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Review. Advances in the management of the wastewater in Turkey: natural treatments or constructed wetlands

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Abstract

As a result of rapid population growth and industrialization with increased water demand, domestic and industrial waste has increased. Wastewater left to streams and rivers without treatment is polluting the environment. The purpose of this study is to explain the importance of the constructed wetlands for wastewater treatment and to provide information about applications in Turkey. In this study, constructed wetlands have been introduced, the types, operation systems, performance evaluation, information about the legal regulations for use of waste water in agriculture has been given. Municipal wastewater can be reused with constructed wetlands in rural areas and water saving will be provided. The constructed wetlands should be developed rearranging Turkey's laws. Thus water used for agriculture will be reduced and other sectors needs will be met.

Additional key words: agriculture, free water surface wetlands, vegetated submerged bed systems, water sources.

Resumen

Revisión. Avances en la gestión de aguas residuales en Turquía, mediante tratamientos naturales o humedales artificiales

Como resultado del rápido crecimiento de la población y de la industrialización, se ha incrementado la demanda de agua y consecuentemente las aguas residuales domésticas e industriales. Las aguas residuales no tratadas que llegan a los ríos están contaminando el medio ambiente. El objetivo de este trabajo es poner de manifiesto la importancia de la construcción de humedales artificiales para el tratamiento de las aguas residuales y proporcionar información sobre sus aplicaciones en Turquía. En este estudio se presenta información sobre los humedales artificiales construidos, sus tipos, sistemas de operación, evaluación del funcionamiento y las regulaciones legales para la utilización de las aguas residuales en la agricultura. Se pueden reutilizar las aguas residuales municipales depuradas con humedales artificiales en areas rurales, ahorrando así agua. Deberían desarrollarse estos humedales artificiales readaptando las leyes turcas. De esta manera se reduciría el agua natural utilizada en la agricultura y se podrían satisfacer las necesidades de otros sectores.

Palabras clave adicionales: agricultura, fuentes de agua, humedales de agua superficial, sistemas de cama de vegetación sumergida.

Introduction

Agriculture is the largest consumer of freshwater reserves in the world, using about 65-75% (Bennett, 2000). At the national level, the biggest part of all national water budgets are devoted to the agricultural sector as seen in Table 1 (Chohin-Kuper *et al.,* 2002). Although Turkey has, at present, more water resources than some of its neighbors, it will be unable to meet its own needs in the near future. Turkey's average annual runoff is approximately $186 \cdot 10^{12}$ m^3. The amount of this capacity available for consumption is more than $110 \cdot 10^{12}$ m^3, including $12 \cdot 10^{12}$ m^3 of groundwater (Table 2). Taking a population of 68 million into

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Abbreviations used: BOD (biological oxygen demand), cfu (colony forming units), DSI (state hydraulic works), EPA (US Environmental Protection Agency), FWS (free water surface), ISKI (Istanbul Water and Sewage Administration), TSS (total suspended solids), VSB (vegetated submerged bed), WWC (World Water Council).

Table 1. Sectorial water consumptions (Chohin-Kuper *et al.,* 2002)

Country	Agriculture (%)	Domestic use (%)	Industry (%)	Year
Egypt	82	8	10	
France	68	24	8	1995[1]
Greece	87	10	3	1997
Israel	79	16	5	1986
Italy	50	20	30	1999
Jordan	69	4	27	1997[1]
Lebanon	68	5	27	1996
Libya	87		13	
Malta	12	87	1	1995
Morocco	92	5	3	1991
Spain	93	4	3	1998[1]
Tunisia	83	12	5	2001[1]
Turkey	74	15	11	1997

[1] Net consumption.

consideration, the quantity of water per capita is 1,700 m^3 but is expected to be reduced to 1,000 m^3 with the population growth by the year 2020. Thus, Turkey cannot be considered as a «water-rich» country, and its per capita potential is nearly the same as those of its neighbors Iraq (2,000 m^3 yr^{-1}) and Syria (1,400 m^3 yr^{-1}). Countries regarded as being rich in water resources have $8\text{-}10 \cdot 10^3$ m^3 water per capita per year. The available water per capita in Turkey is about one-fifth that of the water-rich countries (Cakmak *et al.,* 2004). Currently, agriculture consumes about 75% of the total water resources of Turkey. The growing demand for water by its rapidly increasing population is reducing the amount of water available for use in agriculture. This situation emphasizes the need for optimal water resource management and the economic use of water. Therefore, reuse of water is on the agenda.

Wastewater utilization for agricultural purposes is an important strategy for water resource conservation particularly, and has been increasing due to water scarcity and population growth. This strategy has been reported in developing countries including Morocco, Tunisia, Egypt, Sudan, Namibia, India and China, where sewage is used to irrigate vegetables and other short-term crops and to support fish culture. The most suitable use of municipal wastewater treatment plant effluents is for irrigation practices. Implementation of this aspect creates numerous advantages but requires a thorough analysis of the effects on people, soils and crops, and definition of the proper treatment process to get the required quality levels (Boari *et al.,* 1997). Wastewater can be used to substitute other better quality water sources, especially in agriculture; however, unregulated and unplanned use of wastewater in agriculture certainly carries the risks of pollution of soil profiles, surface waters and groundwater, not to mention health risks to farm workers and possibly crop contamination. This agricultural use of domestic wastewater, if well designed and managed, has the potential to address the problems of local water shortages and can also be viewed as part of a treatment system to reduce environmental pollution.

Table 2. Annual water potential of Turkey (WWC, 2003)

Contribution	Water potential (km^3)
Total runoff	186
Of which exploitable surface runoff	95
Safe yield of groundwater	+12
Incoming flows from neighboring countries	+19
Water allocated to Syria and Iraq	–16
Total exploitable potential	110

Agricultural use of wastewater provides an option to safely handle and discharge the increasing volumes of wastewater under present economic conditions as encountered in many countries of the world. However, it should be stressed that there cannot exist a single design solution, as there are wide differences between locations, not only in climate and physical environment, but also in social acceptance, economic and technical opportunities and perceptions related to the use of (treated) wastewater. A pricing framework, adapted to local situations, would be very helpful to decide on design choices and cost allocations (Carr, 2005; Huibers and Raschid-Sally, 2005).

Wastewater utilization in irrigation is on the agenda all around the world and about one-tenth of the world's population consumes foods irrigated with wastewater. In several countries, wastewater and excreta used in irrigation are not sufficiently treated. It has been estimated that at least $20 \cdot 10^6$ ha in 50 countries are irrigated with raw or partially treated wastewater. Especially in developing countries, wastewater and excreta are used in agricultural practices of urban people who often supply a large proportion of the fresh vegetables sold in many cities. For instance, Dakar and Senegal produce nearly 60% of the vegetables consumed in the cities by using mixture of groundwater and untreated wastewater for irrigation (Carr, 2005).

The main advantages of utilizing effluents for irrigation purposes consist of the fact that many of the substances present in wastewater can be used as nutrients for crops, and would otherwise probably contaminate the receiving water body, and there is the additional advantage that less chemical fertilizers are needed. The salinity level of wastewater, organic and inorganic toxic compound content are usually not high enough to prevent its use for irrigation purposes. Nevertheless, it is advisable to check the presence of these substances. Wastewater must be refined so that the concentration of suspended matter is brought down to a suitable level and its pathogenic load is eliminated (Boari *et al.,* 1997). Compared to conventional treatment systems, wetland technology is cheaper, easier to operate and maintain. Minimal fossil fuel is required and no chemicals are necessary. An additional benefit of using wetlands for wastewater treatment is the multi-purpose sustainable utilization of the facility for various aspects such as swamp fisheries, biomass production, seasonal agriculture, water supply, public recreation, wild life conservation and scientific study. Artificial wetlands with their low-costs and low-technology demands are potential alternative or supplementary systems for wastewater treatment in developing countries (Kivaisi, 2001).

WHO/UNICEF (2000) estimates the percent of wastewater treated by proper treatment plants as 35% in Asia, 14% in Latin America and the Caribbean, 90% in North America and 66% in Europe. Homsi (2000) states that around 10% of all wastewater in developing countries receives treatment. There has been a noticeable increase in the amount of pollution in water resources in Turkey in recent years (Kendirli *et al.,* 2005). Negative environmental factors, such as industrialization, increasing urbanization, improper pesticide and fertilizer applications in agricultural lands, and the drainage of domestic and industrial wastewater into water resources without any waste treatment applications, cause rapid pollution of both surface and groundwater resources. But there are no reliable data which shows the levels of pollution. Therefore, it is necessary to allocate more attention to water resources monitoring, evaluation and wastewater treatment studies. In this study, growing importance of natural treatment systems was emphasized; types of natural treatment systems and natural treatment practices in Turkey were briefly explained.

Constructed wetlands

Wetlands, the transitional area between land and water resources, are identified by wet soils, plants and a high water table. However, there is no accurate definition for wetlands, since land and water can easily be blended. Having high organic compound concentration and the great ability in converting inorganic chemicals into organic materials are important characteristics of wetlands. Due to ample light, water and nutrient supply, primary productivity of wetland ecosystems are typically high. Many artificial and natural wetlands have net primary productivity of more than 1,000 g C m^{-2} yr^{-1} which is greater than most of the other ecosystems (Carr, 2005).

In order to safely reuse treated municipal wastewater for irrigation purposes, all chemical, geological, geochemical, environmental, and public health parameters related to land use ecology should be considered. The basic subject for the safe reuse of treated municipal wastewater from treatment plants is prevention of their disposal into aquatic receptors (creeks, rivers, lakes, the sea) for environmental reasons (Kalavrouziotisa and Apostolopoulosb, 2007).

While the objective of wastewater treatment processes is to eliminate all the pollutants (pathogens, organic, and inorganic chemicals) in developed countries; it is to prevent transmission of waterborne diseases and eutrophication of surface waters and to protect public health through control of pathogens in developing countries (Carr, 2005). The performance of wastewater stabilization ponds in achieving these objectives in developing countries appears to be satisfactory in many cases. With the loading rates of 180-500 kg biological oxygen demand (BOD) per acre day^{-1} in the tropics, removal efficiencies of BOD, nitrogen, phosphorus and indicator bacteria have been reported as 75-90%; 30-50%; 20-60% and 60-99%, respectively. Properly designed and operated stabilization ponds can achieve almost total removal of helminthes (99.99%), enteric bacteria and viruses (99%) and leave an odor free effluent. However, residual nutrients such as nitrogen and phosphorus could become a problem unless they can be directly utilized to support agriculture or fish farming. When the stabilization pond effluents are released back into environment without any further treatment, they can contaminate downstream ground and surface water and make them unsafe for drinking and other uses. In this case, wetland technologies employing natural systems can be used in combination with already constructed stabilization ponds to achieve better removal of nutrients and pathogens from the wastewater prior to final release into the water supplies. Although the tropics have about half of the world's wetland area

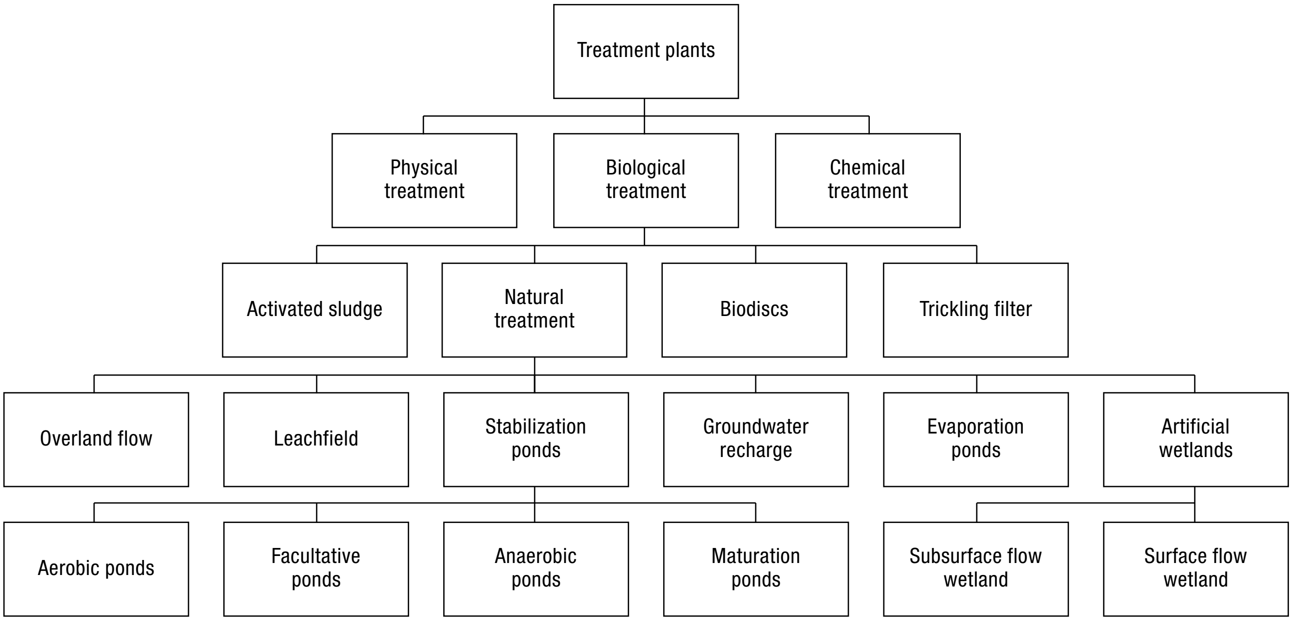

Figure 1. Treatment plants (EPA, 1999).

($450 \cdot 10^6$ ha), the rate of adoption of wetlands technology for wastewater treatment in these regions has been slow.

Wetlands are classified as natural wetlands and constructed (artificial) wetlands (Fig. 1). Constructed wetlands are artificial wastewater treatment systems consisting of shallow (usually less than 1 m deep) ponds or channels which have been planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes to provide wastewater treatment. They typically have impervious clay or synthetic liners, and engineered structures to control the flow direction, liquid detention time and water level. They are usually located near the source of the wastewater and often in upland areas depending on different type of system and whether they have the inert porous media such as rock, gravel or sand. Constructed wetlands have been used to treat a variety of wastewater types including urban runoff, municipal, industrial, agricultural and acid mine drainage discharges. Constructed wetlands providing advanced treatment to wastewater that has been pretreated to secondary levels, and also offering other benefits for wildlife habitat, research laboratories, or recreational uses are sometimes called enhancement wetlands (EPA, 1999).

Artificial wetlands were initially developed about 40 years ago in Europe and North America to exploit and improve the biodegradation ability of plants. Advantages of these systems include low construction and operating costs and their suitability for both small communities and as a final stage treatment in large municipal systems. A disadvantage of the systems is their relatively slow rate of operation in comparison to conventional wastewater treatment technologies (Shutes, 2001).

Constructed wetlands have been classified by literature and practitioners into two types. Free water surface (FWS) wetlands (also known as surface flow wetlands) closely resemble natural wetlands in appearance because they contain aquatic plants that are rooted in a soil layer on the bottom of the wetland and water flows through the leaves and stems of plants. Vegetated submerged bed (VSB) systems (also known as subsurface flow wetlands) do not resemble natural wetlands because they have no standing water. They contain a bed of media (such as crushed rock, small stones, gravel, sand or soil) which has been planted with aquatic plants. When properly designed and operated, wastewater stays beneath the surface of the media, flows in contact with the roots and rhizomes of the plants, and is not visible or available to wildlife (EPA, 1999).

Figure 2 illustrates the main components of a FWS constructed wetland. A typical FWS constructed wetland consists of several components that may be modified among various applications but retain essentially the same features. These components include berms to enclose the treatment cells, inlet structures that regulate and distribute influent wastewater evenly for optimum

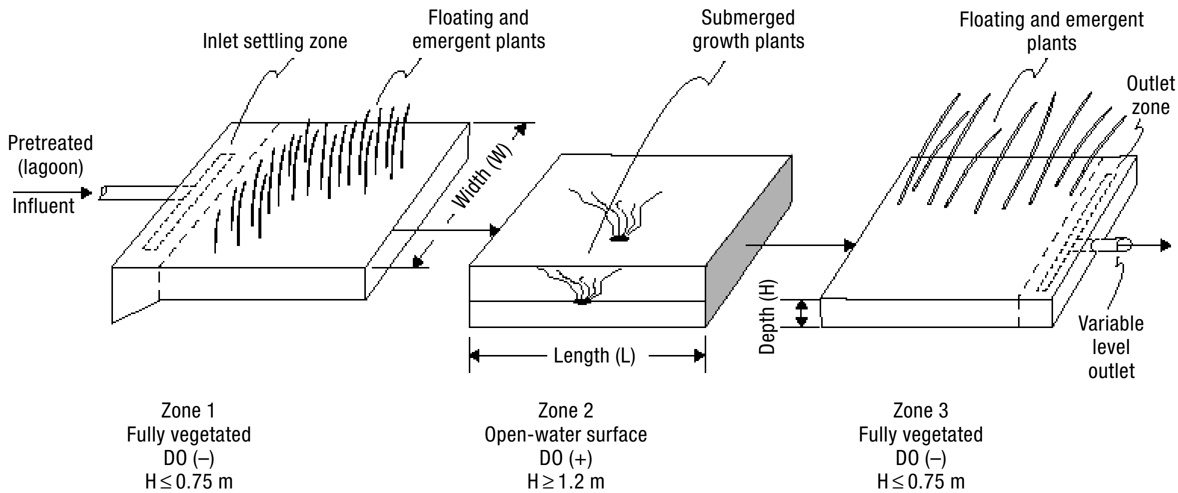

Figure 2. The main components of a free water surface constructed wetland (EPA, 1999).

treatment, various combinations of open-water areas and fully vegetated surface areas, and outlet structures that complement the even distribution provided by inlet structures and allow adjustment of water levels within the treatment cell. Shape, size, and complexity of design are often the functions of site characteristics rather than preconceived design criteria (EPA, 1999).

Vegetated submerged bed wetlands consist of gravel beds that may be planted with wetland vegetation. Figure 3 provides a schematic drawing of a VSB system. A typical VSB system, like the FWS systems described above, contains berms and inlet-outlet structures for regulation and distribution of wastewater flow. In addition to shape and size, other variable factors are choice of treatment media (gravel shape and size, for example) as an economic factor, and selection of vegetation as an optional feature that affects wetland aesthetics more than performance (EPA, 1999).

Many of the processes that operated in constructed and natural wetlands also operated in municipal wastewater treatment plants. Most municipal treatment plants are designed to provide primary and secondary treatment of wastewater generated at residences, industrial plants, and public facilities. Primary treatment consists of three steps: raw wastewater is screened to remove foreign objects that could damage machinery, and then aerated grit basins allow sand, gravel and other abrasive materials to settle down, and, finally, primary clarifiers are used to slow flows still further allowing separation of solids by gravity or floatation. Solids remaining in the wastewater at this point are either suspended or dissolved solids (Lesikar and Lindemann, 2005).

In secondary treatment, primary treated wastewater flows to aeration basins or tanks where air is bubbled from pipes at the bottom to provide mixing and oxygen for microorganisms. These microorganisms consume

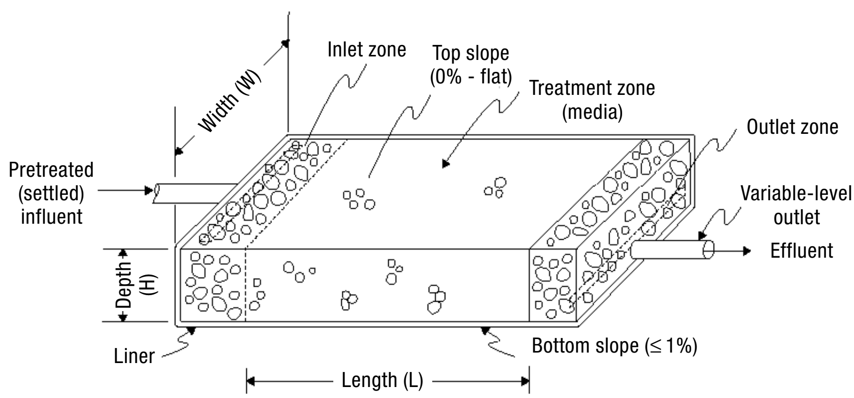

Figure 3. A schematic drawing of a vegetated submerged bed system (EPA, 1999).

the majority of the organic contaminants in the wastewater and represent the heart of the treatment process. Final clarifiers allow the microorganisms to settle down to the bottom where they form sludge. The clear wastewater (effluent) is either discharged or subjected to advanced treatment to remove nutrients or organic and inorganic contaminants. The degree of additional treatment is determined by the conditions set forth in the wastewater discharge permit (Lesikar and Lindemann, 2005).

Constructed wetlands utilize many of these same processes to treat wastewater. Most constructed wetlands are used in combination with other forms of residential or municipal wastewater treatment to provide additional, low-cost treatment and cleaner wastewater before discharge. For example, primary treated wastewater from a septic tank is applied to the constructed wetland where plants and/or porous materials filter out some of the contaminants. Microorganisms attached to the plant roots or the porous media consume most of the organic contaminants to provide secondary treatment. Flow rates through the wetlands are slow so organic particles and microorganisms can settle down to the bottom. Growing plants may aid in removal of nutrients. The clear wastewater effluent is then discharged or applied to soils as irrigation water (Lesikar and Lindemann, 2005).

Primary functions of most constructed wetlands include water storage and water-quality improvement. Some of these constructed wetlands are designed intentionally for ground water recharge. Numerous other functions attributed to natural wetlands also exist in constructed wetlands. Ancillary functions include primary production of organic carbon by plants; oxygen production through photosynthesis; production of wetland herbivores, as well as predator species that range beyond the wetland boundaries; reduction in the export of organic matter and nutrients to downstream ecosystems; and creation of cultural values in terms of educational and recreational resources. One or more of these ancillary functions may be an important goal in some constructed wetland projects (EPA, 1999).

In FWS constructed wetlands, plants play several essential roles. The most important function of emergent and floating aquatic plants is providing a canopy over the water column, which limits production of phytoplankton and increases the potential for accumulation of free-floating aquatic plants (*e.g.,* duckweed) that restrict atmospheric re-aeration. These conditions also enhance reduction of suspended solids within the FWS constructed wetland. Emergent plants play a minor role in taking up nitrogen and phosphorus. The effect of litter fall from previous growing seasons as it moves through the water column and eventually decomposes into humic soil and lignin particles may be significant in terms of effluent quality (EPA, 1999).

Removal of pollutants in constructed wetlands

Nitrogen removal

Nitrogen is limited in drinking water to protect the health of infants and should be limited in surface waters to prevent eutrophication. Nitrogen can be removed by plant or algal uptake, nitrification, denitrification and release of ammonia gas to the atmosphere (evaporative stripping = volatilization) (EPA, 1988).

Plant uptake accounts for only about 10% of nitrogen removal. Nitrification and denitrification are microbial reactions that depend on temperature and detention time. Nitrifying organisms require oxygen and an adequate surface area to grow on and, therefore, are not present in significant numbers in either heavily loaded systems (BOD loading > 112 kg ha^{-1} day^{-1}) or in newly constructed systems with incomplete plant cover. Based on field experience with FWS systems, one to two growing seasons may be needed to develop sufficient vegetation to support microbial nitrification. Denitrification requires adequate organic matter (plant litter or straw) to convert nitrate to nitrogen gas. The reducing conditions in mature FWS constructed wetlands resulting from flooding are conducive to denitrification. If nitrified wastewater is applied to a FWS wetland, the nitrate will be denitrified within a few days of detention (Action, 2006). Nitrogen removal in aquatic plant systems is 26-96%, primarily due to nitrification/denitrification. In constructed wetlands, nitrogen removal ranges from 25-85% by the same mechanism (EPA, 1988; Cronk, 1996).

Phosphorus removal

Phosphorus removal in wetlands and aquatic plant systems is not very effective because of the limited contact opportunities between the wastewater and the soil (EPA, 1988). The principal removal mechanisms for phosphorus in FWS systems are adsorption, chemical precipitation, and plant uptake. Plant uptake of inorganic phosphorus is rapid; however, as plants die they release phosphorus, so long-term removal is low. Phosphorus removal depends on soil interaction and detention time (Action, 2006). The removal of phosphorus through plant uptake and the decomposition of organic phosphorus increases with temperature (Cronk, 1996). It was emphasized that removal of phosphorus changed seasonally in the literature.

Pathogens

Pathogens of concern in aquatic treatment systems are parasites, bacteria, and viruses. Pathogens in the surface water directly discharged from the constructed wetland or aquatic plant system should be paid attention to, while the groundwater contamination and offsite transmission by aerosols can be ignored. Groundwater will not be contaminated in systems that are sealed by an impervious clay or synthetic material barrier. Public health effects of wastewater treatment facilities include the influence of aerosols from pond aerators on plant workers. Based on several comprehensive investigation projects reported, it can be concluded that people who have been exposed to aerosolized microorganisms from wastewater treatment processes generally do not become infected or ill (EPA, 1988).

When the bacteriological treatments were taken into consideration, an efficiency of 41-99% was achieved in artificial wetlands depending on the nature and plant diversity of the wetland (Zaimoglu and Kekec, 2003).

Metals removal

Heavy metals are common environmental pollutants that are produced as a result of industrial, commercial and domestic activities. New pretreatment standards require some industrial discharges, such as electroplating and metal finishing operations, to limit heavy metal levels to very low residual concentrations (EPA, 1988).

Heavy metal removal is expected to be very similar to that of phosphorus removal although limited data are available on actual removal mechanisms. The removal mechanisms include adsorption, sedimentation, chemical precipitation, and plant uptake. As with phosphorus, metals can be released during certain times of the year, usually in response to changes in the oxidation-reduction potential (ORP) within the system (Action, 2006).

Biological oxygen demand removal

Soluble and particulate BOD are removed by different mechanisms in FWS constructed wetlands. Soluble BOD is removed by biological activity and adsorption on the plant and detritus surfaces and in the water column. The low velocities and emergent plants facilitate flocculation/sedimentation and entrapment of the particulate BOD. Organic solids, removed by sedimentation and filtration will exert an oxygen demand, as does the decaying vegetation. As a result, the influent BOD is removed rapidly along the length down the wetland cell. The observed BOD in the wetland will also reflect the detrital and benthic demand, which leads to a background concentration (Action, 2006).

Total suspended solids (TSS) removal

The principal removal mechanisms for TSS are flocculation and sedimentation in the bulk liquid, and filtration (mechanical straining, chance contact, impaction, and interception) in the interstices of the detritus. Most of the settleable solids are removed within 0.15 to 0.30 m of the inlet. Optimal removal of TSS requires a full stand of vegetation to facilitate sedimentation and filtration and to avoid re-growth of algae. Algal solids may take 6-10 days of detention time for removal (Action, 2006).

Results of research revealed that about 70-96% BOI_5, 60-90% TSS and 40-90% nitrogen elimination were possible (Zaimoglu and Kekec, 2003).

Performance assessments of wetlands

The performance of operating constructed wetland treatment systems reveals the range of effluent quality and the variability of performance with these types of systems. The result reveals that under different types of systems, there is great variety in the range of treatment capacities. Given the wide variety of settings, design criteria, configuration, and inlet/outlet placement, considerable variation in performance should be expected (EPA, 1999).

The brief performance summary included here offers an overview of loading, influent and effluent ranges for a number of water quality constituents, and presents the observed relationship between loading rates and effluent quality for all systems (EPA, 1999).

Table 3. Background concentrations of water quality constituents of concern in free water surface FWS constructed wetlands (EPA, 1999)

Parameter	Range (mg L^{-1})	Typical (mg L^{-1})	Factors governing
TSS	2-5	3	Plant types, plant coverage, climate, wildlife activity.
BOD[1]	2-8	5	Plant types, plant coverage, plant density, climate, wildlife activity.
BOD[2]	5-12	10	Plant types, plant coverage, plant density, climate.
TN	1-3	2	Plant types, plant coverage, climate, oxic/anoxic conditions.
NH_4-N	0.2-1.5	1	Plant types, plant coverage, climate, oxic/anoxic conditions.
TP	0.1-0.5	0.3	Plant types, plant coverage, climate, soil type.
FC[3]	50-5,000	200	Plant types, plant coverage, climate, wildlife activity.

[1] FWS with open water and submergent and floating aquatic macrophytes. [2] Fully vegetated with emergent macrophytes and with a minimum of open water. [3] Fecal coliform (FC) is used as an indicator of pathogens, measured in colony forming units (cfu) per 100 mL.

The effectiveness of both municipal treatment plants and constructed wetlands depends on their design capacities and how they are operated and maintained (Table 3) (Lesikar and Lindemann, 2005). For example, some older cities have combined sewer systems where both sewage and storm water are collected by a common sewer system which routes flows through the wastewater treatment plant. During heavy rains, these combined flows may exceed the capacity of the treatment plant resulting in releases of raw or partially treated sewage. Even in cities with separate sanitary and storm sewers, water infiltrates into the sanitary sewer during periods of heavy rainfall often causing the sanitary sewer flows to double. Constructed wetlands can also be overloaded by heavy rainfall or surface flooding).

Constructed wetland systems may be expected to remove 50-90% of BOD_5, 40-94% of suspended solids, 30-98% of nitrogen and 20-90% of phosphorus from wastewater (Lesikar and Lindemann, 2005). These data were obtained for systems operated under a wide range of conditions for pollutant loading, temperature, design, and management. When properly designed and operated, consistent removal of 80% or more of the wastewater constituents named above appears feasible (Lesikar and Lindemann, 2005).

Legal regulations for wastewater use in agriculture, Turkey

Where water for irrigation is scarce, it is recommended to use treated wastewater with water quality indicators which meet the standards for irrigation in Turkey, which details is given in water pollution regulation. These indicators are found out jointly by State Hydraulic Works, Bank of Provinces, and Rural Affairs of Ministry of Agriculture. Treated wastewater is assessed for use in irrigation according to these indicators. They can be arranged like total dissolved solid concentrations and electrical conductivity, sodium concentration, relative to other salts, concentrations of boron, heavy metals and other toxic substances, calcium and magnesium concentrations, total solids, organic substances and floating substances such as oil, grease and pathogenic microorganisms. Inland waters are classified in four water quality classes, ranging from high quality to highly polluted, on the basis of a range of parameters (Table 4). The 1988 Water Pollution Regulation also describes the types of water uses, for which each of the first three quality classes are suitable (Table 5). Highly polluted water cannot be used for any of these particular purposes. The type of use of wastewater for irrigation in agriculture is given in Tables 6 and 7. Table 6 describes the basic principles and technical limitations to be applied when re-using wastewater in irrigation. Table 7 presents the same when industrial wastewater is used.

There are various institutions in Turkey dealing with wastewater. There is authority confusion among them since each of them has its own authority regulations. Current regulations and institutions relevant to wastewater are given below:

— 1580 numbered municipality law (mayor, governor, lieutenant colonel).

— 1593 numbered public health law (Ministry of Health).

— 2634 numbered tourism incentive law (Ministry of Tourism).

— 2872 numbered environment law (Ministry of Environment, city institutions).

Table 4. The classification of inland waters according to quality (Official Gazette of the Turkish Government, 1991)

Water quality variables	Water quality classes			
	I High quality	II Moderate quality	III Polluted	IV Highly polluted
Physical and inorganic-chemical parameters				
Temperature (°C)	25	25	30	> 30
pH	6.5-8.5	6.5-8.5	6.0-9.0	6.0-9.0
Dissolved oxygen (mg O_2 L^{-1})[a]	8	6	3	> 3
Oxygen saturation (%)[a]	90	70	40	> 40
Chloride ion (mg Cl^- L^{-1})	25	200	400[b]	> 400
Sulfate ion (mg SO_4^{2-} L^{-1})	200	200	400	> 400
Ammonia-nitrogen (mg NH_4^+-N L^{-1})	0.2[c]	1[c]	2[c]	> 2
Nitrite-nitrogen (mg NO_2^--N L^{-1})	0.002	0.01	0.05	> 0.05
Nitrate-nitrogen (mg NO_3^--N L^{-1})	5	10	20	> 20
Total phosphate (PO_4^{3-}-P L^{-1})	0.02	0.16	0.65	> 0.65
Total dissolved solids (mg L^{-1})	500	1,500	5,000	> 5,000
Color (Pt-Co Unit)	5	50	300	> 300
Sodium (MgNa$^+$ L^{-1})	125	125	250	> 250
Organic parameters				
COD (mg L^{-1})	25	50	70	> 70
BOD (mg L^{-1})	4	8	20	> 20
Total organic carbon (mg L^{-1})	5	8	12	> 12
Total Kjeldahl-Nitrogen (mg L^1)	0.5	1.5	5	> 5
Emulsified oil and grace (mg L^{-1})	0.02	0.3	0.5	> 0.5
Methylene-blue-active-substances (MBAS) (mg L^{-1})	0.05	0.2	1	> 1.5
Phenolic substances (volatile) (mg L^{-1})	0.002	0.01	0.1	> 0.1
Mineral oil and derivates (mg L^{-1})	0.02	0.1	0.5	> 0.5
Total pesticides (mg L^{-1})	0.001	0.01	0.1	> 0.1
Inorganic contamination parameters[d]				
Mercury (µg Hg L^{-1})	0.1	0.5	2	> 2
Cadmium (µg Cd L^{-1})	3	5	10	> 10
Lead (µg Pb L^{-1})	10	20	50	> 50
Arsenic (µg As L^{-1})	20	50	100	> 100
Copper (µg Cu L^{-1})	20	50	200	> 200
Chromium (total) (µg Cr L^{-1})	20	50	200	> 200
Chromium (µg Cr^{+6} L^{-1})		20	50	> 50
Cobalt (µg Co L^{-1})	10	20	200	> 200
Nickel (µg Ni L^{-1})	20	50	200	> 200
Zinc (µg Zn L^{-1})	200	500	2,000	> 2,000
Cyanide (total) (µg CN L^{-1})	10	50	100	> 100
Fluorine (µg F L^{-1})	1,000	1,500	2,000	> 2,000
Free chlorine (µg Cl_2 L^{-1})	10	10	50	> 50
Sulfur (µg S^2 L^{-1})	2	2	10	> 10
Iron (µg Fe L^{-1})	300	1,000	5,000	> 5,000
Manganese (µg Mn L^{-1})	100	500	3,000	3,000
Boron (µg B L^{-1})	1,000[e]	1,000[e]	1,000[e]	> 1,000
Selenium (µg Se L^{-1})	10	10	20	> 20
Barium (µg Ba L^{-1})	1,000	2,000	2,000	> 2,000
Aluminium (mg Al L^{-1})	0.3	0.3	1	> 1
Radioactivity (pCi L^{-1}) 1. alfa-activity	1	10	10	> 10
2. beta-activity	10	100	100	> 100
Bacteriologic parameters				
Fecal coliform (MPN/100 mL)	10	200	2,000	> 2,000
Total coliform (MPN/100 mL)		20,000	100,000	> 100,000

[a] Either concentration values or saturation ratios must be satisfied. [b] This concentration limit should be decreased when chlorine-susceptible plants are irrigated. [c] The value of free ammonia-nitrogen should not exceed 0.02 mg NH_3-N L^{-1} due to pH value. [d] The criteria under this group indicate the total concentrations of chemicals. [e] The criteria may have to be decreased down to µg L^{-1} when boron-susceptible plants are irrigated.

Table 5. Suitability of the classified inland waters for different purposes (Official Gazette of the Turkish Government, 1988)

Water quality class	Suitable purpose
I. High quality	Domestic water supply after disinfection. Recreational water uses including swimming Trout fisheries. All types of farming.
II. Moderate quality	Domestic water supply after appropriate or advanced treatment. Recreational purposes. Fisheries other than trout. Irrigation (see also irrigation water quality criteria). All other uses except those in class I.
III. Polluted	Industrial water supply except for food and textile industries.

— 3030 numbered law defining the foundation and responsibilities of the greater cities (municipality).

— 3143 numbered law defining the foundation and responsibilities of Ministry of Industry (Ministry of Industry).

— 5442 numbered law defining the foundation and responsibilities of municipality bank.

Artificial wetlands are completely forbidden by legal regulations in Turkey. There is no exception regarding these legal regulations (Zaimoglu and Bagatur, 2001). Considering the advantages of artificial wetlands, given the details above, they should be enhanced in Turkey.

Table 6. Principles and technical limitations for using wastewater in irrigation (Official Gazette, 1991)

Type of agriculture	Technical limitations
Fruit and grape production	Sprinkler irrigation is prohibited. Fruits that have fallen down should not be eaten. Fecal coliform numbers should be less than 100/1000 mL.
Fiber plants and seed production	Surface or sprinkler irrigation can be applied. Biologically treated and chlorinated wastewater can be used in sprinkler irrigation. Fecal coliform numbers should be less than 1000/100 mL.
Fodder, flower plantation, oil plants	Surface irrigation can be applied using mechanically treated wastewater.

Table 7. Suitability of wastewater from different types of industries for irrigation (Official Gazette, 1991)

Suitability	Industries
Appropriate for irrigation	Brewery, winery, malt, yeast, potato, vegetable processing, marmalade, fruit processing, dairy, potato starch industries.
Appropriate for irrigation only if the water is treated so as to comply with the values of providing quality criteria in law	Sugar, rice and cereal starch, tannery-glue, animal-glue, slaughterhouse, meat-packing, margarine, pulp and paper, textile, fish, metal industries.
Not appropriate as irrigation water	Soap, inorganic heavy chemical, dye stuffs and intermediates, pharmaceutical, metal, cellulose, pyrolisis plant, fuel and oil, coal washing, steam power plants, explosive industries.

Istanbul Water and Sewage Administration (ISKI) is responsible for collection of domestic wastewaters within the boundaries of Istanbul, the largest city and municipality of Turkey, removal of them from settlement areas, conveyance to a discharge point without causing any damage or risk, and reuse (1st and 2nd articles of 2,560 numbered law defining the foundation and responsibilities of General Directorate of ISKI). According to ISKI law, water users do not have any right to make any technical regulation related to domestic wastewater. Responsibility is assigned to State Hydraulic Works (DSI) for the areas out of the boundaries of the Municipality of the Greater City (article 2 of 6,200 numbered law defining the organization and responsibilities of DSI). Responsibility for the water supply and discharge are assigned to municipalities in towns and to village council in villages according to village law (articles 1 and 4 of 831 numbered law related to waters). Institutions, organizations and enterprises are enforced by law to build their wastewater treatment facilities (11th article of 2,872 numbered environment law). For this purpose, institutions, organizations and enterprises have to take joint measures with the above-specified responsible authorities for wastewater treatment, removal and discharge without causing any damage or risk. It was stated that this issue would be organized by regulations. The inspections will be carried out by General Directorate of Environment (Dogrusoz, 1997; Zaimoglu and Bagatur, 2001).

There is a basic regulation constituting the basis of inspections to be carried out by General Directorate of

Environment (Official Gazette, 1988). According to the 25th article of this regulation, wastewater has to be connected to network in places where there is a sewage system. According to 28th article of the same regulation, «utilization of wastewaters in irrigation applications in places where insufficient irrigation water supplies» should be supported. Within this framework, Water Pollution Regulation Technical Principles Notification was published on 7 January 1991 and 20,748 numbered Official Gazette. Wastewater utilization was specified in the 46th and following articles of this technical notification. In Turkey, it is necessary to change the current regulations and laws to reuse the domestic wastewaters or in other words to create artificial wetlands especially in the greater cities (Zaimoglu and Bagatur, 2001).

Treatment facilities in Turkey

Farmers using wastewater in developing countries are often limited by adopting safeguards for human, animal and environmental health control and in improving beneficial use of water and nutrients. Case studies from Ghana, Bolivia, Pakistan, Tunisia and Mexico are used to illustrate the complex factors that influence the use of wastewater by farmers. Limitations are identified as: nutrient management, choice of crops, irrigation methods, health risk regulation and land and water rights (Martijn and Redwood, 2005). In some cases, the most viable approach is to acknowledge irrigation as a land-based treatment method, which requires sharing of costs and responsibilities between wastewater producers, government institutions and farmers.

Wastewater treatment applications are recent issues in Turkey. According to Turkish Statistical Institute Data for the year 2004, about 78% of population has a water supply network and 68% has a sewage network. About 1 of every 4 people is deprived of sufficient water supply and wastewater services. Among all municipalities, there are a total of 172 treatment facilities; 35 of them are physical, 133 of them are biological and only 4 of them are advanced treatment facilities. About 58 municipalities have deep-sea discharge. Only 17 (28.8%) of 59 organized industrial regions have industrial wastewater treatment facility. Also, only 848 (19%) of 4 459 touristic enterprises have a wastewater treatment facility. While 34% of country population is receiving treated water service, only 36% of them are able to properly treat wastewaters. Changes in data related to drinking and utility water and wastewater were given in Table 8.

Municipality Bank initiated related technical preparations for wastewater treatment during the 1980s and put the first deep-sea discharge in Yalova and Cinarcik in 1983 and the first wastewater treatment facility in Ilgın in 1984 into operation. From that date to the end of the year 2003, constructions of 52 wastewater treatment facilities and 53 deep-sea discharges were completed (Fig. 4). There is a great increase in waste water treatment plants during the year 2000-2004 due to application of the 1988 Water Pollution Regulation.

In the project targeted to be implemented in 5,200 villages by Ministry of Agriculture and Rural Affairs, plants with high treatment capacities consume water polluting elements such as nitrogen, phosphorus and carbon, release oxygen into water via their roots and perform the treatment process. Treated water is used in agricultural lands and livestock production and consequently $546 \cdot 10^3$ m^3 of water will be recycled. For natural treatment processes, wide rooted plants enjoying water and watery environments such as cannas, *Canna generalis,* sedges, *Juncus* and Tyhia type plants are preferred. This method is known as «green technology» and applied in several developed countries. The system cost is 40 times less than the traditional methods. The cost of a facility serving for 5,000 population is about $7,500.

Sewage services were successfully put into operation in 4,605 villages and some of them have a treatment

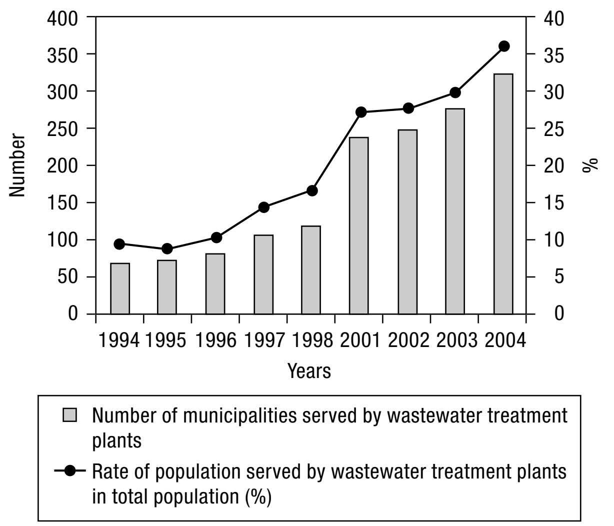

Figure 4. Development of waste water treatment plants (TUIK, 2007).

Table 8. Development of some values relating drinking and waste water in recent years (TUIK, 2007)

	2001	2002	2003	2004
Main drinking water indicators of municipalities				
Total number of municipalities	3,227	3,227	3,227	3,225
Number of municipalities receiving drinking water network services	3,092	3,140	3,161	3,159
Rate of population served by drinking water network in total population (%)	75	76	77	78
Amount of water supplied (million m^3 yr^{-1})	4,664	4,815	4,920	4,956
Number of drinking water treatment plants	113	123	131	140
Total capacity of water treatment plants (million m^3 yr^{-1})	3,245	3,526	3,736	3,718
Amount of drinking water treated by treatment plants (million m^3 yr^{-1})	1,667	1,711	1,894	2,081
Number of municipalities served by drinking water treatment plants	236	252	303	304
Rate of population served by drinking water treatment plants in total population (%)	27	29	31	34
Main wastewater indicators of municipalities				
Number of municipalities served by sewerage system	2,003	2,115	2,195	2,226
Rate of population served by sewerage system in total population (%)	64	65	67	68
Amount of wastewater discharged (million m^3 yr^{-1})	2,301	2,498	2,861	2,923
Number of wastewater treatment plants	126	145	156	172
Physical	25	28	31	35
Conventional	98	114	121	133
Advanced	3	3	4	4
Total capacity of wastewater treatment plants (million m^3 yr^{-1})	2,287	2,358	2,805	3,410
Physical	770	771	1 046	1 385
Conventional	1,250	1,320	1,484	1,750
Advanced	267	267	275	275
Amount of wastewater treated by treatment plants (million m^3 yr^{-1})	1,194	1,312	1,586	1,901
Physical	325	344	482	599
Conventional	663	746	877	1,071
Advanced	206	222	227	231
Number of municipalities served by wastewater treatment plants	238	249	278	322
Rate of population served by wastewater treatment plants in total population (%)	27	28	30	36

facility. In previous years, domestic wastewater was being collected in a septic tank, partially treated and discharged by receiving bodies. Since the proper methods were not selected for better utilization of natural resources, the desired success from the treatment facilities was not reached. High costs of selected methods and financial incapability of village people for operational costs also negatively affected the works toward this issue.

With the «Natural Treatment Project», started in the year 2003 and aimed to remove wastewaters in villages having proper drinking water supply without causing any harmful effect on environment and human health, a real size water treatment technology over the natural wetlands was started to be applied in villages. The number of natural treatment systems is about 330. The first pilot study was initiated in Ankara-Haymana-Dikilitas village. It was targeted to put natural treatment systems into operation in all villages with completed sewage infrastructure.

Distribution of natural treatment systems based on their service areas and population was given in Figures 5 and 6. Wastewater analyses were carried out in about 61.4% of them and plantation was carried out in 31.7% of them.

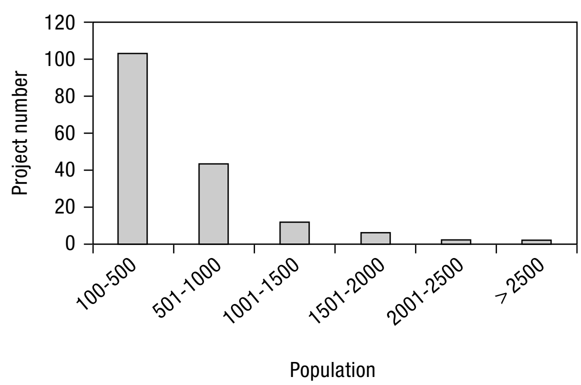

Figure 5. Natural treatment projects as to served population (GDRS, 2006).

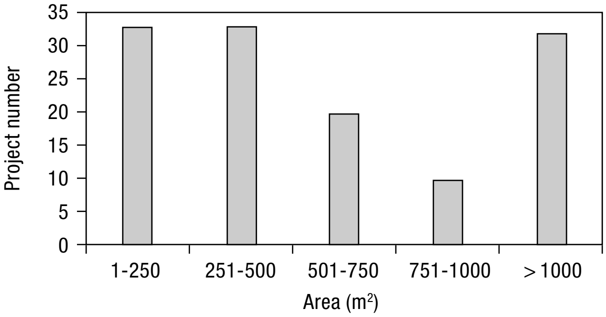

Figure 6. Natural treatment projects as to served area (GDRS, 2006).

Conclusions and recommendations

Natural treatment systems are relatively new technologies in Turkey. With efficient utilization of this technique, domestic waste will be reused and water saving will be increased and consequently a contribution to country economy will be provided. With the development of the natural treatment systems to be established in rural areas, environmental pollution by wastewaters will be prevented, and environmental health will be preserved and also regional landscape will be enriched by plantation of non-agricultural lands.

The laws and regulations in Turkey should be gathered under one frame covering wastewaters also. Then, the confusion brought by several regulations and laws will be eliminated.

Although legal regulations do not allow constructing wetland, it should be recommended to develop in Turkey considering its advantages. Natural treatment systems play a significant role in treatment and reuse of domestic wastewater and in providing a landscape to the region via plantation. Easy construction of these systems even with simple technology is the main advantage of these systems. In Turkey, 75% of utilized water is allocated to the agricultural sector and that is why this technology should be widespread in Turkey. Then, water saving in agriculture can be possible and this saving can be allocated to other sectors.

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