Chapter 2
The Treatment of Landfill Leachate and Other Wastewaters Using Constructed Wetlands

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1 Introduction

The world we are living in is slowly getting urbanized. The world's urban population which accounts for 55% today will rise to 66% by 2050 (World Urbanization Prospects: the 2014 Revision UN) (United Nations 2014). This increasing influx of the population into the cities has increased the stress in the water demand, as most of the cities are already facing severe water crisis (Hanjra and Qureshi 2010; Jury and Vaux 2007). Even if the water demand is met, it will create an additional challenge to treat wastewater generated, which accounts for almost 80% of water supplied. The latest report by United Nations World Water Assessment Programme (WWAP) (2017) highlighted that the 80% of the wastewater generated in the entire world is disposed without treatment, directly into the water bodies or open drainage and this figure is 95% in some poor countries. Disposal of this untreated wastewater in the lake, river, and stream will lead to unprecedented deterioration of health of these water bodies (Edokpayi et al. 2017; Lee et al. 2016; Khan and Ansari 2005). Untreated wastewaters have a very high concentration of nutrients, possibly heavy metals, emerging contaminants, suspended solids and pathogens, which alter the physical, chemical and biological properties of water, and thereby affect natural properties of water bodies, and biological life that thrive in it (Khan and Ansari 2005). Eutrophication, also known as an algal bloom, is one of the worst ramifications of excessive nutrient loading in water bodies due to discharge of nutrient-rich (nitrogen and phosphorus) wastewater in it (US EPA 1999; Khan and Ansari 2005).

The increase in the nutrient content in the water bodies increases the productivity of the lake, thereby increasing the growth of phytoplankton. This phytoplankton becomes the food for the algae (Huang et al. 2017; Ngatia et al. 2017; Ulloa et al.

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2017). Excessive growth of algae, fuelled by nutrient-rich wastewater covers the surface of water bodies, which is known as eutrophication, often called as an algal bloom (Anza et al. 2014; Khan and Ansari 2005; Glibert 2017). Other effects like pathogenic activity and accumulation of heavy metal and emerging pollutants have a direct implication on public health (Daley et al. 2015). The problem of treating wastewater has become even more serious in the developing nations, where availability of modern day wastewater treatment technology is in scarce (Chatterjee et al. 2016; Morel 2006). Taking into account the repercussion of untreated wastewater discharged in natural water bodies, and its effect on human health and environment, the need of decentralized treatment facility, which is less energy extensive, easily acceptable by locals, require less skill manpower and has zero carbon footprint, has become a necessity (Zaharia 2017).

When water flows through river, lake and streams, it gets purified naturally and one of these purifying processes is filtration (Cronk and Fennessy 2016; Gopal 1999; Idris et al. 2014). The other purification process that takes place in natural water bodies are sedimentation, biological assimilation of nutrients by plants and microorganism, adsorption etc. Natural wetland is one such body, where purification is relatively faster due to its complex composition of plant, soil and microorganism. Wetland soil could be always saturated with water or gets saturated occasionally. Availability of water determines the kind of plants it grows and kind of microorganism that thrives. A natural wetland is one among other several natural systems that were included into the definition of wetland by Ramsar Convention on Wetland of International Importance in 1971. Ramsar convention is an intergovernmental treaty for sustainable and wise use of natural wetland, which came into force in 1974, 4 years after it was adopted. It provides framework for conservation of wetland and its resources. A function of wetland is advantageous to both human and wildlife, due to its rich biodiversity (Knight 1997). Turbulent water becomes calmer as it enters wetland due to its interaction with vegetation; as a result suspended particle gets time to settle down and becomes a part of wetland sediment. Other pollutants are transformed to less soluble forms and some are taken up by the plants. The root matrix of wetland plants where biofilms get formed creates necessary conditions for microorganism to live and thrive on (Brix et al. 2002; Tu et al. 2014). A series of complex biochemical processes by these microorganisms makes transformation and removal of pollutants from wastewater possible (Brix et al. 2002; Stottmeister et al. 2003). The nitrogen and phosphorous which are major nutrients found in stormwater runoff, agricultural runoff and landfill leachate get deposited in wetland sediment, and are often absorbed by wetland soils and assimilated by plants and microorganisms (Koskiaho et al. 2003).

In the last few decades, natural wetland processes have been engineered in smaller scale for water quality improvement (Vymazal 2002, 2010a, b). This smaller, engineered version of wetland is known as constructed wetland (CW) (Brix 1993). The CW is an engineered system, designed to mimic natural treatment processes in the close conglomeration of wetland plants, sediment, and microorganism to improve water quality. Ever since West Germany built the first CW in 1974 (Zhang and Weiming 2011), different kinds of CW have been created to treat wastewater around the world (Hernandez-Crespo et al. 2017; Liu et al. 2017; Wang et al. 2017). The CW can be designed to treat different types of wastewater cost effectively with minimum usage of energy and manpower (Gazea et al. 1996; Liu et al. 2017; Wang et al. 2017). The CW can also be designed to remove nitrogen, phosphorous, heavy metals, solids, organic matter and pathogens from the wastewater (Vymazal 2013; Konnerup et al. 2009; Kivaisi 2001).

For underdeveloped countries of Asia and Africa treating wastewater by using conventional sewage treatment plants has always been a costly affair. These countries have neither the resource to meet energy demand much needed for treatment plants nor have skilled manpower to run the plant, except in the capital and big cities (Chatterjee et al. 2016). The minimum use of energy, no use of chemicals, the establishments of ecological habitat, aesthetically appealing are some of the added advantages of choosing CW as a wastewater treatment system which makes CW an epitome of sustainable approach, where science and nature go hand in hand. Thus integrating the wetland into treatment infrastructure will unleash its potential without affecting its basic utility as an ecosystem.

2 Introduction to the Constructed Wetland

The CW is an engineered system of water bodies designed as per need to treat pollutants found in sewage, industrial effluent or stormwater runoff (Jiang et al. 2016; Guo et al. 2017). The constructed wetlands are generally used in a decentralized manner in small communities, but in recent times it is being seen as a treatment alternative attributed largely to its evolution for treating few of the emerging pollutants (Sgroi et al. 2017; Matamoros et al. 2017; Dan et al. 2017). Vegetation (roots, stems and leaves) in a CW acts as a substrate upon which microorganisms can grow and develop biofilms as they breakdown organic materials (Kadlec and Wallace 2009; Shelef et al. 2013; Brix 1997). The community of microorganisms that thrive on the soil and root matrix of wetland is known as the periphyton (Liu et al. 2016). The biochemical activities by periphyton and natural physico-chemical processes are responsible for approximately 90 percent of pollution removal and breakdown (Tilley et al. 2014). The plants remove about 7–10% of pollutant by assimilation. It also acts as a carbon source for the microbes when they decay. Different species of aquatic plants have different rates of heavy metal uptake capacity, so knowledge of same is must while designing the CW for removing specific pollutants.

2.1 Types of Constructed Wetland

A CW can be categorized into two major groups according to the flow regime of wastewater that passes through it (Vymazal 2001; Brix 1997). These major groups are: surface flow CW and subsurface flow constructed wetland. The subsurface flow CW is further categorized as horizontal flow CW, vertical flow CW and hybrid flow constructed wetlands. In the free surface flow CW, the water flows freely above the ground, in a saturated media. The floating vegetation or emigrant plants are grown in this type of CW. Baffles are also used to control the flow of wastewater flowing through it, which gives more opportunity for a suspended matter to settle. Filtration and adsorption by wetland media, oxidation, reduction and precipitation by physicochemical processes catalyzed by the internal and external agent (sunlight, pH etc.) are the few mechanism by which the pollutants get removed from wastewater when it passes through the CW (US EPA 2000). It is very important to note that the wastewater should undergo preliminary treatment (sedimentation) before it is treated with CW. This preliminary treatment is done to minimize the clogging of filter media by settable solids. The plant root releases oxygen into its vicinity of its roots hair, which creates a condition necessary for the diverse biological and chemical processes to take place (Tilley et al. 2014).

Unlike in surface flow, where wastewater flows above the saturated media, in a subsurface flow CW, wastewater flows below the surface, within the media. The media are made up of sand or gravel. The media is kept unsaturated periodically. The subsurface flow CW is further classified into horizontal and vertical flow CW depending on the direction of flow of wastewater.

Figure 2.1 presents the different type of CW based on the flow direction. The direction of arrow tells us the direction of wastewater that flow in a CW. Based on

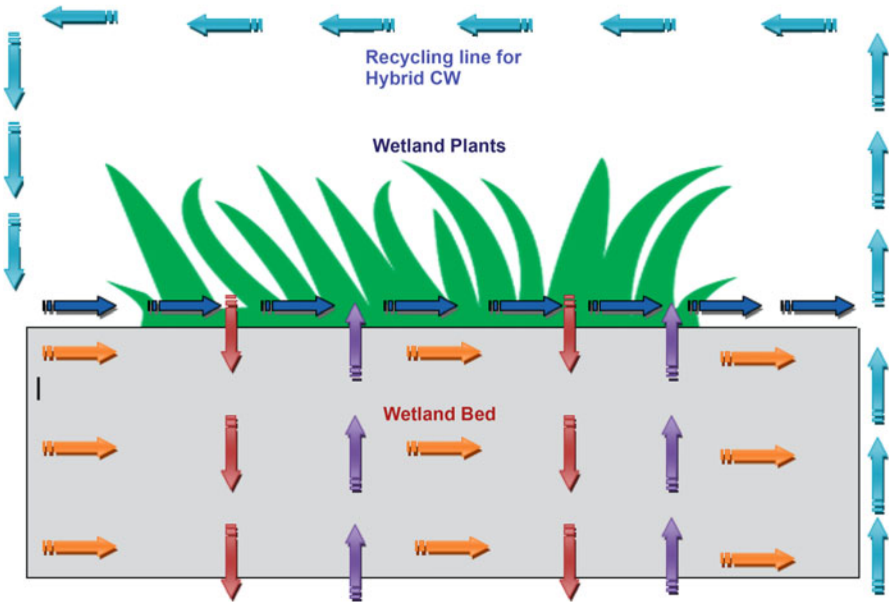

Fig. 2.1 Schematic presentation of different type of constructed wetland (CW) based on types of flow: Horizontal flow CW = →; Down flow vertical CW = ↓; Up flow CW = ↑; Surface flow CW = →; Recycling line for hybrid CW = ←

this flow, the CW is named as surface flow, subsurface flow, vertical flow or hybrid flow constructed wetland. As the name suggests, horizontal flow CW is one in which the flow of wastewater is horizontally in the subsurface. The media generally used are sand and gravel. Generally, the media is placed in well graded fashion with the large size gravel placed at the bottom to facilitate the drainage layer. In the top layer, the wetland plant is grown, roots of which grow to the layers below as well, making dense root matrix needed for effective pollutant removal.

The sand-gravel media not only act as a media for plant to grow on, but also act as the filter media for straining the solid particles in the voids it forms during interlocking. The media further provides the surface, upon which the bacteria can get attached to form bio-slime layers when organic-rich wastewater washes it. The root also transfers small amount of oxygen to its vicinity, thereby allowing the aerobic bacteria to colonize and degrade the organic matter. The permeability of the filter is maintained well by the plant's roots, generally through the area of root media interface (Tilley et al. 2014).

In the vertical flow constructed wetland, the flow of water is kept vertical to the subsurface layer. The flow is either upward or downward. The wastewater is intermittently applied throughout the bed. The filter undergoes the phases of the saturated and unsaturated condition during loading and non-loading of wastewater.

The wastewater percolates down the unsaturated bed, as the bed drains; air is also drawn along with it. The porous media give sufficient time for oxygen to diffuse throughout the media. The organic matter can be degraded by the aerobic bacteria near the root zone, where the oxygen is transferred by root. The deep root growth maintains the permeability of filter media. To decrease the excess biomass growth and to increase the porosity of media dosing rate and time is varied which forces the microorganism to starve (Hoffmann et al. 2011). To increase the treatment efficiency, different types of CW are linked to form a hybrid system. The water flowing out (effluent) of one wetland will be the influent for the second wetland in a series for a hybrid CW. The hybrid system reduces total nitrogen concentration from wastewater by enhancing nitrification and denitrification (USEPA 2000).

2.2 Plants Used in Constructed Wetland

The plants used in the CW can be broadly classified into three groups (Brix 2003): (1) Free-floating plants (e.g. *Eichhorniacrassipes, Lemna, Spirodella, Wolffia*); (2) Emergent plants (e.g. *Phragmites, Scirpus, Typha, canna*) and (3) Submerged plants (e.g. *Isoteslacustris, Elodea canadensis*). It should be understood that all the type of plant, namely, floating, submerged and emergent, all help in increasing oxygen concentration within the system thereby provide necessary biological as well as the chemical condition for degradation of pollutants. The floating plants derive nutrient from wastewater but very less from the substrate, unlike emergent and submerged which derive nutrient mostly through substrate. The nutrient gets adsorbs in the filter media which the microorganism and plant can assimilate upon.

The submerged and emergent plants provide a maximum surface area for biofilms growth; they are also better in increasing sedimentation rate of solid as their roots and stem hinder the flow rate of incoming wastewater.

2.3 Role of Plant Macrophytes in Constructed Wetland

The performance of CW largely depends on the root matrix created by wetland. The hollow system in the plant tissues enables oxygen to be transported from the leaves to the root zone and to the surrounding soil, which helps in creating aerobic condition in its premises. Figure 2.2 illustrates the role of the plant in CW. This diffused oxygen by plant facilitates aerobic degradation of pollutants. The role of wetland plants in CW systems can be divided into six categories as explained below.

1. **Physical** – Plant controls the surface of media beds, helps in a filtration, and provides a large surface area for microbial growth. The growth of plants minimizes inflow velocity of wastewater which increases sedimentation rate of solids (Brix et al. 2002).
2. **Increase in porosity** – The plant root is seen to improve the porosity of wetland soil media through root media interface. The increase in porosity improves

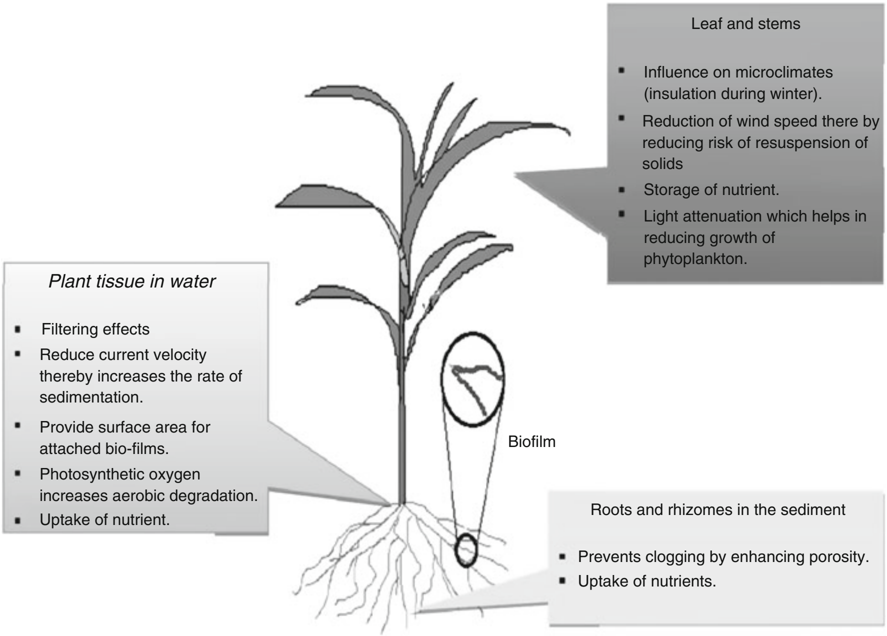

Fig. 2.2 The role of plants in the constructed wetlands (Brix 1997)

aerobic condition in the system which helps in aerobic degradation of pollutants (Brix et al. 2002).
3. **Microbial growth** – Macrophytes provide a large surface area for growth of microbial biofilms. These biofilms are responsible for a majority of the microbial processes in a CW, including nitrogen removal (Brix et al. 2002).
4. **Creation of aerobic soils** – Macrophytes facilitates the transfer of oxygen through the pores of plant tissue and transfers it to rhizosphere via root system where aerobic removal of organic matter and nitrification takes place (Reddy et al. 1990; Brix et al. 2002).
5. **Aesthetic values** – The wetland plants provide a habitat for wildlife and makes wastewater treatment systems aesthetically and publicly acceptable.

Flower bearing wetland plants like canna lilies increases the aesthetic value which is easily accepted by public (Ojoawo et al. 2015; Brix et al. 2002). The wetland premise can be open up for public which helps in generating revenue.

3 Landfill Leachate Treatment Using Constructed Wetland

To better understand the treatment of landfill leachate using CW, it becomes imperative to understand characteristics of landfill leachate. Landfill leachate is a complex polluted liquid that gets formed due to passing of rainwater through landfill and brings along out with it high amount of dissolved as well as suspended matter. The formation of the dissolved and suspended matter is due to biochemical process that takes place inside the landfill. The landfill leachate is characterized by high amount of organics (BOD and COD), nutrient (nitrogen and phosphorus), dissolved solids, heavy metal etc. The characteristics of typical landfill leachate are presented in Table 2.1. However, the composition of landfill leachate varies significantly with respect to landfill age (Renou et al. 2008). The main mechanisms through which the contaminants are leached through the landfill are dissolution of soluble materials, biodegradation of organic matters, chemical reduction and washing of fine materials (Bricken 2003).

Section below explains in detail about contaminant from landfill leachate gets removed in a CW. Removal mechanism of nutrient like nitrogen and phosphorus is explained in detail.

3.1 Organic Matter Removal

The removal efficiency of the organics (BOD_5 and COD) in the CW is very high. Up to 90–99% removal efficiency of BOD_5 and COD is reported in literature (Vymazal et al. 1998; Kadlec and Knight 1996). Under normal condition, the settleable organic is removed by simple sedimentation and filtration. Both anaerobic and aerobic activity

Table 2.1 Characteristics of raw landfill leachate

Parameters	Units	Ghafari et al. (2009)	Al-Hamadani et al. (2011)	Othman et al. (2010)	Akinbil et al. (2012)	Nivala et al. (2007)	Bulc (2006)	Yalcuk and Ugurlu (2009)
pH		8.4	8.13	8.26	8.42	–	–	–
Colour	TCU	3869	3140	2933	3360	–	–	–
Turbidity	NTU	–	–	–	140	–	–	–
TSS	mg/L	80	380	130	685	186	38.3	–
COD	mg/L	1925	2130	3180	923.44	781	485	4770
$BOD_5^{20\ °C}$	mg/L	–	–	231	686	116	76	–
NH_3-N	mg/L	1184	1950	2050	238	212	496	2865
Phosphorus (P)	mg/L	–	–	–	117	–	2.3	75
Nitrogen (N)	mg/L	–	–	–	400	–	–	67.7
Iron	mg/L	–	–	5.3	6.19	21	–	–
Manganese	mg/L	–	–	0.23	24.8	–	–	–
Magnesium	mg/L	–	–	–	660	–	–	–
Zinc	mg/L	–	–	3.4	7.43	–	–	–

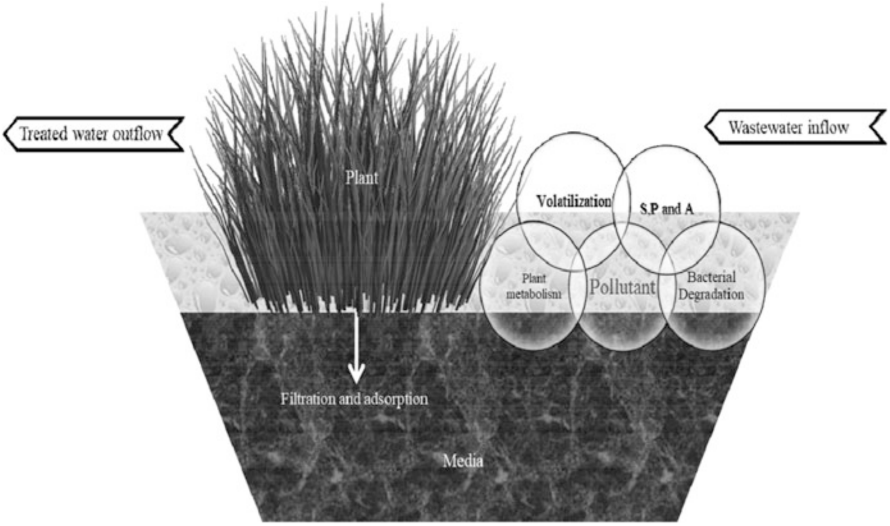

Fig. 2.3 Fate of pollutant in the constructed wetland (S, P&A = Sedimentation, Precipitation and Adsorption)

takes place to degrade the organics in wetlands. Figure 2.3 illustrates the fate of pollutants in the constructed wetland. The degradation of organics takes place in the biofilms established by microorganism around the filter media, roots etc. (Kadlec 2009).

The oxygen required for the process to undergo is met through direct diffusion, also called as surface transfer, or by oxygen leakage from the root of macrophytes. The root system that gets developed deeper into the lower media layer will maximize the pollutant removal in all parts of media (Tilley et al. 2014). The deep root system which increases the porosity of media also enhances the movement of oxygen diffused through wastewater from surface, thus enhancing oxygen availability (Hoffmann et al. 2011).

3.2 Phosphorous Removal

Phosphorus is present in wastewater as orthophosphate, polyphosphate and organic phosphorus. The conversion of most phosphorus to the orthophosphate forms is caused by biological oxidation (Vymazal et al. 1998). The phosphorous removal is achieved by adsorption, assimilation and precipitation reaction involving iron and aluminum; so it can be said that the removal of phosphorus depends on the concentration of iron and aluminum in the filter media. The phosphorous is removed through precipitation by iron (Fe) and aluminum (Al) (Vymazal et al. 1998). It is to be understood that only ortho phosphorous is believed to be directly utilized by algae and macrophytes (Vymazal 1995).

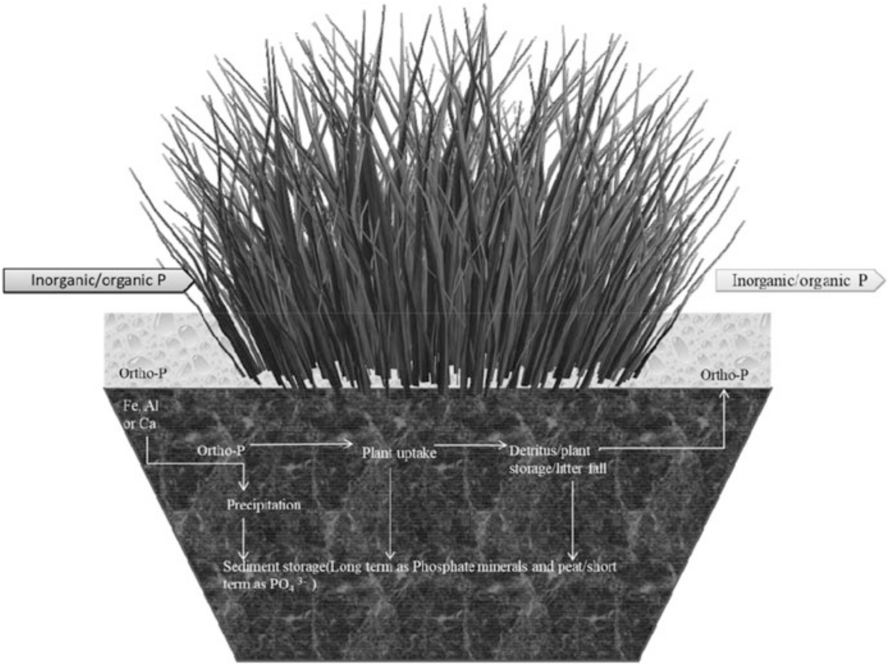

Fig. 2.4 Fate of phosphorous in the constructed wetland

Uptake by macrophytes is accounted to be low, as it removes only small fraction of the total phosphorus. The harvesting of biomass to enhance the uptake of phosphorus by plants and thus removal is recommended (Vymazal et al. 1998; Wang et al. 2015). The fate of phosphorus in the constructed wetland is illustrated in Fig. 2.4. It is estimated that a phosphorus removal ratio by plant growth of up to 10% is possible depending on the climate, plant and type of wastewater. The phosphorous removal efficiency decreases over time due to the decrease in the adsorption sites in the filters (sand and gravel). To overcome this problem, a separate unplanted filter media is advised to be constructed in downstream to enhance phosphorous precipitation (Hoffmann et al. 2011) and to keep treatment system running.

Phosphorus is an essential requirement for biological growth. An excess of phosphorus can have secondary effect of triggering eutrophication within a wetland which is caused by an algal blooms. The phosphorous removal in all types of CW is low but this can be increased by using proper substrate, the substrate with high Al and Fe content (Vymazal 2007). The red soil has high iron content which has a potential to reduce the phosphorous in the wastewater by forming the phosphorus complex. The high phosphorous removal efficiency in the vertical CW with red soil is observed (Villar et al. 2012).

3.3 Nitrogen Removal

Nitrogen concentration in wastewater is often of concern because of its potential to cause adverse effect in receiving water systems. Among various nitrogen groups, dissolved inorganic nitrogen species like nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3) or ammonium (NH_4) have the greatest impact on aquatic systems, because they are easily available for uptake by microorganisms. The removal mechanisms for nitrogen in constructed wetlands include ammonification, nitrification/denitrification, plant uptake and root system adsorption (Chang-gyun et al. 2009; Korkusuz et al. 2004). The removal of organic substances, typically 80–90%, is achieved in constructed wetlands. However, the nitrogen removal rates are often not up to the mark. A variety of nitrogen forms in constructed wetlands can be removed through specific treatment processes, such as combined nitrification-denitrification and sedimentation, particularly at the sediment-water and water-plant interface (Vymazal et al. 1998; Lee et al. 2009). Figure 2.5 elucidates the fate of nitrogen in CW.

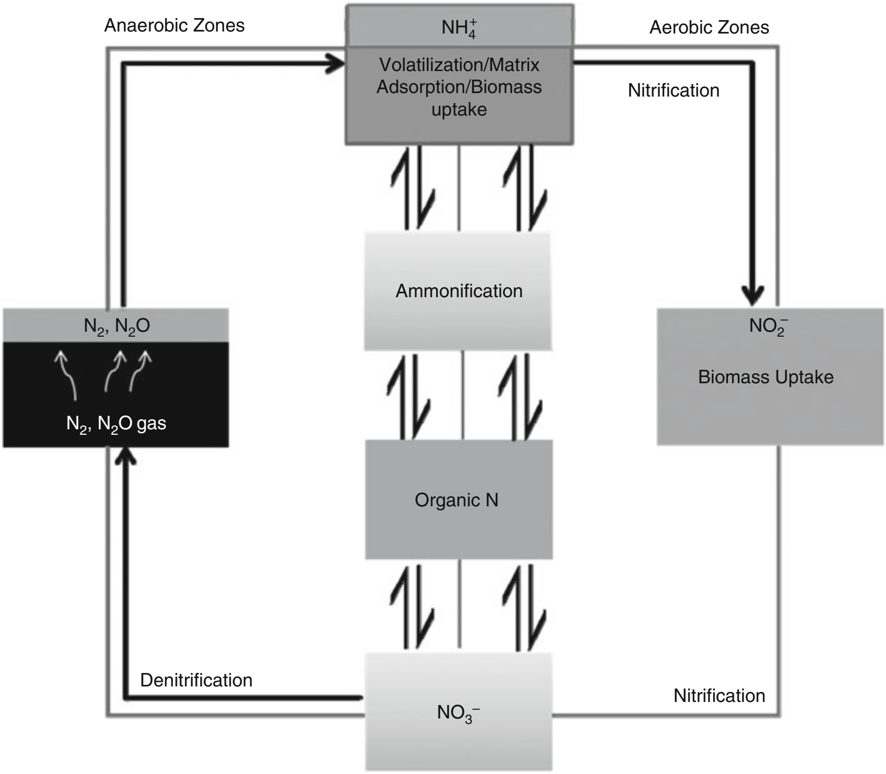

Fig. 2.5 Nitrogen fate in the constructed wetland

With proper aeration facility the total nitrogen removal efficiency can be increased up to 90% or even greater (Davies and Hart 1990). Vymazal (2007) found out that the total nitrogen removal efficiency in his established constructed wetlands varied between 40% and 50%, depending on CW type and inflow loading. It was inferred that single stage treatment wetland is less efficient than the hybrid system due to inability to provide both the conditions of aerobic and anaerobic needed for nitrification and denitrification to take place. It was further quoted that vertical flow CW successfully removes ammonia but very little denitrification takes place and on the contrary, the horizontal flow CW provides good condition for denitrification but its ability is limited for nitrification only (Vymazal and Kröpfelová 2011). Wang et al. (2009) found out that, with increasing hydraulic load, the removal efficiency of COD was stable. The wetland can resist the impact of COD but the removal rate of TN (total nitrogen) decrease with the increase in hydraulic and pollution concentration loading rate. The increase in hydraulic loading rate and decrease in oxygen release by plant in the wetland can be the reason for less TN removal (Wang et al. 2009). The C:N (carbon-nitrogen ratio) is also the reason for less removal of TN in the constructed wetland. The TN removal happens best in the high ratio of carbon and nitrogen. Both of the bacteria nitrosomonas and nitrobacteria use the inorganic carbon compound for cell synthesis. The denitrification is the process by which nitrite and nitrate are eventually converted to nitrogen gas while oxidizing the carbon for energy (Khanitchaidecha et al. 2010; Carley and Mavinic 1991). Nitrogen can also get adsorbed to sand and soil differently, the substrate of the sands can absorb N to a certain degree, which has a significant effect in TN removal (Zhang et al. 2007).

3.4 Nitrification

Nitrification is a two-step process, where conversion of ammonia to nitrate takes place in strict aerobic condition.

(a) Ammonia to nitrite

$$\left(\mathrm{NH_4}^{+} + 1.5\mathrm{O_2} \rightarrow \mathrm{NO^{-}}_2 + \mathrm{H_2O} + 2\mathrm{H}^{+}\right)$$

(b) Nitrite to nitrate

$$\left(\mathrm{NO^{-}}_2 + 0.5\mathrm{O_2} \rightarrow \mathrm{NO^{-}}_3\right)$$

Vymazal et al. (1998) pointed out that the nitrification is influenced by temperature and pH. The intermittently loaded vertical flow CW have the high rate of oxygenation; therefore it provides good nitrification (Brix 1998). The oxidation reactions release energy used by both nitrosomonas and nitrobacter cell synthesis. The combined processes of cell synthesis create 0.17 g of dry weight biomass per gram of ammonia nitrogen consumed (Kadlec and Wallace 2009). Nitrification is an aerobic process carried out by autotrophic bacteria, commonly nitrosomonas and nitrobacteria. They derive energy from the oxidation of ammonia and nitrite. The nitrosomonas only oxidize ammonia to nitrite while later can only oxidize nitrite to nitrate. Both of the bacteria use the inorganic carbon compound for cell synthesis. The growth rate for nitrosomonas is less than that of nitrobacter, thus nitrite accumulation should not occur in the aerobic basin unless nitrobacter is inhibited (Khanitchaidecha et al. 2010).

3.5 Denitrification

The first oxidation process to occur after oxygen depletion is the reduction of nitrate to molecular nitrogen and nitrogen gases, which is called as denitrification. In a vertical-flow constructed wetlands very high nitrification process takes place because of entirely aerobic conditions but no denitrification takes place. In order to achieve effective removal of total nitrogen, vertical flow CW should be combined with horizontal flow CW which provides suitable conditions for reduction of nitrate formed during nitrification to free nitrogen (Brix and Arias 2005). Denitrification is the process by which nitrite and nitrate are eventually converted to nitrogen gas while oxidizing the carbon for energy. The denitrifying bacteria are *Pseudomonas*, *Micrococcus*, and *Bacillus* (Khanitchaidecha et al. 2010).

3.6 Pathogen Removal

The public health is always the centre of reason for treating wastewater. All the treatment methods try to address this centre reason (Metcalf and Eddy 1991). Pathogens are seen predominantly in domestic wastewater. The conventional treatment process adds up some chemicals like chlorine and ozone to get rid of this pathogen. Also, the higher operational and maintenance cost limits the use of ozonation and ultraviolet disinfection for pathogen removals (Metcalf and Eddy 1991). The CW is better known to eliminate these constraints with its suitable combination of a physical, chemical and biological factor for pathogen removal (Vymazal 2005). The pathogen treatment in wetland systems relies on sedimentation, natural die-off, temperature, oxidation, predation and UV radiation (Vymazal 2005; Alufasi et al. 2017). The pathogen removal is most often required when dealing with domestic wastewater. The reduced microbial activity, reduced plant activity, and freezing of the water can all occur due to cold temperature. The human pathogens function most efficiently around internal body temperatures (~37 °C). It is found out that decreased temperatures outside will inactivate pathogens. The inactive pathogens are easy to treat (Weber and Legge 2008). Some bacteria are facultative or anaerobic and thus the presence of oxygen creates unfavourable conditions for these organisms (Vymazal 2005).

Song et al. (2008) investigated the efficiency to remove pathogen by the construal wetland and found out that the system effectively removes *E. Coli*, fecal and total coliforms. Zhang and Weiming (2011) have investigated the effect of water temperature, water quantity, water loads, influent concentration and pH in the treatment efficiency of the constructed wetland. These five impact factors selected were used in PCA (principal component analysis) method which helps to establish relation between the removal efficiency and the impact factors. The analysis was done for total nitrogen (TN), total phosphorous, BOD_5, suspended solids and fecal coliform. The average removable rate of each was greater than 60% and for fecal coliform it was 99%. It was also found that the temperature, concentration, and load have significant impact than the pH and water quantity. It was found out that the temperature plays vital role in microbe's activity.

4 Constructed Wetland for Treatment of Different Types of Waste Water

4.1 *CW for Removal of Emerging Contaminant*

Emerging contaminants are called so as they are new groups of compound with little to nil knowledge about its eco-toxicological effect. This includes pharmaceutical products, personal care products, surfactants, plasticizers, herbicides etc. (Murray et al. 2010). The antibiotic resistance gene (ARG) is also labeled as the emergent contaminant (Pruden et al. 2006). The CW tends to remove emerging pollutants like diclofenac, ketoprofen, caffeine etc. with higher efficiency as compared to a pond (Matamoros and Bayona 2006; Matamoros and Salvadó 2012). The reason of better functioning of CWs for removal of emerging contaminants is attributed to higher HRT (Hydraulic Retention Rate) and presence of plants. The specific condition which prevails in a wetland matrix enhances the removal of these emerging contaminants. For example, Avila et al. (2013) found out that the ibuprofen biodegradation takes place under aerobic condition in their horizontal flow CW. Better removal of emerging contaminants from CW is also credited for high temperature and different physico-chemical condition prevailing in the wetland which facilitates different abiotic/biotic factors for its effective degradation. These different factors are biodegradation, sorption, volatilization, hydrolysis, and photo-degradation (Avila et al. 2015). Table 2.2 highlights few emerging contaminants removed by the different type of CW and its removal mechanism. The study by Chen et al. (2015) found that to remove antibiotics and antibiotic resistance gene from wastewater using CW, the major mechanism for removal of antibiotics in CW is due to adsorption onto media and sludge and very little is attributed to biodegradation.

Table 2.2 Few emerging contaminants removed (percentage removal) by different type of constructed wetlands and its removal processes

Some emerging contaminants	Diclofenac	Kteoprofen	Ibuprofen	Salicylic acid	Caffeine	Naproxen	Types of CW	References
Percentage removal	<50	>85	50–85	>85	50–85	50–85	SSFCW	Zhang et al. (2012)
	<50	<50	50–85	>85	>80	50–85	SSFCW	Matamoros and Bayona (2006)
	55–95	–	>98	–	–	–	VFCW	Avila et al. (2014)
	89	–	99	–	–	–	HFCW	Avila et al. (2015)
	19–21	–	12–44	–	–	57–75	HFCW	Matamoros et al. (2017)
	70–90	>95	>95	>95	70–90	–	VFCW	Matamoros et al. (2007)
Removal mechanism of different emergent contaminants	Bio degradation, photo degradation and plant uptake[a]	Temperature dependent bio-degradation[b]	Aerobic degradation[c]	–	Anaerobic bio-degradation and plant uptake[d]	Plant uptake[e]		[a] Matamoros et al. (2012), [b] Zhang et al. (2012), [c]Hijosa-valsro et al. (2010a, b), [d] Zhang et al. (2013), and [e]Hijosa-valsero et al. (2010a, 2011)

Note: SSFCW = Sub surface flow constructed wetland; VFCW = Vertical flow constructed wetland; HFCW = Hybrid flow constructed wetland

Table 2.3 Domestic wastewater treatment by constructed wetland (Influent and effluent concentration)

	Influent, mg/L	Effluent, mg/L	References
BOD_5	100–400	0–12	Shrestha et al. (2001)
	392	81	Karathanasis et al. (2003)
COD	177–687	7–72	Shrestha et al. (2001)
Nitrogen	4–26	0–2	Shrestha et al. (2001)
	1681	635	Nakamura et al. (2017)
Phosphorous	1–5	1–4	Shrestha et al. (2001)
	561	15	Nakamura et al. (2017)

The photo-degradation also contributes to the abiotic transformation of the emergent contaminant in the wetland; this transformation is however limited by pH and dissolved organic carbon (Jasper and Sedlak 2013).

The major antibiotics removed in the study by Chen et al. (2015) were ofloxacin, anhydrous-erythromycin and sulfamethazine. The ARGs removal is mainly attributed to biodegradation and sorption onto media. Chen et al. (2016) in his studies found out that mesocosm scale CW can remove antibiotic and ARG on par with conventional wastewater treatment systems. The study further suggested that using different filter media, this removal efficiency can be further enhanced.

4.2 *Constructed Wetland for Sewage Treatment*

Since the water demand in the urban area is very high and if the cheap treatment alternative provides reusable water, the stress in water demand will be greatly reduced. The constructed wetland can treat the domestic wastewater with high removal of BOD_5, nitrogen, phosphorous etc. (Liu Wen et al. 2011) and make water fit for reuse for various purposes (Vymazal 2010a, b).

Table 2.3 highlights removal of few organic contaminants by CW. Shibao Lu et al. (2015) constructed a multi-layer CW for treatment of domestic wastewater for research purpose. The wetland was evaluated for the removal of COD, BOD_5, nitrogen and phosphorous. The results were positive and the removal rates were 90.6%, 87.6%, 66.7% and 90% respectively.

4.3 *Constructed Wetland for Industrial Wastewater Treatment*

The alternative treatment system like CW faces a lot of question when it is used for industrial wastewater treatment. Most of the industries use the conventional mechanical and chemical based treatment process. For any process to replace this system it should meet few prerequisite like fast and easy treatment process and low area requirements. However, the need for industries to implement green norms can be a great driving factor to accept CWs as a treatment infrastructure which helps them maintain their green image (Wallace 2010). Ongoing research related to the CW focus mainly on industries specific contaminant removal unique to the particular industry. Some of the applications of CW in the industrial wastewater treatment are:

- Leachate control from landfill (Yi et al. 2017; Mojiri et al. 2016; Madera-Parrra et al. 2015).
- Mines drainage (Mitsch and Wise 1998; Gandy et al. 2016)
- Pulp and paper industry (Choudhary et al. 2001; Arivoli et al. 2015)

Zhang et al. (2010) studied metal uptake test by Vallisneriaspiralis in a constructed wetland. Chromium was effectively removed by adsorption and absorption into plant tissue but this drastically reduced the photosynthetic activity in the plant. Further, eight laboratory-scales CW were set up to remove metals in mine wastewater containing lead (Pb) and zinc (Zn). It was found that the wetland system can remove 90% Pb and 72% Zn. The harvest of biomass is very necessary to increase metal uptake, as new plant tissue that grow after harvest will take up metal more quickly.

4.4 Constructed Wetland for Agro-dairy Industries

Kadlec and Wallace (2009) found out that the constructed wetland treatments are compatible with typical farm and ranch operations. Types of livestock wastewater being treated by constructed wetlands include dairy manure and milk-house wash water, runoff from concentrated cattle feeding operations, poultry manure and swine manure (Cronk 1996; Julie et al. 1995). The most important constituents in animal wastewater are nitrogen and phosphorus and both of these can be reduced in constructed wetlands if conditions are suitable.

Nitrogen makes its way to an animal wastewater treatment CW in either as an organic or inorganic form. Nitrate and nitrite are inorganic forms, which may be eliminated from the wetland through volatilization, plants uptake or by nitrification process. Above satisfactory nitrogen removal rate have been found in many wetland studies as the removal of nitrogen involves microbial processes. Nitrogen removal is high during the growing season when high temperatures facilitate microbial growth. In addition, uptake of nitrogen by plants occurs during the growing season only. Adsorbed phosphorus on soil particles is taken up by the plants. Adsorption is the main process for phosphorus removal in constructed wetlands. Aerobic condition favours the phosphorus adsorption, and in the anaerobic conditions adsorption of phosphorus in wetlands is found to be less than on dry soil. As phosphorus loading to a CW happens over a period of several years, the adsorption capacity decreases and the phosphorus gets released.

4.5 Constructed Wetland for Urban Storm Water Treatment

Kadlec and Wallace (2009) found out that the CW can be effectively used to treat urban storm water which generally contains high suspended solids (SS), suggesting that the sedimentation pond should also be constructed along with CW to reduce the loading of SS in the constructed wetland.

The CW removes many contaminants from the water like organics, suspended solids, nitrogen, phosphorous, pathogens and trace metals (Vymazal et al. 1998). The ability of the CW to remove metals like Zn, Ni, Pb, Cu etc. from urban runoff was demonstrated (Scholes et al. 1998) in south-east England. The hybrid CW coupled with sedimentation was constructed by Choi et al. (2015) to remove COD, TN, TP and heavy metals like Fe, Cu and Zn. The removal efficiency of 51–70% was observed. In a study Griffiths and Mitsch (2017) has observed the potential removal of nutrient by wetland from urban runoff in tropics condition and have seen the significant removal of nitrogen and phosphorus. The heavy metal uptake by wetland plant is very less as compared to heavy metal deposition into wetland sediment (Gill et al. 2017). On an average 86% removal of Zn and 60%, Cu was documented over a 9-year study by Gill et al. (2017) using free flow CW which was designed to treat motorway runoff. Schmitt et al. (2015) in their study found out that CWs can remove solids and COD upto 98%. The removal mechanism for total nitrogen and total phosphorus was mainly attributed to biochemical transformation. The sediment storage of micro pollutants from storm water was also observed in CWs (Schmitt et al. 2015). However due to occurrence of large amount of suspended solids in storm water, frequent clogging of CW media may arise, thereby, reducing its utility as treatment unit.

5 Integration of Constructed Wetland and Microbial Fuel Cell

In recent years, researchers have explored the potential of harvesting dual benefits from engineering CW in such a way that it treats wastewater and at the same time it also produces electricity. This dual benefit is made possible by integrating microbial fuel cell (MFC) within the strata of CW. The integration is made possible after identifying few common grounds. Both the systems (MFC and CW) largely depend on the microbial action for their performance (Doherty et al. 2015a). The MFC consists of the cathode, an anode, an external circuit and a separator. It requires anode to remain anaerobic while the cathode is exposed to oxygen and both the electrodes are separated by the separator. At either side of this separator oxidation and reduction take place (Yadav et al. 2012). Interestingly CWs provide both this type of aerobic as well and anaerobic zone, where oxidation and reduction take place (Doherty et al. 2015a). Since the ability of CW to treat wastewater is time tested and well established, a natural concern is the fact that will the integration of MFC with

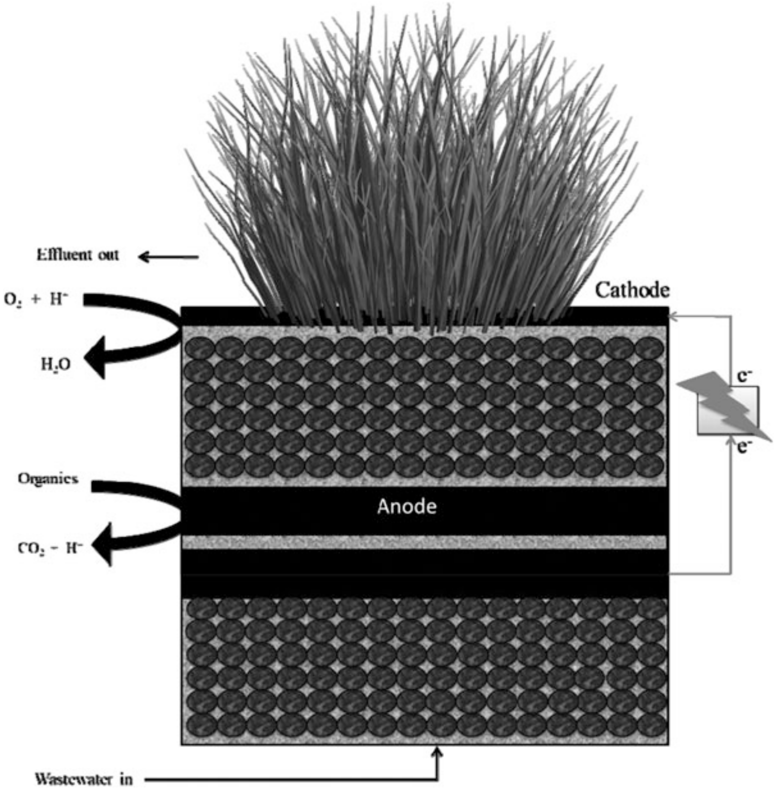

Fig. 2.6 Integration of constructed wetland and microbial fuel cell. (Adopted from Fang et al. 2017; Doherty et al. 2015a)

CW undermine the other's performance. To answer this question, researchers have found that coupling two systems actually in fact increase the performance by providing synergy effect (Fang et al. 2013; Doherty et al. 2015).

Figure 2.6 illustrates the integration of CW with the microbial fuel cell. The study by Fang et al. (2013) for decolorization of azo dye in MFC coupled CWs found out that the presence of anode significantly improved dye decolorization by 15%. The result was tested with the open circuit which shows less percentage decolorization. The dyes get adsorbed at anode surface where bio-films get developed and later get oxidized by bacteria which releases more electrons which ultimately helps in functioning of MFCs (Fang et al. 2013). Similar result was also obtained by Fang et al. (2015), where dyes decolorization varied from 36% to 66%. The integration of CWs and MFC is subject to great optimization of different parameters such as organic loading rate (COD loading significantly affects the system), redox condition (redox gradient between anode and cathode needs to be prudently optimized), wetland plants and bacteria (Doherty et al. 2015).

6 Recommendation and Conclusions

The following points highlight our suggestion for successful implementation of CW in developing nations:

- Use of free land/arid land: Using available free and arid land will bring down the cost to a large extent. Constructing CW in the arid land will also help in creating habitat for many species of amphibians and reptiles.
- Using cheap clay liner as an impermeable layer will eliminate groundwater contamination.
- More pilot scale studies and modelling studies similar to the study by Galanopoulos et al. (2013) will help us predict different attributes that may contribute to design better full scale CW with improved function and resiliency.
- Control of vector and odour: Bottom leaves of the plant will get dipped in water and gets decomposed; many dead leaves and dead plants will also decompose. Therefore it is advised to occasionally remove such fallen leaves and dead plants to minimize odour and vector problem.
- Introduction of nematodes and local fish will help in getting rid of mosquitoes larvae, thereby, reducing breeding of vectors.
- The CW premise can be upgraded as a tourist spot and environmental education centre; revenue generated from it can be used to run lab and R&D programme within wetland premise.

Constructed wetland provides beneficial treatment alternatives in many of the developing nations owing to its cost-effectiveness. The urban wetland system which is currently being researched and implemented in many countries can not only provide pleasing aesthetic appeal but also helps in treating storm-water runoff and other types of wastewater. One of the main drawbacks which arise while planning to adopt CW is the larger land requirement. For developing nations with sparse population, land requirement may not pose serious problem but, for many developed and developing nation with dense population, making land available is nearly impossible. As a result they opt for costly, modern day treatment facilities. Modern-day wastewater treatment facility comes with the high capital cost and requires skilled labour. However, developing nation lack both skill manpower as well as capitals cost.

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