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CONSTRUCTED WETLAND TECHNOLOGY TO PREVENT WATER RESOURCES POLLUTION

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Abstract
Discharge of untreated waste waters into surface waters creates significant pollution in these resources. Wastewaters are most of the time discharged into seas, rivers and other water bodies without any treatments due to high treatment costs both in Turkey and throughout the world. Constructed wetlands, also called as natural treatment systems, are used as an alternative treatment system to conventional high-cost treatment systems because of their low construction, operation and maintenance costs, energy demands, easy operation and low sludge generation. Today, constructed wetland systems are largely used to treat domestic wastewaters, agricultural wastewaters, industrial wastewater and runoff waters and ultimately to prevent water pollution and to improve water quality of receiving water bodies. In present study, currently implemented practices in design, construction, operation and maintenance of constructed wetlands were assessed and potential mistakes made in different phases these systems were pointed out and possible solutions were proposed to overcome these problems.

Keywords: Constructed wetland, water resources, pollution, rural

1. INTRODUCTION

Demands for fresh water resources are continuously increasing together with increasing world population. Domestic, industrial and agricultural sectors are in continuous competition for these limited fresh water resources. Therefore, there is also an ever-aggravating pressure exerted on water resources. Haphazard discharge of wastewaters into receiving bodies creates significant environmental problems and pollutes both surface and groundwaters. Continuously polluted waters, decreasing water resources with current global warming and climate chance, increasing labor and energy costs all brought the water and treatment technologies into the first place of the world's agenda. To solve the water-related problems, initially water losses in agricultural, domestic and industrial uses should be prevented, efficient water use should be provided, water-saving technologies should be implemented and possible use of wastewater and treated water should be investigated (Gökalp and Çakmak, 2013).

As it was in most parts of the world, wastewater effluents are most of the time discharged into seas, rivers and other water bodies without any treatments due to high treatment costs. Municipal wastewater indicators for Turkey are provided in Table 1. With the new municipality laws, number of municipalities decreased from 3227 in 2002 to 1396 in 2014. Of these 1396 municipalities, 1309

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are served by sewerage systems (90%). About 44.6% of 4.3 billion m^3 wastewater is discharged into seas, 44.2% into rivers, 2.8% into dams, 2.2% into lakes, 0.4% into lands and 5.8% into other receiving bodies. About 81% of discharged wastewater is treated. The rate of advanced treatment was 38.3%, while the rate of biological treatment was 32.9%, the rate of physical treatment was 28.5% and the rate of natural treatment was 0.3%. About 52.7% of the treated wastewater was discharged into sea, 39.2% was discharged into river, 1.9% was discharged into dam, 1.1% was discharged into lake and artificial lake, 0.3% was discharged into land and 4.8% was discharged into other receiving bodies (Anonymous, 2014).

Table 1. Municipal wastewater indicators

Indicator	**2006**	**2008**	**2010**	**2012**	**2014**
Total number of municipalities	3225	3225	2950	2950	1396
Number of municipalities served by sewerage systems	2321	2421	2235	2300	1309
Rate of population served by sewerage systems in total municipal population (%)	87	88	88	92	90
Total amount of wastewater discharged into receving bodies (million m^3/year)	3367	3261	3582	4073	4297
Sea	1523	1458	1499	1843	1915
Lake-reservoir	46	67	76	75	94
River	1411	1404	1741	1817	1899
Land	121	50	35	36	18
Dam	122	115	130	114	121
Other	145	166	101	187	250
Amount of wastewater treated in wastewater treatment plants (million m^3/year)	2140	2252	2719	3257	3484
Average amount of wastewater discharged per capita per day (liters/capita-day)	181	173	182	190	181

Beside advanced treatment systems and ordinary conventional systems, natural treatment systems, also called constructed wetlands, have started to be implemented especially in rural parts of Turkey. Constructed wetlands with their cheaper and easy construction, low energy and labor costs, easy operation, maintenance and monitoring were also specified as the primary issue in rural development strategy document of State Planning Organization of Turkey (Anonymous, 2006). In present study, constructed wetlands were briefly introduced and general criteria to be considered in their design, construction, operation and maintenance were provided, problems encountered in currently constructed and operating ones were pointed out and prospective solutions were provided for those problems experienced in in their design, construction, operation and maintenance.

2. CONSTRUCTED WETLANDS

Constructed wetlands totally imitate the processes going on in natural wetlands. The natural wetlands are transition zones between lands and water bodies and include the sites with specific flora and fauna adapted to these regions and characterized with their high water tables and high organic matter contents (Çiftçi et al., 2007). Nutrient inflow to wetlands supports the growth of vegetation and such vegetation constitute the primary component of wetland food-chain and converts inorganic materials into organic materials (Hammer and Bastain, 1989).

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Natural wetlands provide a habitat for a rich flora and fauna, stabilize the water regimes, purify waters through retaining residues and poisonous materials or using nutrients (nitrogen, phosphorus), raise the humidity of the region and have positive impacts primarily on local climate parameters.
Although researches indicated high waste water treatment performance of natural wetlands (Knight el al., 1987; Kadlec and Knight, 1996), such implementations may have some adverse effects with regard to preservation of these sites. Toxic elements in wastewaters, negative impacts of pathogens and additional hydraulic loading and nutrients can cause long-term degradations in these natural systems. Therefore, constructed wetland technologies have been developed instead of natural ones for wastewater treatment purposes.
Constructed wetlands are specially designed systems imitating the natural wetlands and include soil, plant and microorganisms to remove the pollutants from wastewaters. An excavated constructed wetland basin is lined with compacted clay or synthetic membrane and filled with graded sand-gravel substrate (Anonymous, 2011). Today, constructed wetlands are widely used to treat domestic wastewaters (Cooper et al., 1997), agricultural wastewaters (Rivera et al., 1997), industrial wastewater and runoff waters (Dombush, 1989). Constructed wetlands (Figure 1) are natural treatments systems employed as an alternative to conventional treatment systems because of their low construction, operation and maintenance costs, low energy demands, simple operation and low sludge generation.

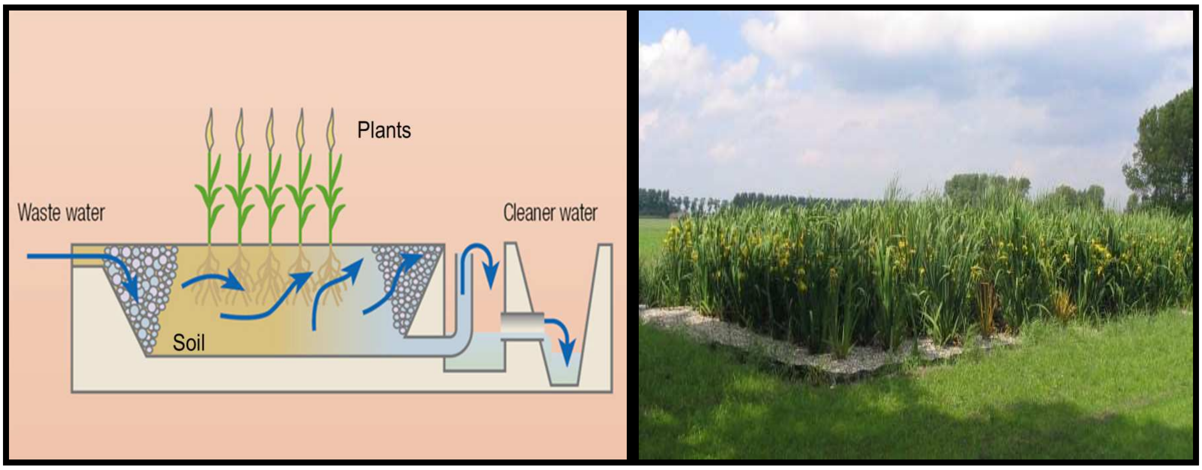

Figure 1. Constructed wetlands

2.1. Contaminants removal

Physical, chemical and biological processes combine in wetlands to remove contaminants from wastewater. An understanding of these processes is fundamental not only to designing wetland systems but to understanding the fate of chemicals once they enter the wetland. Theoretically, wastewater treatment within a constructed wetland occurs as it passes through the wetland medium and the plant rhizosphere. A thin film around each root hair is aerobic due to the leakage of oxygen from the rhizomes, roots, and rootlets. Aerobic and anaerobic micro-organisms facilitate decomposition of organic matter (Figure 2). Microbial nitrification and subsequent denitrification releases nitrogen as gas to the atmosphere. Phosphorus is co-precipitated with iron, aluminium, and calcium compounds located in the root-bed medium. Suspended solids filter out as they settle in the water column in surface flow wetlands or are physically filtered out by the medium within

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subsurface flow wetlands. Harmful bacteria and viruses are reduced by filtration and adsorption by biofilms on the gravel or sand media in subsurface flow and vertical flow systems (Hammer, 1989).

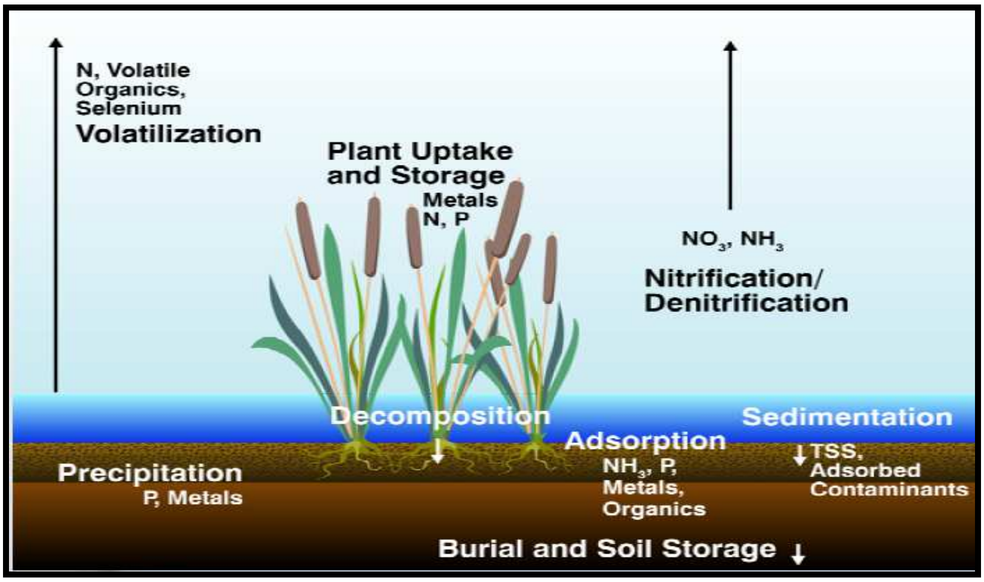

Figure 2. Pollutant removal mechanisms in constructed wetlands

Constructed wetlands can either be designed as the primary treatment unit or integrated into multi-stage treatment systems. They are commonly designed as surface flow and sub-surface flow constructed wetlands. Based on flow regime, sub-surface flow wetlands are also classified as vertical and horizontal flow constructed wetlands.

2.2 Surface flow constructed wetlands

As it was shown in Figure 3, surface flow constructed wetland systems are typically composed of a bed or canal, a compacted impervious layer, soil or another media for plant rooting and relatively low water level flowing through the system. Water surface is above the filtrate or fill material. These systems resemble the natural wetlands and provide various benefits for wild life beside water treatment. While the sections closer to surface are aerobic, deeper sections and substrate material are anaerobic. The primary advantage of these systems are their low investment, operation and maintenance costs, easy construction and operation and the basic disadvantage is the land requirement to construct such systems since they require significantly larger areas than the other constructed wetland or conventional treatment systems (Gökalp et al., 2012).

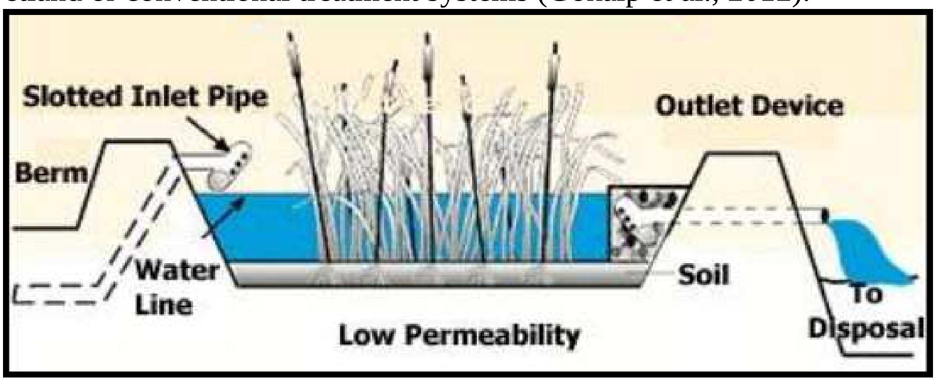

Figure 3. Surface flow constructed wetlands

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The primary criteria to be considered in design of surface flow systems are biological oxygen demand (BOD), total suspended solids (TSS), nitrogen, phosphorus, coliform bacteria, metal and other particulate pollutant. The recommended design criteria for optimum performance from surface flow constructed wetlands for relevant pollutants are provided in Table 2 (EPA, 1999).

Table 2. Design parameters for surface flow constructed wetlands

Parameter	**Design Criteria**
Influent quality	BOD $\leq$20 – 30 mg L^{-1} TSS $\leq$20 – 30 mg L^{-1}
Pre-treatment	Oxidation basins
Design flows	Q_{max} (maximum monthly flow) Q_{ave} (average flow)
Maximum BOD loading	20 mg L^{-1} : 45 kg ha^{-1} day^{-1} 30 mg L^{-1} : 50 kg/ha^{-1} day^{-1}
Maximum TSS loading	20 mg L^{-1}: 45 kg ha^{-1} day^{-1} 30 mg L^{-1}: 50 kg ha^{-1} day^{-1}
Water depth	0.6 – 0.9 m (full plant cover sections) 1.2 – 1.5 m (Open water surfaces) 1.0 m (Inlet settling section)
Maximum HRT	2 days (full plant cover sections) 2 – 3 days (Open water surfaces)
Basin geometry	Optimum 3:1 – 5:1
Inlet settling section	In case of failed pretreatment in settling
Inlet	Uniform influent distribution in inlet
Outlet	Uniform effluent collection in outlet

2.3. Sub-surface flow constructed wetlands

The subsurface flow constructed wetlands primarily composed of a compacted clay or synthetic impermeable liner overlaid by graded sand-gravel substrate material planted with aquatic plants and water level control structures (Figure 4). They are designed in either horizontal flow or vertical flow and can be used with and without emergent plants (Young et al., 2000). Contrary to surface flow systems, water does not come out to surface in these systems and flows through a substrate material and reaches to outlet. Same parameters are considered in design and recommended design criteria are provided in Table 3 (EPA, 1993).

Table 3. Design parameters for sub-surface flow constructed wetlands

Parameter	**Design Criteria**
BOD	6 g m^{-2} day^{-1} – 30 mg L^{-1} for inlet
TSS	20 g m^{-2} day^{-1} – 30 mg L^{-1} for inlet
Depth	Substrate: 0.5-0.6 m Water 0.4-0.5 m
Length	Minimum 15 m
Width	Maximum 61 m
Bed bottom slope	0.5 – 1%
Bed surface slope	Flat or almost flat
Hydraulic conductivity	1000 m day^{-1} for the first 30% of length 10000 m day^{-1} for the last 70% of length
Substrate	Inlet section: 40-80 mm Process section: 20-30 mm Outlet section: 40-80 mm Planting section: 5-20 mm

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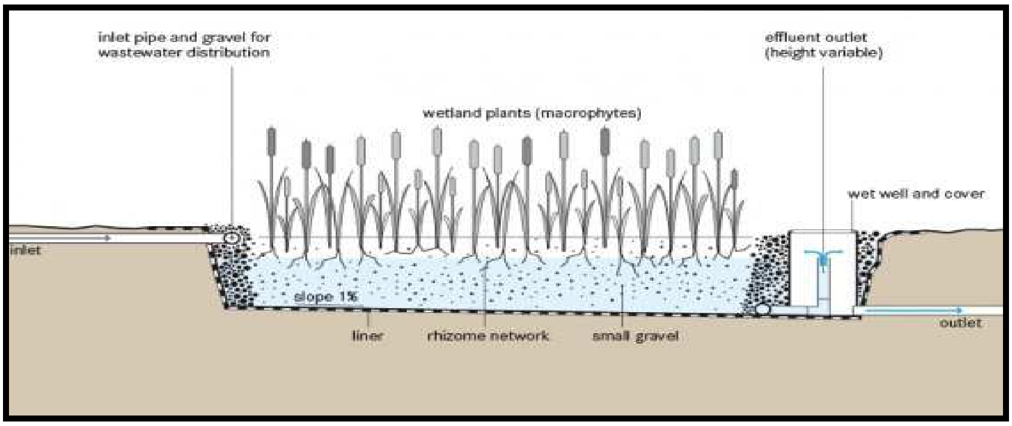
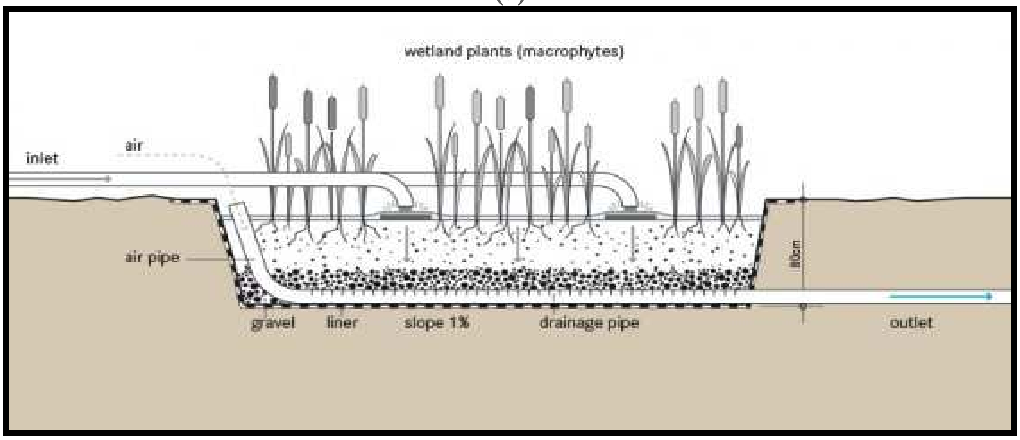


(a)



(b)

Figure 4. Horizontal (a) and vertical (b) flow sub-surface constructed wetlands

The most significant component of these systems is the substrate material filtering the wastewater. The material both provides a medium for rooting of aquatic plants and distributes influent, directs and collects effluent, provides surface area for microbial activity and filters suspended solids. Although various size and composition of substrate materials have been tried, there are not any concrete evidences about which size or type of material is the best. The basic criterion is not to allow small particles settle into the pores of coarser ones. Substrate upper surface should be leveled and about 1% slope should be provided at bottom surface. Inlet pipes should be so arranged to prevent short-circuit and substrate clogging and provide an equal flow. Outlet pipes should also prevent short-circuits, provide equal water collection and allow the operators to arrange the water level and effluent drainage.

In Turkey, sub-surface horizontal flow constructed wetlands are commonly used for domestic wastewater treatment in rural parts, especially in villages. Usually the type-projects designed by Special Provincial Administrations just by taking the total population to be served into consideration are implemented (Figure 5). Most of the time, local conditions, influent quality parameters, hydraulic loading rates, retention times and site-specific characteristics are not taken into consideration. Therefore, various failures occur because of such design errors and most of the already constructed systems are not either well-operating or not-operating at all (Gökalp et al., 2014). The common failures are classified as: failures in site selection, inlet clogging, substrate

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clogging and consequent water poundings over the surface, outlet clogging, leakage through slopes, plantation failures, failures in operation and maintenance (Gökalp and Çakmak, 2013). Effluents of properly operating systems can also be used for irrigation purposes. However, irrigation water quality parameters should definitely be taken into consideration before using treated effluents.

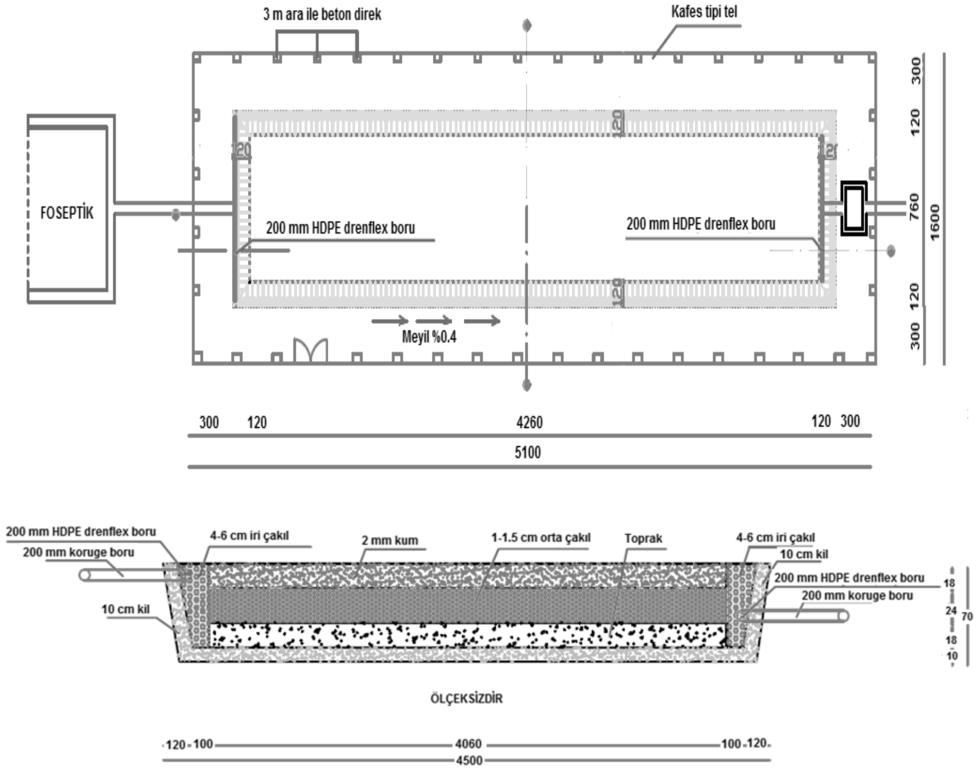

Figure 5. A pilot project designed for a population of 500 people

3. CONCLUSIONS

Constructed wetlands can be used in sites with low land costs and limited labor force. In Turkey, these systems are especially used in villages to treat domestic wastewater. They were also specified as the primary issue in rural development strategy document of State Planning Organization. Sub-surface horizontal flow constructed wetlands are common in practice. However, most of the already constructed systems are not either well-operating or not operating at all just because of errors and mistakes made in their design, operation and maintenance processes. Such errors must urgently be corrected to prevent the waste of investment made on these systems. Re-use of treated effluent for irrigation purposes is also a critical issue to be considered. Almost 70% of renewable water resources are allocated to irrigations and re-use of constructed wetland effluents may provide significant water savings in irrigated agriculture. But, irrigation water quality parameters must be taken into consideration before the re-use of treated effluents. As to conclude, constructed wetlands are the significant systems to prevent water resources pollution since the wastewater previously was being discharged into receiving bodies without any treatments. Now, treated effluents are discharged into water bodies with these systems and consequently both water quality and aquatic life are preserved against the toxic and hazardous impacts of untreated sewage.

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