Efficacy of Constructed Wetland in the Improvement of Effluent from Soba Stabilization Ponds, Khartoum, Sudan 2021

Ibrahim Ahmed Bdal, Babiker Ahmed Babiker and
Aziza Abd Algadir Mohammed Abd Ulla

May 28, 2022

EFFICACY OF CONSTRUCTED WETLAND IN THE IMPROVEMENT OF EFFLUENT FROM SOBA STABILIZATION PONDS, KHARTOUM, SUDAN 2021

Ibrahim Ahmed Suliman Bdal, University of Khartoum, Sudan, ibrahimahmed4488@gmail.com.

Babiker Ahmed Babiker, University of Khartoum, Sudan, Babiker1964@yahoo.com.

Aziza abd Elgadir Mohammed Abd Ulla, University of Khartoum, Sudan, ezzoamn@yahoo.com.

ABSTRACT

Background: *Wetland is one of the natural treatment systems, where contaminants are removed via a range of natural processes mediated by complex interaction between water, plant, microorganisms, soil/gravel media and atmosphere. While utilizing the power of nature and energy from the sun, polluted water can be cleaned in sustainable way, with minimum operation and maintenance cost.* ***C****onstructed wetlands (CWs) are planned systems designed and constructed to employ wetland vegetation to assist in treating wastewater in a more controlled environment than occurs in natural wetlands.*

Methods: *This is a descriptive study carried out in Khartoum state. Aimed to assess the role of constructed wetland in improvement of effluent characteristics from Soba stabilization ponds in Khartoum – Sudan.*

A small prototype of a constructed wetland was constructed in an open area in Khartoum. The treatment is done by passing wastewater through substrate media that rely on physical, chemical, and biological processes for removal of contaminants. These are removed via a range of natural processes mediated by complex interaction between water, plant, microorganisms, soil/gravel media and atmosphere. The used prototype with dimensions (1.5×3) m, depth (0.8) m, (1) % slope, daily flow (0.257) m3/d, and with retention time 14 days. Samples were systematically collected from the inlet and outlet of prototype during the whole month. Subsequently, samples were subjected to analysis in the laboratory.

Results: *The study reached good results in effluent characteristics such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and Pathogens, which were removed by 85.4%, 95%, 98%, and 95%, respectively. And the performance is moderate in removing of Metal, Nitrogen, Phosphor, and Ions.*

Conclusion: *The system is most cost effective and sustainable.*

This study recommended Stop discharge effluent of Soba Stabilization ponds directly into White Nile River, applying constructed wetland technique in treatment of wastewater in Sudan due to availability of wild lands, good climatic conditions that fit

to the plant growth requirements, and also availability of plant species to be used in these systems (reed is recommended).

INTRODUCTION:

Most aquatic ecosystems around the world, especially rivers, lakes and reservoirs, have been polluted by untreated domestic sewage/wastewater, mining waste, industrial wastewater, agricultural waste, and other pollutants (von,*et al*., 2005).
Sewage is the wastewater generated by a community, namely; domestic wastewater, from bathrooms, toilets, kitchens, etc., raw or treated industrial wastewater discharged in the sewerage system, and sometimes rain-water and urban runoff. Domestic wastewater is the main component of sewage, and it is often taken as a synonym.
Wastewater contains a number of pollutants and contaminants, including plant nutrients (nitrogen, phosphorus, potassium), pathogenic microorganisms (viruses, bacteria, protozoa and helminthes), heavy metals (e.g. cadmium, chromium, copper, mercury, nickel, lead and zinc), organic pollutants (e.g. polychlorinated biphenyls, polyaromatic hydrocarbons, pesticides), and biodegradable organics (BOD, COD), and micro-pollutants (e.g. medicines, cosmetics, cleaning agents). All of these can cause health and environmental problems and can have economic/financial impacts (e.g. increased treatment costs to make water usable for certain purposes) when improperly or untreated wastewater is released into the environment; nutrient contamination and microbial water quality issues are considered (Brears, 2018).

The concept of sanitation on the other hand, includes wastewater collection and treatment systems that become a matter of concern in order to protect public health and the environment, especially the sources of drinking water (Feigin,*et al*., 2012).

Sewage treatment is the process of removing contaminants from wastewater, primarily from household sewage. It includes physical, chemical, and biological processes to remove these contaminants and produce environmentally safe treated wastewater (Bressani, 2019).
Today, a wide range of treatment technologies are available for use in our efforts to restore and maintain the chemical, physical, and biological integrity of the nation's waters. During the past 20 years, considerable interest has been expressed in the potential use of a variety of natural biological systems to help purify water in a controlled manner (Mitsch,*et al*., 2003).

One of the natural treatment systems is wetland, where contaminants are removed via a range of natural processes mediated by complex interaction between water, plant, microorganisms, soil/gravel media and atmosphere. While utilizing the power of nature and energy from the sun, polluted water can be cleaned in sustainable way, with minimum operation and maintenance cost. **C**onstructed wetlands (CWs) are planned systems designed and constructed to employ wetland vegetation to assist in treating wastewater in a more controlled environment than occurs in natural wetlands.

Hammer (1990) defines constructed wetlands as a designed, manmade complex of saturated substrate, emergent and submerged vegetation, animal life, and water that simulate wetlands for human uses and benefits. CWs are “eco-friendly” alternatives for secondary and tertiary municipal and industrial wastewater treatment. The pollutants removed by CW’s include organic materials, suspended solids, nutrients, pathogens, heavy metals and other toxic or hazardous pollutants. In municipal applications, they can follow traditional sewage treatment processes**.** The objective of using CWs is to remove organic matter, suspended solids, pathogenic organisms, and nutrients such as ammonia and other forms of nitrogen and phosphorus. The growing interest in wetland system is due in part to recognition that natural systems offer advantages over conventional activated sludge and trickling filter systems. When the same biochemical and physical processes occur in a more natural environment, instead of reactor tanks and basins, the resulting system often consumes less energy, is more reliable, requires less operation and maintenance and, as a result costs less. They also are used for removing heavy metals and toxic compounds (Stefanakis,*et al*., 2014).

Constructed wetlands for wastewater treatment can be categorized as either Free Water Surface (FWS) or Subsurface Flow (SSF) systems. In FWS systems, the flow of water is above the ground, and plants are rooted in the sediment layer at the base of water column. In SSF systems, water flows through a porous media such as gravels or aggregates, in which the plants are, rooted (Tatum, 2015).

FWS systems are very appropriate for polishing secondary and tertiary effluents, and for providing habitat. The environment in the FWS systems is generally aerobic at, and near, the surface, tending toward anoxic conditions near the bottom sediment. The microbial film grows on all available plant surfaces, and is the main mechanism of pollutant removal. FWS usually exhibits more biodiversity than does SSF systems.

On the contrast, SSF systems are most appropriate for treating primary wastewater, because there is no direct contact between the water column and the atmosphere. There is no opportunity for vermin to breed, and the system is safer from a public health perspective. The system is particularly useful for treating septic tank effluent or grey water, landfill leach ate and other wastes that require removal of high concentrations organic materials, suspended solids, nitrate, pathogens and other pollutants. The environment within the SSF bed is mostly either anoxic or anaerobic. Oxygen is supplied by the roots of the emergent plants and is used up in the Bio film growing directly on the roots and rhizomes, being unlikely to penetrate very far into the water column itself. SSF systems are good for nitrate removal (denitrification), but not for ammonia oxidation (nitrification), since oxygen availability is the limiting step in nitrification (Tatum, 2015).

The advantages of Constructed wetlands are:

(1) Relatively inexpensive to construct and operate.

(2) Easy to maintain.

(3) provide effective and reliable wastewater treatment.

(4) Relatively tolerant of fluctuating hydrologic and contaminant loading rates (optimal size for anticipated waste load), and

(5) Provide indirect benefits such as green space, wildlife habitats and recreational and educational areas (Davis, 1995).

Even though the potential for application of wetland technology in the developing world is enormous, the rate of adoption of wetlands technology for wastewater treatment in those countries has been slow. It has been identified that the current limitations to wide spread adoption of CW technology for wastewater treatment in developing countries is due to the fact that they have limited knowledge and experience with CW design and management (Zhang *et al*.,2015).

The Constructed Wetland is assumed to be a suitable system for Sudan due to availability of wild lands; the system is most cost effective and sustainable. Also good climate condition of Sudan that fit to the plant growth requirement (moderate high Temperature, Relative Humidity, long summer, clear sky less smoke), and also availability of plant species to be used in these systems. Constructed wetland technology is environmentally friendly and less expensive than other physical–chemical methods, because it involves natural processes resulting in the efficient conversion of hazardous compounds (Fakhru, *et al*., 2009).

Justification:

- The characteristics of wastewater effluent from Soba treatment plant are not satisfying the national and international standards for discharge into surface water but they are satisfying standards for unregistered irrigation due to the high values BOD_5^{20} 38.5 mg/l, COD 74 mg/l, TSS 70 mg/l, and total coliform $1.9x10^{10}$ CFU/ml (Mohamed, 2011).
- With regard to water quality improvement and best treatment of the sewage water, Constructed wetlands (CWs) have a great potential for the treatment of wastewater. These systems consist of beds or channels which have been planted with helophytes (water loving plants, that are available and naturally grow in Sudan), which rely upon physical, chemical and biological processes to remove contaminants from wastewater. All types of the constructed wetlands are capable of removing nitrogen, phosphorus, biochemical oxygen demand, chemical oxygen demand, total suspended solids, metals and pathogens from different types of domestic and industrial wastewaters (Choudhary,*et al*., 2011).
- Treatment wetlands Provide cost-effective and sustainable alternative to treat sewage water.

Expected outcome

This system is expected to have Aesthetics and enhances the landscape, through provision of acceptable quality of treated wastewater for irrigation of recreational areas, good and cheap alternative of treatment systems that operated by unskilled workers with less cost compared to the other more costly systems

Use of outcomes

Results of this study are expected to be useful for different governmental institutions such as ministry of urban planning and ministry of health.

Objectives:

General objective:

To assess the role of constructed wetland in improvement of effluent characteristics from Soba stabilization ponds in Khartoum – Sudan.

Specific objectives:

- To measure the efficacy of the constructed wetland in the reducing BOD and TSS.

- To measure the efficacy of the system in the reduction of organic and inorganic matter.

- To determine the efficacy of the system to reduce the pathogenic bacteria.

- To identify efficacy of the system in the reduction of heavy metals and soluble ions.

MATERIALS AND METHODS:

Study design: This is a descriptive study.

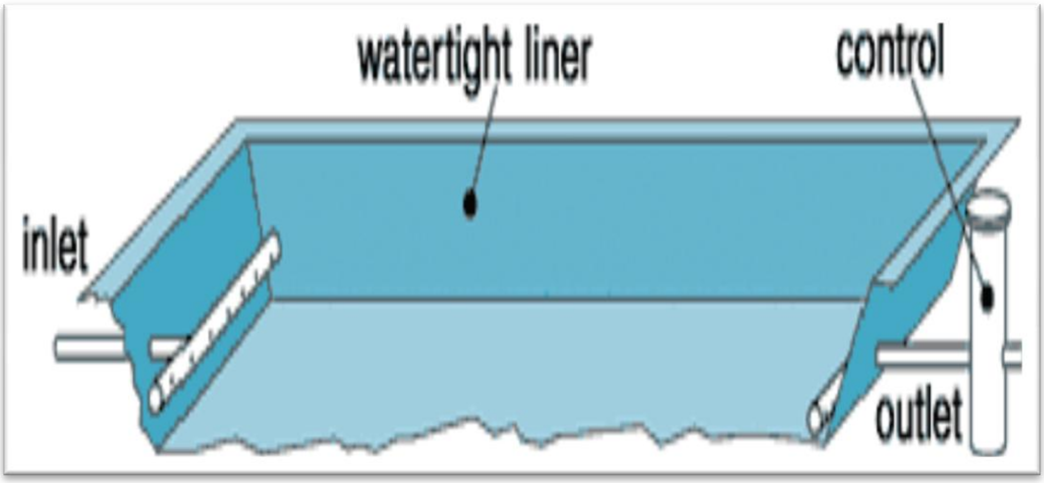
Study area:

A small prototype of a constructed wetland was constructed in an open controlled area in Khartoum which bordered White and Blue Nile.

The main climatic conditions of Greater Khartoum are conditioned by its location on the southern fringes of the Sahara. The city experiences four climatic seasons, winter season extends from mid-November to March, cool and dry air from the north-east, a minimum temperature ranging between 8ºC to 10ºC which falls to 5ºC during night, and maximum temperatures varying from 23ºC to 25ºC, relative humidity sometime be as low as 20%. The hot, dry summer season is well in place by the end of March. The maximum temperatures may exceed 45ºC by the end of May. Weather instability is indicated by the recurrence of dust storms. The rainy season covers the period from July to September, with August being the rainiest month, generally annual rainfall ranges between 110 and 200 mm, A short hot (about 40ºC) transitional season occurs between mid-September and the beginning of winter. This changeover season from south-westerly to north-easterly winds is accompanied by dust storms. Where the system will be operated under ambient air conditions of temperature (2o – 30), relative humidity 20 %.

Designing criteria of the system:

The prototype:



Inlet and Outlet pipe

A pipe of 3-inch diameter at both inlet and outlet of prototype with nozzles fixed to ensure optimum distribution in the inlet zone, and optimum collection in the outlet zone. Filters media of gravel put into the inlet and outlet zones with the size of 15 cm of prototype, then the remaining area of prototype filled out with sand, fine gravel and soil for normal setup.

Vegetation:

Common Reeds (Phragmites australis) as local wetland species were used in this study.

Reeds are tall annual grasses with an extensive perennial rhizome. Reeds have been used in Europe in the root-zone method and are the most widespread emergent aquatic plant. Systems utilizing reeds may be more effective in the transfer of oxygen because the rhizomes penetrate vertically, and more deeply than cattails (Crites, 1988).

Planting techniques:

Seedlings should be planted as (8 pieces /m^2).

Study population:

Samples of treated wastewater (effluent) were collected by jerry cans from the final stage of the treatment at Soba wastewater treatment plant, and samples of final effluent from the constructed wetland prototype.

Sampling techniques:

Samples were systematically collected from the inlet and outlet of prototype during the whole month due to suitability of the weather conditions to the plant growth. Two samples (one from the inlet and one from outlet) were collected each 14 days that results in approximately 4 samples (4 weeks) in addition to three blank samples for quality control. Subsequently, samples were subjected to analysis in the laboratory.

Methods of data collection:

Running of the experiment and quality control:

- The operation and management were checked on a regular basis.
- Water levels, water quality, habitat, flora and fauna, structures and embankments, and other parameters were reported and documented regularly, with possible immediate repair of damage to the structures and control weeds.

Data collection and Laboratory analysis of the samples:

Data were collected over a period of 4 weeks on a bi-weekly basis from the outdoor pilot prototype treatment system.Method of analysis used is procedure described in the Standard Methods for the Examination of Water and Wastewater. (APHA, 23RD edition 2015).

RESULTS AND FINDINGS:

Samples	BOD5
1st sample influent	550 mg/l
2nd sample effluent 1	190 mg/l
3rd sample effluent 2	80 mg/l
BOD5 Removal	65.4% - 85.4%

Table 1: *BOD_5 Removal*

.

Samples	COD
1st sample influent	720 mg/l
2nd sample effluent 1	42.6 mg/l
3rd sample effluent 2	30 mg/l
COD Removal	94% - 95%

Table 2: *COD Removal*

Samples	TSS
1st sample influent	5258 mg/l
2nd sample effluent 1	70 mg/l
3rd sample effluent 2	74 mg/l

TSS Removal	98%

Table 3: *TSS Removal.*

Samples Metals	1st sample influent	2nd sample effluent 1	3rd sample effluent 2	Removal percent
Fe	0.14 mg/l	0.11 mg/l	0.04 mg/l	21.4%-71.4%
Cr	0.16 mg/l	0.07 mg/l	0.07 mg/l	56.2%
Mg	22 mg/l	0 mg/l	12 mg/l	45.4%-100%
Mn	0.003 mg/l	0.001 mg/l	0.002 mg/l	33.4%-66.7%
Cu	0.08 mg/l	0.02 mg/l	0.04 mg/l	50% - 75%

Table 4: *Heavy metals Removal.*

Samples	Plate count
1st sample influent	3 *106 cfu
2nd sample effluent 1	275 * 102 cfu
3rd sample effluent 2	150 * 102 cfu
Bacterial removal	99% - 95%

Table 5: *Bacterial Removal.*

Samples	Nitrate No3	Nitrogen	Nitrite No2	Nitrogen
1st sample influent	4.470 mg/l	1.010 mg/l	0.132 mg/l	0.040 mg/l
2nd sample effluent 1	2.390 mg/l	0.540 mg/l	0.086 mg/l	0.026 mg/l
3rd sample effluent 2	3.115 mg/l	0.705 mg/l	0.102 mg/l	0.030 mg/l
Removal percent	30.3% - 46.5%	30.1% - 46.5%	22.7% - 34.8%	25% - 35%

Table 6: *Nitrogen Removal.*

Samples	Po4	P
1st sample influent	204.8 mg/l	67.6 mg/l
2nd sample effluent 1	148.8 mg/l	49.2 mg/l
3rd sample effluent 2	160.5 mg/l	55.4 mg/l
Removal percent	21.6% - 27.3%	18 % - 27.2%

Table 7: *Phosphate Removal.*

Samples Ions	1st sample effluent	2nd sample influent 1	3rd sample influent 2	Removal percent
K	53 mg/l	11.5 mg/l	8.3 mg/l	78.3%-84.3%
Cl	175 mg/l	10.4 mg/l	0.9 mg/l	94% - 99.4%

Table 8: *Ions Removal.*

DISCUSSION

This study's results demonstrated efficacies for constructed wetland in BOD_5 reduction ranging from 65.4 to 85.4 %, as shown in Table 1. This result agrees with Khazaleh and Gopalan (2018) who found in their study of constructed wetlands BOD removal of 77%.

Sudanese Standards Metrology Organization has set the standard for BOD_5 mean concentration in effluent discharged into surface waters at 15 mg/l and for irrigation uses at 50 mg/l. It is thus seen that the study plant prototype do not satisfies the standards for discharge into surface waters but it almost satisfies the standards for irrigation uses.

This study showed that the efficacy of the constructed wetland in COD removal ranged from 94 to 95%, as shown in Table 2. Sudanese Standards Metrology Organization has set the standard for COD mean concentration in effluent discharged into surface waters at 75 mg/l and for irrigation uses at 150 mg/l, it is seen that the study plant prototype do satisfies the standards for discharge into surface waters and also satisfy the standards for irrigation uses.

Sudanese Standards Metrology Organization has set the standard for TSS mean concentration in effluent discharged into surface waters at 30 mg/l and for irrigation purposes at 50 mg/l, observed that the study plant prototype does not satisfies the standards for discharge into surface waters but it is near to satisfies the standards for environmental and irrigation uses. In this study the efficacy of constructed wetland in TSS removal is 98% as shown in Table 3. This result agrees with UN HABITAT Constructed wetlands Manual (2008) as it reported as 95% that mean the performance of constructed wetland in TSS removal is better.

The study showed that the efficacy of CW_S in reducing of heavy metals 60.7 as shown in Table 4, this result agrees with Mthembu (2013), who found in his study the treatment efficiency of vegetated beds in removal of metals is 26% to 76%. These results do satisfies the Sudanese Standards for heavy metal concentration to be discharge into surface water and irrigation uses.

From the plate count test the study shows that the efficacy of CW_S in pathogenic removal is 99 to 99.5% as shown in Table 5, this result agrees with Vymazal (2001), who found in his study the treatment efficiency of vegetated beds in removal of pathogens is 92%. Standards set by Sudanese Standards Metrology Organization for mean total coliform concentration in effluent discharged into surface waters are 500/100 ml and for irrigation uses are 1000/100 ml, it is seen that the study plant prototype do satisfies the standards for discharge into surface waters and satisfies the standards for irrigation uses.

The study showed that the efficacy of CW_S in nitrogen removal is 34.6 as shown in Table 6. this result agrees with Vymazal (2001), who found in his study the treatment efficiency of vegetated beds in removal of Nitrogen is about 35%. These results do satisfies the Sudanese Standards for nitrogen concentration to be discharge into surface water and irrigation uses.

The study also shows the efficacy of CW_S in phosphate removal 22.6 as shown in Table 7. this result agrees with Okurut (2000), who found in his study the treatment efficiency of vegetated beds in removal of Phosphor is an average of 24% in tropical aeries. These results do not satisfy the Sudanese Standards for phosphor concentration to be discharge into surface water and irrigation uses.

CONCLUSION

This study was carried out in Khartoum state, aimed at measuring the efficacy of sub surface constructed wetland for the improvement of the final effluent from Soba Stabilization Ponds in Khartoum, Sudan. From the result of these investigations, we can conclude that:

Constructed wetlands have great potential to improve the characteristics of wastewater. Moreover the Constructed wetland is cost effective in terms of maintenance, and simple in terms of operation.

The performance of constructed wetland is high in removing BOD_5, COD, TSS, and Pathogens, with efficiencies of 85.4%, 95%, 98%, and 95% respectively. However the performance of constructed wetlands is moderate in removing Metal, Nitrogen, Phosphor, and Ions.

The results of this study clearly recommended the application of constructed wetlands for the treatment of wastewater in Sudan due to availability of wild lands, good climatic conditions that fit to the plant growth requirements, and also availability of plant species to be used in these systems.

REFERENCES:

Brears, R.C., 2018. The green economy and the water-energy-food nexus. In The green economy and the water-energy-food nexus (pp. 23-50). Palgrave Macmillan, London.

Bressani-Ribeiro, T. ed., 2019. Anaerobic Reactors for Sewage Treatment: Design, Construction and Operation. IWA Publishing.

Brix, H. (1993) Use of constructed wetlands in water pollution control: Historical development, present status, and future perspectives. *WaterScience Technology*, 30(8), 200–223.

Chatterji, A.K., 2011. *Introduction to environmental biotechnology*. PHI Learning Pvt. Ltd.

Choudhary, A.K., Kumar, S. and Sharma, C., 2011. Constructed wetlands: an approach for wastewater treatment. Elixir Pollut, 37(8).

Choudhary, A.K., Kumar, S. and Sharma, C., 2011. Constructed wetlands: an approach for wastewater treatment. *Elixir Pollut*, *37*(8), pp.3666-3672.

Dallas, S., and Ho, G., 2005, 'Subsurface flow reed beds using alternative media for the treatment of domestic greywater in Monteverde, Costa Rica, Central America', *Water Science and Technology*, Vol.51, No.10, Pp. 119-128.

Davis, L., 1995. A handbook of constructed wetlands: A guide to creating wetlands for: agricultural wastewater, domestic wastewater, coal mine drainage, stormwater. In the Mid-Atlantic Region. Volume 1: General considerations. USDA-Natural Resources ConservationService.Ecosystem restoration. John Wiley & Sons.

Derr, J.F. (2008) Common Reed (*Phragmites australis*) response to mowing and herbicideapplication. *Invasive Plant Science and Management*, 1, 12–16. 9789522160355.pdf.

Fakhru'l-Razi, A., Pendashteh, A., Abdullah, L.C., Biak, D.R.A., Madaeni, S.S. and Abidin, Z.Z., 2009. Review of technologies for oil and gas produced water treatment. Journal of hazardous materials, *170*(2-3), pp.530-551.

Feigin, A., Ravina, I. and Shalhevet, J., 2012. Irrigation with treated sewage effluent: management for environmental protection(Vol. 17).Springer Science & Business Media.

Hansson, P.A. & Fredriksson, H. (2004) Use of summer harvested common reed (*Phragmitesaustralis*) as nutrient source for organic crop production in Sweden. *Agriculture, Ecosystems& Environment*, 102(3), 365–375.

Hua, T. and Haynes, R.J., 2016. Constructed wetlands: fundamental processes and mechanisms for heavy metal removal from wastewater streams. International Journal of Environmental Engineering, 8(2-3), pp.148-178.

Inamori, R., Gui, P., Dass, P., Matsumura, M., Xu, K.Q., Kondo, T., Ebie, Y. and Inamori, Y., 2007. Investigating CH4 and N2O emissions from eco-engineering wastewater treatment processes using constructed wetland microcosms. *Process Biochemistry*, *42*(3), pp.363-373.

Kadlec, R.H. and Wallace, S., 2008. *Treatment wetlands*. CRC press.

Khazaleh, M. and Gopalan, B., 2018. Constructed wetland for wastewater treatment. *Journal of Modern Science and Technology*, *6*(1), pp.78-86.

Köbbing, J.F., Thevs, N. and Zerbe, S., 2013. The utilisation of reed (Phragmites australis): a review. *Mires & Peat*, *13*.

Komulainen, M., Simi, P., Hagelberg, E., Ikonen, I. & Lyytinen, S. (2008) *Reed Energy - Possibilities of Using the Common Reed forEnergy Generation in Southern Finland*. Reports from Turku University of Applied Sciences, 67, 81 pp. Online at: http://julkaisut.turkuamk.fi/isbn

Korkusuz, E.A., Beklioglu, M., and Demirer, G.N., 2005, 'Comparison of the treatment performances of blast furnace slag-based and gravel-based vertical flow wetlands operated identically for domestic wastewater treatment in Turkey', *Ecological Engineering*, Vol.24. No.3, Pp. 187-200.

Mitsch, W.J. and Jørgensen, S.E., 2003. Ecological engineering andpp.3666-3672.

Mthembu, M.S., Odinga, C.A., Swalaha, F.M. and Bux, F., 2013. Constructed wetlands: A future alternative wastewater treatment technology. African Journal of Biotechnology, 12(29).

Okurut, T.O., 2000. *A pilot study on municipal wastewater treatment using a constructed wetland in Uganda*. CRC Press.

Prochaska, C.A., and Zouboulis, A.I., 2009, 'Treatment performance variation at different depths within vertical subsurface-flow experimental wetlands fed with simulated domestic sewage', *Desalination*, Vol.237, No.1-3, Pp. 367-377.

Qasim, S.R., 2017. *Wastewater treatment plants: planning, design, and operation*. Routledge.

Rastegari, A.A., Yadav, A.N. and Yadav, N. eds., 2020. *New and Future Developments in Microbial Biotechnology and Bioengineering: Trends of Microbial Biotechnology for Sustainable Agriculture and Biomedicine Systems: Perspectives for Human Health*. Elsevier.

Rousseau, D., 2005. *Performance of constructed treatment wetlands: model-based evaluation and impact of operation and maintenance* (Doctoral dissertation, GhentUniversity).

Scholz, M., 2015. *Wetland systems to control urban runoff*. Elsevier.

Shah, A.I., Dar, M.U.D., Bhat, R.A., Singh, J.P., Singh, K. and Bhat, S.A., 2020. Prospectives and challenges of wastewater treatment technologies to combat contaminants of emerging concerns. *Ecological Engineering*, *152*, p.105882.

Shatu, M.S., 2016. *Characterization of a selected refinery wastewater streams for treatability assessment*. Lamar University-Beaumont.

Sheoran, A.S. and Sheoran, V., 2006. Heavy metal removal mechanism of acid mine drainage in wetlands: a critical review. *Minerals engineering*, *19*(2), pp.105-116.

Stefanakis, A., Akratos, C.S. and Tsihrintzis, V.A., 2014. Vertical flow constructed wetlands: eco-engineering systems for wastewater and sludge treatment.

Tatum, K., 2015. The use of constructed wetlands as secondary wastewater treatment for the removal of pharmaceuticals and personal care products: A review.

Tunçsiper, B., 2007, 'Removal of nutrient and bacteria in pilot-scale constructed wetlands', *Journal of Environmental Science and Health* - Part A Toxic/Hazardous Substances and Environmental Engineering, Vol.42, No.8, Pp. 1117-1124.

Von Sperling, M. and de LemosChernicharo, C.A., 2005. Biological wastewater treatment in warm climate regions(Vol. 1). IWA publishing.

Vymazal, J. and Březinová, T., 2016. Accumulation of heavy metals in aboveground biomass of Phragmites australis in horizontal flow constructed wetlands for wastewater treatment: a review. *Chemical Engineering Journal*, *290*, pp.232-242.

Vymazal, J., 2011. Constructed wetlands for wastewater treatment: five decades of experience. *Environmental science & technology*, *45*(1), pp.61-69.

Vymazal, J., 2009. The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. *Ecological engineering*, *35*(1), pp.1-17.

Wild, U. (2001) Cultivation of *Typha* spp. In constructed wetlands for peat land restoration. *Ecological Engineering*, 17(1), 49–54.

Zhang, Y., 2012. Design of a constructed wetland for wastewater treatment and reuse in Mount Pleasant, Utah.