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Irrigation with Waste Water Treated by Constructed Wetlands

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Abstract: *The use of wastewater in agricultural irrigation has the potential for positive and negative environmental impacts.With careful planning and management, the use of wastewater can be beneficial to the environment. Constructedwetlands are usedworldwideforwastewater treatment, and this study discussesthe resultsofthesewetlandsincold and moderateregions ofthe world.Results show a remarkable BOD5 removal efficiency (58.8–99.84% of the influent BOD5 concentration) , even though only 62% of these wetlands were constructed following the U.S. EPA guidelines. The constructed wetlands can help remove TSS up to a level that is compatible with the quality standards for most reuse application in irrigation of crops. These wetlands cannot provide a water reclamation solution from a microbiological quality perspective that can meet reuse quality standards for irrigation.In terms of acidity, the effluent from constructed wetlands in cold climate is appropriate for irrigation of all crops. As a result, for reusing constructed wetland effluent in irrigation, combined systems like WSP-CW system require complying with the standard effluent for reuse water*

Keywords: *Constructed wetlands, feasibility, irrigation, removal efficiency, reuse water*

1. INTRODUCTION

The use of wastewater in agricultural irrigation has the potential for positive as well as negative environmental impacts. With careful planning and management, the use of wastewater in agricultural irrigation can be beneficial to the environment. Wastewater is an important source of water and nutrients for many farmers in arid and semi-arid climates. Sometimes it may be the only source of water available for agricultural irrigation. When Wastewater use is well managed, it helps recycle nutrients and water and therefore diminishes the cost of fertilizers or simply makes them accessible to farmers (WHO, 1991).

The rapid population growth in many cities or towns in the world has increased not only the demand for freshwater but also the volume of wastewater discharge. As other sources of water are decreasing, treated wastewater appears to be the only water resource that is increasing. In the development of new strategies for freshwater supply, the treatment and recycling of wastewater can play an important role in addressing water shortage. Reuse of treated wastewater for irrigating landscapes is often viewed as one of the approaches to maximize the existing water resources and to expand urban water supplies (U.S. EPA, 2004a). The exiting pollutants may have significant negative impacts on the surrounding environment and may endanger the ecosystem and public health. The proper treatment of wastewater before it is discharged into the environment may help mitigate these dangers. With the development of treatment systems, domestic wastewater can primarily be considered for reuse in agricultural irrigation. Nowadays, as more developed technologies are used for water reclamation, the quality of recycled water can match or even exceed drinking water quality, based on most conventional parameters. The conventional treated wastewater process includes a series of physical, chemical and biological processes. Typically, treatment includes three stages, known as primary, secondary and tertiary treatment. Primary treatment, that includes screening, grit removal, and primary sedimentation, is applied to separate and remove inorganic materials and suspended solids that harm the pipes. Secondary treatment cleans dissolved and suspended biological matter. Typically, up to 90% of the organic matter in the wastewater can be cleaned via tertiary treatment which is sometimes defined as advanced treatment. The tertiary treatment is the final treatment stage to raise the effluent quality to the expected level. Before discharging treated wastewater, a disinfection process is sometimes needed. The purpose of disinfection in the treatment of wastewater is to substantially reduce the number of microorganisms in the water to be discharged back into the environment, and it is almost always the final stage in the treatment process regardless of the level or type of treatment applied. The treated water can be discharged into a river, lagoon, or wetlands, or it be applied for landscape irrigation. If it is probably cleaned, it can also be used for groundwater recharge or agricultural purposes.

1.1. History of Constructed Wetlands

Investigations into the use of constructed wetlands (CWs) for wastewater treatment started in the middle of the last century. The first investigations were probably conducted by Käthe Seidel in Germany in the early 1950s at the Max Planck Institute in Plön (Seidel, 1955). Her report discussed the possibility “of lessening the over fertilization, pollution and silting up of inland waters through appropriate plants, thereby allowing the contaminated waters to support life once more” (Seidel, Happel, &Graue, 1978, p. 2). It was clarified that macrophytes (e.g., Schoenoplectuslacustris) were capable of removing large quantities of organic and inorganic substances from polluted waters. Moreover, Schoenoplectus spp. not only enriched the soil in which grew bacteria and humus but apparently removed antibiotics. Bacteria and heavy metals in the polluted water were removed by passing through the macrophytes.

In North America, experimentation with FWS wetlands started with the observation of assimilative capacity of natural wetlands at the end of the 1960s and the beginning of the 1970s (Spangler, Sloey, & Fetter, 1976; Wolverton, 1987). Between 1967 and 1972, a five-year study started in Chapel Hill, North Carolina, that used a composition of constructed coastal ponds and natural salt marshes for the recycling and reuse of municipal wastewater (Odum, 1977). In 1973, the first fully CW made up of a series of constructed marshes, ponds and meadows was built in Brookhaven, New York (Kadlec& Knight, 1996). About the same time, an interdisciplinary research team at the University of Michigan started the Houghton Lake project. This research was the first application of a treatment wetland in a cold climate area (Kadlec, et al., 1975; Kadlec& Tilton, 1979). Since then, FWS CWs have been expanded in the United States for various types of wastewater treatment. A CW is a low energy-consumption ecosystem. This wetland system uses natural biogeochemical cycles to eliminate sediments and pollutants from wastewater. Unlike complex high-maintenance treatment systems, the use of CWs will lead to a more ecologically-sustainable wastewater treatment in the future. This system provides an advanced treatment of wastewater that pretreats to secondary level. The pollutant removal efficiency is associated with multiple factors, including temperature, the size and number of wetlands, the volume and quality of influent water, and the retention time.

CWs are engineered that mimic natural wetlands that are gniebincreasingly considered for wastewater treatment worldwide. Constructed wetlands are constructed to utilize the natural processes that involve wetland vegetation, soils, and associated microbial assemblages for assisting with the treatment of wastewaters. CWs may be classified according to the life form of the dominating macrophyte, wetland hydrology (free water surface and subsurface systems), and subsurface flow CWs can be classified according to the flow direction (horizontal and vertical) (Vymazal, 2010).

1.2. Advantages and Disadvantages of Conventional Treatment

A conventional sewage treatment system needs relatively less land area and provides a better control of the wastewater treatment process. For example, CWs require 4 to 10 times more land area than does a conventional wastewater treatment facility (U.S. EPA, 1988). The treatment facilities usually work under a well-controlled environment. Thus, this system is less sensitive to the environment. The high cost of construction and maintenance is the main disadvantage of conventional wastewater treatment systems. Also, the management and monitoring of mechanical systems require expert personnel. Generally, the complication and cost of wastewater treatment technologies increase with the quality of reclamation produced (Organization of American States, 1997, Ostad-Ali-Askari et al., 2015., Bahmanpour et al., 2017., Dehghan et al., 2017). Table 1 shows advantages and disadvantages of FWS and SSF.

Table1: *Advantages and Disadvantages of Free Water Surface (FWS) Constructed Wetlands and Subsurface Flow (SSF) Wetlands*

	FWS	SSF
Advantages	Lower installation and operating costs	Greater assimilation rate, less land required
	Good integration into landscape	No visible surface flow
	More Secondary benefits(such as wildlife habitat), but contamination exposure concern	More cold tolerant
	Shorter development period to reach full performance	Reduction in odor and insect problems
Disadvantages	Less cold tolerant	Not attractive to wildlife
	More land required	more isolated from humans

1.3. Cold Climate

Important physical processes, such as sedimentation and decantation, and in particulate organic matter removal, are mostly not affected by winter conditions. However, biological processes are dependent on temperature, and winter removal efficiency of HSSFCWs for nitrogen and soluble organic matter that both are highly affected by biological activity, and may be reduced (Plamondon et. al. (2006), Eslamian et al., 1999., Eslamian et al., 2001., Eslamian et al., 2005).

Wastewater treatment by wetlands rely largely on biological and biochemical processes. Since hydraulics, and chemical and biochemical processes cause a possible decrease of dormant plants and a slow response rate of soil or aquatic microbes at low temperatures, these are considerably affected by cold winter climate (Maehlum et. al. (1995)). Because wetland treatment is usually land focused, it can be concluded that wetland treatment is more dependent on climatic conditions than are conventional wastewater treatment methods. Though the wide opinion for successful wetland treatment is for the warm regions, but studies in North America and Scandinavia have indicated that wetland treatment may also be possible in cool regions. Hence, wetland treatment can be accepted as a serious alternative method for treatment or as a supplement to more conventional methods in a number of treatment situations (Wittgren and Mrehlum (1997), Ostad-Ali-Askari et al., 2016, Eslamian et al., 2006).

Since treatment in SSF wetlands occurs below the ground surface, these wetlands have an advantage in colder climate. The reason is that treatment happens below the ground surface, and bacterial activity is thereby protected somewhat from the frigid air (Wittgren and Maehlum, 1997, Ostad-Ali-Askari et al., 2017, Eslamian et al., 2010).Wetland systems used in cold climate are larger and deeper with an extended detention time to remove pollutants with better removal efficiency. The minimum detention time for wetlands in cold climate is 10 to 13 days to ensure high quality effluent (Gustafson et. al. (2002)). Significant design considerations in cold climate areas are required for water storage during winter months, and inflow and outflow structures that withstand long periods of below frost temperatures, and high freeboard for year-round systems (Pries et. al. (1996), Eslamian et al., 2011).

There are opposing views on the presence or absence of temperature dependence in the BOD removal within treatment wetlands. To be stably removed from solution, organic nitrogen must be changed to ammonia ($NH4+$), then oxidized to nitrite ($NO2-$) and nitrate ($NO3-$), and finally denitrified to nitrogen gas ($N2$). Longer reaction times and various environmental conditions must be present to assimilate organic nitrogen in flow than a nitrate inflow. Nitrification and denitrification have all been indicated to be temperature dependent in wetlands during winter months. Therefore, the rate of total nitrogen removal depends on temperature. If oxygen transmission by diffusion and by plants through their aerenchym a and roots becomes in-sufficient to satisfy the carbonaceous oxygen demand during winter months, then the resulting anaerobic environment would avoid the nitrifying activity (Ham-mer and Knight, 1994). Nitrogen removal from wastewater is a complex process requiring a diverse microbial selective environment. Decreasing nitrogen removal efficiency during winter months may be due directly to temperature or it may be due to associated parameters, such as plant dormancy or reduced oxygen transport (Werker et. al.(2002),Eslamian et al., 2012, Eslamian et al., 2013, Eslamian et al., 2014,Eslamian et al., 2015).

1.4. Literature Review

Morari and Giardini (2009) investigated the treatment effect of two pilot-scale vertical flow constructed wetlands (VFCWs) on urban wastewaters and their feasibility of reusing for irrigation.

Typhalatifolia and the phragmitesAustral were used for covering two VFCWs. The efficiency of these VFCWs was investigated in terms of mass removal and water quality improvement. In this study, the accumulation of factors in plant organs and VFCW sandy surface layer and their off take with macrophyte harvest were also evaluated. Higher removal efficiencies for COD, BOD, N and K were observed in quantitative terms, while the removal efficiency was lower for Na and Mg. Because of the huge growth of macrophytes, these plants directly contribute to the removal of N, P and K. The results of water quality were less desirable because of high evapotranspiration losses. Higher concentrations were observed in outflow rather than inflow. At the end, the use of efficient pre-cleaning systems or innovative integrated systems for decreasing the effect of ET on water quality was suggested to obtain high removal efficiencies (Ostad-Ali-Askari et al., 2016. Ostad-Ali-Askari et al., 2017, Eslamian et al., 2016, Eslamian et al., 2017).

In some studies, further treatment combining constructed wetlands and wastewater stabilization ponds for treated wastewater was done. Incorporating CWs with the original evaporation lagoons would not only increase wastewater quality but also store great amounts of water that could be used for other goals, such as irrigation (Zhang (2010)). Overall, wastewater treatment and agriculture reuse with the application of a CW-WSP system could be a practical wastewater management measure for protecting receiving water bodies and overcoming water shortages in decentralized rural areas (Ham et. al. (2007)).

Zhang (2010) and Ham, et al. (2007) applied combination of constructed wetland and wastewater stabilization pond for treated wastewater and its reuse in irrigation. In central Utah with hot dry summers and cold winters where the changes of normal mean temperature were from 20.9℃ to –4.1℃, Yue Zhang (2010) investigated the design and possibility of using free water surface constructed wetland system to treat the municipal wastewater. Results showed that after a relatively long retention time, the overall biochemical oxygen demands decreased by 93.6% to 97.8% and the total suspended solids decreased by 87.2% to 87.9%. The treated water was adequate to irrigate approximately 45 acres of turf grass or 37 acres of pasture grass.

In a feasibility study, Ham, et al. (2007) investigated the performance of a constructed wetland (CWs) and wastewater stabilization pond (WSP) system for sewage reclamation and paddy rice irrigation in a decentralized rural area. These experimental CWs have been working steadily since 1997 in Seoul, Korea where the average ambient air temperature in the winter period for the study period was -0.2°C. The CWs had good removal efficiency, even in the winter period, but the effluent concentration was relatively large in the winter period. So a WSP was used for further treatment and the WSP effluent was introduced as safe for crop irrigation with respect to sewage-borne pathogens. Recycled water irrigation did not adversely affect the yield of rice, also this experiment showed an approximately 50% greater yield than in controls and the chemical characteristics of soil did not change considerably during the experimental period of irrigation with recycled water.

Moreno et al. (2007) evaluated the effectiveness of constructed and natural wetlands in removing nutrients from agricultural wastewater and their potential contribution to landscape heterogeneity in semiarid Mongers area, Northeast Spain., where the mean annual temperature was 14.5 ◦C and samples of water were collected at the inflow and outflow of the plots for two years. This study investigated how to neutralize the problems related to non-point pollution from irrigation of agricultural fields by constructed wetlands in a dry environment. The experimental wetlands showed significant N removal efficiency, despite being at the initial stages of their development. For phosphorus, the experimental wetlands ranged from exportation to removal of 80% of the phosphorus input. Results showed that the larger the wetland, the more removal efficiency was for N. Some differences between the first and second years of wetland operation were observed, meaning that these wetlands were progressing in their nutrient removal function towards advanced state with high nutrient removal efficiency as it was usual in similar wetlands.

Justin and Zupancic (2009) combined leachate pretreatment in a horizontal and vertical subsurface water flow constructed wetland (CWs), planted with phragmitesAustral is and subsequent reuse for irrigation of the closed and vegetated part of the landfill site. The mean temperature of leachate was at the inflow to CWs was 16.5 °C between October and March, when mean air temperatures reached 3°C. The retention of water peaks occurred due to contributed pre-treatment of leachate in CWs. Despite high concentrations of several pollutants and nutrients in pre-treated leachate, irrigation of vegetated landfill covers with high leachate input did not occur due to excessive accumulation of salts, heavy metals, or nutrients. The growth of plants on the irrigated landfill cover was better than the surrounding vegetation, because of further input of water and nutrients from the leachate.

Gross et al. (2007) developed a combination of vertical flow constructed wetland with a water recycling and trickling filter(RVFCW) that would provide safe and sustainable use of grey water for landscape irrigation in small communities and households. The treated grey water had no remarkable negative impact on plants or soil during the study period. In this study, the RVFCW was introduced as a sustainable and promising treatment system for grey water use that can be performed by unskilled operators.

In other area, the effect of temperature, hydraulic residence time (HRT), vegetation type, and porous media material and grain size on the performance of horizontal subsurface flow (HSF) constructed wetlands treating wastewater was investigated. During the operation period, four HRTs (i.e., 6, 8, 14 and 20 days) were used, while the wastewater temperature varied from about 2.0 to 26.0◦C.The removal efficiency of the constructed wetlands was obtained to be high and also showed a dependence on temperature. Results showed that an 8-day HRT was adequate for acceptable removal of organic matter, TKN and P-PO43−for temperatures above 15◦C. Also, based on statistical testing, cattails, finer media, and media obtained from a river indicated higher removal efficiencies of TKN and P-$PO4^{3-}$ (Akratos and Tsihrintzis (2007), Eslamian et al., 2014).

Nivala et al. (2007) applied a pilot-scale subsurface-flow constructed wetland equipped with a patented wetland aeration process to aid the removal of organic matter and ammonia nitrogen to demonstrate the use of constructed wetlands as a possible low-cost treatment option for leachate generated at small landfills. Also, due to very cold air temperatures in winter in the study area, a layer of mulch insulation covered the top of the wetland bed to maintain the system from freezing. The high iron content of the leachate caused the aeration system to cease after 2 years into operation. Treatment efficiencies increased with the installation of a pretreatment chamber for iron removal and a new aeration system. Adequate insulation and aeration caused that these systems performed well, even during sub-freezing temperatures. Hence, high treatment efficiencies were observed with the installation of a pretreatment chamber for iron removal and a new aeration system.

Two free water surface (FWS) and two subsurface flow (SSF) pilot-size constructed wetlands were used for treating highway runoff (HRO) over a period of two years. A hydraulic retention time (HRT) of 12 h was considered for One FWS and one SSF, named FWS12 and SSF12, respectively, receiving a maximum HRO of 12.6 m3 d1. The other couple, named FWS24 and SSF24, respectively, and an HRT for these was considered 24 h, each receiving a maximum HRO of $6.3m^3d^{-1}$. The performance among the four sets of experiments was not remarkably different according to ANOVA analysis for almost all the measured physicochemical parameters, so it was suggested that all systems performed in a similar way; A mean of two-year removal efficiencies for all studied systems was almost the same for each of the parameters(Terzakis a,b et al(2008)).

The effect of climate, season, and wastewater quality on pollutant removal efficiency of constructed wetlands in Mediterranean and Continental-Mediterranean climate region of Spain was investigated by Marianna Garfía et al (2012). To this end, two experimental horizontal subsurface flow constructed wetlands were implemented. Phragmitesaustral is planted in both constructed wetlands. Total suspended solids, biochemical oxygen demand, and ammonium mass removal efficiencies showed a dependence on season, with higher amounts in summer rather than in winter. Results of this work showed that horizontal subsurface flow constructed wetland was a successful technology for both regions considered, even if winter appeared to be a critical period for ammonium removal in continental climate regions (Marianna Garfía et al (2012)).

In northern Japan, another cold climate area, the performance of six multi-stage hybrid wetland systems was investigated. The systems were designed to treat four kinds of wastewater: dairy wastewater, wastewater from a pig farm, including liquid food washing wastewater, wastewater from potato starch processing, and wastewater containing pig farm swine urine. These systems combined three to four vertical (V) flow beds with self-priming siphons and surface partitions and no or one horizontal(H) flow bed (total of three to five beds). In order to avoid clogging and frost and maintain dry conditions and plentiful growth of reeds and earthworms, the safety bypass structure and floating cover material were used. The mean treated rates were 70–96% for chemical oxygen demand

(COD), 39–90% for total nitrogen (TN), 36–82% for NH4 –N, and 70–93% for total phosphorous (TP). The estimated mean oxygen transfers rates (OTRs) were 16–99 g O2 m−2d−1. By treating higher organic loads per area without clogging, it was possible to minimize the area and cost of treating high-content wastewater. At the end, it was suggested that more information was obtained concerning load and OTR to design a more efficient multi-stage wetland system. (Kato et al (2013))

Bulk (2006) used a constructed wetland (CW) as a pilot integrated system consisting of three interconnected beds, two of vertical flow and one of horizontal flow stage for the capital city's old sanitary landfill site. The efficiency of the CW system was investigated for 7 years using physical and chemical parameters. The implementation of the system did not change considerably with regard to temperature; however, it changed with precipitation. Results indicated that the CW system, as a tertiary system or as an independent system, could be a low-cost alternative for the treatment of leachate from old landfill sites.

The present study discusses the results of wetlands in cold and moderate regions of the world. The goal here is to investigate the feasibility of using effluent constructed wetlands for irrigation. Also it provides models for estimating the effluent of these wetlands with influent.

2. Feasibility and Modeling

Although irrigation has been done worldwide for several thousand years, the importance of quality of irrigation water has been emphasized only in the last century. The feasibility of irrigation with water treated by constructed wetlands was investigated, based on several parameters in various studies in different areas of world with cold and moderate climate, that contain nutrient levels; BOD5, biological oxygen demand over a 5-day period; COD, chemical oxygen demand; TSS, total suspended solids; T-P, total phosphorus; T-N, total nitrogen; NH4, ammonium; EC, electric conductivity, and FC; Fecal coliform (Shayannejad et al., 2017.,

Electrical conductivity (EC) is the most convenient way of measuring water salinity. The salinity of studied system effluent was in the range of 0.237-2.12 dS/m. Based on the Food and Agriculture Organization (FAO) irrigation water quality guidelines (FAO, 1985), the degree of reuse restriction for these effluents was insignificant to moderate (0.7 – 3.0 dS/m) for irrigation crops.

The presence of nutrients in treated wastewater can provide a fertilizer value for crop production. Nitrogen is the most useful nutrient that often exists in high concentrations in reclaimed wastewater. However, excessive nitrogen causes increased vegetative growth, delayed or uneven maturity, reduced crop quality, and may be injurious to many crops. The average nitrate (NO3) concentration of the studied constructed wetland effluent was 22 mg/L. According to the guidelines for interpretation of water quality for irrigation (Ayres and Westcott, 1976) more than 5 mg/L is considered no problem, almost 51.28% investigated effluents are classified as no problem and 15.38% of these create severe problems. However, because the reclaimed irrigation water may be mixed with about precipitation water, a volume about two or three times greater than that of the irrigation water during the irrigation season in some areas. Classification of NO3 effluent concentration according to Ayres and Westcott (1976) is shown in figure 1.

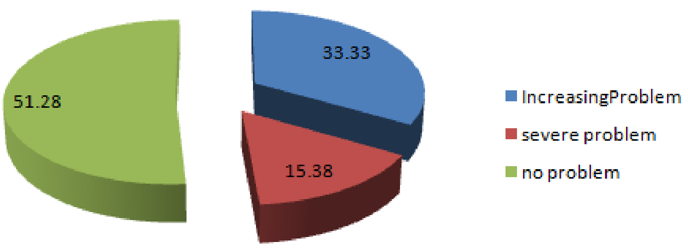

Figure1: *Classification NO3 effluent concentration according to Ayres and Westcott (1976)*

To reuse the WSP effluent as crop irrigation water, blending the WSP effluent with other irrigation water keeps salinity under control (0.7 dS/m), and its supplemental use is therefore recommended.

The CW studied by Ham et al. (2007) and Nivala et al. (2007) showed that in summer and the growing season, higher temperatures caused the increase of wetland performance for wastewater contaminant removal. Hence, to decrease effluent levels in the study wetlands, it is suggested that this system is operated in summer and the season growing for cold climate areas.

As seen in Table 2, more than half of the influent concentration of BOD5 was removed in the study constructed wetlands. This table shows that the BOD5 removal rates were high. The correlation was significant at the level 0.01 between mean removal efficiency and influent concentration of BOD5 but the correlation coefficient was low and this was equal to 0.23. Ran et al. (2004) showed that the organic removal rates were high and increased linearly with organic and hydraulic load. This study was conducted in warm climate. The correlation coefficient between effluent and influent concentrations of BOD5 was not significant and the regression coefficient was poor. The data was divided into three zones and all these zones had strong regression.

Table2: *Removal efficiency of study CWs*

Area	Removal Efficiency%
Slovenia	65.80
Padova, Italy	59.31
Padova, Italy	61.11
Padova, Italy	93.78
Padova, Italy	92.17
Ben-Gurion, Israel	99.85
Indiana, USA	98.41
Greece	88.59
Greece	85.07
Greece	86.13
Greece	89.26
Greece	87.48
Iowa ,USA	87.63
Iowa ,USA	95.45
Iowa ,USA	96.89
Iowa ,USA	88.54
Iowa ,USA	80.84
Iowa ,USA	78.95
Iowa ,USA	75.29
Iowa ,USA	75.28
Seol, Korea	82.06
Seol, Korea	58.78
Barcelona, Spain	89.67
Leon, Spain	64.55
Slovenia	63.16
Negev, Israel	71.58

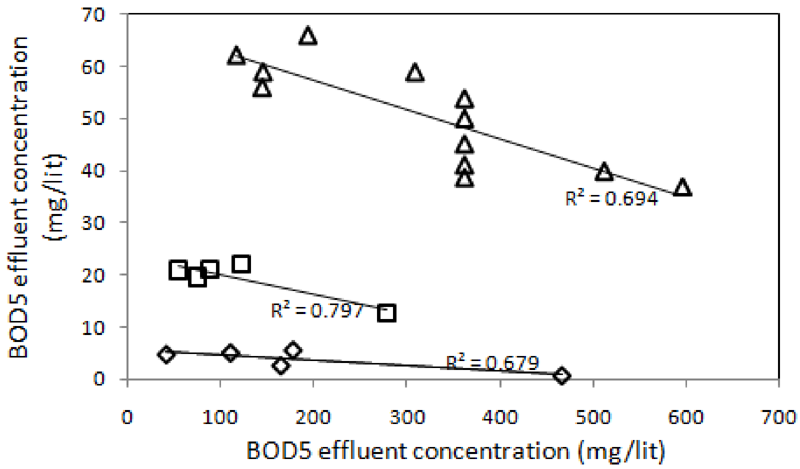

Figure2: *Correlation between BOD5 effluent and removal efficiency*

In 14 out of 39 cases, the concentration of BOD5 in the effluent of wetland was more than 30 mg O_2/l and therefore these cases were not appropriate for reuse according to the U.S. EPA guidelines (U.S. EPA, 2012). In 12 cases, the concentration is included between 10 mg O_2/l and 30 mg O_2 /l; according to the U.S. EPA guidelines this reclaimed water was suitable for irrigation in restricted access areas, for irrigation of crops which are not consumed by humans including fodder, fiber, and seed crops, or to irrigate pasture land, commercial nurseries, and sod farms and food crops which are intended for human consumption, commercially processed. In the other 13 cases, the effluent concentration was lower than 10 mg O_2/l and therefore also suitable for surface or spray irrigation of food crops which are intended for human consumption, as consumed raw (U.S. EPA, 2012).

Investigated wetlands showed a remarkable BOD5 removal efficiency (58.8–99.84% of the influent BOD5 concentration), in spite of the fact that only 62% of these were according to the U.S. EPA guidelines.

The maximum removal efficiency of BOD5 was obtained when grey water for landscape irrigation was used as wastewater in constructed wetland. Also small landfills treated by these systems had high efficiency and low influent concentration, hence constructed wetland effluent was appropriate (according to the U.S. EPA guidelines).

Overall, wastewater treatment and agronomic reuse using a CW-WSP system or aerated subsurface-flow constructed wetland could be a practical integrated wastewater management measure for protecting receiving water bodies and overcoming water shortages.

Aerated subsurface-flow constructed wetlands were presented as a viable low-cost treatment alternative for the treatment of landfill leachate by Nivala et al. (2007). This system can be implemented even during subfreezing temperatures if it is insulated and aerated enough.

The correlation between TSS influent and effluent was significant at the 0.01 level and followed an equation as $y = 0.359x - 21.58$. This correlation is shown in figure 4. The regression coefficient of this correlation was very strong and equal to 0.87.

The mean removal of TSS in the investigated wetlands was 51.18 %(in same study). This value was lower than the removal of BOD5. The Removal efficiency for BOD5 and TSS in the investigated wetlands was compared in Figure 5 which shows that the removal efficiency BOD5 was more than the removal efficiency of TSS in most cases.

The average TSS concentrations of influent and effluent were 277.5 and 79.7 mg/l, respectively. Hence, it can be concluded that many wetlands actually work as sources of suspended solids. In most cases, the concentration of TSS in the wetland effluent was less than 30 mg O_2/l and therefore wetlands were able to remove this parameter, based on the U.S. EPA guidelines for reuse (U.S. EPA, 2012). In 25% of cases, the effluent concentration was high and good removal efficiency could be due to high influent concentration. Also, the suspended solids in the effluent of CWs were of a different nature than those in conventionally treated wastewater. While the effluent of activated sludge systems largely included sludge flocks, the effluent from the wetland included mostly algae and small organisms (Kampf and Claassen (2004), Shayannejad et al., 2015. Eslamian et al., 2017., Eslamian et al., Godarzi et al.,2017., Shojaei et al., 2017., Sayedipour et al., 2017. Eskandari et al., 2017, Chavoshi-Boroujeni et al., 1999, Feyzi et al., 2005).

Results indicated that constructed wetlands in cold and moderate climate helped the removal of TSS up to a level that reflected their background concentration and were compatible with the quality standards for most reuse application in irrigation of most crops.

Investigation of constructed wetlands in several areas with cold climate showed that using domestic and municipal wastewater did not create appropriate TSS effluent concentration due to both low removal efficiency and high influent concentration, so treated domestic and municipal wastewater by CW was not recommended for irrigation, unless combined methods were used for further polishing of constructed wetland effluent.

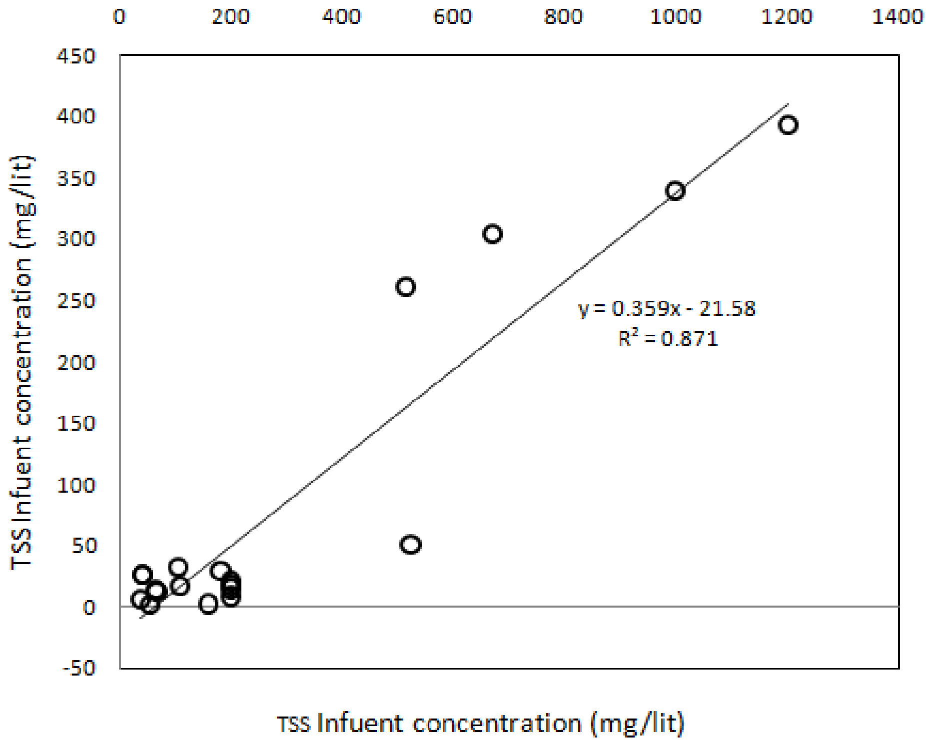

Figure4: *Correlation between TSS influent and effluent concentrations*

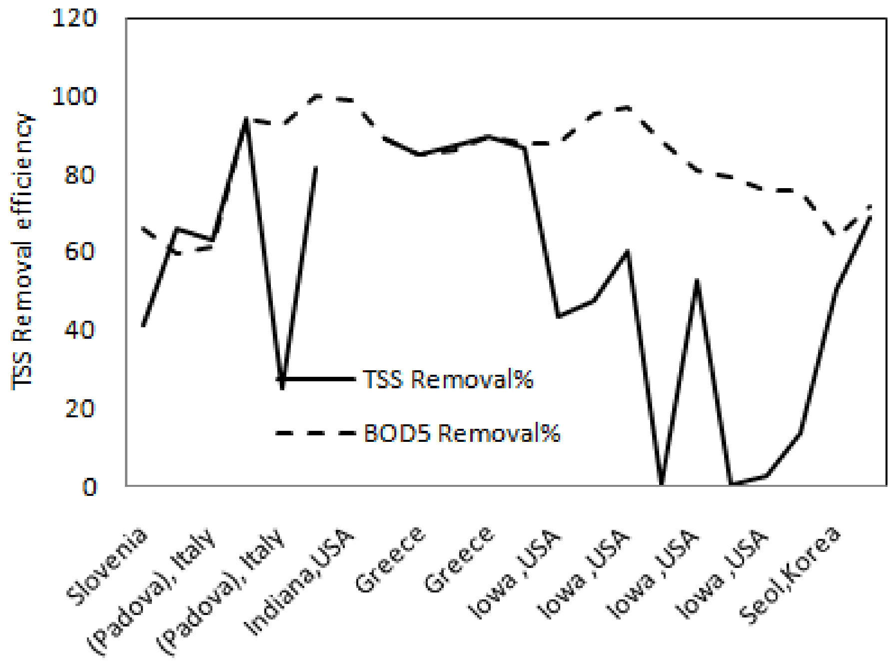

Figure5: *Removal efficiency for BOD5 and TSS in investigated wetlands*

Table 5 summarizes the findings concerning the removal of FC in the investigated systems. Faucal coliforms (FC) are by far the most commonly used indicator of pathogenic contamination that has been monitored in tertiary FWS wetlands (Ghermandi et al., 2006, Shayannejad et al., 2016., Ostad-Ali-Askari et al., 2015), but few studies have reported this parameter. Removal percentages in figure 6 show that CW is able to remove FC even up to 99%. In spite of high removal efficiency in all wetlands, only in one case out of six cases, the FC concentration effluent was appropriate for irrigation according to the U.S. EPA guidelines (U.S. EPA, 2012). In 3 out of 6cases there was improvement, according to the quality standards set by NWQMS (1996) for landscape irrigation, irrigation of pasture and fodder,horticulture, irrigation of food crops not in direct contact with water or sold to consumers cooked or processed. Inadequate concentration in effluent was because of too high concentration.

Table3: *Influent and effluent concentrations of FC and removal efficiency*

Area	Influent	Effluent	Removal Efficiency%
Slovenia	50000000	440	99.99
Ben-Gurion, Israel	50000000	200000	99.6
Seol, Korea	693800	7667	98.89
Seol, Korea	564910	5256	99.06
Seol, Korea	7883.3	431.7	94.52
Negev, Israel	838500	76500	90.87

Also based on the World Health Organization (WHO) microbiological guidelines for treated wastewater (WHO, 1989, 2000), FC counts should be less than 1,000 MPN/ 100 mL for irrigation of crops for human consumption. In this investigation, in four cases the FC effluent from study systems was still too high for reuse as irrigation water.

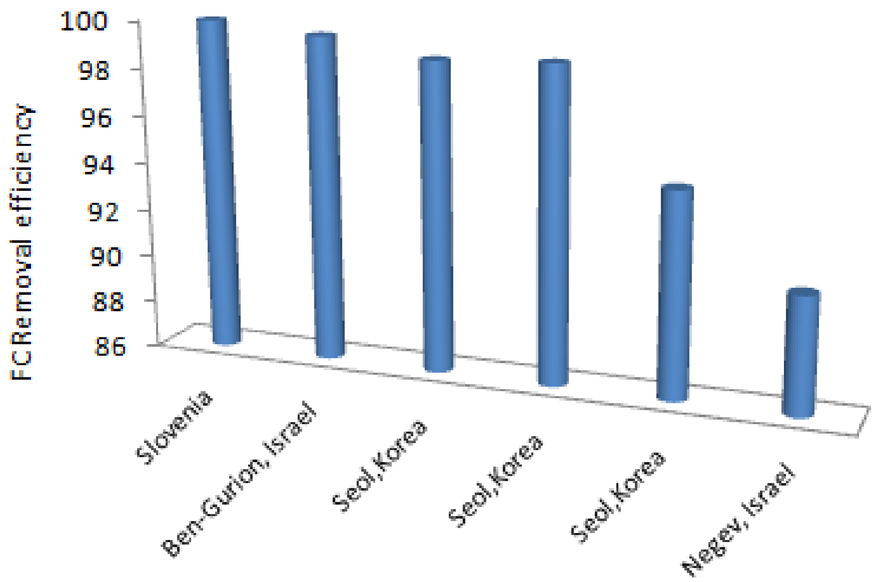

Figure6: *Removal efficiency for FC in investigated wetlands*

Figure7 shows that the acidity of effluent from study systems was in the range of 6-9 according to US EPA guidelines. So this effluent from CWs in cold climate was appropriate for irrigation of all crops. CWs did not have a significant effect on PH parameters and didn't change outside of the standard range. Also there was a significant correlation between pH influent and effluent. This correlation was a polynomial of second degrees $y = -1.863x^2 + 26.19x - 84.27$. Figure 8 shows the correlation of between pH of wastewater influent and of effluent.

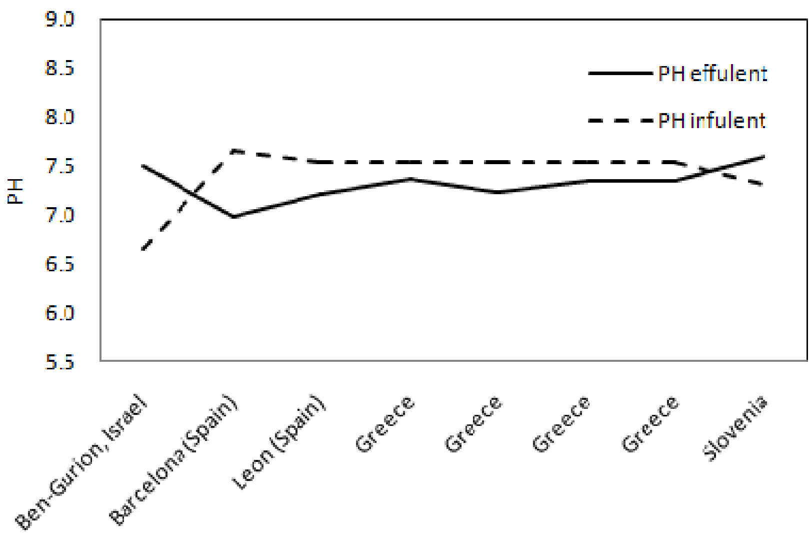

Figure7: *Acidity of influent and effluent constructed wetlands*

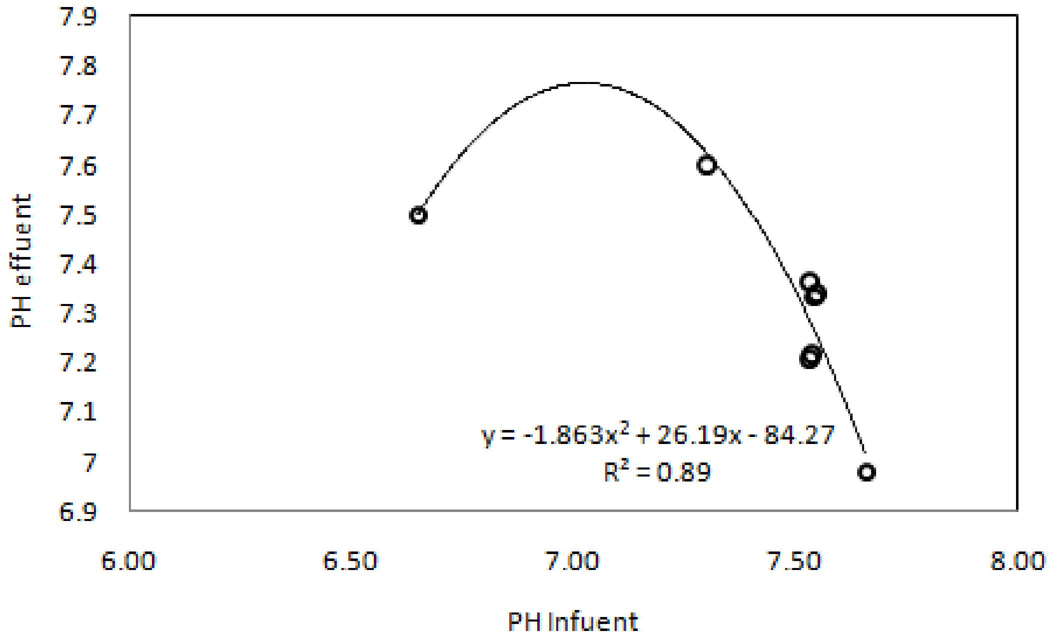

Figure8: *Correlation of between pH of influent and of effluent*

3. Conclusion

By means of an extensive investigation of relevant studies on tertiary constructed wetlands in cold climate worldwide, the following conclusions can be drawn from this study:

Investigated wetlands showed a remarkable BOD5 removal efficiency (58.8–99.84% of the influent BOD5 concentration) , in spite of the fact that only 62% of these were according to the US EPA guidelines.

Constructed wetlands in cold and moderate climate can help the removal of TSS up to a level that reflects their background concentration which is compatible with the quality standards for most reuse application in irrigation of most crops, but in 25% of the cases, the effluent isn't suitable for all reuse applications in irrigation for which a threshold on the concentration of TSS is foreseen in the U.S. EPA guidelines. The removal efficiency of BOD5 is more than the removal efficiency TSS in most cases.

Constructed wetlands cannot provide a water reclamation solution from the viewpoint of microbiological quality that can meet reuse quality standards for irrigation. The microbiological quality of the water is improved but still it isn’t appropriate for irrigation according to the U.S. EPA. Also, based on the World Health Organization (WHO) the four cases of FC effluent from study systems were still too high for reuse as irrigation water.

The acidity of effluent from the study systems is the range of 6-9 according to U.S. EPA guidelines. So this effluent from constructed wetlands in cold climate is appropriate for irrigation all crops.

For reusing constructed wetlands effluent in irrigation, combined systems like WSP-CW system require complying with the standard effluent of reuse water.

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