

Scope of BOD, Nitrogen and Phosphorous Removal through Plant-Soil Interaction in the Wetland

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Abstract—Constructed and natural wetlands are being used extensively to treat different types of wastewater including the domestic one. Considerable removal efficiency has been achieved for a variety of pollutants like BOD, nitrogen and phosphorous in the wetlands. Wetland treatment appears to be the best choice for treatment or pre-treatment of wastewater because of the low maintenance cost and simplicity of operation. Wetlands are the natural exporters of organic carbon on account of decomposition of organic matter. The emergent plants like reeds, bulrushes and cattails are commonly used in constructed wetland for the treatment process providing surface for bacterial growth, filtration of solids, nutrient uptake and oxygenation to promote nitrification as well as denitrification. The present paper explored different scopes of organic matter (BOD), nitrogen and phosphorous removal from wastewater through wetlands. Emphasis is given to look into the soil chemistry for tracing the behavior of carbon, nitrogen and phosphorus in the wetland. Due consideration is also made to see the viability for upgrading the BOD, nitrogen and phosphorus removal efficiency through different classical modifications of wetland.

Keywords—BOD removal, modification, nitrogen removal, phosphorous removal, wetland.

I. INTRODUCTION

WETLANDS are water logged landscape features and often developed at the margins of river and lakes. In the latter case the lakes may, eventually through the deposition of silt and peat, become converted wholly to wetland. The large wetlands, however, generally form on very flat terrain in which damp mineral soils are invaded in their wettest parts by peat forming vegetation. Peat impedes and damps up the natural drainage and brings about an expansion of the waterlogged area, eventually swamping large areas of upland forest. Very large peat lands often develop intricate and beautiful landscape patterns, which represent perhaps the most delicate mutual interaction between hydrology and vegetation on the surface of the earth. The fresh water wetland can play a significant role in municipal wastewater treatment, in turn urban water quality management. The wide use of such wetlands needs sustainable utilization to maintain the natural resources of the ecosystem. Constructed wetland (CW) is regarded as a simple cost-effective ecological technology for wastewater treatment in small communities or decentralized villages [12].

Wetlands are being used for at least 90 years for the disposal of wastewater [27]. Study on the constructed

wetlands for wastewater treatment was initiated in the 1950's at the Max Planck Institute in Germany [20]. Research initiatives in the United States were developed in the 1970's and 1980's. Some systems were installed in the 1970's with an increasing number in the 1980's. A major increase in the number of those systems was observed as the application expanded not only to treat municipal wastewater, but also storm water, industrial and mining wastes, and agricultural wastes.

Constructed and natural wetlands are often used as a low-tech treatment system for domestic wastewater effluent, single-residence septic tank effluent and large municipal wastewater [5]. Similarly, wetlands may be used effectively for treatment of animal and aquaculture wastes. A variety of industrial wastes from pulp and paper, food processing, slaughtering, chemical manufacturing, petroleum refining and landfill leachates are amenable to wetland treatment. Pretreatment, such as primary sedimentation or aeration, is often required for industrial effluents. The organic material in the sewage may decompose within the wetland under aerobic or anaerobic condition. The aerobic process is the most efficient method for reducing the organic content of dilute liquid wastes, whereas anaerobic process is effective for settled organic solids.

Nitrogen is a major component of municipal wastewater, storm-water runoff from urban and agricultural lands, and wastewater from various types of industrial processes. Municipal and industrial wastewater may contain significant amount of both inorganic and organic forms of nitrogen. Inorganic nitrogen, which includes nitrate, nitrite and ammonium, may also be present at high concentration in agricultural and urban runoff. Nitrate and nitrite are usually found in the well-aerated waters, with nitrate being the predominant form, while ammonium is the more persistent form of inorganic nitrogen in anaerobic wetland soils. Elevated nitrogen concentration causes eutrophication in surface water. Also, the unionized ammonia found in certain types of wastewater effluent, is potentially toxic to many aquatic and marine organisms.

Wetland is considered to be low cost treatment tool, which is well suited for nitrogen removal, although the natural background level of total nitrogen in wetland outflows is typically greater than 1 mg/L. As there is also organic carbon in wetlands, it is common for organic nitrogen compounds to be utilized as a consequence of decomposition of organic matter. In the wetland inflow, removal of nitrogen takes place substantially through settling of particulate matter containing nitrogen. Since, nitrogen is an essential plant nutrient it can

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also be removed through plant uptake of ammonium or nitrate and stored as organic form in wetland vegetation. As plants die and decompose, a large portion of nitrogen may later be released and recycled. Ammonium may be chemically bound in the soil on a short-term basis, while organic nitrogen from dead plant material can accumulate in the soil as peat by a long-term storage mechanism. In general, nitrogen removal efficiency is extremely high in wetlands. The biological process of denitrification, i.e., conversion of nitrate to nitrogen gas, provides a mean for complete removal of inorganic nitrogen from wetlands, as opposed to storage within the vegetation or soil. Denitrification usually accounts for the bulk of the inorganic nitrogen removal in wetlands [5].

Enhanced eutrophication of surface water leads to problems with its use for fisheries, recreation, industry due to the increased growth of undesirable algae and aquatic weeds. Severe oxygen shortage in the water body can take place due to their senescence and decomposition. Also many drinking water supplies throughout the world experience periodic massive surface blooms of *cyanobacteria*. These algal blooms contribute to a wide range of water-related problems including summer fish kills, unpalatability of drinking water, and formation of trihalomethane during water chlorination. It is also established that consumption of cyanobacterial blooms can kill livestock and may pose a serious health hazard to humans. Most attention has focused on phosphorus, although nitrogen is also associated with accelerated eutrophication in wetland. This is because of difficulty in controlling the exchange of nitrogen and carbon between the atmosphere and a water body, and fixation of atmospheric nitrogen by some blue-green algae. Thus phosphorus is often the limiting element and its control is very important in reducing the accelerated eutrophication.

Phosphorus is one of the most important elements that occur in wastewater primarily as phosphate, typically called orthophosphate. The removal of phosphate in constructed wetlands can be accomplished by physical-chemical separation as well as biological transformation. Phosphorus sorption can be promoted by both of the slag and iron ore in the anaerobic condition due to continuous formation of amorphous ferrous hydroxides. Macrophyte based plants in wetland act as a storage and deposit significant phosphorus in their root section. Formation of iron and aluminum phosphate minerals (low-pH wetlands) and calcium phosphate minerals (high-pH wetlands) is observed to be the major pathway for P removal in some wetlands. Organic forms of P are generally not biologically or chemically reactive in wetlands. Looking into this background, the present paper explored on various scopes of removal of organic matter (BOD), nitrogen and phosphorous by different wetland systems.

II. TYPES OF WETLAND

The wetland can be classified as either surface-flow (SW) or sub-surface flow (SSW) systems. The surface-flow and sub-surface flow systems can also be designated as "Free water surface flow (FWS)" and "Vegetated surface bed (VSB)" wetland respectively. The schematic diagram of surface-flow

and sub-surface flow wetland systems is shown in Fig. 1. The FWS design typically incorporates a shallow layer of surface water, flowing over mineral (sandy) or organic (peat) soils. Vegetation often consists of marsh plants, such as cattails and reeds, but may also include floating and submerged aquatic vegetation, as well as wetland shrubs and trees. A typical submerged aquatic plant species of wetland is shown in Fig. 2. In addition, the matured typical growth of Cattails and Reeds during summer period is shown in Fig. 3, whereas the typical growth of Reeds during spring period is shown in Fig. 4 [25]. In a SSF wetland, the basin is filled with gravel or some other coarse substrate, and the water level is maintained below the ground. Water flows horizontally, or sometimes vertically, through the gravel and the root mat of the wetland vegetation. Each type of wetland has characteristic advantages and limitations for treatment of various wastes.

Vegetation plays an integral role in wetland treatment by transferring oxygen through their roots and rhizome systems to the bottom of basins. It also provides a medium beneath the water surface for the attachment of microorganisms that perform most of the biological treatment. Emergent plants, those rooted in the soil or granular support medium are used in wetland systems. Harvesting of wetland vegetation is generally not required, especially for SW system. However, dry gases in SW systems are burned off periodically to maintain free-flow conditions and to prevent channeling of the flow.

III. FUNCTION OF WETLAND IN TREATMENT OF SEWAGE

The wetlands are essentially subjected to the following processes to carry out the treatment of sewage.

A. Aerobic Process

In the aerobic metabolism of organic matter, much of the carbon serves as a source of energy for the organism and is respired as carbon dioxide. The organisms involved are mostly bacteria, but also include fungi and protozoa. They use the remainder of the carbon, together with phosphorus and nitrogen to form new cells. In typical domestic wastewater, the weight of cells produced is roughly equal to 40% and 60% respectively, of the weight of chemical oxygen demand (COD) and BOD₅ removed. The oxygen requirement for stabilization of organic material is fulfilled by photosynthetic mean, oxygen transfer across the air water interface, or obtained from oxygen-containing compounds such as nitrates, phosphates, and sulfates.

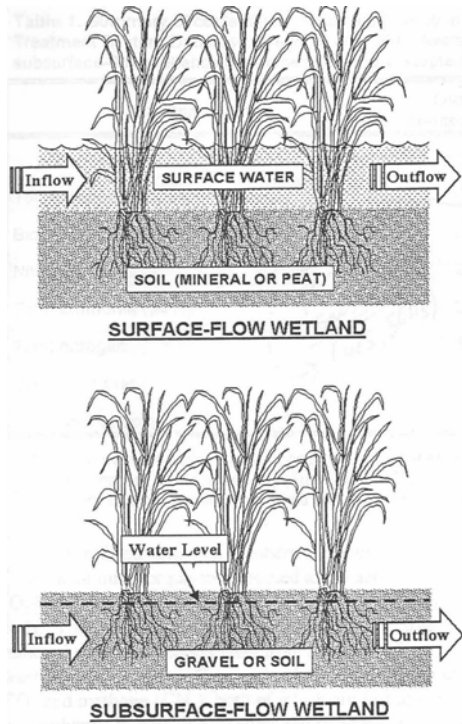


Fig. 1 Schematic Diagram of Surface-flow and Sub-surface Flow Wetland [5]

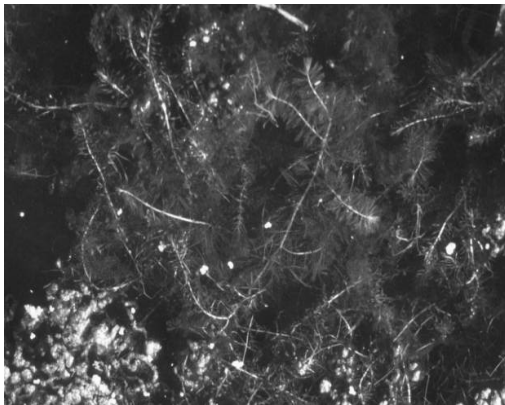


Fig. 2 Submerged Aquatic Plants [25]

B. Anaerobic Process

Putrefactive breakdown of organic material takes place during anaerobic fermentation, which is a two-step process. Firstly, a special group of acid producing bacteria known as facultative heterotrophs (acidogens) degrades organic matter into fatty acids, alcohols etc. Then a group of methane bacteria converts the intermediate products to methane (CH_4), ammonia (NH_3), carbon dioxide and hydrogen (H_2). Like the aerobic process, the anaerobic process also converts carbon, nitrogen, phosphorus, and other nutrients to cell protoplasm. In anaerobic decomposition the end products are quite complicated, the reactions are slower and the products may be odorous. There is always some anaerobic activity in the bottom mud and sediments, even the ponds are designed to operate aerobically. In deep ponds, too, there is likely to be a layer of liquid near the bottom that will support anaerobic

organisms.

The settleable solids eventually undergo anaerobic decomposition; the residual products remaining after anaerobic decomposition diffuse into the upper liquid of a wetland, so increasing the oxygen demand. Thus an organic load in terms of Biochemical Oxygen Demand (BOD) in the upper aerobic section of the wetland is developed. The total oxygen requirement for the aerobic zone is the amount needed to stabilize the dissolved and suspended material together with the fraction of the settleable organic material that is subjected to anaerobic decomposition.



Fig. 3 Summer Reed and Cattail [25]



Fig. 4 Reed in spring [25]

IV. GENERAL FUNCTIONS OF WETLAND

The cleaning potential of the wetland system is envisaged in following activities.

A. Organic Carbon (BOD) Removal

Organic matter comprises of approximately 45 to 50% carbon (C), which can be utilized by a wide variety of microorganisms as a source of energy. These microorganisms consume oxygen (O_2) to break down organic C to carbon dioxide (CO_2) and to provide energy for growth. The discharge of excessive amount of organic C to surface waters results in a significant depletion of dissolved oxygen, and subsequent mortality of fish and other oxygen-dependent aquatic organisms. Wetlands contain a large number of organic C-utilizing microorganisms adapted to the aerobic (oxygen-rich) surface waters and anaerobic (oxygen-depleted) soils. Wetlands are capable of high effective removal of organic compounds from a variety of wastewaters. Organic

carbon in wetlands can be broken down to CO₂ and CH₄ (methane) under anaerobic condition and both are lost to the atmosphere. Wetlands also play an important role in storing and recycling copious amount of organic C, contained in plants and animals, dead plant material, microorganisms and peat. Therefore, wetlands appear to be natural exporters of organic C as a result of decomposition of organic matter into fine particulate matter and dissolved compounds [5].

The readily degradable organic carbon compounds typically found in municipal wastewater is rapidly removed in wetlands. Biological removal of a number of recalcitrant (not readily degradable) organic carbon compounds, including lignin-based compounds and petroleum products, are also observed in wetlands, although the removal rates are substantially low. The parameter for biologically available carbon is biochemical oxygen demand (BOD), which is actually a measure of the rate of oxygen consumption by microorganisms utilizing the available organic carbon in the water or soil.

B. Nitrogen Removal

Nitrogen (N) is a distinguished component of municipal wastewater, storm-water runoff from urban and agricultural lands, and wastewater from various types of industrial processes. Environmental and health problems associated with excessive amount of certain forms of N in the environment have been established already. For example, high concentrations of nitrate in drinking water supplies can cause methemoglobinemia, or "blue baby" syndrome, in infants. Unionized ammonia (NH₃), found in some wastewater effluent is potentially toxic to many aquatic and marine organisms. Moreover, eutrophication of surface water is frequently linked with elevated N concentrations, especially in coastal and estuarine environments.

Nitrogen is available in many forms in the environment, and transformations among different forms may occur rapidly and frequently. Municipal and industrial wastewater may have significant amounts of both organic and inorganic forms of N. Inorganic nitrogen, i.e. nitrate, nitrite and ammonium, may also be present at high concentrations in agricultural and urban runoff. Ammonium is the more persistent form of inorganic N in anaerobic wetland soils. Similar to organic carbon in wetlands, it is common for organic nitrogen compounds to be exported as a consequence of decomposition of naturally occurring organic matter within the wetland.

It is already stated that nitrogen is an essential plant nutrient and a considerable fraction of nitrogen can be released and recycled when plants die and decompose. Ammonium may be chemically bound in the soil on a temporary basis, while organic nitrogen from dead plant material can accumulate in the soil as peat, through a long-term storage mechanism. In general, nitrate removal efficiency is extremely high in wetlands.

C. Phosphorus Removal

Phosphorus (P), like nitrogen, is also an important plant nutrient and therefore addition of P to the environment often contributes to eutrophication of lakes and coastal waters. In

most cases, wetlands do not perform the high level of long-term removal for phosphorous that they provide for nitrogen. This is partially due to the lack of a metabolic pathway for phosphorous removal, in comparison to denitrification for nitrogen removal. However, most wetlands can provide significant phosphorous removal from wastewater through a combination of physical, chemical and biological processes. Orthophosphate is the predominant inorganic form of phosphorous available in surface waters. This form of phosphorous readily accumulates in wetland vegetation and soils, as a result of biological uptake and chemical bonding. Both dissolved and particulate organic phosphorous may be biologically broken down to inorganic phosphorous (mineralization) and subsequently removed through biological and chemical processes.

V. BOD REMOVAL MECHANISM IN WETLAND

The mechanisms of BOD removal in case of a FWS wetland is the bioconversion by aerobic, facultative and anaerobic bacteria on plants and debris surfaces, adsorption, filtration and sedimentation of particulates (to account for insoluble BOD). On the other hand the VSB wetlands remove BOD basically by facultative and anaerobic bacteria on plant and media surface [19]. A number of studies showed that wetlands are effective, after some kind of pretreatment, in removing carbonaceous BOD to achieve effluent discharge quality [27], [8].

Biochemical oxygen demand (BOD) is a quantitative measurement of the amount of oxygen consumed by microorganisms to oxidize of organic matter and it includes nitrogenous and carbonaceous oxidation. The function of wetlands in removing BOD is envisaged only when the incoming BOD is higher than the natural background level. Most of the wetlands have a background BOD, which is induced from the partial decomposition of previously settled influent solids, plant, and additional by-products from anaerobic digestion. The anaerobic digestion contributes BOD load from spring and continues until the materials that have accumulated during winter are consumed. The uptake rate of BOD varies from SF to SSF wetlands. It has been observed that SSF wetlands possess a faster uptake of BOD compared to SF by a factor of five. The rate of movement of organic constituents through wetlands can be determined by several transport mechanisms, which often act simultaneously on the organics and may include the processes like convection, diffusion, dispersion, and zero- or first-order production or decay [2].

VI. NITROGEN REMOVAL MECHANISM IN WETLAND

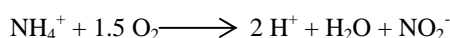
A. General Mechanism

The removal of nitrogen can be performed biologically under anoxic condition by conversion from nitrate to nitrogen gas. Transformation of nitrate-nitrogen to a readily removable form can be accomplished by several genera of bacteria, such as *achromobacter*, *aerobacter*, *alcaligenes*, *brevibacterium*, *flavobacterium*, *lactobacillus*, *micrococcus*, *proteus*,

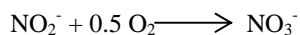
pseudomonas, and *spirillum*. These bacteria are heterotrophs and capable of dissimilatory nitrate reduction, a two-step process. The first step involves conversion of nitrate to nitrite. The subsequent stage is production of nitric oxide, nitrous oxide, and nitrogen gas. The last three compounds are gaseous products, which are released to the atmosphere. In denitrifying environment, dissolved oxygen concentration becomes a critical parameter. The presence of dissolved oxygen can suppress the enzyme system required for denitrification. Alkalinity is produced during the conversion of nitrate to nitrogen gas that causes increase in pH. The pH of the system should lie between 7.0 and 8.0 for different bacterial populations. Temperature also affects the removal rate of nitrate and the microbial growth rate, because the organisms are sensitive to fluctuation in temperature [13].

The chemistry of nitrogen in wastewater is much complicated because it exists in so many oxidation states, which may be changed by the biochemical operations of the microorganisms. The organic form of nitrogen is available in wastewater primarily as protein and urea. In the septic tank after undergoing anaerobic decomposition the nitrogen form changes to ammonia nitrogen (NH_3) by a process known as ammonification. In water surface zone, if dissolved oxygen is present, the ammonium can be converted to nitrite (NO_2^-) and then to nitrate (NO_3^-) in a two-step process called nitrification.

The first step is conversion of the ammonium ion to nitrite by the bacteria genus *nitrosomonas*:



The second step is conversion of nitrite to nitrate by the bacteria genus *nitrobacter*:



The denitrification step requiring a carbon source takes place almost in the absence of oxygen that produces N_2 gas. The production of this gas to the atmosphere indicates a removal of nitrogen from the wastewater [23]. The carbon source may be available from plant litter and natural detritus. The denitrification reaction is observed primarily in the wetland sediments and in the periphyton films on the submerged vegetation. The inorganic nitrogen may be fixed and converted to organic nitrogen, by the microorganism present in the sediment, in the oxidized rhizosphere of the plants, and on the stem surfaces of submerged plants. In the free water surface (FWS) constructed wetlands, if the nitrogen is intended for removal, then suitable plants must be harvested there. Also, it is not wise to take any attempt to accomplish nutrient removal by harvesting and subsequent off-site disposal as it involves considerable time and labor. Thus without considerable area for aerobic and anaerobic zones in the FWS wetland, it cannot be undertaken for any nitrogen removal from wastewater [19]. Literature showed that significant nitrogen removal rates greater than 50% could be achieved when temperatures are favorable for nitrification in the intermediate open water zones.

B. Influence of Soil for Nitrogen Removal

The organic soils showed the highest nitrogen removal rates whereas the sandy soil showed the lowest rate, indicating a stimulating effect of the peat carbon source on denitrifying bacteria. Nitrogen removal is influenced by availability of soil organic matter, because it sustains a larger microbial population and provides electron donors in respiratory processes. It has been demonstrated in several studies that various forms of organic carbon are strong regulators in the denitrification process in soil medium. The pool of organic material in the wetland is practically so large that its reducing capacity exceeds oxidizing capacity of nitrogen inputs. It does not corroborate the results regarding the regulatory capacity of organic carbon on denitrification in soils. One explanation to this anomaly could be that particulate soil organic carbon provides surface structure for bacteria, which does not contribute dissolved carbon. Another explanation is that the regulatory effect of "organic carbon induced oxygen consumption" decreases in wetland soils because the oxygen diffusion in waterlogged soil is slower than in air-filled pores [4].

VII. BEHAVIOR OF PHOSPHORUS IN NATURAL ECOSYSTEM

A. Phosphorus Sorption in Wetland Soil

The rate and extent of inorganic and organic phosphorus transformations in wetlands can be controlled by intermittent aerobic and anaerobic conditions. Under aerobic environment the solubility of phosphorus associated with amorphous aluminum and iron compounds may be increased, but some phosphorus associated with crystalline aluminum and iron oxides are desorbed only under extended water logged conditions. Although aluminum-phosphorus complexes are not affected by oxidation-reduction reactions brought about by aerobic-anaerobic conditions, pH and organic matter affect the solubility of this form of phosphorus. Thus, iron speciation tends to dominate over the dynamics of phosphorus solubility in many wetland soils. Ferric oxyhydroxides in the surface oxidized zone of a waterlogged soil can act as a sink for phosphorus in both the overlying water column and underlying anaerobic soil bed. The thickness of this surface layer that depends on oxygen-demanding species at the interface determines the mobility of phosphorus associated with iron-complexes in wetland soils, to a large extent [11].

Increase in soil pH is a concern because the binding of phosphate to free aluminum is a major mechanism of phosphorus sorption in wetland soils, and free aluminum activity decreases with the increase in pH. Organic phosphorus mineralization can be enhanced by alternate soil wetting and drying cycles, changing the soil pH and increasing the microbial activity. In general, the bio-availability and mobility of phosphorus in wetland soils under aerobic conditions are greater than that for anaerobic or dry-land soils. It increases the potential for phosphorus movement in runoff and water from wetland soils. Wetland soils can act as sinks and sources of phosphorus depending on hydraulic retention time, physicochemical properties of sediment and vegetative

assimilation. When the dissolved phosphorus concentration of influent water is greater than that present in the pore water of wetland soils, phosphorus is retained by aluminum, iron, organic matter, and to a lesser extent by calcium-complexes [21].

B. Plant Uptake of Phosphorus

Several environmental factors influence plant uptake of phosphorus from soil or fertilizer. These include temperature, soil compaction, soil moisture, soil aeration, soil pH, type and amount of clay content, status of phosphorus and other nutrients in wetland soil. Phosphorus uptake gets reduced during early plant growth when the soil temperature is low. Compaction of soil reduces pore size and consequently amount of water and oxygen, which in turn reduces phosphorus uptake. Soil pH greatly influences the availability of phosphorus to plants, with phosphorus being tied up by calcium at high pH and by iron and aluminum at low pH. Soils with high clay content tend to fix more phosphorus than sandy soils having low clay content. The presence of ammonium increases phosphorus uptake by creating an acid environment around the root when ammonium ions are absorbed. High concentration of ammonium-nitrogen in the soil with phosphorus from fertilizer may interfere and delay normal phosphorus fixation reactions, prolonging the availability of fertilizer [16].

C. Microorganism for Phosphorus Removal

Acinetobacter is one of the primary organisms responsible for removal of phosphorus. This organism responds to volatile fatty acids (VFA) in the influent wastewater under anaerobic environment by releasing stored phosphorus. The VFA is an important substrate for the Acinetobacter during competition with heterotrophic organisms. In case of an anaerobic zone is followed by an aerobic zone, the microorganism exhibits phosphorus uptake above the normal level. After utilization for cell maintenance, synthesis and energy transport phosphorus can also be stored for subsequent use of the microorganism. The sludge containing the excess phosphorus is either wasted or removed or treated in a side stream to release the excess phosphorus. It has been observed that the release of phosphorus occurs under anoxic conditions. The biological phosphorus removal requires both anaerobic and aerobic zones within a reactor [13].

D. Phosphorus Removal in Free Water Surface (FWS) Constructed Wetlands

Basically in FWS system of wetland phosphate is removed by accretion on and burial in the bottom sediments. Plant uptake of soluble phosphate by sorption into plant biofilm is one of the mechanisms for removal. At the onset, there may be some sorption of negatively charged phosphate particles to the bottom soil liner particles. The insoluble organic phosphate is not generally available to plants unless transformed to a soluble form. The microorganisms, suspended in the water-column of a FWS are able to transform these phosphates into a soluble inorganic form. Once the phosphate is available to plant, its uptake occurs during the growing season; but during

plant's senescence and winter it falls till the plant death followed by its decomposition. Therefore, FWS wetland cannot be relied upon for phosphorus removal because the early plant uptake is negated by the plant's senescence and the diminishment of the soils sorption capacity as the system matures.

E. Phosphorus Removal in Vegetated Surface Bed (VSB) Constructed Wetlands

The removal of phosphate from a VSB relies upon the accretion of phosphorus from decomposing plants and largely depends on the plant uptake. Hence, cycling of phosphorus in a VSB produces seasonal results similar to FWS system. Plant uptake of phosphorus is quite small in respect to septic tank effluent loading and therefore its phosphorus removal capacity is limited. Estimation of realistic long-term phosphorus removal capacity by plant harvesting is also very limited [18].

VIII. PAST EXPERIENCES OF BOD, NITROGEN AND PHOSPHOROUS REMOVAL BY WETLAND

A. BOD Removal

The Constructed Wetlands are widely being used to treat domestic wastewater as a viable alternative in India. A pilot scale study was performed to examine the feasibility of constructed wetland system for treatment of sewage at National Environmental Engineering Research Institute (NEERI), Nagpur. Treatment efficiency was monitored for the parameters like BOD, N, P, TSS and Faecal Coliform (FC). The results showed high removal efficiencies particularly for BOD, TSS and FC. Wetland beds were prepared with some locally available plants like elephant grasses, cattails, etc and other similar species. The study also dealt with effectiveness of various plant species towards the efficient performance of the constructed wetland for domestic wastewater. From this study, Sub-surface flow (SSF) constructed wetlands are observed to be a viable tertiary treatment alternative for municipal wastewater. These systems may be considered as a potentially good, low-cost, appropriate technology for the treatment of domestic wastewater in rural areas where land is inexpensive [24].

The performance of constructed wetlands for the removal of BOD, nitrogen, phosphorus and pathogens from primary treated wastewater has also been studied in India. One such constructed wetland comprised of emergent macrophytes like *Typha latifolia* and *Phragmites carca* grown in cement pipes having 0.1256 m² area and 0.8 meter deep filled with 30% soil and 70% sand. The hydraulic loading rate was maintained at the rate of 5 cm/day. The BOD removal in wetlands was found to be 78-91% while the nitrogen content reduced from 30.8 mg/L to 9.5 mg/L and the phosphate reduced from 14.9 mg/L to 9.6 mg/L. India's first constructed wetland, of size 90m x 30m was installed at Sainik School, Bhubaneswar in the State of Orissa. Presently, 180-200 m³ of wastewater is being treated through this wetland system. BOD and nitrogen removal were observed to be 67-90% and 58-63% respectively. From this study, the constructed wetland treatment was found to be efficient and economically viable in

the removal of BOD and N [7].

Wastewater treatability study was carried out through wetland in Nepal. Surface water pollution becomes a serious environmental problem in urban centres in Nepal due to the discharge of untreated wastewater into the river-system, turning them into open sewers. Wastewater treatment plants do not exist in the country except for a few in the Kathmandu valley and even those are not functioning well. A two-staged subsurface flow constructed wetland for hospital wastewater treatment and constructed wetlands for treatment of gray water & septage were successfully implemented as a demonstration site of constructed wetland systems in Nepal [22].

B. Nitrogen Removal

The wastewater has been treated in surface flow wetlands in the town of Oxelösund, Sweden by mechanical and chemical methods for removal of BOD, phosphorus along with nitrogen to reach 50% removal. In the town of Oxelösund, one wetland of area 21 hector was constructed with 5 cells, where both two cells were operated in parallel mode with a final common cell. The design flow was estimated to be 6000 m³/day. In the first year, from August 1993 to July 1994, the wetland removed 720 kg per hector of total nitrogen from the input nitrogen load of 1810 kg per hector. Ammonium nitrogen was the dominant fraction of the total nitrogen and it was observed as 79% and 90% of total nitrogen at inlet and outlet respectively. The large fraction of NH₄⁺-N at the outlet revealed that the nitrification was the limiting step. In May 1994, it was noted after intensive monitoring that neither wastewater toxicity nor oxygen deficiency were likely to limit nitrification. Sub-optimal hydraulic loading conditions, lack of suitable surface for ion exchange of NH₄⁺-N, as well as for attachment of nitrifiers and deficiency of phosphorus were considered as the potentially vital factors for limiting nitrification [30].

Wetland system is found to be more promising for the removal of carbonaceous material than that of nitrogen. Nitrification occurs in conventional wetland treatment system but generally requires long hydraulic retention time. In a research study, treatability of high strength seafood processing wastewater in the sub-surface flow constructed wetland was evaluated through the configuration of passive aeration as well as effluent recirculation. In that 2-stage wetland treatment system, the first stage was designed for BOD removal only by providing short hydraulic retention time. The second stage provided an unsaturated inlet zone and effluent recirculation to enhance nitrification. In this study, the removal efficiency of ammonia nitrogen up to 65-70% was achieved with the hydraulic retention time of about 3.5 days [10].

In Wiedersberg, Germany multi-stage configuration with primary settling, reed bed horizontal and vertical flow constructed wetland ultimately followed by ultra-violet disinfection and a special phosphorus filter bed showed a number of possibilities of nitrification-denitrification. It was observed that denitrification could be improved by the process of recirculation through the vertical flow bed and sedimentation tank or by the addition of carbonaceous water from the primary stage to a secondary stage within the vertical

flow bed. It could also be enhanced by means of recirculation directly to the subsequent horizontal flow bed. The median denitrification rate at vertical flow bed and horizontal flow bed was 1.3 g N/m²/d and 0.25 g N/m²/d respectively. The low denitrification rate in horizontal flow bed was supposed to be due to a very high level of wastewater dilution by storm and ground water in the range of 100 to 200 % [17].

The effect of plant and influent organic matter on nitrogen removal was investigated in four experimental surface-flow wetlands treating a nitrified meat processing effluent. In this study, three wetlands were provided with a floating mat of the plant *Glyceria* and the fourth contained a simulated nylon fabric plant mat. The 50% effluent recycle was irrigated over two of the plant-retaining wetlands, whereas the other wetlands were fed with influent at one end as per normal practice. In the study, it was observed that the nitrogen removal capacity of planted wetlands was about two times of that in the non-planted wetlands and averaged 46-49% at the loading rate of 5.2-5.5 g N /m²/d. Furthermore, summer time removal of nitrogen reached 75% at the loading rate of approximately 9.5 g/m²/d. Denitrification occurred in order of about 87% nitrogen removal by the planted wetlands and 13% due to accumulation in sediment and plant biomass. The plants (including plant litter) and influent organic matter accomplished about 50% of nitrogen removal, mainly through supplying organic carbon and creating anaerobic environment favorable for denitrification. It was further observed that irrigation of wastewater over the plant mat did not increase nitrogen removal [15].

Constructed wetland systems are found to be appropriate as low cost treatment option for tropical countries and used for treatment of pig farm wastewater in Thailand. During this study, a combined system consisting of a vertical flow bed planted with *Cyperus flabelliformis* and a horizontal flow sand bed without plants was used to treat settled pig farm wastewater. This system was observed to be appropriate for similar application, where land is limited. The average COD and nitrogen loading rate of the vegetated vertical flow wetland were 105 g/m².d and 11 g/m².d respectively. The wastewater was fed intermittently at the time interval of 4 hours with a hydraulic loading rate of 3.7m³/d. The recirculation of the effluent increased total nitrogen (TN) removal efficiency from 71 to 85%. The COD and Total Kjeldahl Nitrogen removal efficiency were determined as 95% and 98% respectively. The extent of nitrification was considerable in vertical flow wetland bed, and the nitrate concentration was enhanced by a factor of 140. The horizontal flow sand bed improved COD removal and the nitrate reduction was observed to be 60%. The uptake of nitrogen by the plant was estimated to be 1.1g N/m².d and the dry biomass production was 2.8 kg/m² over a period of 100 days [9].

A green house experiment was conducted at Alabama, USA, in the summer of 1993 to study ammonium and nitrate removal processes in constructed wetlands. In this study, microcosm wetlands cells were employed which consisted of plastic containers with 0.40 x 0.35 m² surface area and 0.5 m depth. Two experiments were conducted separately during the

study. In one experiment $\text{NH}_4^+\text{-N}$ removal was examined while the other studied $\text{NO}_3^-\text{-N}$ removal. Nutrient solutions comprising of approximately 48 mg/L $\text{NH}_4^+\text{-N}$ or $\text{NO}_3^-\text{-N}$ were added in batch mode to the wetland microcosms to establish the reaction chemistry with the progress of time. The experimental studies were conducted on unplanted cells and cells planted with Canarygrass (*Phalaris arundinacea*), Reed (*Phragmites communis*), Bulrush (*Scirpus atrovirens georgianus*) or Typha (*Typha latifolia*).

Another study was also carried out with added nutrient solutions containing no carbon and with carbon of 112 mg/L. In case of $\text{NH}_4^+\text{-N}$ removal experiment, the order of $\text{NH}_4^+\text{-N}$ elimination was observed to be as reed > canarygrass = bulrush > typha >> unplanted wetland cells with and without carbon. The order of $\text{NH}_4^+\text{-N}$ removal was assumed to be related with the density of root biomass in the gravel. It was also observed that the greater the root biomass, the higher the chance for plant nitrogen uptake or nitrification facilitated by oxygen transport to the rhizosphere. In case of $\text{NO}_3^-\text{-N}$ experiment, the order of $\text{NO}_3^-\text{-N}$ removal was observed to be as reed = canarygrass > typha = bulrush > unplanted cells. Measurement of nitrogen in the plant biomass revealed the removal of $\text{NO}_3^-\text{-N}$ through plant uptake by the combined process of denitrification and immobilization. The removal of $\text{NO}_3^-\text{-N}$ was found to be 55 to 70% through denitrification and immobilization when carbon was added with the treatment process. The quantity of $\text{NO}_3^-\text{-N}$ removed via denitrification and immobilization without adding carbon was decreased to 14 to 30% in case of bulrush, reed and typha. However, in canarygrass cells, $\text{NO}_3^-\text{-N}$ removal through the process of denitrification and immobilization was appreciable – about 72% of added $\text{NO}_3^-\text{-N}$ due to release of high amount of organic carbon from the canarygrass roots [26].

C. Phosphorus Removal

The subsurface flow (SSF) constructed wetland was investigated to check the phosphorous retention capacity of iron-ore and blast furnace slag over a period of four months in Institute of Agricultural Engineering, Germany. In this study, dairy farm wastewater was allowed to percolate through buckets planted with reed. One group of buckets was retained under aerobic environment and the other group under anaerobic conditions, monitored by continuous redox potential measurements. Even at high phosphorous loading rates of 0.65g P/m/d the slag ensured 98% removal efficiency and showed no decrease in performance with time. However, phosphorus fractionation data highlighted that the high phosphorus retention capacity under aerobic condition is to a great extent, attributable to unstable sorption onto calcium compounds. Phosphorus sorption of both the slag (200 g P/g) and the iron-ore (140 g P/g) was encouraged by predominantly anaerobic conditions due to continuous formation of amorphous ferrous hydroxides. It was also observed that none of the substrates had adverse affects on reed growth [6].

In another study, phosphorous retention capacity of wetland treatment was investigated in the Everglades construction project of South Florida, USA. The respective water

management district planned to utilize large constructed wetlands for the reduction in phosphorus concentration in runoff entering the Everglades. The said district constructed and operated a prototype treatment plant of area 1545 ha. Everglades nutrient removal project (ENRP) was initiated to work out the efficacy of subtropical wetlands for improving regional water quality with a focus on reducing total phosphorus (TP). During five years of operation, the ENRP consistently exceeded its performance goal of TP outflow concentrations < 50 g P/L and a 75% TP load reduction. Since August 1994, the ENRP stored 70.3 metric tons of TP that otherwise would have entered the Everglades. When the design was corrected for surface area and inflow TP load, TP removal efficiency was highest in the inflow buffer cell and decreased mainly in a downstream fashion through the wetland. High TP removal efficiency in the treatment cell number 4 was attributed to better performance of its submerged aquatic vegetation community relative to the emergent and floating macrophyte community in the other cells [14].

Experimental study was also conducted to remove phosphorus from Trout farm effluents by constructed wetland in Canada. A three-stage system was developed and operated with a view to retain the solids by a 60 m nylon rotating microscreen followed by treatment with a phosphorus-retaining constructed wetland system. Wastewater from the microscreen was pumped to a series of two horizontal flow beds of volume 100 m³ each (0.6 m deep). Coarse (2 mm) and finer (< 2 mm) crushed limestone were provided in each bed, with the first one being planted with reeds (*Phragmites australis*) and the second one was designed to remove even more phosphorus by means of adsorption and precipitation. Preliminary results showed that the microscreen captured about 60% of the suspended solids. It was also observed that greater than 95% of the suspended solids and greater than 80% of the total phosphorus were retained in the beds. The potential of constructed wetlands as an ecologically attractive and economical method for treating fish farm wastewater to reduce solids and phosphorus appeared to be promising [3].

IX. SCOPE OF WETLAND MODIFICATION FOR BOD, NITROGEN, AND PHOSPHOROUS REMOVAL

A. Common Modification

In the United States, it is common to provide some preliminary treatment prior to a Free Water Surface (FWS) wetland. About 45% of operational FWS wetland system adopt facultative lagoon for preliminary treatment. Some of the largest FWS systems are designed for the polishing of tertiary effluent received from conventional treatment plant. In arid parts of United States, non-discharging and total retention FWS systems are employed, where the water gets completely lost through a combination of seepage and evapotranspiration. However, this system requires careful attention on account of long-term accumulation of salts and other substances, which might become toxic to plants or wildlife in the system. It is practically impossible to eliminate wildlife from FWS

wetlands. It can only be prevented by restricting open water zones to the rear part and using dense stand of emergent vegetation in the front part of the wetland. In colder climates or in case of land scarcity for wetland removal of nitrogen and phosphorus, a smaller wetland system can be introduced for BOD/TSS removal. Phosphorus and nitrogen removal can be achieved by separate wetland process. An integrated gravel trickling filter for nitrification of ammonia can also be successfully adopted. Seasonally operated FWS wetlands are useful in very cold climates, where the wastewater is retained in a lagoon during the winter months and then discharged to the wetland at a controlled rate during the warm summer months [28].

B. Modification of Wetland by Adding a Bio-Reactor

Traditional natural methods do not efficiently remove the nutrients and toxic components from the wastewater and they also have considerable limitations in colder climates. Combination of bioreactors and natural process may be an approach to overcome the limitations of the conventional methods. Such a configuration comprising of three units - septic tank for pre-treatment, aerated bioreactor with sedimentation and constructed wetland as tertiary treatment have been proposed. The biofilm reactor may be either up-flow packed bed reactor or a fixed, submerged biofilm process. The packed bed is aerated from the bottom by means of a low-pressure compressor. The filter media in the bed consists of 0.8 m of 12-16 mm gravel at the bottom and 1.55 m of 2-5 mm vulcanized clay. The post-treatment is accomplished in form of a horizontal sub-surface flow wetland, where varying inlet and outlet levels induced the horizontal flow through sand media. The filters possess inlet and outlet zones with 12-22 mm gravel and treatment zones containing 0.2 – 1.5 mm sand; with a depth of about 0.8 m and a target hydraulic retention period of 10-15 days. The filters are covered with about 0.30–0.50 m of soil and plants. In some treatment plants the sand of the wetland filters is mixed with 1% (by weight) of cast iron cuttings to increase phosphorus removal. In this modification, total Nitrogen removal varies from approximately 40 to 80%. It has been observed that most of the nitrogen is removed in the reactor part of the process and only 18 to 35% is removed in the wetland. The results also showed that the total phosphorus removal was consistently well above 80% with a slight reduction with respect to time [1].

Another study on the operational performance of a combined eco-system of ponds and surface flow constructed wetland was made for municipal wastewater treatment and reclamation/reuse in Donging City, Shandong, China. The removal efficiencies for various performance parameters were : TSS $84.8 \pm 7.3\%$, BOD₅ $87.2 \pm 5.3\%$, COD_{Cr} $70.2 \pm 18.6\%$, TP $52.3 \pm 23.1\%$, and NH₃-N $54.8 \pm 23.9\%$ with effluent concentration of TSS 9.12 ± 5.12 mg/l, BOD₅ 6.44 ± 4.58 mg/l, COD_{Cr} 42.8 ± 6.7 mg/l, TP 0.94 ± 0.27 mg/l and NH₃-N 7.95 ± 2.36 mg/l. Furthermore, the removal efficiencies for faecal coliforms and total bacteria were more than 99.97% and more than 99.99% respectively, satisfying the Chinese

National standards for effluent quality of municipal wastewater treatment plants. The composition of TSS was commensurate to COD_{Cr} and BOD₅ variations and nitrification-denitrification was the major mechanism of nitrogen removal both in ponds and wetlands. Apart from that, sedimentation had also an important role towards the removal of TSS, nitrogen, phosphorus and BOD₅. The removal efficiencies increased gradually with the ecological maturation of the system [29].

C. Using Vetivier Grass in Constructed Wetland

Solids removal and stabilization have been studied in two types of constructed wetlands, where water flow either (i) vertically down through a porous substrate or (ii) horizontally, over soil and through hedges. These two wetland types denoted as VFW and HFW are different in physical characteristics, hydraulic distribution and collection. Both the created wetlands were planted with 'vetivier grass' (*Vetiveria zizanioides*). Vetivier grass was selected because of its tolerance to a wide range of environmental conditions. It has also been proven capable to control soil erosion throughout the world when planted in form of narrow hedges. It was further observed that the dense vetivier shoots acted as a filter, allowing water to pass through while holding back soil to settle by virtue of gravity and thus preventing erosion.

The results of the above investigation established that solid removal and stabilization satisfactorily occurred within both the wetlands. TSS removal of 98% and 96%, total COD removal of 91% and 72%, soluble COD removal of 81% and 30% were attained for VFW and HFW cells respectively. It has been observed that both the wetland types removed mostly 82–93% of soluble phosphate and Total Kjeldahl Nitrogen (TKN). Nitrate was produced in both wetland types; however there was sufficiently more nitrate in the effluent from VFW cells in comparison to the HFW cells. Nitrate production revealed that there was some aerobic bacterial activity to cause nitrification in both types of wetland cells. Although the saturated zones of both VFW and HFW cells were mostly anaerobic, there might have several localized aerobic zones created within the wetlands. Denitrification possibly accounted for the removal of some nitrate from both wetland types, but low level of nitrate in the effluent from HFW cells may be due to insufficient oxygenation for nitrification. At the end of the experiment, root growth was also envisaged when all the material was removed from the wetland vessel [23].

X. CONCLUSION

Constructed Wetlands can be employed as a low cost tool for municipal wastewater treatment, intended for organic carbon, nitrogen and phosphorous removal. Wetlands are capable of effective removal of organic components from a variety of wastewaters and it can act as a carbon sink. To prevent eutrophication in water body due to excessive nitrogen and phosphorous loading, different types of wetland are found to be effective. The anoxic denitrification requires organic carbon, which can be supported by the soil environment in the wetland. The carbon source is also available from plant litter

and natural detritus in case of vegetated submerged wetland. The organic soils showed the highest nitrogen removal rates and the sandy soil the lowest rate. Nitrogen removal gets influenced by availability of soil organic matter, because it acts as electron donor. The reserve of organic material in the wetland is sufficiently large to provide reducing capacity higher than the oxidizing capacity of nitrogen inputs.

Wetlands are becoming most efficient, high performance and low cost wastewater treatment technology around the world. Thus, these natural treatment technologies are attracting a significant interest due to their low capital costs, ease maintenance, longer life cycles and their ability to recover variety of resources. Constructed and natural wetlands can also be used extensively to treat several types of wastewater and runoff. Some modification would enhance the BOD, nitrogen and phosphorus removal efficiency of the wetland. Wetland treatment is often the best choice for treatment of nitrogen and phosphorous bearing wastewater or secondary effluent after adequate pre-treatment.

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