and (3) prevent soil erosion and the distribution of the toxic metal to other areas.

Plants were identified as hyper tolerant which can be used for phytostabilization. Two plant species, *Hyparrhenia hirta* and *Zygophyllum fabago*, that have naturally colonized some parts of mine tailings in South-East Spain, have been reported to tolerate high metal concentrations in their rhizospheres. These plant species do not take up high concentrations of metals, providing a good tool to achieve surface stabilization of tailings with low risk of affecting the food chain. Phytostabilization efforts in the Mediterranean region have been found to be improved by using mixtures including local metallicolous legume and grass species.

Some of the advantages associated with this technology are that the disposal of hazardous material/biomass is not required (USEPA, 2000b), and it is very effective when rapid immobilization is needed to preserve ground and surface waters. The presence of plants also reduces soil erosion and decreases the amount of water available in the system (USEPA, 2000b). The lack of appreciable metals in shoot tissue also eliminates the necessity to treat harvested shoot residue as a hazardous waste.

### 3. Rhizofiltration

Rhizofiltration is defined as the use of plants to absorb, concentrate, and precipitate contaminants from polluted aqueous sources with low contaminant concentration in their roots. Mechanisms involved in biosorption include chemisorption, complexation, ion exchange, micro precipitation, hydroxide condensation onto the biosurface, and surface adsorption. Rhizofiltration can partially treat industrial discharge, domestic wastewater, agricultural runoff. It can be used for lead, cadmium, copper, nickel, zinc and chromium, which are primarily retained within the roots. Rhizofiltration uses terrestrial plants instead of aquatic plants because the former feature much larger fibrous root systems covered with root hairs with extremely large surface areas.

Root exudates and changes in rhizosphere pH may also cause metals to precipitate onto root surfaces. As they become saturated with the metal contaminants, roots or whole plants are harvested for disposal. The translocation of metals to shoots would decrease the efficiency of rhizofiltration by increasing the amount of contaminated plant residue needing disposal. However, the efficiency of the process can be increased by using plants with a heightened ability to absorb and translocate metals. Several aquatic species have the ability to remove heavy metals from water, including water hyacinth, pennywort, and duckweed. However, these plants have limited potential for rhizofiltration because they are not efficient in removing metals as a result of their small, slowgrowing roots. Sunflower (*Helianthus annuus* L.) and Indian mustard (*Brassica juncea* Czern.) are the most promising terrestrial candidates for removing metals from water. The roots of Indian mustard are effective in capturing Cd, Cr, Cu, Ni, Pb, and Zn, whereas sunflower removes Pb, U, <sup>137</sup> Cs, and <sup>90</sup> Sr from hydroponic solutions.

The advantages of rhizofiltration include its ability to be used as in-situ (floating rafts on ponds) or ex-situ (an engineered tank system) applications and species other than hyperaccumulators can also be used.

Disadvantages and limitations include the constant need to adjust pH, plants may first need to be grown in a greenhouse or nursery; there is periodic harvesting and plant

disposal; tank design must be well engineered; and a good understanding of the chemical speciation/interactions is needed. The cost of remediation by rhizofiltration has been estimated to be \$2-\$6 per 1000 gallons of water.

#### **4. Phytovolatilization (Inorganics and Organics)**

Phytovolatilization involves the use of plants to take up contaminants from the soil, transforming them into volatile form and transpiring them into the atmosphere, usually through the leaf stomata. This technique is only suitable for contaminants that do not pose a significant air pollution hazard.

Phytovolatilization occurs as growing trees and other plants take up water and the organic and inorganic contaminants. Some of these contaminants can pass through the plants to the leaves and volatilise into the atmosphere at comparatively low concentrations. Phytovolatilization has been primarily used for the removal of mercury, the mercuric ion is transformed into less toxic elemental mercury, could convert hazardous methyl-Hg and ionic Hg to the less toxic volatile elemental Hg, which is released to the air. However, the Hg released into the atmosphere is likely to be recycled and deposited back into lakes and oceans, repeating the production of methyl-Hg via bacterial methylation.

Some aquatic plants, such as cattail (*Typha latifolia* L.), have potential for Se phytoremediation. Volatile Se compounds such as dimethylselenide are 1/600 to 1/500 as toxic as inorganic forms of Se found in soil. The volatilization of Se and Hg is also a permanent site solution, because the inorganic forms of these elements are removed, and gaseous species are not likely to redeposit at or near the site.

The disadvantage is, mercury released into the atmosphere is likely to be recycled by precipitation and then redeposit back into ecosystem. Gary Banuelos of USDS's Agricultural Research Service have found that some plants grow in high Selenium media produce volatile selenium in the form of dimethylselenide and dimethyldiselenide. Phytovolatilization has been successful in tritium (<sup>3</sup>H), a radioactive isotope of hydrogen, it is decayed to stable helium with a half-life of about 12 years reported Dushenkov.

#### **5. Phytodegradation/transformation (Organics)**

Phytodegradation/transformation, "the breakdown of organic contaminants either internally, through metabolic processes, or externally, through the release of plant-produced enzymes into the soil" can be divided into two components: first, absorption, translocation and metabolism of contaminants by the plant; Plants contain enzymes that can breakdown and convert ammunition wastes, chlorinated solvents such as trichloroethylene and other herbicides. The enzymes are usually dehalogenases, oxygenases and reductases and, second, degradation of the contaminant by root exudates. Although the definition of phytodegradation refers solely to direct degradation of contaminants by root exudates, root exudates may aid remediation in a number of other ways such as by: increasing the bioavailability of the contaminant, lubricating the soil, and acting as cometabolites with PHC. Research has found that root exudates were able to degrade some organic contaminants. I was shown that specific plant-derived enzymes are able to degrade 2,4,6-trinitrotoluene and trichloroethylene.

The microbial breakdown and removal of contaminants in the soil occurs through two distinct but interrelated processes, biodegradation and microbial uptake. Biodegradation is the “microbially mediated chemical transformation of organic compounds” while microbial uptake is the direct removal of the contaminant by adsorbing compounds to the membrane surface or absorbing compounds through the membrane. These two processes are interrelated in that the contaminant taken up may be the original contaminant or a biotransformation product.

### **Constructed treatment wetlands:**

Wetlands are transitional areas between land and water. The boundaries between wetlands and uplands or deep water are therefore not always distinct. The term “wetlands” encompasses a broad range of wet environments. Natural wetlands are called by other names such as bogs, swamps, and marshes. Bogs occur at higher elevations and are described as spongy, with poorly drained soil. Swamps are characterized by the presence of trees, while marshes have a lot of sedges and grasses with trees growing on the edges of the wetland. Construction wetlands have a small ecological footprint utilize "low tech" technology, and have an aesthetic value similar to that of natural wetlands.

Construction wetlands are engineered system that have been designed and constructed to utilize the natural processes. Constructed wetlands are one of the many types of natural systems that can be used for treatment and pollution control. According to (USEPA, 1993), a constructed wetland is defined as “a wetland specifically constructed for the purpose of pollution control and waste management, at a location other than existing natural wetlands.” Constructed wetlands are characterized by the growth of emergent plants using soil, gravel, or rock as a growth substrate in a lined channel or bed. Within the bed, facultative microbes attach to the media and plant roots, thereby contacting the wastewater that flows horizontally through the bed while remaining below the surface of the media.

The treatment of industrial and domestic wastewaters by passage through beds containing common reed plant species (e.g., *Phragmites australis*, *Typha latifolia*) has been widely practiced for many years in a number of countries with varying degrees of success. Although good removal of organic components of effluents and suspended solids is a common finding, poor removal of ammoniacal nitrogen is also typically reported.

Construction wetlands for wastewater treatment have proven to be an effective, low-cost sustainable alternative for conventional wastewater treatment technologies. The removal of pollutants in these systems relies on a combination of physical, chemical and biological process that naturally occur in wetlands and are associated with the vegetation, the sediment and their microbial communities.

Today, due to the increased awareness for natural processes, the necessity of wastewater treatment in low density areas and demand for simple operation and maintenance, the use of constructed wetlands for wastewater management and water pollution control is becoming more popular and effective in many parts of the world.

### **History of construction wetland:**

Constructed wetlands have been used for the treatment of municipal wastewater for over thirty years (USEPA, 1999). The first work deliberately investigating wastewater treatment by wetland plants was conducted at the Max Planck Institute in Plon, Germany.

In 1953, Seidel explored the removal of phenols from wastewater by *Scirpus lacustris* and in 1956 began testing dairy wastewater treatment with *S. lacustris* (Bastian and Hammer, 1993). From 1955 through the late 1970s, Seidel published numerous studies on water and wastewater treatment with wetland plants (Seidel, 1955, 1961 and 1976). One of her students, Kickuth, continued with the experimental work and popularized this concept with his co-workers in Europe, resulting in nearly 200 municipal and industrial waste treatment systems.

Throughout the 1970s, in the U.S., land treatment alternatives were developed with the support of a significant research and development effort funded by the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers and other agencies.

The Tennessee Valley Authority was one of the US pioneers in the use of wetlands during the 1980s. The first full technology assessment was published by the USEPA in 1993 (USEPA, 1993). This also outlined topics needing further investigation. Hans Brix, one of the researchers who brought this technology to the forefront, authored a 1994 article that presented a large world-wide database of results that showed impressive wastewater treatment by subsurface flow wetlands. Eight years later, Jan Vymazal published a summary of ten years experience in the use of constructed wetlands (CWs) for wastewater treatment in the Czech Republic.

Recently, a variety of applications for CW technology for water quality improvement were initiated in developing countries as a result of the transfer of the knowledge, technical collaboration and co-operation by the developed countries.

### **Advantages and disadvantages of constructed wetlands:**

#### **1. Advantages of constructed wetlands:**

Constructed wetlands are designed to take advantage of many of the same processes that occur in natural wetlands, but do so within a more controlled environment. (Haberl, 1999) and (Wallace, 1998) has summarized the main advantages of the constructed wetlands. These are as follows:

- 1) Simple construction, wetlands can be less expensive to build than other treatment options. Operation and maintenance expenses (energy and supplies) are low ( Brix, 1987).
- 2) Operation and maintenance require only periodic, rather than continuous, on-site labor( Brix, 1987).
- 3) Wetlands are able to tolerate fluctuations in flow. They facilitate water reuse and recycling.
- 4) They provide numerous benefits in addition to water quality improvement, such as wildlife habitat and the aesthetic enhancement of open spaces
- 5) Generation oxygen and consume carbon dioxide, thereby helping improve air quality and fight global warming.

- 6) The ability to operate on ambient solar energy (Wallace, 1998).
- 7) Organize and increase treatment capacity over time (Wallace, 1998).
- 8) No chemical use (Haberl, 1999).
- 9) Utilization of the harvested aquatic plants for a variety of purposes (biomass, biogas, animal feed, fertilizer, fencing, etc.).
- 10) Little excess sludge production (Haberl, 1999).
- 11) Treated effluent can be reused for restricted or unrestricted irrigation of agricultural crops, depending on its quality. Other applications are watering of gardens, golf courses, public parks, etc. (Merz, 2000)

## **2. Disadvantages or limitations of Constructed wetlands:**

Hilton, (1993) has summarized the main disadvantages or limitations of the constructed wetlands. These are as follows:

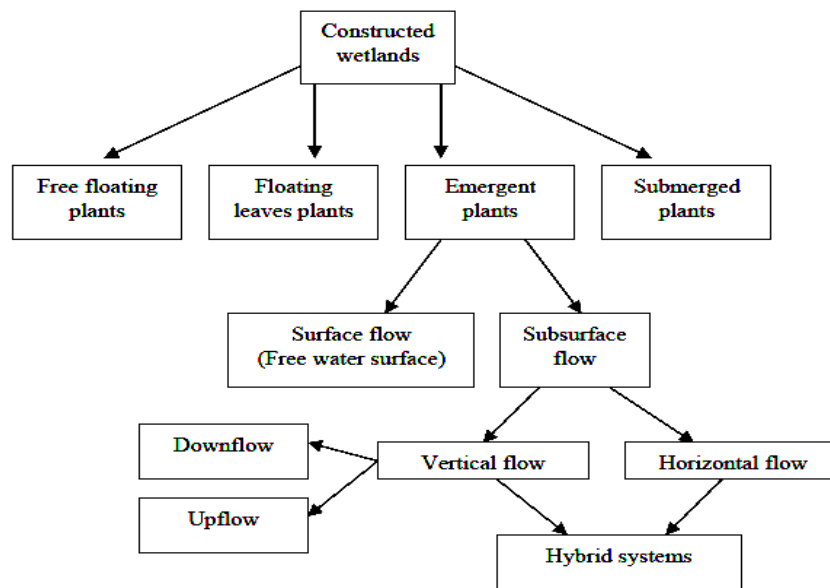
- 1) They generally require larger land areas than do conventional wastewater treatment systems (Hilton, 1993). Wetland treatment may be economical relative to other options only where land is available and affordable
- 2) Wetland treatment efficiencies may vary 'seasonally in response to changing environmental conditions, including rainfall and drought. While the average performance over the year may be acceptable, wetland treatment cannot be relied upon if effluent quality must meet stringent discharge standards at all times.
- 3) the biological components are sensitive to toxic chemicals, such as ammonia and pesticides. Flashes of pollutants or surges in water flow may temporarily reduce treatment effectiveness or cause them to survive. While wetlands can tolerate temporary drawdowns, they cannot withstand complete drying.
- 4) Also, the use of constructed wetlands for wastewater treatment and stormwater control is a fairly recent development. There is yet no consensus on the optimal design of wetland systems nor is there much information on their long-term performance

## **Types of constructed wetlands systems:**

There are several types of constructed wetlands; surface flow wetlands, subsurface flow wetlands, and hybrid systems that incorporate surface and subsurface flow wetlands. Constructed wetlands systems can also be combined with conventional treatment technologies. The basic classification is based on the type of macrophytic growth, further classification usually based on the water flow regime as illustrated in Figure 1.

But there are two main types of constructed wetlands:

- 1) Constructed wetlands with free-water-surface (FWS) or surface flow (SF) (the majority of water flows above the soil surface)
- 2) Constructed wetlands with Subsurface flow (SSF) (all flow is directed through the rooting media with no overland flow).



**Figure(1):Clacification of constructed wetlands for wastewater treatment**

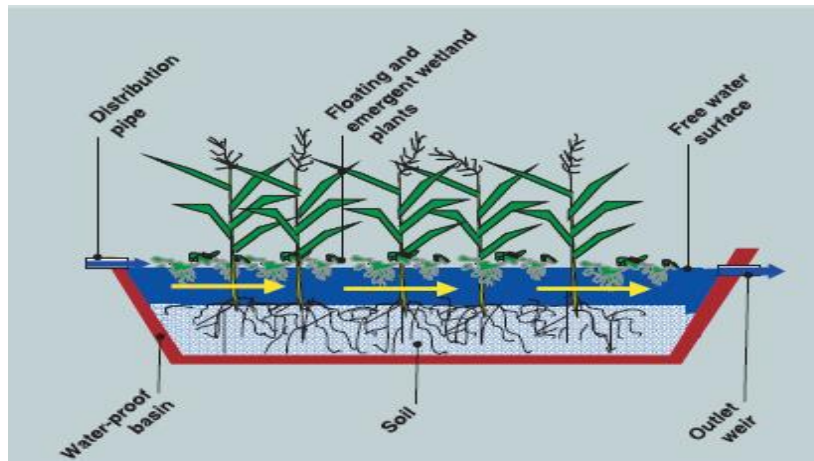
### 1. Constructed Wetlands with Free Water Surface ( FWS):

FWS wetlands consist of shallow basins in soil or any other media that will support plant roots. This wetland as most closely mimicking natural marshes. In generally, surface flow wetlands, the water is distributed on the ground surface and allowed to flow on top of the ground surface until collected at the outlet, and a water surface exposed to the atmosphere; the bed contains emergent aquatic vegetation; a layer of soil to serve as a rooting media; a liner if necessary to protect the groundwater and appropriate inlet and outlet structures.

The water depth in this type of wetland can range from a few centimeters to  $\geq 0.8$  m, depending on the use of the wetland. A normal operating depth of 0.3 m is typical. Design flows for these FWS wetlands range from less than 1000 gpd ( $4 \text{ m}^3 \cdot \text{d}^{-1}$ ) to over 20 gpd ( $75000 \text{ m}^3 \cdot \text{d}^{-1}$ ). The water surface moves through the wetland above the substrate at low velocities in a quiescent manner.

Areas of open water may or may not be incorporated into the design A general view of subsurface constructed wetlands is given in Figure 2.

The use of FWS constructed wetlands for urban stormwater treatment was pioneered in California in the early 1980s. Free water surface CWs are also commonly used in Australia and New Zealand, especially for treatment of municipal wastewater, stormwater and pasture runoff.



**Figure (2): Schematic cross-section of a constructed wetlands with free water surface and emergent macrophytes for wastewater treatment**

## 2. Subsurface Flow Constructed Wetlands

In this case, the excavated basin is filled with a porous medium, usually gravel. Also known as reed beds, rock-reed filters, gravel beds, vegetated submerged beds, and the root method, SSF wetlands are generally constructed with a porous material such as soil, sand, or gravel for a substrate. Reed beds and rock-reed filters use sand, gravel, or rock as substrates, while the root method uses soil. They are designed so that water flows below ground surface through the substrate.

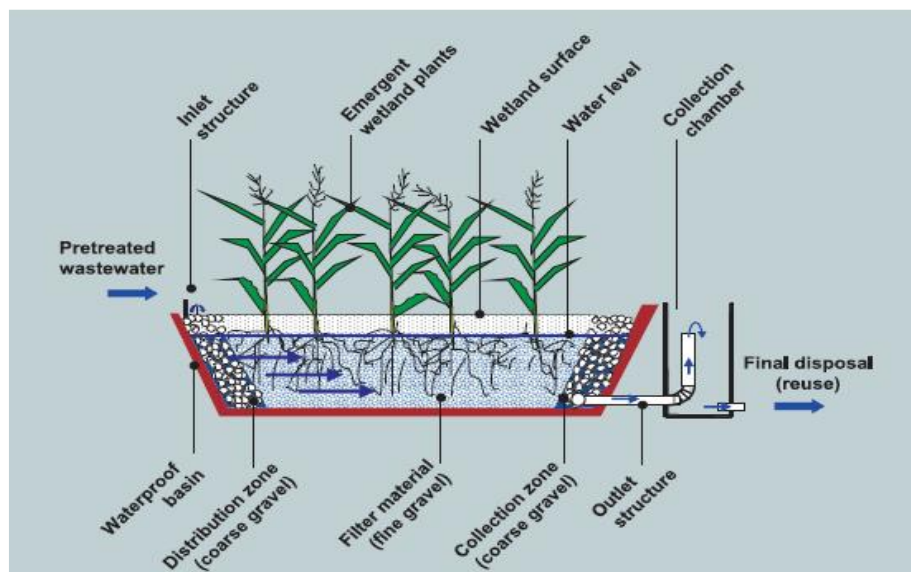
In these constructed wetlands water enters through an inlet and flows slowly below the ground surface until it reaches the outlet collection system. The depth of the flow-through bed for a constructed wetland is generally between 0.6 to 0.3 meters (Cooper, 1993). In the UK, layers of graded material are used. In France, VF systems treating raw sewage use graded gravel layers from top to the bottom (2-8 mm, 10-20 mm and 20-40 mm) in the first stage and layers of sand (0-2 mm) and gravel (3-8 mm and 10-20 mm) in the second stage.

Emergent aquatic plants are planted in the top surface of the media. Bed depth is normally shallow because at greater depths the roots and rhizomes get smaller and weaker. Any depth less than 0.3 meters decreases the effectiveness of the treatment zone. Walls should be constructed as steep as possible to provide the most effective area. The beds are normally sealed on all sides with either clay or a plastic liner/membrane to prevent leakage. Existing systems of this type range from those serving single-family dwellings to large-scale municipal systems. Nowadays, constructed wetlands are common alternative treatment systems in Europe in rural areas and over 95% of these wetlands are subsurface flow wetlands. In the following years, the number of these systems is expected to be over 10,000 only in Europe. Pretreatment for these systems normally involves a settling tank or fine screens. Volatilization, adsorption and plant uptake play much less important role in nitrogen removal in SSF constructed wetlands.

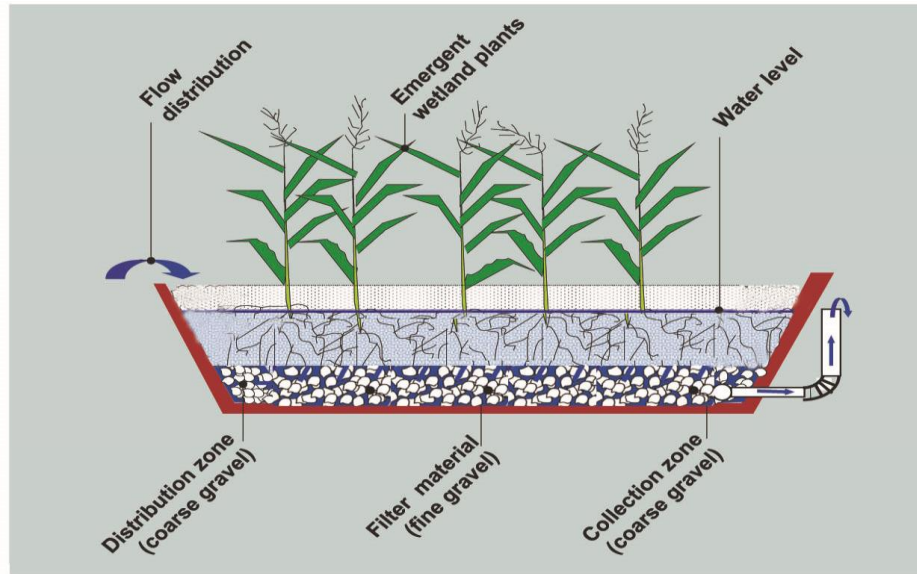
A general view of subsurface constructed wetlands is given in Figure 3. There are mainly two types of flow directions used in these systems. These are horizontal flow (HF) and vertical up/down flow (VF) shown in ( Fig 4).

The SSF type of wetland is thought to have several advantages over the FWS type.

- 1) SSF systems include increased treatment efficiencies, fewer pest problems, reduced risk of exposing humans or wildlife to toxics, decreased waterfowl use (advantageous near certain facilities such as airports), and increased accessibility for upkeep (no standing water).
- 2) The substrate or media provides greater available surface area for bacterial biofilm growth over an SF wetland, so increased treatment effectiveness may require smaller land areas. For BOD removal, this advantage may not exist. Saving land area is important at many installations and translates into reduced capital cost for projects requiring a land purchase.
- 3) The water surface is maintained below the media surface there is little risk of odors, exposure, or insect vectors.
- 4) SSF wetlands are also better suited for cold weather climates since they are more insulated by the earth.
- 5) The subsurface position of the water and the accumulated plant debris on the surface of the SF bed offer greater thermal protection in cold climates than the FWS type.
- 6) In the majority of cases, the flow path was vertical through each cell to an underdrain and then onto the next cell. Excellent performance for removal of BOD<sub>5</sub> TSS, nitrogen, phosphorus, and more complex organics was claimed.
- 7) Finally, many industrial waste streams, such as landfill leachate, can be treated in reed-bed systems with minimal ecological risk since an exposure pathway to hazardous substances does not exist for wildlife and most organisms.



**Figure (3): Schematic cross-section of a constructed wetlands with horizontal sub-surface flow(HSSF,HF) for wastewater treatment**



**Figure (4): Constructed wetlands with vertical sub-surface flow (VSSF,VF) for wastewater treatment**

#### **Components of constructed wetlands:**

A constructed wetland consists of a properly designed basin that contains water or wastewater, a substrate or media, and, most commonly, vascular plants. These components can be manipulated in constructing a wetland. Other important components of wetlands, such as the communities of microbes and aquatic invertebrates, develop naturally.

##### **1. Water:**

Wetlands are likely to form where landforms direct surface water to shallow basins and where a relatively impermeable subsurface layer prevents the surface water from seeping into the ground. These conditions can be created to construct a wetland. A wetland can be built almost anywhere in the landscape by shaping the land surface to collect surface water and by sealing the basin to retain the water.

##### **2. Filtration Media:**

Media in the root zone bed serves many different purposes. The first role of the media is physical treatment of the wastewater. Filtration and sedimentation of suspended solids and pathogens occurs along with the sorption of phosphorus, and dissolved organics. Smaller media, such as sand, are more effective in sorption and filtration than gravel or rocks because the smaller media contain smaller pore sizes and larger surface areas. The media also provides a stable surface area for the attachment of microbial biofilms which perform biological treatment of the wastewater passing thorough the root zone bed. The third function of the media is the solid support it gives for wetland plant growth. In most cases a layer of small diameter material is placed at the top of the bed to allow for better plant root establishment. It has been shown that gravel, rocks, or soils containing sharp-edged material can inhibit prolific plant growth. Plants that usually grow in soils may not be able to develop their root networks properly in substratum that has large void spaces. Wetland beds have been

constructed of many different types of materials. The characteristics of typical media used in SF wetlands are shown in (Table 1).

**Table (1): Characteristics of tapical media for SSFCW systems.**

Type	Effective Size, $D_{10}$ , (mm)	Porosity (%)	Hydraulic Conductivity ( $m^3/m^2/d$ )
Coarse Sand	2	32	1000
Gravelly Sand	8	35	5000
Fine Gravel	16	38	7500
Medium Gravel	32	40	10000
Coarse Rock	128	45	100000

From US EPA, 1993

It is observed that wetland areas must be increased to provide the contact time between the wastewater and the microbial communities necessary for adequate biodegradation to occur. In certain cases the wetland areas were not increased to allow for this reduced contact time. It have shown that coarser gravel at the inlet and outlet helps prevent clogging. For FWS CWs, a substrate rich in iron, calcium and aluminium is recommended. For SSHF CWs, a soil or gravel is recommended. In SSVF CWs, an active sand layer with a depth of 1.0 m (effective grain size,  $d_{10} = 0.25-1.2$  mm ) is recommended. The new version of U.S. EPA manual (U.S. EPA, 2000c) recommended gravel size between 20 and 30 mm.

### 3. Macrophyte:

The plants used in constructed wetland systems are known as emergent hydrophytes and macrophytes. The major portion of these plants (leaves and flowers) emerge above the media surface and are exposed to the air, while their roots and rhizomes are submerged beneath the water and media. Three of the commonly used plant species in constructed wetlands are bulrush (*Scirpus* spp.), reeds (*Phragmites* spp.), and cattails (*Typha* spp.). The extensive rooting structures of these species make viable options for wastewater treatment.

Therefore, it is best to use plant species that are found in nearby natural wetlands. However, in area where some of the commonly used species are not locally found, local species should be tested for survivability and effectiveness and used in preference to non-indigenous species. Ganjo *et al.* (2006) used *Typha angustifolia* L. as wastewater purifier for irrigation purpose. They constructed a small reclamation project consisted of sand filtration pots implanted with *T. angustifolia* L. in a field beside the main sewage canal of Hewlêr City. They studied many physico-chemical and bacteriological variables as well as they determined the vertical distribution of ions in different sand depths. They showed that the raw wastewater of Hewlêr City will cause irrigation problems, while the effluent qualities with macrophyte system were much better than those without macrophyte.

According to (Tanner, 1996) wetland plants are often central to wastewater treatment wetlands. The following requirements of plants should be considered for use in such systems

- 1) Ecological adaptability (no disease or weed risk to the surrounding natural ecosystems);
- 2) Tolerance of local conditions in terms of climate, pests and diseases;
- 3) Tolerance of pollutants and hypertrophic waterlogged conditions;
- 4) Ready propagation, rapid establishment, spread and growth; and
- 5) High pollutant removal capacity, through direct assimilation or indirect enhancement of nitrification( via root-zone oxygen release), denitrification ( via production of carbon substrates) and other microbial processes.

### **The role of vegetation:**

Plants have a vital role in constructed wetlands for the maintenance of the system. The most visible role of plants in wetlands is their impact on the aesthetics of the area and on the quality of wildlife habitat. However, it has been widely demonstrated that plants are also involved in almost every major function within wetland treatment systems. The main roles are:

- 1) Providing the conditions for physical filtration of wastewater and a surface area for microbial growth, as well as a source of carbohydrates for microbes (Brix, 1997).
- 2) Macrophytes vary with the species also have the ability to remove nutrients, trace elements, and organics from the water through biological uptake and surface adsorption (Gopal, 1999). Taking up nutrients and incorporating them into tissues. Although some of these nutrients are released when plants senesce and decompose, some nutrients remain in the un-decomposed litter that accumulates in wetlands, building organic sediments (Kadlec, 1995).
- 3) Leaking oxygen into the sediments and creating a zone in which aerobic processes and chemical oxidation can occur (Armstrong, 1978). Many aquatic plants actively transport oxygen from the atmosphere to the anaerobic layers of soil (Armstrong and Armstrong, 1990; Brix, 1993). Some oxygen leaks from the root hairs into the rhizosphere, supporting aerobic and facultative anaerobic microorganisms in the otherwise anaerobic sediments and soils. Facultative anaerobic microorganisms are those that usually respire aerobically but can grow under anaerobic conditions. Thus help in oxidation and precipitation of heavy metals on the root surfaces.
- 4) During photosynthesis, plants consume carbon dioxide and release oxygen. Submerged aquatic plants growing within the water column raise the dissolved oxygen level in the wetland surface water and deplete the dissolved carbon dioxide, resulting in an increased pH.
- 5) (Technical Guiding book)
- 6) Having additional site-specific values by providing habitat for wildlife and making wastewater treatment systems aesthetically pleasing (Knight, 1997).
- 7) The stems and leaves of macrophytes that are submerged in the water column provide a huge surface area for biofilms (Chappell and Goulder, 1994). The plant tissues are colonised by dense communities of photosynthetic algae as well as by bacteria and protozoa. Likewise, the roots and rhizomes that are buried in the wetland soil provide a substrate for attached growth of microorganisms.

## **Classification of macrophytes growing in constructed wetlands:**

A wide variety of aquatic macrophytes have been used in wetland systems designed for wastewater treatment. May be classified in the following major groups according to their life form (Brix and Schierup, 1989 and Cronk and Fennessy, 2001):

### **1. Emergent aquatic macrophytes:**

These are the dominating life form in wetlands and marshes, growing within a water table range from 50 cm below the soil surface to a water depth of 150 cm or more. In general they produce aerial stems and leaves and an extensive root and rhizome-system. The plants are morphologically adapted to growing in a water-logged or submersed substrate by virtue of large internal air spaces for transportation of oxygen to roots and rhizomes. The depth penetration of the root system and thereby the exploitation of sediment volume is different for different species.

The emergent aquatic macrophytes are the most commonly found species in the marsh type of constructed wetlands used for wastewater treatment. The most frequently used are cattails (***Typha***), reeds (***Phragmites communis***), rushes (***Juncus*** spp.), bulrushes (***Scirpus***), and sedges (***Carex***). Bulrush and cattails, or a combination of the two, are the dominant species on most of the constructed wetlands in the United States.

### **2. Floating-leaved aquatic macrophytes:**

These includes both species which are rooted in the substrate, e.g. *Nymphaea* spp. and *Nuphar* spp. (Waterlilies), *Potamogeton natans* (Pondweed), and *Hydrocotyle vulgaris* (Pennyworth), and species which are freely floating on the water surface, e.g. *Eichhornia crassipes* (Water Hyacinth), *Pistia stratiotes* (Water Lettuce) and *Lemna* spp. and *Spirodella* spp. (Duckweed). The freely floating species are highly diverse in form and habit, ranging from large plants with rosettes of aerial and/or floating leaves and well-developed submerged roots (e.g. *Eichhornia*, *Trapa*, *Hydrocharis*), to minute surface-floating plants with few or no roots (e.g. *Lemnaceae*, *Azolla*, *Salvinia*).

The water hyacinth is one of the most productive plants in the world. It can be used both for tertiary treatment purposes and integrated secondary and tertiary treatment systems for BOD and nutrient removal. Water hyacinth based wastewater treatment systems have been developed to be successfully applied in the tropics and the subtropics.

### **3. Submerged aquatic macrophytes:**

These have their photosynthetic tissue entirely submerged but usually the flowers exposed to the atmosphere. Species like *egeria* (*Egeria densa*), *elodea* (*Elodea canadensis* and *Elodea nuttallii*), hornwort (*Ceratophyllum demersum*) and hydrilla (*Hydrilla verticillata*) are the most promising submerged macrophytes used in wastewater treatment. Information on some typical plant species a discussion of advantages and disadvantages for their use in a constructed wetland are provided in the following text.

### **4. Microorganisms:**

A fundamental characteristic of wetlands is that their functions are largely regulated by microorganisms and their metabolism. A diverse Microorganisms community including

a variety of bacteria, fungi, algae and protozoa is present in both the aerobic and anaerobic zones of wetlands. Moreover, most wetland species have a symbiotic relationship of their roots with specialized fungi, known as mycorrhizas ('fungus roots'). The microbial biomass is a major sink for organic carbon and many nutrients.

Microbial activity:

- 1) Transforms a great number of organic and inorganic substances into innocuous or insoluble substances
- 2) Alters the reduction/oxidation (redox) conditions of the substrate and thus affects the processing capacity of the wetland
- 3) Is involved in the recycling of nutrients.

### **Removal Mechanisms for pollutants and efficiency in Constructed Wetlands:**

A variety of complex biological, physical, chemical and ecological mechanisms improve the water quality in constructed wetlands. These mechanisms are based on the interaction between the wastewater, microorganisms, plants, and filter material.

#### **1. Total suspended solids removal:**

Constructed wetlands are capable of achieving a high efficiency of Suspended solids removal from the water column. The removal mechanism for total suspended solids consists of sedimentation, filtration and absorption. Physical processes play an important role in contaminant reduction, especially for removal of suspended solids. Gravitational settling is responsible for most of the removal of suspended solids. Gravity promotes settling by acting upon the relative density differences between suspended particles and water. Efficiency of TSS removal is proportional to the particle settling velocity and length of the wetland. Wetlands promote sedimentation by decreased water velocity and the filtering effect of plant stems and leaves. While settling and sedimentation are often used interchangeably.

Non-settling/colloidal solids are removed by bacterial decomposition, adsorption to the wetland media and plant root system. Solids may also stick to media surface due to adhesive forces. The extensive root system adds surface area to the wetland media, which reduces water velocity and reinforces settling and filtration in the root network.

However, plant effects are usually observed after three years of establishment in many of the wetlands. In order for adequate filtration to occur, the hydraulic conductivity of the bed must be large enough to allow the wastewater to contact the media. Removal percentages for suspended solids in Surface Free constructed wetlands typically range from 40% to 94%.

The removal percentages seldom drop below 70% regardless of the hydraulic or solids loading rate. Gerard *et al*, (2002) investigation constructed wetland planted with *T. latifolia*, *Ph. australis* and *Scirpus maritimus*. They found that the removal of total suspended solids (TSS) all year around with an average of 95.6%.

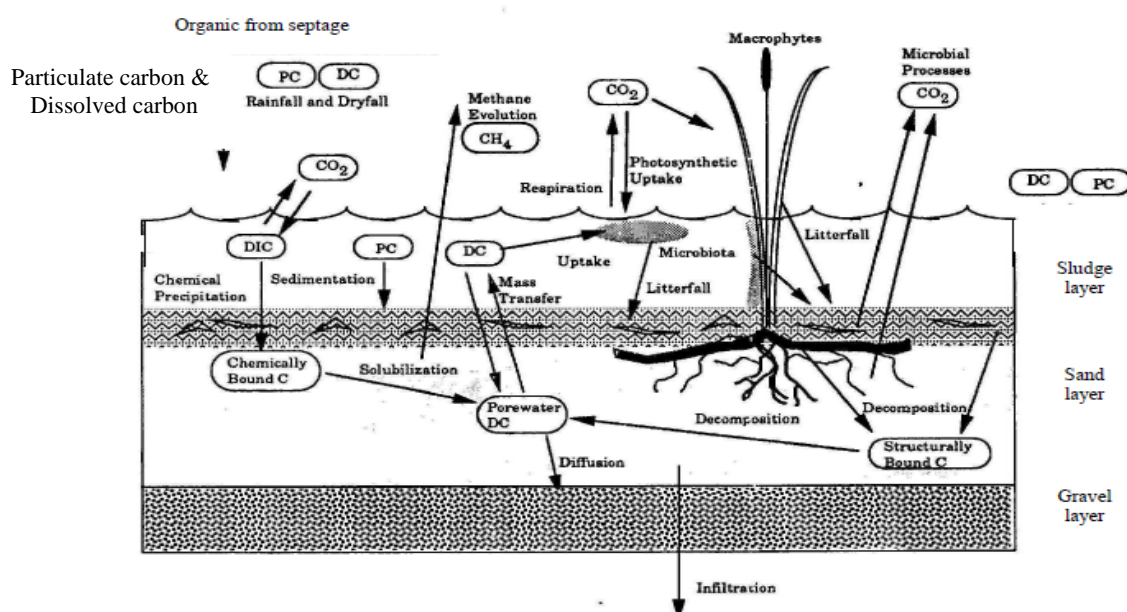
In many systems, to prevent clogging, the majority of settleable solids are removed in a mechanical pretreatment unit (e.g. sedimentation tanks) before the wastewater is discharged to the actual wetland system.

## 2. Organic Carbon (BOD) removal:

The main routes for organic carbon removal include volatilization, photochemical oxidation, sedimentation, sorption, and biodegradation (see Figure 5). The efficiency and rate of organic carbon degradation by microorganisms is highly variable and depends on the organic compound present in the influent. Volatilization may also be a significant removal mechanism in the microbial breakdown products of organics.

Treatment efficiency of the constructed wetlands for the removal of organics (BOD<sub>5</sub>) is generally high. In wetland systems, settleable organics are rapidly removed under quiescent conditions by deposition and filtration.

Coarse media beds act primarily as filters with most BOD being removed in association with the filtration and settling of suspended solids. With the availability of oxygen in the rhizosphere being questioned, aerobic activity may be limited to the very top portions of the wetland bed. This leaves the anaerobic microorganisms to perform the remaining treatment. Although the specific processes for BOD removal are not known, the treatment efficiencies have been quantified. A survey of 43 reed bed systems in the United Kingdom revealed an average BOD removal of 71.3 %. Of the 43 systems surveyed, 14 had effluent BOD concentrations in excess of 25 mg/L. An evaluation of ten systems utilizing Surface Free constructed wetlands by Conley *et al*, (1991) showed BOD removal rates ranged from 64% to 96%.



**Figure (5): Organic compound removal mechanisms in constructed wetlands**

Depending on the wetland design, the oxygen required for aerobic degradation can be supplied by diffusion, convection and oxygen leakage from the macrophyte roots into the rhizosphere. Thus, treatment efficiency of the constructed wetlands for the removal of organics is generally highly dependent on the oxygen concentration in the bed; the wetland design; treatment conditions; the characteristics of the fill medium.

BOD removal by plants. It has been suggested that Lemnaceae can take up simple amino acids and other organic compounds from the water, but it was concluded from

laboratory studies with *Lemna ibba* that heterotrophic uptake of small organic compounds is not important. Nevertheless, they found that COD removal was significantly faster in the presence of duckweed than in uncovered controls. Few comparative studies with respect to BOD removal have been reported in literature for wastewater treatment ponds with and without duckweed. Constructed wetland planted with *T. latifolia*, *Ph. australis* and *S. maritimus*. They found that the removal of BOD<sub>5</sub> reach more than 90% at the outlet of the plant with relatively weak variability. The use Water hyacinth system for the treatment of wastewaters from a tool factory in Santo Tomé, Argentina. The 2,000 m<sup>2</sup> system was quite effective in removing BOD<sub>5</sub> (inflow 195 mg L<sup>-1</sup>, outflow 38 mg L<sup>-1</sup>),

### 3. Nitrogen removal:

Major treatment mechanisms for nitrogen removal in the constructed wetlands consist of Nitrogen plant uptake, nitrification/denitrification, NH<sub>3</sub> volatilization, filtration/sedimentation of particulate N and N adsorption onto substrata. Nitrogen removal mechanisms also involve several interactions and reactions in the constructed wetlands as shown in Fig. 6. Nitrification/denitrification was the most important process for nitrogen removal. This meant that the limiting step was the nitrification process, which requires oxygen. Plants have a finite ability to flux oxygen to the roots, an ability that is further reduced in cold weather. There is evidence that dissolved organic carbon, as shown by a high BOD, is required to drive the denitrification process and some of this is provided by the plants.

According to U.S. EPA nearly half of municipal wastewater nitrogen received at a treatment system is organic nitrogen. The remaining portion is converted to ammonium in the sewer (USEPA, 1999). Ammonification is the biological transformation of organic nitrogen to ammonium during degradation of organic matter. Plants can absorb ammonium or it can be held in sediments, remain in soluble form in water, be volatilized as ammonia, volatilization of ammonia can result in nitrogen removal rates as high as 2.2 g N m<sup>-2</sup> d<sup>-1</sup>, and under oxygenated (aerobic) conditions it can be nitrified. Nitrification, which occurs in the presence of oxygen and microbes in water or on biofilms, may transform the ammonium to nitrite and then to nitrate nitrogen. Nitrate may remain in the water or in sediment pore water, be absorbed by plants or microbes, or be denitrified. Denitrification occurs when nitrate is reduced by microorganisms in the presence of carbon under anaerobic or low oxygen conditions and is converted to nitrogen gas and nitrous oxide gas, when nitrate is used as an electron acceptor for anaerobic respiration to generation energy. This process occurs mostly in anaerobic sediments. The estimation of denitrification rates varies widely in the literature between 0.003 and 1.02 g N m<sup>-2</sup> d<sup>-1</sup>.

Two other nitrogen processes may occur in wetlands. Nitrogen fixation occurs when nitrogen gas is converted to organic nitrogen by certain organisms. This source of nitrogen is not important in wastewater wetlands. Plant assimilation of nitrogen plays a role in wetlands in that plants use inorganic forms of nitrogen. Nitrogen uptake occurs during the growing season by plants, microbes, and algae. The concern is that plant senescence results in the re-release of nitrogen back to the water in the fall and early spring.

Aquatic macrophytes have been widely used to remove nitrogen from both wetlands and wastewater. For example, some used water hyacinth (*Eichhornia crassipes*) for nitrogen uptake from a nutrient solution. The removal of nitrogen using the settling pond of a secondary sewage treatment plant employing water hyacinth.

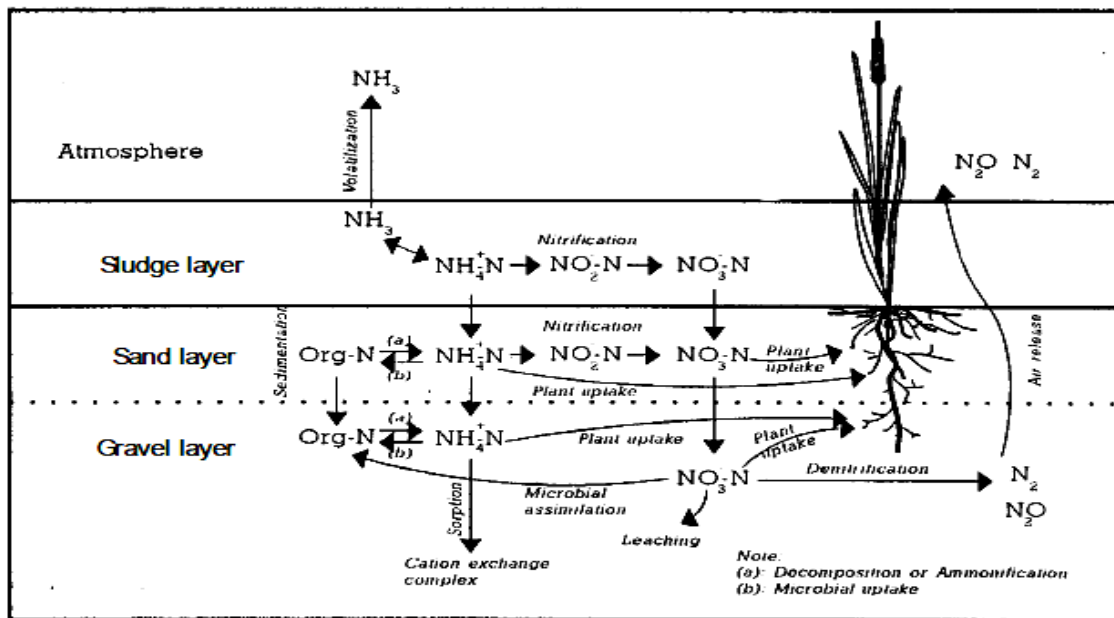
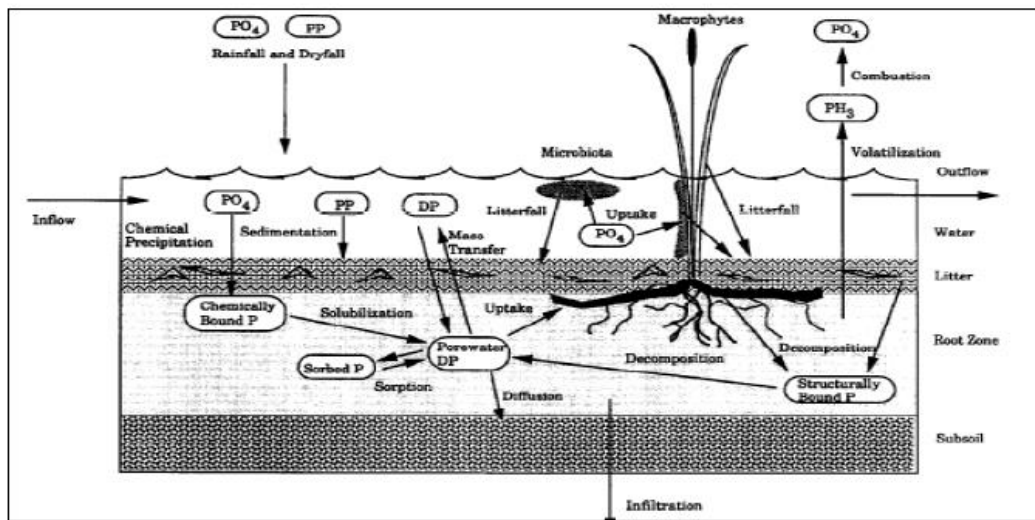


Figure (6): Nitrogen removal mechanisms in constructed wetlands.

#### 4. Phosphorus removal:

Most construction wetlands can provide significant P removal from water and wastewater through a combination of physical, chemical and biological processes. These processes include adsorption, complexation, sedimentation, precipitation and plant absorption as shown in figure 7. Phosphorus in wetlands occurs as phosphate in organic and inorganic compounds. Free orthophosphate is the predominant inorganic form of P in surface waters. This form of P readily accumulates in wetland vegetation and media, as a result of biological uptake and chemical bonding. Formation of iron and aluminum phosphate minerals (low-pH wetlands) and calcium phosphate minerals.

Organic phosphorus forms can be generally grouped into 1) easily decomposable P (nucleic acids, phospholipids or sugar phosphates) and 2) slowly decomposable organic P (inositol phosphates or phytin). Organic forms of phosphorus are generally not biologically or chemically reactive in wetlands. Particulate organic P may be removed by settling from the water column. Both dissolved and particulate organic P may be biologically broken down to inorganic P (mineralization), and subsequently removed through biological and chemical processes.



**Figure 2-8. Phosphorus Storage and Transfers in the Wetland Environment**

$\text{PO}_4$  = orthophosphate, PP = particulate phosphorus, DP = dissolved phosphorous, and  $\text{PH}_3$  = phosphine. PP may consist of all forms shown in the root.

### Figure (7): Phosphorus removal mechanisms in constructed wetlands.

Most of the phosphorus is taken up by plant roots, absorption through leaves and shoots is restricted to submerged species but this amount is usually very low. Phosphorus uptake by macrophytes is usually highest during the beginning of the growing season (in most regions during the early spring), before maximum growth rate is attained.

Biomass increases, however, should not be counted as part of the long-term sustainable phosphorus removal capacity of wetlands. Microbial uptake is very fast, but the magnitude (amount stored) is very low. The uptake by microbiota (bacteria, fungi, algae, microinvertebrates, etc.) is rapid because these organisms grow and multiply at high rates. It seems that the amount of microbial storage depends also on trophic status of the wetland. In less enriched sites the microbial uptake may store more phosphorus as compared to more eutrophic sites.

The concentration of phosphorus in the plant tissue varies among species and sites and also it varies during the season. The phosphorus standing stock for emergent species in the range of  $1.4$  to  $37.5 \text{ g P m}^{-2}$  with more than 50% of this amount stored belowground. Aboveground phosphorus standing stock values were reported in the range of  $0.1$ – $6.8 \text{ g P m}^{-2}$  (Johnston, 1991),  $0.1$ – $11 \text{ g P m}^{-2}$  (Vymazal, 1995)  $0.01$ – $19 \text{ g P m}^{-2}$  (Vymazal *et al.*, 1999) or  $3$ – $15 \text{ g P m}^{-2}$  (Brix and Schierup, 1989). Phosphorus standing stock may amount up to  $45 \text{ g P m}^{-2}$  for **water hyacinth** (*E. crassipes*). Due to the high productivity of this plant, the annual amount of phosphorus taken up by water hyacinth could be as high as  $126 \text{ g P m}^{-2} \text{ yr}^{-1}$  (Vymazal, 1995). Devai and Delaune (1995) measured  $\text{PH}_3$  emissions from a constructed wetland (1.0 hectares, phragmites and bulrushes) in Hungary and estimated that  $1.7 \text{ g m}^{-2} \text{ year}^{-1}$  of phosphorous was being lost through this route. To date, all North American wetland phosphorus mass balance studies have ignored this possibility.

## 5. Metals removal:

Removal of metals in wetlands may occur through a number of processes, including Sedimentation, filtration, plant uptake, adsorption (binding to sand particles and root), precipitation (formation of solid compounds) Cation exchange, and microbial-mediated reaction, especially oxidation.

Plants have the ability to remove trace metals from the water through biological uptake and surface adsorption (ITRC, 2003 and Collins *et al.*, 2005). In the biota, biological conversion occurs through assimilation and metabolism of microorganisms living on and around the macrophyte and plant uptake and metabolism. In permanently anoxic water conditions in wetlands, decomposition of organic matter is by reduction and organic matter accumulates on the sediment surface. The resulting organic sediment surface is responsible for scavenging heavy metals from influent AMD.

Metal uptake may be accelerated by roots that release carriers or solubilizing agents to the rhizosphere, because many of these substances act as metal-specific chelators or ligands. Emergent macrophytes play very important role in heavy metal recycling in wetlands. While sediments of wetlands form primary sinks for heavy metals, macrophytes may absorb heavy metals through roots and also shoots.

It is well documented that several metals (e.g., Cu, U, and Ni) have a high affinity to bind to organic matter. The interactions are mediated by the carboxyl and phenolic hydroxyl groups from organic matter, e.g., humic acids with the formation of stable complexes.

## 6. Fats, Oils and Greases:

Biological treatment via an immobilization system is best expressed by the biofilm concept considered as the most efficient biological tool for oil and grease removal. Biological treatment via an immobilization system is best expressed by the biofilm concept considered as the Bacterial biofilm attached to solid surfaces has recently been used to treat polluted water effluents. Biofilm systems have proved to play an important role in the removal of contaminated industrial wastewater. However, across time and space, biofilm communities after formation, are more stable, because the biofilm members are immobilized onto the matrix-particles, and this stability is primarily due to the complexity of biofilm communities. Through the metabolic activities of the biofilm system, degradable organic matter present in the surrounding water is gradually broken down.

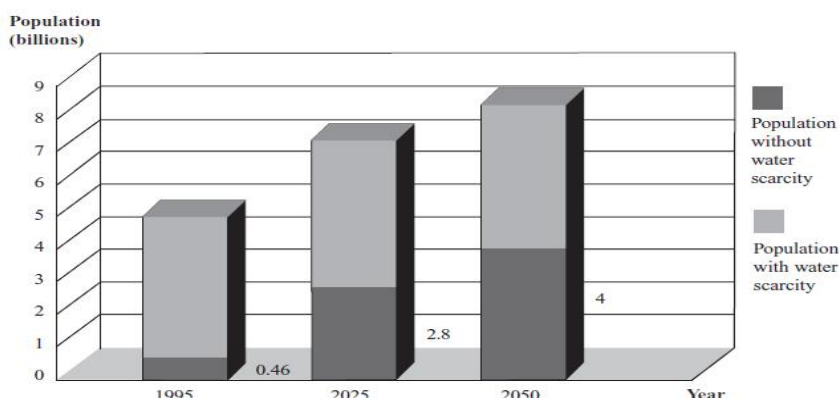
## Reuse of wastewater for irrigation:

Agriculture is the largest consumer of freshwater resources currently accounting for about 70 percent of global water diversions (but even up to 80-95 percent sometimes in developing countries). With increasing demand from municipal and industrial sectors, competition for water will increase and it is expected that water now used for agriculture will be diverted to the urban and industrial sectors. A number of examples from Asia, North Africa, and Latin America, are witness to this fact. One observed response to this squeeze on agricultural water supply is to promote greater use of and untreated treated urban wastewater for irrigation.

Wastewater is being increasingly used for the irrigation of agricultural crops in both developing and industrialized countries. The principal forces driving the increasing use of wastewater are: 1) increasing water stress, and degradation of freshwater resources resulting from improper disposal of wastewater. 2) population increasing and related increased demand for food and fiber. 3) a growing recognition of the resource value of wastewater and nutrients it contains, and 4) the millennium Development Goals, especially the goals for ensuring environmental sustainability and eliminating poverty and hunger.

During the last decade, there has been growing concern that the world is moving towards a water crisis. There is increasing water scarcity in dry climate regions, for example, in Africa and South Asia, and there are major political implications of water scarcity in some regions e.g. Middle East. Water quantity and quality issues are both of concern. Recycling of wastewater is one of the main options when looking for new sources of water in water scarce regions

Within the next 50 years, it is estimated that more than 40% of the world's population will live in countries facing water stress or water scarcity (figure 8) most population growth is expected to occur in urban and periurban areas in developing countries.



**Figure (8): Population living in water-scarce and water-stressed countries, 1995-2050**

In some countries most of the sewage sludge and sewage effluent generated in the cities is applied to lands as a form of sewage disposal system. The waste can either be utilized for its value as a fertilizer and soil amendment or as a landfill. Sewage sludge applications to soil, improve the nutrient status and cation exchange capacity of the soil. Although composition of the wastewater depends upon the source of contamination, nitrogen and phosphorus is the main integrate which can be good source of fertilizer in agriculture. Use of wastewater in agriculture is good as an irrigation and fertilization.

Treated domestic wastewater has been used in agricultural products since many years in many part of the world with varying degree of environmental safeguards and protection of public health. Early developments in the field of water reuse are synonymous with the historical practice of land application for the disposal of wastewater. With the advent of sewerage systems in the ninetieth century, domestic wastewater was used at "sewage farms" and by 1900 there were numerous sewage

farms in Europe and in the United States. Many farms were established in the United Kingdom as early as 1865, the United States in 1871, France in 1872, Germany in 1876, India in 1877, Australia in 1893 and Mexico in 1904 (WHO, 1989) which were used primarily for waste disposal, the incidental reuse of water was made for crop production and to prevent river pollution. In Athens, Greece, 7 x 10<sup>5</sup> m<sup>3</sup>/day of primary effluents were reused and crop and landscape irrigation was the major uses. In China, at least 1.33 x 10<sup>6</sup> hectares of agricultural land are irrigated with untreated or partially treated wastewater from cities. In Mexico City, Mexico, a metropolis of 15 million inhabitants, more than 70,000 hectares of cropland are irrigated with reclaimed wastewater. Sewage effluents have been used for crop irrigation at a municipality operated farm for over 60 years in Cairo, Egypt. Wastewater reclamation and reuse in Israel, Saudi Arabia, Iran, South Africa, The Netherlands, and Germany. Judging from the origins of these activities, land application is practiced on every continent.

The foundation of water reuse is built upon three principles: (1) ) the treated effluent is used as a water resource for beneficial purposes, (2) ) the effluent is kept out of streams, lakes, and beaches; thus, reducing pollution of surface water and groundwater or protecting public health, and (3) gaining public acceptance.

In a developing urban society, the wastewater generation is usually approximately 30-70 m<sup>3</sup> per people per year. In a city of one million people, the wastewater generated would be sufficient to irrigate approximately 1500-3500 hectare. In the United States, it was reported that in 1995 the reuse of recycled wastewater approached 3.85 million cubic meters of which 2.72 million cubic meters were reused in irrigating agricultural crops. This amount of reclaimed water reuse for 1995 in the United States represented an increase of 36% from 1990.

The reuse of wastewater has been successful for irrigation of a wide array of crops, and increases in crop yields from 10-30% have been reported. In addition, the reuse of treated wastewater for irrigation and industrial purposes can be used as strategy to release freshwater for domestic use, and to improve the quality of river waters used for abstraction of drinking water (by reducing disposal of effluent into rivers). Wastewater is used extensively for irrigation in certain countries e.g. 67% of total effluent of Israel, 25% in India and 24% in South Africa is reused for irrigation through direct planning, though unplanned reuse is considerably greater.

At least 10% of the world,s population is thought to consume foods produced by irrigation with wastewater. The water and nutrient value of wastewater are important resources for farmers in both industrialized and developing countries.

Worldwide, it is estimated that 18% of cropland is irrigated, producing 40% of all food. A significant portion of irrigation water is wastewater. For example, at least 20 million hectares in 50 countries are irrigated with raw or partially treated wastewater. One tenth or more of the world's population consumes foods produced by irrigation with wastewater. Wastewater and excreta are also used in urban agriculture, which often supplies a large proportion of the fresh vegetables sold in many cities, particularly in less developed countries. For example in Dakar, Senegal, more than 60% of the vegetables consumed in the city are grown in urban areas using a mixture of groundwater and untreated wastewater. In most developing countries, where

wastewater is used for irrigation, it is commonly used without adequate treatment. For example, only around 10% of all wastewater in developing countries receives treatment.

In Kurdistan region generally grain crop is depending on rainfall. Meanwhile, vegetables are depending on irrigation. Scarcity of rainfall after June leads the farmers to irrigate their crops by well water. Many of the farmers have no well water and because of the expensive costs of drilled wells they depend on other water resources, mainly the wastewater. Indications for self-purification in Kurdistan region sewer system have not been documented because of: 1) short distance; 2) the system is closed (little aeration); 3) no control of wastewater use, therefore the use of wastewater is in a very risky distance; and 4) the self-purification takes place after reuse by crops. Most of these studies suggested treating wastewater before reusing it for irrigation purposes or discharge to stream and River. The quantity of sewage discharge differs from time to other, as a mean, it may reach ( $21760 \text{ m}^3.\text{d}^{-1}$ ) during the dry seasons and ( $108000 \text{ m}^3.\text{d}^{-1}$ ) during rainfall seasons. Only at Arab-Kand area more than 350 farmer families irrigate about 600-700 donums for agriculture (vegetable products) by untreated wastewater.

### 1. Advantages and disadvantages wastewater reuse for irrigation:

When considering wastewater reuse for irrigation an evaluation of the advantages, disadvantages and possible risks should be made.

The following table summarizes the advantages, disadvantages and possible risks regarding water conservation, different substances in the water and influences regarding the soil.

**Table (2) Advantage, disadvantage and possible Risks of wastewater reuse.**

Advantage	Disadvantage	Risks
<ul style="list-style-type: none"> <li>-Improvement of economic efficiency of investments in wastewater disposal and irrigation.</li> <li>-Conservation of freshwater sources</li> <li>-Recharge of aquifers through infiltration water (natural treatment)</li> </ul>	Wastewater is normally produced continuously throughout the years, whereas wastewater irrigation is mostly limited to the growing season.	Potential harm to groundwater due to heavy metal, nitrate and organic matter.
<ul style="list-style-type: none"> <li>Use of the nutrients of the wastewater (e.g. nitrogen and phosphate)</li> <li>- Reduction of the use of synthetic fertilizer.</li> <li>- Improvement of soil properties ( soil fertility, higher yields)</li> </ul>	Some substances that can be present in wastewater in such concentration that they are toxic for plants or lead to environmental damage.	Potential harm to human health by spreading pathogenic germs.
Reduction of treatment costs: Soil treatment of the pre-treated wastewater via irrigation (no		Potential harm to the soil due to heavy metal accumulation

tertiary treatment necessary, highly dependent on the source of wastewater)		and acidification
Beneficial influence of a small natural water cycle		
Reduction of environmental impacts ( e.g. eutrophication and minimum discharge requirements)		

## 2. Guidelines and standard for irrigation and wastewater reuse:

Several guidelines and manuals have become available for using reclaimed wastewater for crop irrigation. Human health issues related to the introduction of toxic pollutants via wastewater irrigation, however, were not explicitly addressed.

The most important irrigation water quality characteristics and guidelines are listed in (Tables 3 and 4) for Agriculture situations. Salinity aspects are given in Table 1 and nutrients in Table 2. Westcot and Ayers (1985) present guidelines for trace elements. Huck *et al.* (2000) provides an in-depth discussion of the various salinity and nutrient constituents in wastewater and how they impact Agriculture management. Assessing and management of turfgrass sites receiving wastewater high in salinity are discussed in detail by (Carrow and Duncan, 1998) and on-site treatment of irrigation water for specific problems is addressed by Carrow *et al.* (1999).

**Table (3): Guideline for interpretation of Water Quality for Irrigation.**

Parameter	Units	Degree of Restriction of use		
		Slight to Non	Moderate	Severe
Salinity, EC <sub>w</sub>	dS/m or mmhos/cm	<0.7	0.7-3.0	>3.0
Total dissolved Solids, TDS	mg/L	<450	450-2000	>2000
Total suspended solids, TSS	mg/L	<50	50-100	>100
Bicarbonate, (HCO <sub>3</sub> )	mg/L	<90	90-500	>500
Chloride(Cl <sub>2</sub> ), total residual	mg/L	<1.0	1.0-5.0	>5.0
Chloride(Cl <sup>-</sup> ),sensitive crops	mg/L	<140	140-350	>350
Chloride(Cl <sup>-</sup> ),sprinklers	mg/L	<100	100	>100
Boron(B)	mg/L	<0.7	0.7-3.0	>3.0
Hydrogen Sulfide (H <sub>2</sub> S)	mg/L	<0.5	0.5-2.0	>2.0
Iron (Fe), drip irrigation	mg/L	<0.1	0.1-1.5	>1.5
Manganese (Mn), drip irrigation	mg/L	<0.1	0.1-1.5	>1.5
Nitrogen (N), total	mg/L	<5	5-30	>30
Sodium (Na <sup>+</sup> ), sensitive crops	mg/L	<100	100	>100
Sodium (Na <sup>+</sup> ), sprinklers	mg/L	<70	70	70
SAR (Sodium Absorption Ratio)	mg/L	<3.0.0	3.0-9.0	>9.0
RSC (Residual	mg/L	<0	0-2.5	>2.5

Hardness	Grain/gallon	<200	200-300	>300
Oil and grease	mg/L	<5.0	5.0	>5.0

Source: (Ayers and Westcott, 1985).

**Table (4): Guideline for nutrients and heavy metals contained in irrigation water**

Nutrient or Element	Nutrient Content in Water in mg/L ( ppm)			
	Low	Normal	High	Very High
Nitrogen(N), total	<1.1	1.1-11.3	11.3-22.6	>22.6
Nitrate (NO <sub>3</sub> <sup>-</sup> )	<5	5.-50	5.-100	>100
Phosphorus (P), total	<0.1	0.1-0.4	0.4-0.8	>0.8
(PO <sub>4</sub> <sup>-</sup> )	<0.30	0.30-1.21	1.21-2.42	>2.42
(P <sub>2</sub> O <sub>5</sub> )	<0.23	0.23-0.92	0.92-1.83	>1.83
Potassium (K <sup>+</sup> )	<5	5-20	20-30	>30
(K <sub>2</sub> O)	<6	6-24	24-36	>36
(Ca <sup>+2</sup> )	<20	20-60	60-80	>80
(Mg <sup>+2</sup> )	<10	10-25	25-35	>35
(S)	<10	10-30	30-60	>60
(SO <sub>4</sub> <sup>-2</sup> )	<30	30-90	90-180	>180
Aluminium (Al)	-	-	5.0	50
Cadmium (Cd)			0.01	0.05
Chromium (Cr)			0.1	1.0
Copper (Cu)			0.2	5.0
Cobalt (Co)			0.05	5.0
Fluoride (F)			1.0	15.0
Iron (Fe)			5.0	20.0
Lead (Pb)			5.0	10.0
Lithium (Li)			2.5	2.5
Manganese (Mn)			0.2	10.0
Molybdenum (Mo)			0.01	0.05
Nickel (Ni)			0.2	2.0
Selenium (Se)			0.02	0.02
Zinc (Zn)			2.0	10.0

### Water Quality Index:

The water quality index (WQI) has been considered as one of an important criteria for surface of water classification. Water quality indices (WQIs) are useful tools to derive spatio-temporal patterns from a large amount of environmental monitoring data as well as to communicate related information to non scientific community including decision-makers.

The index is a numeric expression used to transform large quantities of water characterization data into a single number, which represents the water quality level. which provides a simple and understandable tool for managers and decision makers on the quality and possible uses of a given water body. Water quality indices appeared in the literature as early as 1965. The general WQI was developed by. Advantages of WQIs include their abilities to reduce a large number of water quality data to a single number, to integrate measurement units of various water quality variables into a single metric, and to provide an easy and simple way to understand spatio-temporal states of water quality for public.

The WQI approach has many variations in the literature and comparative evaluations have been undertaken. Some of the water quality index approaches that have been frequently employed in public domain for the purpose of water quality assessment are: US National Sanitation Foundation Water Quality Index, NSFQI, Canadian Water Quality index, British Columbia Water Quality Index, BCWQI. Water quality index of river Gango in India Their calculated WQI based on five water variables (DO, BOD<sub>5</sub>, temperature, pH and faecal coliform).

Whereas, it has evaluated Erbil wastewater channel and downstream of Greater Zab river in Erbil according to (turbidity, EC, DO, BOD<sub>5</sub>, COD, TDP, NO<sub>3</sub>, NO<sub>2</sub>, NH<sub>4</sub>, temperature and pH). It was found that the value of WQI increasing throughout the Erbil wastewater channel from 47 to 53.7 then to 55.4%. On the other hand, the water quality improved considerably downstream of Greater Zab river were 71.3%. Five parameters were analyzed, namely, nitrate, pH, total dissolved solids, turbidity, and temperature. Water quality index of water treatment plant, in Delhi, India. They found that the WQI was around 73–80 were classified as “good” quality.

***Dr. Dilshad G.A. Ganjo***