# Treatment and Reuse of Wastewater Using Surface and Subsurface Wetlands

**L. Al-Hadidi[1], M. Dukah[2], M. Shatanawi[2].**

**[1] The National Center for Agricultural Research and Extension. Baqa. Jordan.**
**lunah@ncare.gov.jo**
**[2]Faculty staff member. University of Jordan. Amman, Jordan.**
**mmduqqah@ju.edu.jo , shatanawi@ju.edu.jo**

**Abstract -** This research was carried to evaluate the use of two types of constructed wetlands on partially treated wastewater and improve the quality of treated wastewater effluent. A free water surface (FWS) wetland composed of three cells in series of which two are open water surface and one is a channel bed planted with *Cyperus alternifolius* was designed and constructed. Four different mixtures of TWW effluent and the primary TWW effluent were used under different hydraulic retention times of 3, 6, 9, and 12 days within the FWS wetland. Water quality parameters (turbidity, EC, P, TKN and pathogens; fecal & total coliforms) were monitored for both inflow and outflow on regular basis. A sub-surface flow (SSF) wetland was constructed and evaluated. The outflow from the wetlands along with a TWW effluent (control) was directed to irrigate a fodder crop field. The quality of wastewater and/or HRtime in FWS constructed wetland significantly affected the pH, EC, TSS, E.coli, P and turbidity to greater levels and insignificantly affected the concentrations of $BOD_5$, COD, TKN, and $NO_3$. It appears that, evapotranspiration from the surface wetland increased hydraulic retention time and constituent concentrations. Lower HRTimes were attributed to either short circuiting effects or overloading of the wetland. The SSF wetland affects the concentration of pH, EC, TSS, nitrate, E.coli, P, turbidity Fe, Cu, Zn and Mn to greater levels. Results also indicated the possibility of using the SSF wetlands for the production of specific fodder crops with high feeding value.

**Keywords** – Wastewater, wetlands, cyperus alternifolius, HRtime.

## INTRODUCTION

The increasing scarcity of water in the world along with rapid population increase in urban areas give reasons for concern and the need for appropriate water management practices. Jordan suffers from shortage in water resources to meet its increasing demands for water consumption by different sectors (Al-Zu'bi, 2007). It is considered as one of the 10 poorest countries worldwide in water resources. Currently, the interest in wastewater reuse in various parts of the world has promoted the development of wastewater treatment technologies (Al-Zboon and Al-Ananzeh, 2008). Wastewater is widely recognized as a significant, growing and reliable water source (Ismail and Yuliwati, 2010). This study was brought in an attempt to provide a technical solution to improve the quality of reclaimed wastewater effluent of Ramtha treatment plant. Constructed wetlands can be used as a major unit process in a system to treat municipal wastewater. While some degree of pre- or post- treatment will be required in conjunction with the wetland to treat wastewater to meet reuse requirements, the wetland will be the central treatment component. As a result of both extensive research and practical application, insight will be gained into selected design parameters, performance, operation, and maintenance of constructed wetlands for water quality improvement (EPA, 1995).

## MATERIAL and METHODS

Field experiments were conducted near Ramtha wastewater treatment plant, where irrigation with treated wastewater is highly practiced. The area allocated for the construction of both types of wetlands and the field experiment was approximately 25 m width by 125 m length. The site was shaped and graded using the natural gravity. The surface wetland was designed using the multi-cell, multistage approach with different water levels at each cell as the water flows across the wetland. In constructing the free surface wetland, the flow path was divided into a series of zones perpendicular to the flow path similar to those observed in natural wetlands. The layout of the free water surface wetland was comprised of deep, open water basin (cell 1) followed by a shallow vegetated channel bed (cell 2) then another shallow, open water basin (cell 3) and a collection basin (cell 4). The first three cells were constructed for the treatment of wastewater and the fourth one was for the collection of the treated effluent (Figure 1). The soil was compacted within all the treatment cells that were also lined to prevent seepage to the groundwater and to maintain the water level in the cells using a 600 micron polyethylene layers**.**

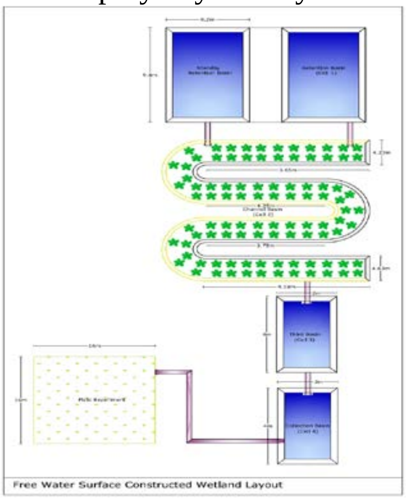


**Figure 1.** Free waster surface constructed wetland layout.

Planting was done by hand. Planting layout patterns for emergent species include band planting (across the wetland) and parallel to the wetland edge (Queensland, 1995). *Cyperus alternifolius* was planted in early December, 2007 inside the channel bed cell. The potted plants were placed in the soil in two rows across the wetland with a distance ranging from 0.75 to 1 m between the plants and the rows as shown in (Photo 1).

**Photo 1. Plantation of *Cyperus alternifolius* in the FWS Wetland.**

A horizontal subsurface flow system was constructed. The wastewater is fed in at the inlet and flows slowly through the porous medium under the surface of the bed until it reaches the outlet zone where it is collected. The sub-surface flow (SSF) wetland have a dimension of $2\times4m^2$ (W: L) with a 0.85 cm media depth. The soil was compacted and lined using a 600 micron polyethylene layer. Four different gravel size layers were used as the treatment media in the construction. The gravel media was washed to remove fines that can lead to premature clogging. The gravel diameters in the first, second, third and fourth layer ranged between 18-20, 10-12, 6-8 and 2-3mm, respectively. The complete description of the SSF wetland is illustrated in Figure 2.

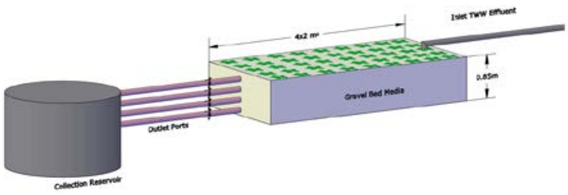


**Figure 2**. **Sub-surface Constructed Wetland Diagram.**

To simulate different qualities of treated wastewater and study the removal efficiency of different pollutants by the free water surface constructed wetland, the primary treated wastewater effluent was taken from Ramtha treated wastewater plant and mixed with the treated wastewater effluent with different mixtures. To study the removal efficiency of the free water surface wetland, both HRT and mixture were used as experimental factors. Each mixture was tested under various hydraulic retention times of 3, 6, 9, and 12 days (Tables 1 and 2). In order to allow the vegetation and the bio-film of the wetland to establish growth, inflow and outflow wastewater sampling was started in April, 2008 after five months of continuous calibration. Water quality parameters (Turbidity, EC, $PO_4$, TKN and pathogens; fecal coliform and total coliform) were monitored for both inflow and outflow on a regular basis between April and September, 2008. Samples were taken at equal frequencies, both at the beginning and at the end of each mixture treatment under each HRT.

**Table1. Different Hydraulic Retention Times Tested in the FWS Wetland.**

| HRT (days) | Flow rate ($m^3$/day) |
|---|---|
| 3 | 26.67 |
| 6 | 13.33 |
| 9 | 8.89 |
| 12 | 6.67 |

**Table 2. Types of Wastewater Quality Mixture Tested in the FWS Wetland.**

| Treatment (Mixture) | Fully treated wastewater | Primary treated wastewater | Legend of mixture used in the text |
|---|---|---|---|
| **1.** | 100 | 0 | T100 |
| **2.** | 75 | 25 | T75, P25 |
| **3.** | 50 | 50 | T50, P50 |
| **4.** | 25 | 75 | T25, P75 |

All statistical tests were performed using the SAS software. In all cases, significance was defined by $P<0.05$. Test for significant difference in water quality between hydraulic retention times and influent mixtures of the treatment wetland was tested using the mixed procedure analysis of variance (ANOVA) at which time and mixture were factorially arranged.

The SSF wetland was calibrated to estimate the volume of treated wastewater needed to fill this wetland and the porosity of the media. This amount was calibrated to move through the bed with a hydraulic retention time of 1 day. Water quality parameters (turbidity, EC, P, TKN and pathogens; fecal coliform and total coliform) were monitored for both inflow and outflow effluents on a regular basis (one sample/week) from April to September, 2008. All statistical tests were performed using SAS software. In all cases, significance was defined by $P< 0.05$ and test for significant difference in water quality was tested using a regression model.

The treated effluent out of both wetlands was directed to irrigate a forage crop field run in 4*4 m2 plots in 4 replicates in a randomized complete block design. The three types of treated effluents that were used: a) treated wastewater from the surface wetland, b) treated wastewater from the sub-surface wetland and c) control treatment with the treated wastewater effluent of Ramtha wastewater plant (Figure 3). At the first season, the field experiment was planted with barley crop (*Hordium vulgare*). In the second season, the field was planted with corn crop (*Zea mays* L.). Irrigation scheduling was based on crop water requirements using FAO reference evapotranspiration and crop coefficients (Allen, et al., 1998), (Dooenbos and Pruitt, 1988). Yield data was collected and standard statistical analysis (ANOVA) was used to evaluate the differences between treatments.

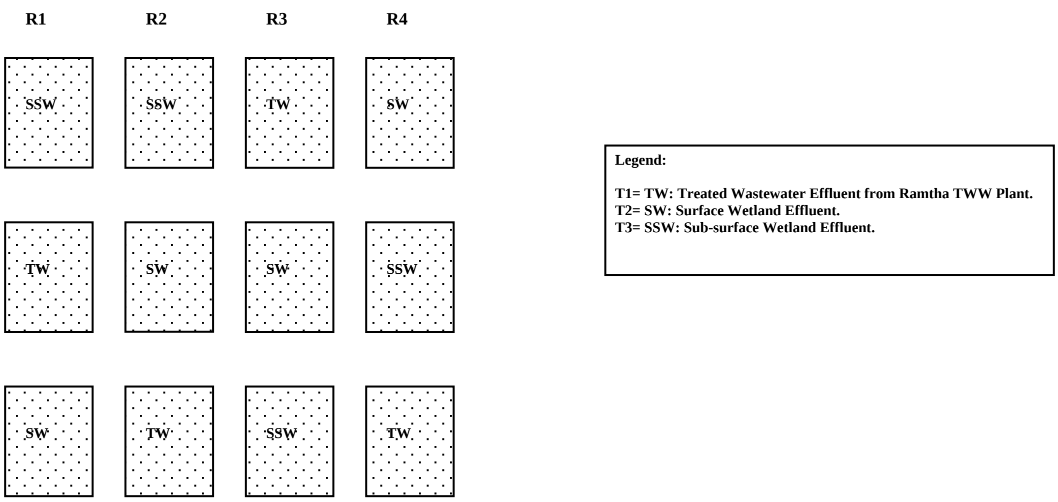


**Figure 3. Forage Crops Field Experiment Layout.**

## RESULTS & DISCUSSION

### Wastewater Characterization:

Results of biological and chemical analysis for both the treated wastewater effluent (TWW) and the primary treated effluent (PE) are listed in Tables 3 and 4. Both effluents exhibited a pH and EC (dS/m) values of (7.3 and 1.85) for TWW and (6.5 and 1.89) for PE. Both effluents showed a high concentration of Na and Cl. Phosphorus ($PO_4$), nitrate and total Kjeldahl nitrogen (TKN) concentration (mg/l) were (2.6, 9.4, 74) and (11.3, 55, 185) for TWW and PE, respectively. Results of biological analysis indicated excellent biological standards for TWW in terms of fecal coliform, $BOD_5$, and COD. The primary treated wastewater exhibited poor biological standards in terms of the fecal coliform and had a high organic loading related to $BOD_5$ and COD.

**Table 3.** Chemical Analysis of Fully and Primary Treated Wastewater Effluents.

| | | (dS/m) | meq/l | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Effluent** | **pH** | **EC** | **Ca** | **Mg** | **Na** | **K** | **Cl** | **$HCO_3$** | **$SO_4$** |
| **TWW** | 7.30 | 1.80 | 2.20 | 2.70 | 14.90 | 1.20 | 12.50 | 3.50 | 5.00 |
| **Primary treated** | 6.50 | 1.90 | 2.70 | 4.90 | 12.20 | 0.90 | 10.00 | 6.30 | 4.50 |
| | | mg/l | | | | | | | |
| | **SAR** | **Fe** | **Cu** | **Zn** | **Mn** | **Cd** | **Pb** | **P** | **TKN** |
| **TWW** | 9.50 | 0.07 | 0.01 | 0.06 | 0.03 | <0.002 | <0.01 | 2.60 | 74 |
| **Primary treated** | 6.30 | 0.34 | 0.01 | 0.07 | 0.03 | <0.002 | <0.01 | 11.30 | 185 |

**Table 4.** Biological Analysis of Fully and Primary Treated Wastewater Effluents.

| | Parameters | | | |
|---|---|---|---|---|
| **Treatment** | **TC/100ml** | **(FC) E.coli/100ml** | **$BOD_5$ (mg/l)** | **COD (mg/l)** |
| **TWW** | 800 | 40 | 15 | 73 |
| **Primary treated** | ≥ 1600 | $160\times10^5$ | 570 | 831 |

### Free Water Surface Wetland:

The quality of wastewater and / or HRT in FWS constructed wetland significantly affected the pH, EC, TSS, E.coli, PO4 and turbidity to greater levels and insignificantly affected the concentrations of $BOD_5$, COD, TKN, and $NO_3$. The reduction (change) for all quality parameters was calculated based on the following equation:

$$\%\,Reduction* = ((Inlet conc. - Outlet conc.) / Inlet conc.) * 100 \quad (1)$$

*Positive values mean that reduction or removal occurred, while negative values reflect the occurrence of accumulation.

***Changes of EC.*** Results showed a significant difference due to mixture and time effect. Mixture 2 showed the lowest salinity change. According to the effect of time, results indicated that salinity change under HRT=3 days was the lowest with significant difference from HRT = 9 and 12 days.

***Changes of TSS.*** The surface wetland significantly reduced the TSS and results showed a significant effect due to the interaction effect of mixture and time.

***Changes of E.coli***. The surface wetland significantly reduced the numbers of E.coli and results showed a significant difference due to interaction between mixture and time. It is believed that the longer HRT the longer the bacteria are exposed to unfavorable conditions.

***Changes of Biochemical Oxygen Demand.*** Wetlands tend to be natural exporters of organic C as a result of decomposition of organic matter into fine particulate matter and dissolved compounds. This may explain why the system was sometimes inefficient in achieving high $BOD_5$ removal (DeBusk, 1999).The lack of statistical significance is more of a reflection of inappropriate sample size or number or other technical and analytical errors. Variability of the wetland influent is also a major factor contributing to the resultant insignificance (Maciaszek et.al, 2002). Results showed almost a tendency to remove about 15% of inlet $BOD_5$ and when inlet BOD is equal to zero then the outlet should equal zero.

***Changes of Total Kjeldahl Nitrogen (TKN)***. It is common for organic N compounds to be exported as a consequence of naturally-occurring organic matter decomposition within the wetland (DeBusk, 1999). Results from the graph indicated that many values are at or above the regression line, indicating that there is a net production of TKN from the anaerobic decomposition of the organic nitrogen. The system was not effective for nitrogen removal and results showed almost zero removal.

***Changes of Phosphorus.*** Phosphorus removal in most constructed wetland systems is not very effective because of the limited contact opportunities between the wastewater and the soil (media). Phosphorus removal in FWS is a result of bacteria removal, plant uptake, adsorption and precipitation. Results showed a significant difference with due respect to time. P removal was the highest under HRT of 12 days due to the longer contact between the effluent and the soil. Results indicated the tendency of the system to remove 13% of the inlet $PO_4$.

***Changes of Trace Elements.*** Wetlands are capable of removing large quantities of trace elements from wastewater (Ye, et.al, 2001). The three main wetland processes that remove heavy metals are binding to soils, sedimentation and particulate matter, precipitation as insoluble salts, and uptake by bacteria, algae and plants (Kayombo, et,al 2004, Kadlec and Knight, 1996). The quality of influent mixture and/or HRT in FWS wetland affected significantly the removal of Fe and Mn and insignificantly affected the removal of Cu and Zn. Cadmium and lead were below the detection limit. Results indicated the tendency of the system to remove 30% and 10% of the inlet Fe and Mn, respectively.

***Changes of Turbidity.*** Turbidity measurement is important as a guide to quality as well as an essential parameter for proper control and operation of treatment plants (Rowe and Abdel Magid, 1995). Turbidity reduction showed a significant response with respect to mixture, time and interaction of both mixture and time. Significant removal was achieved under mixture 2 and 3 and under hydraulic residence times of 3, 6, and 9 days.

***Suitability of Wastewater for Irrigation.*** Barley season: results indicated a significant response with due to treatment effect. Treatment 3 (sub-surface wetland effluent) had resulted in the highest biological and straw yield and with a significant difference from T1 and T2. No significant difference was found between the three treatments with respect to seed yield (Table 5).

**Table 5**. Treatment Effect on the Different Components of Barley Yield

| Obs | TRT | Biological yield (Ton/du) | Standard Error | Letter Group |
|---|---|---|---|---|
| 1 | 1 | 0.330 | 0.02062 | B |
| 2 | 2 | 0.285 | 0.02062 | B |
| 3 | 3 | 0.590 | 0.02062 | A |
| **Obs** | **TRT** | **Straw yield (Ton/du)** | **Standard Error** | **Letter Group** |
| 1 | 1 | 0.1975 | 0.03853 | B |
| 2 | 2 | 0.1750 | 0.03853 | B |
| 3 | 3 | 0.3775 | 0.03853 | A |

Corn season: ANOVA analysis was carried out for the data of biological yield. Results indicated a significant response with due to treatment effect. Treatment 2 (FWS wetland effluent) and treatment 3 (SSF Wetland effluent) had resulted in the highest biological yield as (30.6 and 30.1 ton/ha) and with a significant difference from T1 (TWW effluent) as (26.8 ton/ha) (Table 6).

**Table 6.** Treatment Effect on Corn Biological Yield.

| Obs | TRT | Biological Yield (Ton/du) | Standard Error | Letter Group |
|---|---|---|---|---|
| 1 | 1 | 2.6765 | 0.09107 | B |
| 2 | 2 | 3.0582 | 0.09107 | A |
| 3 | 3 | 3.0092 | 0.09107 | A |

**Sub-surface Wetland Processes:** The SSF wetland affects the concentration of pH, EC, TSS, NO3, E.coli, PO4, turbidity Fe, Cu, Zn and Mn to greater levels.

Regression analysis was carried out to study changes in some of the chemical and biological water quality parameters. Changes in the inlet and outlet concentration of theses selected water quality parameters were figured to find the best fit relationship with the removal equation. Statistical analysis was carried out regarding the linear regression model and significance was defined by $P<0.05$. Results are listed below:

- pH: Results indicated a negative weak correlation between the input and the output pH. This means that the system was not able to moderate pH over the entire research period.

- Salinity: The inlet – outlet concentrations were similar in the linear model and with high $R^2$ of 0.96. However, results indicated the inability of the system to reduce salts and very small removal was achieved.
- Total suspended solids: The inlet – outlet concentrations were similar in the linear model and with high $R^2$ of 0.95. Results showed the tendency of the system to remove 20% of inlet TSS.

- Total Kjeldahl Nitrogen: Results showed a tendency to remove almost 2% of inlet TKN. The inlet – outlet concentrations were similar in the linear model and with high $R^2$ of 0.76. Results also indicated that there is a net production of TKN as the wastewater passes through the bed.

- Nitrate: Results showed a tendency of the system to remove 18% of inlet $NO_3$. The inlet-outlet concentrations were similar in the linear model and with low $R^2$ of 0.25.
- Phosphorus: Results indicated the inability of the SSF wetland to remove $PO_4$ but showed a tendency to accumulate it. Inlet- outlet concentrations were similar in the linear model and with high $R^2$ of 0.89.

- Heavy metals: The SSF wetland showed a tendency to remove 30% of inlet Fe. Inlet-outlet concentrations were similar in the linear model and with $R^2$ of 0.52. The SSF wetland showed a tendency to remove 10% of inlet Cu. Inlet- outlet concentrations were similar in the linear model and with $R^2$ of 0.73. Also, the system showed a tendency to remove 28% of inlet Zn. Inlet- outlet concentrations were similar in the linear model and with low $R^2$ of 0.33. Results showed that the SSF wetland has no tendency to remove Mn. Inlet- outlet concentrations were similar in the linear model and with low $R^2$ of 0.35.

- Fecal coliform (E.coli/100 ml): Inlet- outlet concentrations were similar in the linear model but with negative correlation. This means that as the inlet FC increase, the outlet FC decrease.

- Biochemical oxygen demand: Inlet- outlet concentrations were similar in the linear model but with negative correlation. This means as the inlet $BOD_5$ increase, the outlet $BOD_5$ decrease and vice versa. Sub-surface and free water surface wetland systems, are unique in that $BOD_5$ is actually produced within the system due to the decomposition of plant litter and other naturally occurring organic materials. As a result, the systems can never achieve complete $BOD_5$ removal (USEPA, 1993).

- Chemical oxygen demand: The SSF wetland showed a tendency to remove 48% of the inlet COD. Inlet- outlet concentrations were similar in the linear model and with very low $R^2$ of 0.16.

## 4. CONCLUSIONS and RECOMMENDATIONS:

### 4.1. Surface Wetland Processes:

1. FWS constructed wetland was able to treat different qualities of pre-treated wastewater. For effective removal of nutrients from wetland systems and to avoid nutrient recycling when plants die, periodic harvesting from systems with high biomass productivity is not only desirable but a requirement.

2. Water balance study figured out that percentage effluent varied with respect to each influent mixture and hydraulic retention time and summarized the worst and the best case. Evapotranspiration from the surface wetland has the effects of increasing hydraulic retention time and increasing constituent concentrations. Higher loading or short circuiting implies smaller or decrease in HRT and thus lower removal efficiency.

3. The treated wastewater effluents were within the Jordanian standards for irrigating corn and barley crops. Effluents were suitable for irrigation and without creating particular problems related to the soil, crop, irrigation system and human health. However, the rational use of the three effluents ensures the long-term application to the field avoiding possible problems related to soil salinity, alkalinity or emitter clogging.

### 4.2. Sub-surface Wetland Processes:

1. SSF constructed wetland was able to treat the quality of the treated wastewater effluent. For significant phosphorus removal sand or fine river gravel with iron or aluminum oxides is needed. The results of the research for the first season indicated the possibility of using the SSF wetlands for the production of specific fodder crops. Vegetation plays a significant role in constructed wetlands, especially on nitrogen and phosphorus removal. Specific wetland vegetation could be tested. Also, results indicated that SSF wetlands could be used for the production of specific forage crops with certain management.

## 6. REFERENCES:


1. Allen, R.G., L.S. Pereira, Dirk, Raes, and Martin Smith. (1998), Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56.
2. Al-Zboon, K., and N. Al-Ananzeh. (2008), Performance of Wastewater Treatment Plants in Jordan and Suitability for Reuse. **African Journal of Biotechnology** Vol. 7 (15), pp: 2621-2629.
3. Al- Zu'bi, Y. (2007), Application of Multicriteria Analysis for Ranking and Evaluation of Waste Water Treatment Plants and its Impact on the Environment and Public Health: Case Study from Jordan. **Journal of Applied Sciences Research**, 3(2), pp: 155-160.
4. DeBusk, W.F. (1999), Wastewater Treatment Wetlands: Applications and Treatment Efficiency. **A fact sheet of the Soil and Water Science** Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
5. Dooenbos, J., and W.O. Pruitt. (1988), **Guidelines for Predicting Crop Water Requirement**. FAO Irrigation and Drainage Paper No. 24.
6. EPA, 1995. A Handbook of Constructed Wetlands. General Considerations: volume 1.
7. Ismail, A.F., and Yuliwati, E. 2010. Membrane Science and Technology for Wastewater Reclamation, in Water**.** Sciences and Engineering, Encyclopedia of Life Support System (EOLSS) Elsevier Limited, Oxford, UK
8. Kadlec, R.H., Knight, R.L. (1996). **Treatment Wetlands**. CRC Press/Lewis Publishers: Boca Raton, FL, 893 pp.
9. Kayombo, S., T.S. Mbwette, J.H.Y. Katima, N. Ladegaard, and S.E. Jorgensen. (2004), **Wastewater Stabilization Ponds and Constructed Wetlands Manual**, A joint publication by UNEP-IETC with the Danish International Development Agency (Danida).
10. Maciaszek, E., E. Schiller, L. Fernandes and Miglio R. (2002), Wastewater Treatment Using Artificial Wetlands, (Electronic Version) 28th WEDC Conference, **Sustainable Environmental Sanitation and Water Services**, Calcutta, India.
11. Queensland Environmental Protection Agency. (1995), Guidelines for Using Free Water Surface Constructed Wetlands to Treat Municipal Sewage. **Retrieved from http:// www.epa.qld.gov.au./**
12. Rowe, D. and I, Abdel Magid. (1995), **Handbook of Wastewater Reclamation and Reuse**. Lewis Publishers. 550 pp.
13. U.S. Environmental Protection Agency. (1993), **Subsurface Flow Constructed Wetlands for Wastewater Treatment A Technology Assessment**. EPA 832-R-93-008. Office of Water, Washington, DC.
14. Ye, Z.H., S.N. Whiting, J.H. Qian, C.M. Lytle, Z.Q. Lin and N. Terry. (2001), Trace Element Removal from Coal Ash Leachate by a 10-Year-Old Constructed Wetland. **Journal of Environmental Quality** (30), pp 1710-1719.