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Review

Constructed wetlands: A future alternative wastewater treatment technology

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Wastewater treatment will always pose problems if there are no new alternative technologies in place to replace the currently available technologies. More recently, it has been estimated that developing countries will run out of water by 2050. This is a course for concern not only to the communities but also a challenge to the scientist to find new ways of wastewater recycling. Water losses can be avoided through implementation of easy and inexpensive technologies for wastewater treatment. Environmental concerns over insufficiently performing septic systems and high expenses in the construction of sewer systems as well as their operations with centralized water purification systems have spurred investigation into the appropriateness of the use of wetland technology for wastewater treatment. Constructed wetland efficiency and potential application in wastewater treatment has been reported decades ago. However, the logistics and research for their commercial applications in wastewater treatment has not been documented in details. Research has shown that wetland systems can achieve high treatment efficiencies with regards to both organic and inorganic nutrients as well as pathogen removal if properly managed and efficiently utilized. This can have a profound effect in the management and conservation of our scarce and yet depleting water resources.

Key words: Constructed wetlands, rhizofiltration, microbial biofilms, wastewater treatment, treatment mechanism.

INTRODUCTION

South Africa is made up of approximately 850 municipal wastewater treatment plants, yet according to research by the South African Department of Water Affairs, less than 50% of the 449 wastewater treatment systems which have been assessed meet the regulatory national and international water quality standards for wastewater treatment. These findings are proof that South Africa's wastewater treatment systems are inadequate to meet the effluent required standards. This has resulted in the urgent need for the development and implementation of innovative systems to resolve the wastewater treatment constraints (Kalbar et al., 2012a). It is for this reason that interest has been sparked into the investigation of alternative wastewater treatment technologies for the treatment of wastewater. Constructed wetland systems are a good example of such alternative technologies which have the potential to meet the required influent treatment standards as compared to conventional methods. They are an old technology dating from wetland technology which was dated back in 1952 (Siedel, 1973) and has been in full scale operation from 1974 (Kickuth, 1977). The technology was developed through the

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simulation of natural wetlands resulting from an increase in anthropogenic activities and environmental changes.

Constructed wetlands are designed and engineered low-cost natural technology that has emerged as a useful technology for wastewater treatment (Chong-Bang et al., 2010; Yongjun et al., 2010). They are engineered systems that are constructed to mimic processes found in natural wastewater treatment (Yeh et al., 2009). They exploit natural processes in order to remove pollutants from municipal, industrial wastewater or from mine drainage (Stefanakis et al., 2011). Natural processes employed include vegetation, soil and microbial activities to treat contaminated water. The relationship and interactions between plants and microbial assembles attributes the importance of the performance of the wetland systems (Vymazal, 2005). However, more characteristics that define the ability and the potential of the constructed wetland such as construction and combination of different systems, flow characteristics, loading rate, effect of different operational parameters and the use of different plants need to be considered in the success of any constructed wetland technology (Stefanakis et al., 2011). Constructed wetlands have been studied for years but the above synergistic characteristics have never been dealt with in details. Dealing with the above is imperative if constructed wetland systems are to be introduced as an alternative wastewater treatment technology.

Plants and microorganisms are at the centre of attention to the processes occurring in the wetland systems (Kadlec and Wallace, 2009). Constructed wetlands have earned much of their focus in the research field, not only because of their low operational costs but also to their potential use by small house-holds for wastewater remediation (Brix, 1987). They have been used to treat waste water from point and non-point pollution sources including stormwater runoff, domestic wastewater, agricultural wastewater, and coal mine drainages. However, the mode of action and detailed mechanisms of contaminants removal from these systems has not been proposed yet. The inability of the use of wetland technology for wastewater management own it to the lack of detailed studies as well as understanding of the complex chemical and biological processes involved in wetland treatment systems that can lead to large scale operations. Studies that have been done up to this far cannot permit or allow the introduction of wetlands for large scale as well as long term wastewater treatment. An understanding of these processes is fundamental not only to designing wetland systems but also to the understanding of the fate of contaminants once they have entered the wetland system. This could aid in understanding their potential use for commercial/large scale applications. This review paper elucidates the possible applications of the constructed wetlands as an alternative technology for wastewater treatment by local municipalities and industries. The focus of this research is to explain the role played by microorganisms, plants as well as different configuration systems in the removal of contaminants from wetland system. The constructed wetlands system efficiency and dynamics as well as processes involved in wetland technology are also discussed. The paper discusses the importance of the use of the wetland technology as an alternative means for wastewater treatment.

OPERATIONS AND DESIGN CHARACTERISTICS OF COMMERCIAL CONSTRUCTED WETLAND TECHNOLOGY

There are three main types of constructed wetland systems characterized by configuration design and operation. These are surface flow (SF), subsurface flow (SSF) and vertical flow (VF) constructed systems. The above types of systems are placed in a closed basin with a substrate and the bottom covered by a rubber foil to ensure that the process is completely waterproof. This is essential in any environment where leakage of water from the system can have adverse effects, that is, contaminating source waters. The substrates of the systems are plants, gravel and sand or lava stones (Farroqi et al., 2008). Advances in engineering and technology have now permitted construction of a multi-designed wetland system functioning as vertical, horizontal as well as subsurface system. This type of wetland design represents a new trend and an emerging tool in wastewater treatment using wetland technology. Though these systems are now beginning to be available, no work has thus far been reported about their functioning as well as their abilities. If these systems can be efficiently operated and optimally controlled they may offer maximum contaminant removal in wastewater. Although the design of these systems may be expensive their successful utilization may offer equal advantages because each consists of all type of the systems in one.

These multi-engineered systems (Figure 1) are currently being investigated for their maximal contaminant removal efficiency in municipal wastewater for their potential applications commercially. These wetlands were constructed to permit feeding and collection of effluent from different positions alongside the filter. The systems have vertical, surface flow as well as subsurface influent loading channels. Filters at the collection point/taps are used to determine the flow out of the filter at different points and collect the effluent for measurement purposes.

The wetland medium is made up of different layers of rocks and sand ranging from coarse rocks (100 to 200 mm) at the bottom to crushed rocks (19 to 25 mm) at the top, which is topped off with fine sand on which a thin layer of the crushed rock is placed to protect the sand (Figure 2). The entire system is divided lengthwise, in which one side contains only media (reference section). On the other side (planted section), different wetland plants were planted to determine their effect on the amounts of pathogens, nutrients and metals in the wastewater. This constructed wetland was built in Kingsburgh at

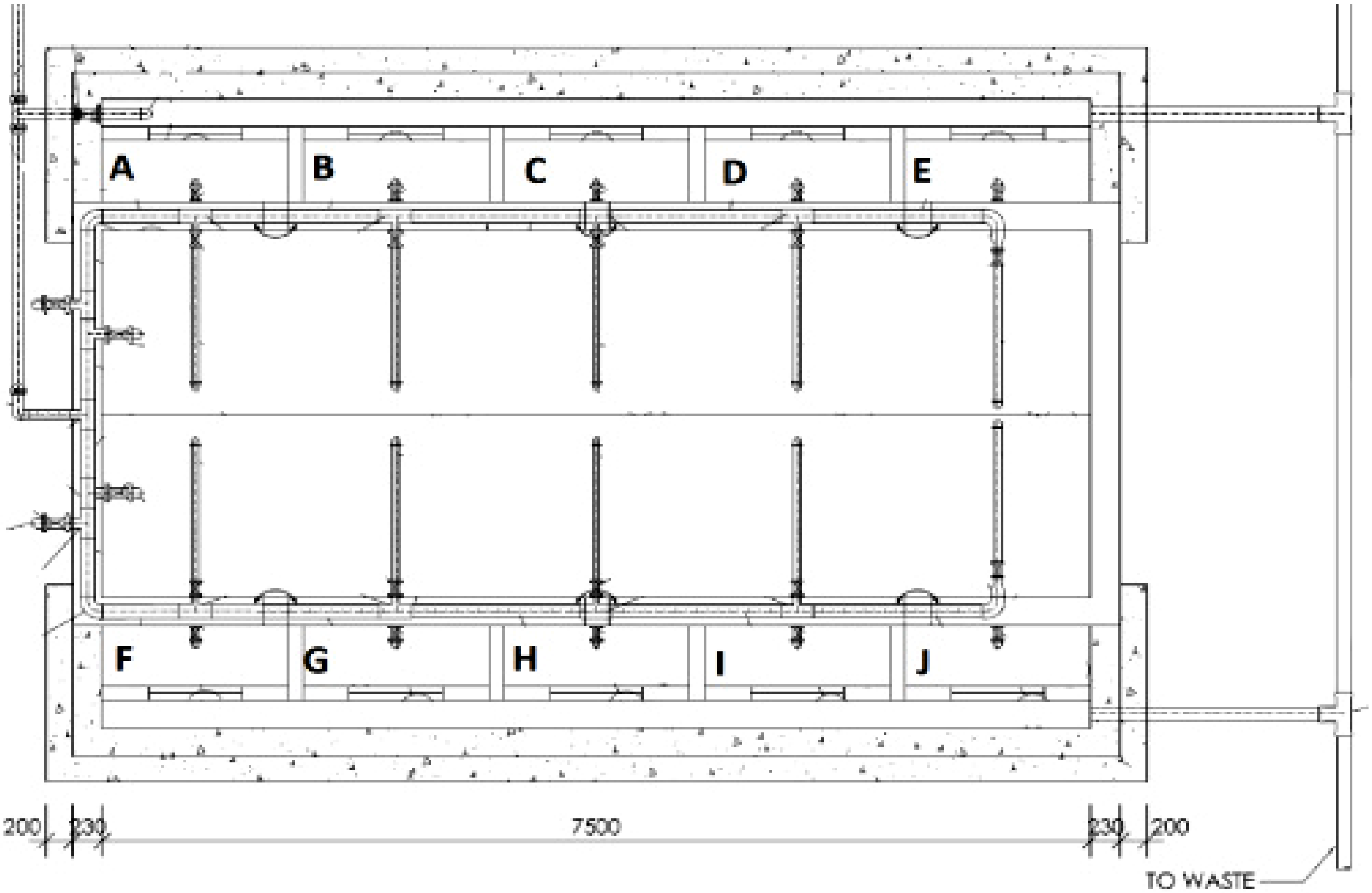

Figure 1. Schematic representation of a multi-designed wetland system in Durban.

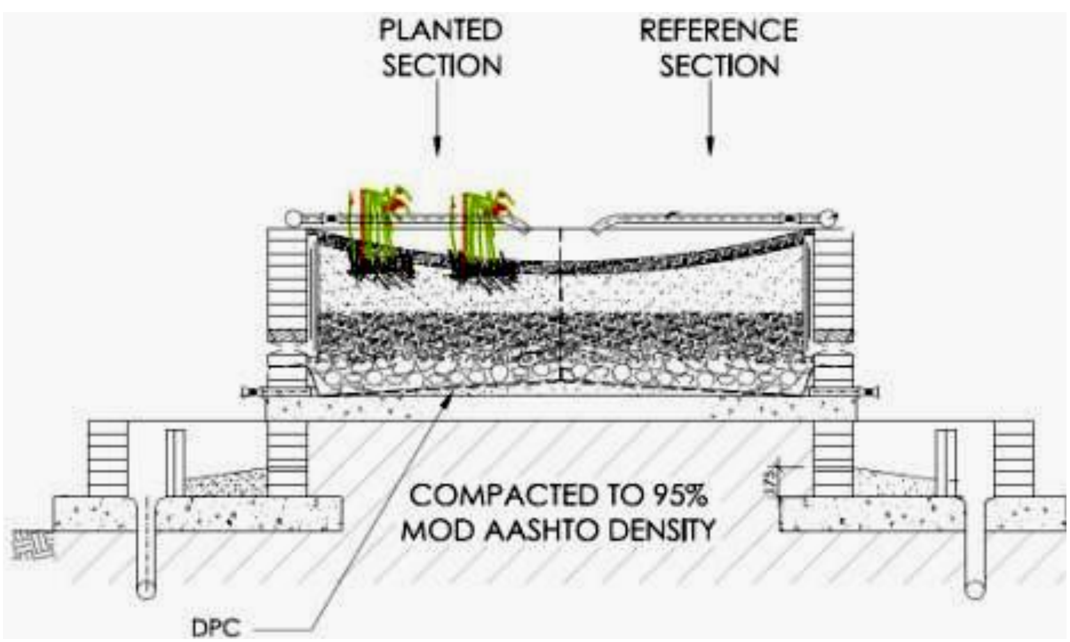

Figure 2. Cross section of the multi-engineerd system. The plants are planted in such a way that they are evenly distributed across the test section of the wetland. The layout of plants in the wetland medium can be seen in Figure 1. Species of the plants used are *Phragmites australis*.

Figure 3. Front view of the multi-engineerd system. The middle vertical pipe comes from the tank. The vertical pipes on the left and right are the pipes to the bottom inlet for subsurface flow. Small pipes on top of the bed along the wetland are for vertical flow, while those of surface flow are at the inside front of the system.

Figure 4. Basins and waste channel with a bypass outlet option in the left hand bottom corner of the multi-engineerd system constructed at Kingsburgh, Durban.

eThekwini wastewater treatment, in Durban. It has the capacity of 4M wide and 8 M in length. The void volume of the system was about 3000L, with a flow rate ranging between 0.2 to 2 l/s. The system recieves wastewater from people around Kingsburgh with an estimated population of about 200 000.

Multi-engineered systems (Figures 3 and 4) should be investigated and encouraged for use commercially. If properly constructed, monitored and controlled these systems can remove up to 100% of the contaminants from wastewater since they have properties and characteristics of all types of constructed wetland sys-tems. For highest removal efficiencies, wastewater will need to flow from one type of flow system to the next within the wetland and for this to be possible, it calls for wetland “separation”. For sustainability, ideal systems designed for municipal or industrial applications should use less or no energy at all. A well-designed wetland should transfer water by gravity through the system. If site topography limits the use of gravity, pumps should be used which would increases the cost of operation. Unlike modern sewage treatment plants, constructed wetlands will reduce

Table 1. Mechanisms of wastewater treatment using wetland technology (Cooper et al., 1996).

Wastewater constituent	Removal mechanism
Suspended solids	Sedimentation Filtration
Soluble organics	Aerobic microbial degradation Anaerobic microbial degradation
Phosphorus	Matrix sorption Plant uptake
Nitrogen	Ammonification followed by microbial nitrification Denitrification Plant uptake Matrix sorption Ammonia volatilization
Metals	Adsorption and cation exchange Complexation Plant uptake Precipitation Microbial oxidation/reduction
Pathogens	Sedimentation Filtration Natural die-off Predation UV irradiation Excretion of antibiotics from macrophytes

or completely eliminate odor. Odor can become a serious problem when handling and treating animal or domestic wastewater, especially if the operation is located in close proximity to residential housing (Farroqi et al*.,* 2008). Our multi-engineered system is currently being tested for its suitability for nutrients removal. Results obtained so far indicates that it can be reliably used for total phosphorus and total nitrogen removal, however providing and discussing those results is not part of the scope of this paper for now.

MECHANISMS OF CONTAMINANTS REMOVALS FROM WASTEWATER

Combinations of biological, chemical and physical processes are responsible for the removal of contaminants from wastewater (Table 1). Biologically, plants and microorganisms play a major role in removal of contaminants by transforming and/or accumulating them and convert them into their own biomass. Wastewater treatment within a constructed wetland occurs as wastewater passes through the wetland soil medium and plants. Interactions between water and plant roots lead to rhizofiltration and sedimentation while that of microorganisms and contaminants lead to biodegradation (Figure 5). Root hairs and rootlets provide an aerobic environment which supports the activities of aerobic microorganisms. Aerobic and anaerobic microorganisms facilitate the decomposition of organic matter and inorganic substances in water through degradation and nutrient uptake. Figure 5 illustrates some of the possible interactions between wetland medium (soil), rhizomes (roots) and microorganism in the removal/transformation of contaminants. During these interaction processes, nitrogen is liberated from the system through microbial nitrification and subsequent denitrification processes. Organic nitrogen, nitrate, nitrite, ammonia, ammonium and nitrogen gases are the most common forms of nitrogenous compounds available/liberated in wastewater (Cooper et al., 1996). These compounds are essential for plant growth and development; however, it is important that they are removed as some of them are toxic in aquatic life. Suspended solids are removed by settling in the water column in

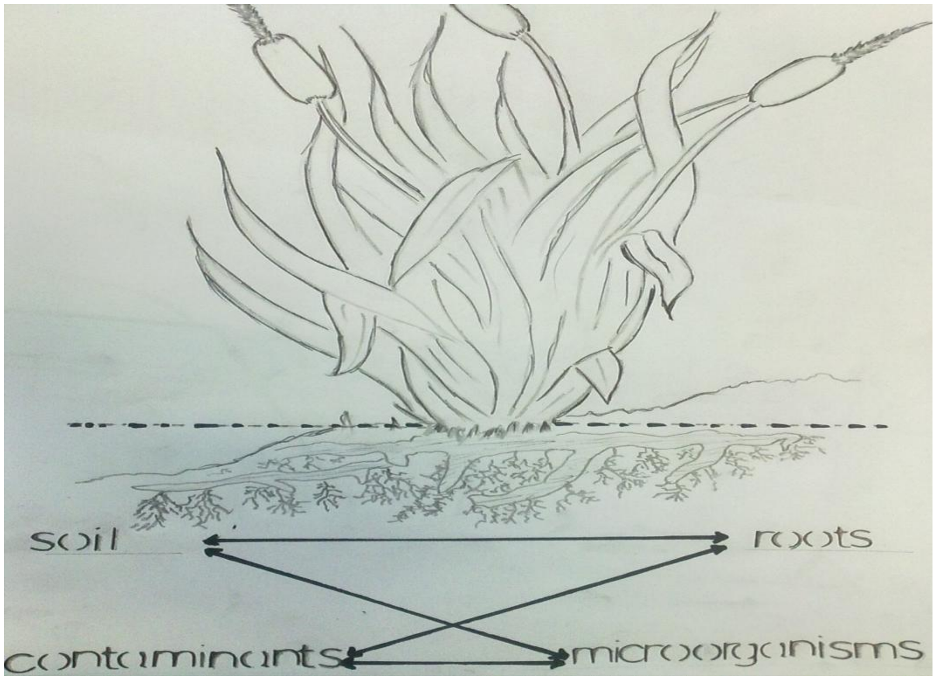

Figure 5. Some possible interactions occurring in wetlands (Stottmeister et al*.,* 2003).

surface flow wetlands or are physically filtered out by the medium within subsurface flow wetlands. Pathogens are removed by filtration and adsorption on biofilms or on plant roots. Heavy metals and phosphates are removed by either plant uptake or through sedimentation.

In order to understand more about the complexities of what happens when contaminants are degraded in a constructed wetland system during treatment, we need to know more about plants and their activities as well as microbial community structure/abundance in the constructed wetland system. This can be done through studying the properties of different macrophytes and characterizing microbial population present in the wetland system.

PLANTS AND THEIR ROLE IN WETLAND TECHNOLOGY

The main mechanisms of nutrient removal from wastewater in constructed wetlands are microbial processes such as nitrification and denitrification as well as physic-chemical processes such as fixation and precipitation. Moreover, plants are able to tolerate high concentrations of nutrients and heavy metals and in some cases even to accumulate them in their tissues (Stottmeister et al., 2003). Plants may also be involved in the uptake of nitrogen, phosphates and heavy metals in water thereby decreasing nutrient content in wastewater (Kalbar et al., 2012a). The most reactive zones of the plant in constructed wetland are in the rhizosphere where all physico-chemical and biological processes take place. These processes are induced by interactions of plants, micro-organisms, soil matrix and contaminants.

Macrophytes are also responsible for approximately 90% of oxygen transport available in the rhizosphere (Vymazal, 2011). Oxygen and nitrogen transport stimulates aerobic and anoxic decomposition of organic matter respectively as well as promoting the growth of nitrifying bacteria and periphytons in the soil matrix (Zhang et al., 2007; Brix, 1997). Table 2 summarizes some of the major roles of macrophytes in a wetland system for wastewater treatment.

For nitrogen removal, nitrogen assimilation processes convert inorganic nitrogen into organic forms that serve as building blocks for plant cells and tissues (Brix, 1997). Ammonia and nitrate are the two main forms of nitrogen assimilation with ammonia being the most preferred source because it is readily utilizable (Vymazal, 2007). They are assimilated by rooted floating-leaved macrophytes in the sediments and by free-floating macrophytes in water. There are many different types of plant species available for use as potential macrophytes and they differ in their preferred forms of nitrogen (Zhang et al., 2007; Dhote and Dixit, 2009). Many plant species are able to take up any soluble form of nitrogen.

The ability of the plants to absorb nutrients, particularly nitrogen, differs seasonally. Nitrogen uptake by macrophytes is a spring-summer phenomenon in temperate climates. Species of plants such as *Typha* and *P. australis* have an annual cycle above ground biomass, which means new shoots start from zero biomass in early spring and grow at a maximum rate in spring and early

Table 2. Major roles of macrophytes in constructed wetland treatment system (Vyamazal, 2011).

Macrophyte property	Role in treatment process
Aerial plant tissue	Light attenuation-reduced growth of photosynthesis Influence of microclimate-insulation during winter Reduced wind velocity-reduced risk of re-suspension Aesthetic pleasing appearance of the system Storage of nutrients
Plant tissue in water	Filtering effect-filter out large debris Reduced current velocity-increased rate of sedimentation, reduced risk of re-suspension Excretion of photosynthesis oxygen-increased aerobic degradation Uptake of nutrients Provision of surface for periphyton attachment
Roots and rhizomes in the sediment	Stabilizing the sediment surface-less erosion Prevention of the medium clogging in vertical flow systems Provision of surface for bacterial growth Release of oxygen increases degradation (and nitrification) Uptake of nutrients Release of antibiotics

summer. During late summer, growth is reduced which later is followed by a complete shoot die off (Vymazal, 2007). This phenomenon of plant growth and nutrient uptake is possible because nutrient concentration of the plant is increased at an early age of plant development (due to high nitrogen demand by the plant) and reduces at later stage. If wetland technology is to be introduced as an alternative technology for wastewater treatment, seasonal variations affecting nutrient uptake by the plants and microbial activities should be considered. This may optimize wastewater treatment efficiency. Systems should always be optimized for the best performances throughout a year circle. The general role of plants in wetlands is shown in Table 2.

During plant shoot die off, plant biomass may be decomposed to release carbon and nitrogen from the plants and the release is important in the wetland nitrogen cycle because it may impair total nitrogen removal. Some portion of nitrogen may be released back into the wetland, some subjected to aerobic process while some may be translocated to rhizomes (Vymazal, 2007). The potential rate of nutrient uptake by plants is ultimately determined by plant growth rate and the concentration of nutrients in the plant tissue, thus nutrient storage of the plant is dependent on plant tissue nutrient concentrations and on plant biomass accumulation. Categorically, this means ideal characteristics for plants to be used as ideal macrophytes in wetland systems are fast growth rate, high tissue nutrient content and the ability to attain a high standing crop (plant sustainability). If constructed wetlands are to be used as efficiently as possible for commercial treatment of wastewater, knowledge of effectiveness of various plant species, colonization characteristics of certain group of microorganisms and information on how biogenic compounds and particular contaminants interact with the soil matrix is essential. This information is also critical in the design strategy and construction of wetland system for commercial applications. Effectiveness of the combination of different macrophytes should also be considered.

MICROBIAL BIOFILMS AND THEIR ROLE IN WETLAND TECHNOLOGY

The growth of macrophytes is not the only potential biological assimilation of organic and inorganic nutrients. The main role in the transformation and mineralization of nutrients and organic contaminants is played by microorganisms. These contaminants/nutrients are metabolized in various ways. In subsurface flow constructed wetlands aerobic processes occurs predominantly near plant roots as well as on root surfaces. In the areas that are largely oxygen free, anaerobic processes such as denitrification, sulphate reduction and methanogenesis occur. Biofilm decomposition of compost is responsible for oxygen removal from the wetland system, and thereby promotes the formation of hydrogen sulphide. Sulphate reducing bacteria degrade and reduce nutrients that contain sulphates and produce hydrogen sulphide in the process.

Microorganisms like autotrophs and microbial heterotrophs incorporate ammonia and convert it into amino acids and proteins (Vymazal, 2007), however this removal mechanism is less significant compared to microbial transformation. Nitrification-denitrification is the main microbial nitrogen removal mechanism (Stottmeister et al., 2003). Nitrogen compounds are continually trans-formed from inorganic to organic compounds and back from organic to inorganic through processes like volatilization, ammonification, nitrification, nitrate-ammonification, denitrification and nitrogen fixation. All these transformations are necessary for wetland ecosystem to function successfully and all chemical changes are controlled by enzymes produced by microorganisms.

NON-BIOLOGICAL MECHANISMS OF CONTAMINANT REMOVAL

Contaminants such as nutrients and heavy metals may be removed from the constructed wetland by means other than biological processes/activities. These include ammonia adsorption and organic nitrogen burials. Ammonia may be adsorbed from solution through cationic exchange reaction with inorganic sediments or soil when it is ionized. It become loosely bound and can be released easily when condition change. This condition decreases the concentration of ammonia in water column. Ammonium ions are generally adsorbed as exchangeable ion clays and fixed within clay lattice (Vymazal, 2007). Some fractions of organic nitrogen incorporated into detritus in a wetland eventually become unavailable for additional nutrient cycling through the process of peat formation and burial (Simeral, 1999; Yeh et al., 2009; Yadav et al., 2010). This process also potentially significantly removes and reduces nutrients in water.

REMOVAL OF HEAVY METALS FROM A CONSTRUCTED WETLAND

Heavy metals are usually found in industrial wastewater and mine drainages. However insignificant quantities may be detected in municipal wastewaters. The main heavy metals associated with wastewater and produced by mines and industries are chromium, iron, mercury, copper, lead, cadmium and zinc. These heavy metals are removed from constructed wetland system by a variety of methods including filtration and sedimentation, adsorption, uptake into plant material and precipitation by geochemical processes (Stottmeister et al., 2003). Removal rates of heavy metals by constructed wetland have been reported to be up to 100% (Romero et al., 2011). Other possible removal rates by a CW as reported by Sheoran and Sheoran (2006) are 75-99% cadmium, 26% lead, 76% silver, and 67% for zinc, while COD, BOD and TSS were removed at a rate between 75 and 80%. Metals were demonstrated to accumulate in the leaves, shoots, rhizomes with roots and lateral roots having the highest content, while the lowest concentrations were found within the shoots. This was demonstrated by sampling the above mentioned parts of the plant and concentrations of the metals were determined using spectrophotometric methods.

In surface flow systems used to treat mine drainage, Fe (II) is oxidized to Fe (III) by abiotic and microbial oxidation. In this system, other inorganic substances such as arsenic may also precipitate. Iron may also be immobilized in the anoxic soil matrix by microbial dissimilatory sulphate reduction, producing hydrogen sulphide. Most heavy metals are taken up and accumulate within the plants. After being taken up, metals concentrate in the plant roots and less concentrated in the stems. Only few heavy metals like mercury are able to translocate to the leaves (Romero et al., 2011). Different plant species have different abilities to take up heavy metals. Some species of plants have high biomass which enhances their phytoremediation capacity. Plants like *Persicaria punctatum* have been proposed as copper and zinc biomonitors and phytoremediators and could be useful in constructed wetland for the treatment of indus-trial wastewater and mine drainages. Though plants are important metal accumulators in constructed wetlands, sediment remain the main metal compartment because its total mass is greater than the corresponding plant biomass in a given area.

Previous studies by Stottmeister (2003), Sheoran and Sheoran (2006) and Romero et al. (2011) indicate that from technological point of view, heavy metal accumulation by plants is insignificant when considering treatment of industrial wastewater and mine drainages. This is because the amount of heavy metals that can be accumulated by plants is far too small when compared to the total load in wastewater.

REMOVAL OF PATHOGENS FROM CONSTRUCTED WETLAND SYSTEM

For successful commercial applications, constructed wetland systems should have an ability to remove pathogens from wastewater. Research over the past years indicates that wetland systems have an ability to reduce pathogens with varying but significant degrees of effectiveness (Karim et al., 2004). Microbial water quality improvements using wetlands have been reported, with some studies reporting up to 57% reduction of total coliforms, 62% of fecal coliforms, 98% reduction of most species of *Giardia,* 87% of most *Cryptosriduim* spp. and 38% of coliphage (Stottmeister et al., 2003; Karim et al., 2004). Human pathogenic viruses were also found to be removed from wetland systems (Juwarkar et al., 1995). Viruses associated with large particles leave water column and settle into the bottom sediments while some are adsorbed on colloidal particles tend to stay suspended in water for longer time (Karim et al., 2004).

Recently, research efforts have begun to consider possible mechanisms for pathogen removal involving the application of constructed wetland systems, with some literature indicating *Escherichia coli (E. coli)* removal efficiencies of between 52% and 99.9% (Boutilier et al., 2011). Greenway (2005) reported a 95% pathogen removal. To mitigate elimination variability, it is necessary to better understand what pathogen removal mechanisms dominate within the wetland and how these mechanisms may be intensified through the manipulation of wetland operational parameters at optimum levels. Previous studies on pathogen removal by CWs treatment systems have been considered a grey zone where studies were mainly aimed at comparing the influent and effluent levels.

Many mechanisms have been associated with the removal of pathogen from constructed wetland systems. These include physical (filtration, sedimentation, adsorption and aggregation), biological (consumed by protozoa, lytic bacteria, bacteriophages, natural death) and chemical (oxidative damage, influence of toxins from other microorganisms and plants) processes. However sedimentation remains a leading mechanism responsible for pathogen removal from wetland system (Karim et al., 2004). This has been demonstrated by many studies which found that total coliforms, fecal coliforms and *Salmonella* had concentrated in sediments of contaminated surface water in wetland systems. They also demonstrated that revival of such organisms from sediments was easier than in water column itself. Jonson et al. (1997) and Chauret et al. (1998) observed higher numbers of fecal coliforms in marine sediments than in overlying water. They also found that about 90% of *Salmonella* isolates from sediments showed high recovery in sediments than in water. *E. coli* was also demonstrated to survive longer in sediments that in overlying water.

Accumulation of microorganisms, pathogens in particular, in sediments of constructed wetland systems designed for wastewater treatment means these systems can be used for elimination/reduction of pathogens from influents. However removal of pathogens using sedimentation process can also pose some serious threats as the bottom sediments of constructed wetland can serve as a potential reservoir of human pathogens. These reservoirs may be released back into the water column by events such as storm and thereby released with effluent to the river. Plants have also been found to reduce pathogens in constructed wetlands. Plants like *Mentha aquatica, P. australis* and *Scorchi lacustric* were studied and were found to inhibit the growth of *E. coli* (Stottmeister et al., 2003). Other than bactericidal effect of the plants, which requires direct effect of the plants in wastewater, other mechanisms and indirect effect of the plants such as adsorption, aggregation and filtration are also involved in the removal/reduction of pathogens. It could be concluded from the above studies that the concerted action of physical, chemical and biological processes are required to achieve high removal efficiencies of pathogen from constructed wetlands. However the removal mechanisms are still not well understood. For efficient removal of pathogens from constructed wetland systems for its commercial applicability, more research is needed to define these mechanisms as well as their synergistic effects in the removal efficiency.

PREDICTING CONTAMINANT REMOVAL EFFICIENCY FROM CONSTRUCTED WETLAND SYSTEM

Contaminant removal from constructed wetlands can be predicted using constructed wetland modeling. During the past few years, many models for processes occurring in a constructed wetland have been described. These models are described based on wetland design and type (Langergraber, 2011; Freire et al*.,* 2009; Odeja et al*.,* 2008). The importance of constructed wetland modeling is in better understanding of the processes involved in wetland systems and thus explain/describe their functioning in a more simplified terms. These models may be numerical, statistical or even software or computational based. More recently a numeric dynamic simulation model was developed for the removal of soluble reactive phosphorus from the vertical flow constructed wetland systems using structural thinking, experiential learning laboratory with animation (STELLA) This model is a dynamic software model whose development was aimed at aiding in simulating the environment and showed succession of relationship between interdependent components and processes occurring in a vertical flow constructed wetland system (Kumar et al., 2011). In this model, alum sludge was used as a main substrate and it indicated high phosphorus removal by both plants and microbial activities.

Ideally, each different wetland configuration should have its own model. Likewise, horizontal and vertical flow systems are modeled differently. Horizontal flow systems are simulated when water flow saturations are considered, and it also uses a network of continuous-stirred tank reactor to describe the hydraulics. Reactions are modeled with various complexities in horizontal flow systems. Transient variable-saturated flow models are required for the modeling of vertical flow constructed wetland systems with intermittent loading. Modeling with these systems is more complex because they are usually highly dynamic due to intermittent loading. Models applicable for use in vertical flow constructed wetland systems use either the Richards equation or a simplified approach to describe variable-saturated flows (Langergraber, 2011).

The most commonly used models in describing subsurface constructed wetland systems are numerical models and are explained in details by Langergraber (2011). They are complex flow models but single-solute transport only, reactive transport models for variable-saturated flow and reactive transport models for saturated flows. These different models offer description for biochemical transformation and degradation process for both organic and inorganic substances in subsurface flow constructed wetland system. They have been intro-duced and published with an aim of providing a widely accepted model formulation for biochemical trans-formation and degradation processes in a constructed wetland system that can thus be implemented in various simulation tools. They describe aerobic, anoxic and anaerobic processes occurring in a horizontal and vertical flow constructed wetland systems requiring prediction of the effluent concentration of organic and inorganic sub-stances. Constructed wetland modeling is one of the most powerful tools that can be used to predict the removal efficiency of contaminants from wastewater. However, microorganisms, organic and inorganic sub-stance's fate and transport modeling within wetlands requires further development if they are to become a reliable predictive forms of wastewater treatment, particularly in commercial wastewater treatment.

POLLUTION TREATMENT EFFICIENCY OF CONSTRUCTED WETLANDS

Previous studies have shown high treatment efficiency of constructed wetlands (Cooper et al., 1996; Shrestha, 2005; Yadav et al., 2010). Regular monitoring of the systems had shown high pollutant removal efficiency achieving close to 100% removal of total coliforms and organic pollutants (Shrestha et al., 2003). Although average removal efficiency of nitrogen and phosphate has been reported, significant difference in removal efficiency is observed among plant species as well as among different type of wetland configuration (Yeh et al., 2009). The main mechanisms leading to contaminant removal in wetlands are microbial activities. However plants also have a huge role in contaminant removal in wastewater. They take up nutrients and incorporate them into plant tissue and thus increase in plant biomass (Zhang et al., 2007).

Various types of wastewater are also treated with varying degree efficiencies. Vymazal and Kropfelova (2009) have used subsurface flow constructed wetland systems to treat wastewater from municipal sewage, agriculture, industry and from landfill leachate. From 400 constructed wetlands in 36 countries it was found that municipal wastewater had, in overall, the highest contaminant removal efficiencies while the lowest removal efficiency were observed from landfill leachates. These observations suggest that most systems have been designed to treat municipal sewage and also the fact that most municipal wastewater contains predominantly labile organics while landfill leachates often contain recalcitrant organics which are difficult to degrade. Constructed wetlands are low maintenance systems. Poor maintenance may result in poor performance due to simple problems such as clogging of pipes (Simeral, 1999). Therefore, all systems need to be regularly monitored and proper systems for operation and maintenance should be established in order to achieve maximum treatment efficiency. Systems designed for commercial applications should be able to achieve and sustain the highest maximum possible removal rates if they are to be introduced.

WHY CONSTRUCTED WETLANDS ARE BETTER ALTERNATIVES AND WHY SHOULD THEY BE EMPLOYED FOR WASTEWATER TREATMENT?

The environment is one of the important aspects in our lives. Recently air pollution is becoming a progressive constrain due to emission of greenhouse gases to the atmosphere. Emissions of greenhouse gases have negatively influenced the quality of air and increase the greenhouse effect. They have direct influence on the environment; causing extreme weather changes, global temperature increases, the loss of ecosystem and potentially hazardous health to people. There are some recent fatal events about the effect of greenhouse gas emission. One of the events is heavy rains that took place on the 20th to the 21st of October 2012 at Eastern Cape, in South Africa, where major roads collapsed, houses were washed away and hundreds of people were cut off. Fears were raised that more than R1-billion damages caused within a week of a heavy rains and flooding in Eastern Cape were dwarfed by even bigger economic losses. On the 31st of October 2012 Sandy, the storm that caused multiple fatalities, halted mass transit and cut power to more than six million homes and businesses. FEMA reported that Sandy dispensed close to $200 million in emergency housing assistance and has put 34,000 people in New York and New Jersey up in hotels and motels. According to World Health Organization report (2005), About 150,000 annual deaths worldwide have been tied to climate change. Climate related deaths are expected to double in the next 25 years. Another case occurred on the 22nd of May 2012 whereby a massive earthquake took place 327 miles away from Durban North. All these cases occur as the result of carbon footprint in our environment. Using technologies that will have less footprint in our ecosystem can greatly reduce these consequences. The use of constructed wetlands in wastewater treatment may have answers in terms of footprint reduction and thus protecting the environment as opposed to convectional wastewater treatment systems.

Apart from their environmental friendliness, constructed wetlands are also proposed as better alternatives in wastewater or industrial wastewater treatments for their significant advantages, including provision of high wastewater treatment levels. Contaminants in wastewater have been demonstrated to be reduced to acceptable levels using this technology. Wetland systems are inexpensive with little or no energy requirements and equipment needs are minimal, which adds to its low-construction cost. This technology need full establishment before it can be considered for full or maximal contaminant removal. In this case, establishment means full development/growth of macrophytes and biofilms responsible for contaminant breakdown. Once established, properly designed and constructed wetlands are largely self-maintaining.

For effective and efficient wastewater treatment using wetland technology, detailed knowledge about the effectiveness of various plant species, colonization characteristics of certain groups of microorganisms as well as their interaction with the soil material is essential. Previously, most research into constructed wetland technology was mainly about technological design issues, with the active reaction zones being ignored. The main issues of concern were the inlet and outlet loads. This was mostly because of the lack of suitable testing systems and study methods. However, small-scale process modeling experiments are now currently being developed for the study of the processes in wetlands. This will make the use of this technology to be even more simplified. For the optimum performance of the systems, research is needed to achieve a better understanding of the complex interactions and processes involved in the systems itself. The understanding of these processes will enable the basic scientific aspects to be optimally combined with the technical possibilities available and thus enabling wetland technologies to be efficiently used on a broader scale or commercially in wastewater treatments. Maintenance and monitoring from time to time of a large scale should also be factored in commercial applications of wetlands technology.

Application of constructed wetland technology for commercial wastewater treatment could signify a step towards “green technology” as this technology is environ-mental friendly and sustainable. It eliminates the use of chemical such as those currently used in conventional wastewater treatment as well as minimizes the amount of carbon dioxide released into the atmosphere. Carbon dioxide released through microbial decomposition is re-used by macrophytes in the process of photosynthesis.

It is recommended that since this technology is relatively new in industrial and municipal applications, there is a need for continuous research and development to test the viability of this system under various condi-tions, including applicability for different types of waste-waters, effectiveness under different climatic conditions and the use of different materials and plants. The performance of existing constructed wetlands should be carefully monitored and additional research is required to optimize design and minimize construction cost. Local governments as well as international organizations involved in water and wastewater sector should promote this technology by building local capacity and scaling up its application.

CONCLUSIONS

In conclusion, constructed wetlands have a great potential for industrial and municipal wastewater treatment. With careful design and planning, they can treat wastewater with highest possible treatment levels. The cost for design, construction and implementation can be considerably lowered compared to other conventional wastewater treatment technologies. They provide a wide range of benefits in wastewater treatment and represent economic benefits in terms of energy consumption as well as providing opportunities for environmental aware-ness. They should be investigated and given a chance for use as an alternative technology in wastewater treatment by local municipalities and industries.

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