EFFECTS OF PLANT HARVESTING ON NUTRIENTS REMOVAL IN CONSTRUCTED WETLANDS.

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Environmental Science, 15 credits
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ABSTRACT

Insufficient access to clean water and sanitation has become one of the most universal problems affecting human health in developing countries, water resources are facing high pollution rate due to improper management of wastewater. Ecological technologies such as constructed wetlands are promising innovative solutions for this universal problem.

Constructed wetlands are engineered wastewater treatment systems that include treatment segments such as physical, chemical, and biological processes like in natural wetlands. Plant harvesting practice is one management strategy that can prevent these systems from clogging and loss of surface area, the effects of this management strategy need to be assessed related to the performance of wetlands.

The aim of this thesis was to investigate the effects of plants harvesting on nutrients removal (N, P, and COD) in constructed wetlands. This is a literature review and experimental based thesis. The literature review involved reviewing 5 studies about effect of harvesting plants in constructed wetlands. The experiment part involved data analysis from 6 experimental wetlands, with 3 wetlands that have been harvested in 2015 and 2016, another 3 wetlands that have never been harvested.

Results from literature review indicated that plant harvesting in wetland has a significant effect in nutrients removal. Experiment results indicated that there was significant difference between these wetlands in TN and NO₃-N removed when the entire operation period was considered (P=0.005). But when each season was considered separately statistical differences were only observed during first summer after harvesting for TN removal. For NO₃-N, differences between wetlands were observed in first summer and winter only.

For summer, harvested wetland performed better than non-harvested wetland, but in winter non-harvested wetland performed better than harvested in terms of NO₃-N removal. For winter, the reason to this could be that, some of plants parts decay and provided denitrification bacteria with a carbon source which accelerates denitrification process.

According to this study, plants harvesting in wetland generally has a positive effect on nutrient removal such as TN, TP, COD, and BOD. Therefore, this practice could be recommended as the best wetland plants management to improve and maintain nutrient removal in constructed wetlands.
LIST OF ABBREVIATIONS

CWs - Constructed wetlands
COD – Chemical oxygen demand
NO₃-N - Nitrate
TN – Total nitrogen
TP – Total phosphorus
BOD – Biochemical oxygen demand
TCOD – Total chemical oxygen demand
TSS – Total suspended solids
SS – Suspend solids
FWS - Free water subsurface
SSF - Subsurface flow
HSSF - Horizontal subsurface flow
VSSF - Vertical subsurface flow
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1. INTRODUCTION.

1.1. Background

Insufficient access to clean water and sanitation has become one of the most universal problems affecting human health in developing countries, and problems with water are expected to worsen in coming decades (Hutton et al., 2007; Zhang et al., 2014). Some ecological technologies such as constructed wetlands for wastewater treatment signify innovative and developing solutions for environmental protection and restoration, employing them in the general context of the need for low-cost and maintainable wastewater treatment systems in developing countries (Babatunde et al., 2008; Vymazal, 2007).

Constructed wetlands (CWs) are engineered wastewater treatment systems that include a variety of treatment segments such as physical, chemical, and biological processes similar to processes happening in natural treatment wetlands (Vymazal, 2007; Zhang et al., 2014). CWs have been effectively and successfully used to alleviate environmental pollution by removing of a wide variety of pollutants from wastewater such as suspended solids, organic compounds, metals, pathogens, and nutrients (Kadlec and Wallace, 2008; Gikas and Tchobanoglous, 2009).

In the past 50 years, CWs have become popular option for wastewater treatment. Also, this option has been recognized as attractive alternatives to conservative wastewater treatment methods (Zhang et al., 2014; Gikas and Tchobanoglous, 2009). This is due to their good contaminant removal efficiency, easy operation and maintenance, little energy requirements, rates of water recycling, and potential for providing significant natural habitat for flora and fauna compared to other wastewater treatment techniques (Kadlec and Wallace, 2008; Vymazal, 2007).

CW treatment systems commonly fall into three types: free water subsurface (FWS) CWs, subsurface flow (SSF) CWs, and hybrid CWs (Kadlec and Wallace 2008). SSF CWs could be further classified according to flow direction into horizontal subsurface flow (HSSF) and vertical subsurface flow (VSSF) systems. Choice of flow regime depends mostly on the targeted ingredients for treatment, available area, geographic location, cost, and treatment goals (Kadlec and Wallace 2008). Free water subsurface (FWS) schemes are shallow basins with water on the surface, the treatment processes happening through complex interactions between the vegetation and the associated biofilms in the water phase (Kadlec and Wallace 2008; Zhang et al., 2014). Like natural swamplands, FWSCWs exhibit a broad range of biological
characteristics that are capable of removing numerous constituents for water quality improvement (Vymazal, 2010).

Subsurface flow (SSF) systems are designed with horizontal or vertical subsurface flow through a porous medium (typically sand, gravel, or crushed rock) (Vymazal, 2007, 2011; Zhang et al., 2014). The most common systems are designed with an HSSF CW configuration. Additional operational data exists for HSSF wetlands than for VSSF systems, but VSSF CW systems are becoming more popular (Vymazal, 2007 Zhang et al., 2014). In HSSF CWs, the wastewater flows parallel through the granular media and comes into interaction with a network of aerobic, anoxic, and anaerobic zones in the subsurface (Zhang et al., 2014). The aerobic zones occur around plant roots and rhizomes that introduce oxygen into the substrate. In the VSSF CW systems, the wastewater is fed through the whole surface area via a circulation system and passes through the media vertically. Bed depth for SSF CWs is normally less than 0.6 m.

Due to the incapability to provide both aerobic and anaerobic conditions simultaneously, single-stage CWs cannot attain high removal of TN (Vymazal, 2007 Zhang et al., 2014). In this respect, various types of CWs may be combined to influence the advantages of individual systems. As various wastewaters may be difficult to treat in a single stage system, hybrid systems which contain of various types of constructed wetlands staged in series have been introduced. Most hybrid systems are contained of VSSF and HSSF systems arranged in a staged manner (Vymazal, 2007 Zhang et al., 2014). The VSSF CW is proposed to remove organics and suspended solids and to provide nitrification, while denitrification and additional removal of organics and suspend solids occur in HSSF CW.

A wide range of contaminants such as TN, TP, total coliforms, metals and TSS can be removed from wastewater with CWs through microbial degradation, substrate adsorption, plant uptake, filtration by the packed media, and biological predation (Abou – Elela et al., 2013). Pollutant removal efficiency in CWs depends on a number of variables including pollutant loading, hydrologic regime, vegetation type, and temperature, all which may be highly variable among various systems (Bojcevska and Tonderski, 2007). Regularly, pollutants that are removed under this method are nitrogen and phosphorus (Kadlec and Wallace, 2008).

Nitrogen and phosphorus are the main pollutants in wastewater that can cause adverse effect to the aquatic organisms, (Bojcevska and Tonderski, 2007). In wastewater nitrogen occurs in both organic and inorganic forms. Nitrogen in organic form can be present in amino acids (that make proteins in forms of peptide chain), urea (dispose in form of ammonia by mammals when
amino acids used for energy production), uric acids (produced by birds and insects) and purine, pyrimidines involved in DNA making) (Abou – Elela et al., 2013; Kadlec and Wallace, 2008). The inorganic forms of nitrogen are ammonium (NH₄⁺), nitrate (NO₃⁻), nitrite (NO₂⁻), nitrous oxide (N₂O), and dissolved elemental nitrogen or nitrogen gas (N₂). Gaseous nitrogen includes nitrogen gas (N₂), nitric oxide (NO₂), nitrous oxide (N₂O), and free ammonia (NH₃) (Kadlec and Wallace, 2008; Zhang et al., 2014).

In constructed wetland systems, the alteration and removal of nitrogen are accomplished by biological (i.e. nitrification, ammonification, plant uptake, denitrification, biomass assimilation, dissimilatory nitrate reduction), as well as physicochemical ways (e.g. ammonia volatilization, and adsorption) (Zhang et al., 2014). Phosphorus in a wetland occurs as phosphate in form of organic and inorganic compounds (Vymazal, 2007). Free orthophosphate is the solitary form of phosphorus believed to be used directly by macrophytes and algae and thus represents a main link among organic and inorganic phosphorus cycling in wetlands (Vymazal, 2007; Kadlec and Wallace, 2008). Other group of inorganic phosphorus compounds are polyphosphates linearly condensed and cyclic. Organically-bound phosphorus is present e.g., in phospholipids, nucleoproteins, nucleic acids, phosphorylated sugars or organic condensed polyphosphates (coenzymes, ATP, ADP) (Vymazal, 2007).

Organic phosphorus forms can be commonly grouped into two categories which are, simply decomposable P (nucleic acids, phospholipids or sugar phosphates) and gradually decomposable organic P (inositol phosphates or phytin). Wetlands provide an environment that is best for the interconversion of all forms of phosphorus (Vymazal, 2007), soluble sensitive phosphorus is taken up by plants and then converted to tissue phosphorus or may develop leakage to wetland soils and sediments (Vymazal, 2007; Kadlec and Wallace, 2008).

The main functions of plants in constructed wetlands are, provision of physical effect through its roots which helps some physical treatment in a wetland such as filtering effect, velocity reduction, promotion of sedimentation, decreased resuspension, prevention of medium clogging, improved hydraulic conductivity (Shelef et al., 2013), plants roots are used as a base for microorganisms, under this function plants provide surface for microbial attachment and release of gas and exudates, also plant roots release oxygen that increased aerobic degradation and supports precipitation of heavy metals (Shelef et al., 2013). Metal uptake is done through phytoremediation processes, also plant increase evapotranspiration that accelerates water loss in wetland (Shelef et al., 2013). Plants provide the microclimatic conditions such as light
attenuation that reduces algal growth, insulation from frost in the winter, insulation from radiation in the spring, reduced wind velocity as well as stabilization of the sediment surface (Chao et al., 2014; Davis, 1995; Shelef et al., 2013). Further roles of plants in wetland are elimination of pathogens, insect and odour control, wastewater gardens, increased wildlife diversity, aesthetic appearance of the system and bioindicators (vymazal, 2007; Shelef et al., 2013). In addition, plants stabilize substrates while enhancing its permeability, and plants add greatly to the aesthetic value of the wetland, also dense stand of vegetation appears to moderate the effects of storms (Shelef et al., 2013).

The plants that are utmost often used in constructed wetlands are persistent emergent plants, such as spikerush (Eleocharis), common reed (Phragmites), bulrushes (Scirpus), other sedges (Cyperus), rushes (Juncus), and cattails (Typha) (Wang et al., 2015). Not all wetland species are appropriate for wastewater treatment because plants for treatment wetlands must at least be able to tolerate the combination of continuous flooding environment and exposure to either wastewater or storm water comprising relatively high and frequently variable concentrations of pollutants (Wang et al., 2015; Shelef et al., 2013).

Due to this importance of plants in CWs, recently several management strategies have been proposed to advance the plant growth as well as productivity and the performance of CWs (Alvarez and Becares, 2008). These proposed strategies include annual harvesting and several or multiple harvesting (Kihila et al., 2014). However, the actual benefit of plants harvesting for the removal of nutrients or the growth of plants biomass remains a highly controversial issue (Vymazal et al., 2010). On other side, some studies have demonstrated that nutrients uptake by plants in a wetland can be definitively removed from the wetland by harvesting the aboveground parts of the plants before senescence and decay during the cold or winter season (Vymazal et al., 2010).

In addition, it has been confirmed that harvesting in a constructed wetland can open dense vegetated areas to indorse the photosynthetic periphyton in the system. Both standing dead (withered) and mature plants shade most of the attached microbial communities, hence, reducing the nutrient retaining capacities of those communities, and donate to short-circuiting of the water flow (Zheng et al., 2015; Wang et al., 2012). Also, there some arguments against plant harvesting show that the regular harvest of constructed wetlands is unreasonable, fixes little to improve water treatment, and decreases the readily existing carbon source that is essential for denitrification. Moreover, some previous studies have shown out that the withered
plants within constructed wetlands may have a thermoregulatory effect during winter time (Kadlec and Wallace, 2009; Zheng et al., 2015). However, some studies on this thermoregulatory purpose, and the competition among the regenerated plants and the withered plants left in the wetland are rare (Vymazal et al., 2010). So, the regrowth of many plants can show noticeable differences in changed plants management practices (Kadlec and Wallace, 2008). Therefore, for maximizing the influence of plants to nutrients removal, a suitable method for handling the plants in a wetland needs to be adopted, and need more research.

More particularly, it is very important to determine the management strategy and plan that does not adversely affect the regeneration of plants in wetland or their capacity to uptake nutrients (Zheng et al., 2015). It is mostly expected that planted wetlands outperform unplanted controls largely because the plant rhizosphere are used stimulate microbial community thickness and activity by providing root surface that is essential for microbial growth, and as a main source of carbon compounds over root exudates (Wang et al., 2015; Vymazal et al., 2010). It appears, however, that in many tropical regions where seasonal translocations are negligible, and several harvest practices is possible, harvesting of emergent plants can play a significant removal way particularly for lightly loaded systems (Vymazal et al., 2010). Upon decay, mostly at the end of the summer and throughout the autumn, wetland vegetation releases carbon (organic) into the wetland system (Zheng et al., 2015). A portion of this organic substance remains in the wetland, and degrade at different rates throughout the rest of the year (Wang et al., 2015).

### 1.2. Motivation of this study

Many researchers agree that plants have a generally positive effect on wastewater treatment in CWs (Alvarez and Becares, 2008). However high plant population density in CWs has negative effect such as habitat alteration, lower biodiversity, it can change nutrients cycling and productivity as well as decreasing the surface area of wetland which can totally lead to the loss of wetland surface area (Alvarez and Becares, 2008). Therefore, to avoid these negative effects, there is a need of managing plant population density, and this can be done through plants harvesting, but before that, study must be conducted to assess if this management strategy has any significance effect in terms of nitrogen, COD, and phosphorus removal in constructed wetlands.
1.3. Research question
The research question of this study states that ‘Does the plant harvesting practice in constructed wetland have any significant effect on its efficiency in terms of nutrients removal?’

1.4. Aim of the study
Aim of this thesis study was to investigate the effects of plants harvesting on nutrients removal (N, P, and COD) in constructed wetlands.

1.5. Research Hypothesis
The hypothesis of this study states that,

a) Null hypothesis (H₀)
Plants harvesting practice in a constructed wetland doesn’t have any significant effect in terms of nutrients removal in constructed wetlands.

b) Alternative hypothesis (H₁)
Plants harvesting practice in a constructed wetland has significant effect in terms of nutrients removal in constructed wetlands.
2. METHODS AND THESIS DESIGN.

This is a literature review and experimental based thesis, literature review work involved reviewing previous studies done about harvesting plants effects in constructed wetlands, experimental part involved data analysis from 6 experimental wetlands. The methods used under these parts are described below in details.

2.1. Literature review

Searches for literatures were made by using Web of Science databases, using the search term described in the table below. This database was preferred because it is one of the database with scientific publication of high quality. Some limitation factors such as time and language were used, all literatures searched were those written in English language, this was due to the lack of translation resources. Time factor was due to the aim of getting current and specific materials, the search was limited within 10 years back, this limit was to make the search more manageable and critically update.

<table>
<thead>
<tr>
<th>Database</th>
<th>Searched terms</th>
<th>No. of hits</th>
<th>Date.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web of science</td>
<td>- Effect of plants harvesting in a constructed wetland.</td>
<td>76</td>
<td>2 – 3 / 4 / 2017</td>
</tr>
</tbody>
</table>

After search process, screening process followed, articles found in the searches were checked for relevance in terms of quality belonging or relating uniquely to this thesis topic (specificity). Afterward, full text screening was done where by all papers were checked its relevance towards aim of this thesis, this was done through reading abstract, methods and results obtained at the end of each study. After full-text screening, 5 articles about study on the constructed or manmade wetlands specifically with that explaining the effects of plants harvesting on COD, phosphorus and nitrogen removal in constructed wetlands were selected.

Last work done on this part was to review selected articles, some information taken from these papers includes, who did the study and where, what was the aim of the study, what methods used during this study, results and findings obtained under that study, discussion made after the study as well as conclusion drawn from the study. All this information is presented in results and findings part of this thesis according to the aim of this study.
2.2. Site visit and data collection.
This was done at 6 experimental wetlands planted with emergent vegetation (*Phragmites australis* and *Glyceria maxima*), 3 wetlands have been harvested in summer for two years since 2015 up to 2016, another 3 wetlands have never been harvested. In all wetlands, standing litter was removed during winter. These wetlands receive water with high nitrate concentration from a nearby groundwater source. Water samples collected from these wetlands at inflow and outflow respectively at different time intervals since June 2015 up to November 2016.

2.3. Water quality analysis (laboratory experiments)
Water samples were analysed in the laboratory soon after sampling process. Parameters analyzed were total nitrogen (TN) and nitrate (NO$_3$-N), while temperature and flow rate were measured at the site during sampling process. For measuring TN concentration of inflow and outflow samples, 8ml of sample was added in the test tube with a digital pipette. Then 1.6ml of digestion solution was added in the same test tube, after that the test tube was closed and shaken very well. For oxidation of nitrogen compounds to nitrate the samples were in an autoclave (120°C and 2.5 atmospheric pressure) where they stayed overnight for sterilization. After that the test tubes with samples were taken out from the autoclave and analyzed in the FIAstar 5000 instrument.

For measuring NO$_3$-N concentration samples were just added in the test tube and analyzed by FIAstar instrument, this doesn’t need to stay in the autoclave overnight, either to add a digestion solution in test tubes.

2.4. Data set and analysis
Data analysis involved existing data that has been sampled over 2 years in 6 experimental wetlands harvesting and non-harvesting. Amount of nitrogen and nitrate removed were computed by taking into consideration the absolute removal efficiency in each wetland to avoid the error that can be due to variation of flow rate, absolute removal means the amount removed per specific time at each wetland, under this analysis the concentration at each inflow and outflow rate of wetlands under study was taken into consideration, also different season were considered, summer (early June to late October), winter (rate November up to early may). Then, comparison was made by using statistics analysis software (SPSS v20), based on difference (t – test), correlation and association.
3. RESULTS AND FINDINGS.

3.1. Literature review

The following are the results and findings obtained in 5 studies reviewed as previous study conducted to investigate the effect of plant harvesting in a constructed or manmade wetlands.

1) The effect of plant harvesting on the performance of a free water surface constructed wetland.

This study was conducted in Spain by Alvarez and Becares in 2008, the study was conducted at two wetlands used to treat municipal wastewater and storm water. The aim of this study was to test the effect of vegetation on the organic matter dynamics of a surface flow wetland comparing a harvested against a non-harvested wetland. During experiment, two free water surface wetlands were planted with plants (*Typha latifolia*) with one of the wetlands harvested. Then, organic matter concentration and nutrients in both harvested and non-harvested wetlands were analysed from December 2004 until August 2005.

Results and discussion on this study was based on difference in terms of nutrients removal between harvested and non-harvested wetland. Effluent pH decreased to 8.5 and 8.0 in the harvested and non-harvested wetlands, correspondingly. Dissolved oxygen and temperature values were lower in the non-harvested wetland in all time (seasons). It was noted that, there were significant differences in these variables among the harvested and non-harvested wetland effluent when the whole operation period was considered, DO: $p < 0.02$, pH: $p < 0.003$, and T: $p < 0.0004$). However, when each season considered separately, statistical differences were only detected for T and pH during winter ($p < 0.005$ and $p < 0.02$ for T and pH, respectively). BOD, TCOD, and nutrient concentrations (NH$_4$, TKN, and TP) were lower in the harvested wetland effluent than in the non-harvested wetland effluent throughout the entire operation period.

No significant differences were found between the harvested and non-harvested wetland effluent for any variable when each season was taken into accounts separately. However, statistical difference in BOD concentration were found within the harvested and non-harvested wetland effluent when the whole process period was considered ($P < 0.005$), BOD concentration was therefore observed significantly higher in the non-harvested wetland. The higher mean differences in TCOD, TSS, and BOD concentrations were observed in spring. TSS and BOD effluent concentrations decreased 37.3% (from 67 to 42 mg/l) and 49.2% (from
63 to 32 mg/l) in the harvested wetland compared to the non-harvested wetland, respectively. In addition, TSS decrease caused a TCOD decrease of 26.2% in the harvested wetland.

With respect to nutrients, important differences for NH₄, TKN, and TP were found after the whole experiment period was taken into account (p < 0.01, p < 0.006, and p < 0.02, for NH₄, TKN, and TP, respectively), although no significant differences were found for each season separately. NH₄, TKN, and TP concentrations were continuously higher in the non-harvested wetland effluent, signifying a nitrogen and phosphorus release due to plant decay.

Discussion part of this study was based on the impact of plants on the wetland environment and effect of vegetation on the performance of constructed wetlands. It was shown under this study that, vegetation influenced temperature (T) and pH variables of the wetland in winter and it influenced T, pH, and OD parameters throughout all operation periods. Also, they come up with agreement that, higher organic matter in the non-harvested wetland was accountable for a higher oxidation activity, triggering lower dissolved oxygen and lower pH in the vegetated wetland. Vegetation also conserved a higher thermal inertia when rated with the harvested wetland. After this study, it was observed that plants assisted to maintain the lower temperatures reached during night (often below 0°C during winter), which resulted in lower temperatures at the sampling time (noon) within the non-harvested wetland rated to the harvested wetland. plants absence in the harvested wetland permitted for higher temperatures at noon throughout higher light intensities in contrast with the vegetated wetland.

This study proves that vegetation harvesting has a significant effect on dissolved oxygen, the pH, and temperature inside the wetland. Furthermore, in comparison with the non-harvested wetland, the absence of vegetation in the harvested wetland allowed the decrease of BOD and TSS effluent concentration in spring by 49.2% and 37.3, respectively. Conclusion of this study was that, the performance of constructed wetland systems can be improved if most of the above ground biomass is harvested at the end of the growing season rather than allowed to return and decay within the wetland, which rises the organic and nutrient load. Harvesting is suggested as the best operation and management strategy under the climatic and wastewater conditions according to this study.

2) Effect of plant harvesting on the performance of constructed wetlands during summer.

This experiment was done in Jinan city - China by Yang et al. 2016. The objective of this study was to examine the impact of summer plants harvesting on the performance of constructed
wetlands (CWs). During this study, three types of microcosms were set up (including the harvested group, cleared group, and unharvested group). Water samples collection from influent and effluent of each microcosms were collected and taken for physical and chemical analysis. Nitrogen analysis, the mass balance method was used to evaluate the effect of biomass harvesting on nitrogen removal.

Results of effluent water parameters showed that, the harvested wetland had higher concentrations of DO than the other wetlands. In the existence of plants root, the harvested wetland had higher DO than the cleared wetland. The characteristics quality of the effluent in each wetland are presented in table 1 below.

Table 1. The characteristics quality of the effluent from each microcosm.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>COD (mg/l)</th>
<th>NH₄⁺-N (mg/l)</th>
<th>Removal efficiency of COD (%)</th>
<th>Removal efficiency of NH₄⁺-N (%)</th>
<th>T (°C)</th>
<th>DO (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>unharvested</td>
<td>22.75</td>
<td>1.17</td>
<td>92.64</td>
<td>63.23</td>
<td>24.36</td>
<td>1.63</td>
<td></td>
</tr>
<tr>
<td>harvested</td>
<td>18.35</td>
<td>1.00</td>
<td>93.70</td>
<td>70.65</td>
<td>24.54</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>cleared</td>
<td>26.14</td>
<td>1.97</td>
<td>87.62</td>
<td>57.75</td>
<td>25.41</td>
<td>1.63</td>
<td></td>
</tr>
</tbody>
</table>

The removal capability of NH₄⁺-N and COD in the harvested group was observed as the maximum. Summer harvesting showed a positive result on NH₄⁺-N and COD removal, and there was a positive correlation among the removal efficiency of DO concentrations and pollutants in effluent (r² > 0.635). Also, it was observed that, unharvested group showed higher contaminant removal effectiveness than the cleared group at same DO concentrations level.

The conclusion drawn from this study was that, harvesting of biomass (plants) in wetlands has positive effects on contaminant removal and microbial abundance during summer. However, harvesting can change the microbial community by reducing the comparative abundance of Proteobacteria. After this experiment it was suggested that, harvesting of biomass during summer can be the best way to improve contaminant removal in wetlands. Though, the mechanism of root exudates and radial oxygen loss in this process needs to be further studied.
3) Effects of annual harvesting on plants growth and nutrients removal in surface-flow constructed wetlands in north western China.

This experiment was done by Zheng et al. 2015 in China. The main objective of this study was to evaluate the effects of plants harvesting on the overall performance of the wetland. The study was conducted on two pilot-scale wetland system for 2 years, at the end of the first year, the aboveground parts of the plants in one constructed wetland were harvested by cutting their upper parts at above the CW bed level. Water samples were taken weekly from the influent and effluent of the two CWs for analysis, then, the removal efficiency of each wetland were calculated basing on the difference in concentration among the effluent and influent of the CWs. Significant differences were determined at the $\alpha = 0.05$ by paired samples t-tests and analysis of variance (ANOVA).

Results of this study showed that, during this experimental period, the average influent TP and TN concentrations in the first year (1.24 mg/l and 24.30 mg/l) were observed to be higher than those of the second year (1.04 mg/l and 18.98 mg/l). PO$_4$–P and NH$_3$–N under this experiment were recorded as the main constituents of the TP and TN, which accounted for 60.5% and 80.6% in the first year and 63.5% and 75.7% in the second year, respectively. This is because several species of wetland plants prefer NH$_3$–N and PO$_4$–P as the nutrients source, which was observed to be profit for the removal of these nutrients from the river water in the wetlands during this experiment. The overall results obtained during this experiment for the two-year study period, mean influent and effluent nutrients concentrations in the two wetlands are presented in table 2 below.

**Table 2:** Influent and effluent nutrients concentrations for the two CWs during the experimental period.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>First year</th>
<th>Second year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Influent (mg/l)</td>
<td>CW1 (harvested) (mg/l)</td>
</tr>
<tr>
<td>TN</td>
<td>24.30</td>
<td>17.07</td>
</tr>
</tbody>
</table>
However, due to the different plant harvesting systems, the performance of the two wetlands showed a minor difference under this experiment. The removal efficiencies of TP and TN in CW1 were higher than those of CW2 by 8.9%, and 5.4% respectively. Though, these differences were not statistically significant ($P > 0.05$). This difference was due to the reason that, the wetland with plants harvested during autumn provided well space and light environment for plants regeneration than the unharvested wetland. Similarly, the vertical withered plants competed for space and light resources with the new plants. Comparative to N removal, the P removal in CW1 was significantly higher than that in CW2 ($P < 0.05$), which showed that the plants harvesting had a greater effect on the removal of phosphorus than nitrogen. Nevertheless, this difference may relay to the different mechanisms of phosphorus and nitrogen removal in wetlands. The nitrogen removal in FWS CWs is mainly achieved through microbial processes while the primary mechanisms for phosphorus removal are plants uptake and physicochemical processes (Vymazal, 2007). Therefore, this experiment results come into agreement that plant uptake can be more important for phosphorus removal than nitrogen removal in the FWS wetlands.

The conclusion after this experiment was that, both harvested and unharvested FWS wetlands verified an increase in nutrients removal efficiencies in the second year, compared to the first year of the wetlands operation. Annual or yearly harvesting it was believed that it had positive effect to plants regeneration through provision of better space and light conditions in experimental wetland. Overall, plants uptake accounted for a larger proportion of the phosphorus removal (32.0–36.7%) than nitrogen (16.2–17.0%).

4) Effect of plant harvesting on the performance of constructed wetlands during winter: radial oxygen loss and microbial characteristics.
This study was conducted in 2012 by Wang et al.2014, the aim of this study was to provide a theoretical knowledge and understanding of the effects of harvesting on wetland performance in the subsequent winter.

The experiment was performed in nine (9) independent microcosm constructed wetland systems, three wetlands in series with integrated plants (Phragmites australis), harvested plants, and completely cleared plants were set up. Each wetland was batch-operated for 7 days. Plants were grown for 8 months before harvesting. In the end of autumn season (November 24, 2012), plant shoots were harvested within three cells (harvested group); thereafter, both roots and plant shoots were harvested in another three cells (cleared group), and the remaining cells with unharvested plants were used as the controls (unharvested group).

At the seventh day of each series, water samples of influent and effluent were collected and directly taken to the laboratory for analysis process. This method involves chemical analysis, laboratory analysis was done on the water samples to determine the ammonium (NH₄⁺-N) and COD content.

The results and discussion part of this experiment was based on the results obtained in effluent water parameters, table 3a, b shows the effluent NH₄⁺-N and COD concentrations for each microcosm. Two conclusions were deduced in this discussion, first, the nutrient concentrations in the empty or cleared wetlands were clearly higher than those in the planted wetlands. This means that the existence of the plants improved COD removal and ammonia oxidation in winter. Second, the concentrations of COD and NH₄⁺-N in the planted wetlands were much higher in the harvested wetlands than those in the unharvested wetlands. The results show that harvesting plants in wetland reduce the NH₄⁺ -N and COD removal during the winter.

**Table 3.** Effluent NH₄⁺-N and COD concentrations for each microcosm.

<table>
<thead>
<tr>
<th>Wetland</th>
<th>Amount of NH₄⁺-N (mg/l) removed within 45 days of experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (days)</td>
<td>5-10</td>
</tr>
<tr>
<td>Unharvested</td>
<td>6.5</td>
</tr>
<tr>
<td>Harvested</td>
<td>4.5</td>
</tr>
<tr>
<td>Cleared</td>
<td>4.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wetland</th>
<th>Amount of COD (mg/l) removed within 45 days of experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (days)</td>
<td>5-10</td>
</tr>
<tr>
<td>Unharvested</td>
<td>27.5</td>
</tr>
</tbody>
</table>
Conclusion made at the end of this study was that, there is minimal microbial activity in empty or clear wetlands which means there is a significant association between microbial activities and vegetation in wetlands. Also, it was concluded that, plant harvesting in a constructed wetland has a significant effect in terms of nutrients removal, as results indicate that harvesting plants in wetland decreased the COD and NH$_4^+$-N removal during the winter.

5) Harvesting effects on biomass and nutrient retention in *Phragmites australis* in a free-water surface constructed wetland in western Ireland.

This study was done by Healy et al. 2007, the aim of this study was to examine the seasonal variation in biomass, total nitrogen (tot-N) and total phosphorus (tot-P) content of *Phragmites australis* in a 3-cell free water surface (FWS) constructed wetland in western Ireland and to investigate the effects of harvesting on their biomass and nutrient content.

One cell of the wetland was divided into two plots: one plot, measuring 80 m$^2$, was completely harvested on the 16$^{th}$ June 2005, while the other plot, the control plot, remained uncut throughout the study duration. Wastewater samples were collected each month at the inlet and outlet of each wetland cell and were analysed.

**Table 4.** Results of Influent and effluent wastewater characteristics from all wetlands.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>First cell</th>
<th>Retention pond</th>
<th>Third cell</th>
<th>Effluent (mg /L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>32.5</td>
<td>29.9</td>
<td>24.9</td>
<td>23.9</td>
</tr>
<tr>
<td>SS</td>
<td>11.5</td>
<td>7.8</td>
<td>4.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Tot-N</td>
<td>10.5</td>
<td>6.4</td>
<td>6.3</td>
<td>5.4</td>
</tr>
<tr>
<td>NO$_3$ -N</td>
<td>9.3</td>
<td>3.2</td>
<td>6.4</td>
<td>4.4</td>
</tr>
<tr>
<td>NH$_4$ -N</td>
<td>1.2</td>
<td>2.1</td>
<td>2.1</td>
<td>1.2</td>
</tr>
<tr>
<td>PO$_4$ -P</td>
<td>2.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.2</td>
</tr>
</tbody>
</table>
There was evidence of a significantly lower mean tot-N for the June-cut plots when compared to the control plots (p<0.001). The estimated difference in mean tot-N in the control plots compared to June-cut plots in September ranged from 7.76 to 19.33 mg/g. There was evidence of a significantly lower mean tot-P for the June-cut plots when compared to the control plots (p<0.001) and of a significant Plot/Date interaction (p<0.001). The estimated difference in mean Tot-P in the control plots compared to June-cut plots in September ranged from 0.63 to 1.65 mg/g. The conclusion after this study was that, harvesting of the above-water biomass in a constructed wetland has a significant effect to the performance of wetland in terms of nutrients removal.

3.2. Results from wetlands experiment.

Results from wetlands experiment (table 5) indicates that, harvesting practice has a significant effect in TN and NO$_3$-N removal in wetlands. Harvested wetland removed high amount of TN & NO$_3$-N compared to non-harvested wetland when the whole experimental period was considered. There was a significant difference in TN & NO$_3$-N removed in these two types of wetlands (P = 0.005, t = 5.732, df = 4 and P=0.005, t = 5.717, df = 4) respectively.

When each season was considered separately (table 5), there was a significant difference in TN removed in summer after first harvesting (figure 1), there was no any significant difference in TN removed in winter and second summer, though it was observed that, there was outflow fluctuation during second some in some points where the TN removal in one point was observed to be high in non-harvested wetland (figure 1) this could have had occurred by chance or due to biomass removal that lead to low mass production in wetland.

The overall average TN percentage removal in harvested wetland was high (25.9%) as the inflow concentration was reduced from 7.875mg/l inflow to 5.837mg/l outflow, non-harvested wetlands percentage of TN were lower compared to harvested wetlands (21.3%) as the inflow concentration were lowed from 7.875mg/l to 6.198mg/l.

There was a relationship between amount of TN removed and outflow temperature in wetlands (r = 0.504, P < 0.001) this association was direct proportional, the increase of one variable was affecting another in positive way and in this association TN removed in wetlands were depending on the temperature on that specific wetland (r$^2$=0.254, F= 60.52, P<0.001). There was weak association between TN removed and flow rate in wetlands (r = -0.167, P = 0.025), this association was in a relation that the decrease in flow in some wetlands increased the
chance of TN retention, also it was observed that amount of TN removed in some wetlands were depending on flow rate ($r^2=0.28$, $F= 5.109$, $P=0.025$).

**Table 5.** Average amount of TN removed in each wetland throughout the entire experiment period and when each season compared separately.

<table>
<thead>
<tr>
<th>Type of wetland</th>
<th>Average amount of TN removed (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>Non-harvested</td>
<td>1.677</td>
</tr>
<tr>
<td>Harvested</td>
<td>2.038</td>
</tr>
<tr>
<td>P-value</td>
<td>0.005</td>
</tr>
</tbody>
</table>

**Figure 1.** Showing amount of TN removed in wetlands throughout the entire experiment period.

Also, there was a significant difference in NO$_3$-N removed in summer after first harvesting (table 6), there was a significant difference in NO$_3$-N removed in winter where non-harvested
wetland showed NO₃-N high efficiency removal compared to harvested (figure 2), while the next summer wetlands didn’t show significance difference in terms of NO₃-N removed (table 6).

The overall average NO₃-N percentage removal in harvested wetland was high (26.3%) as the inflow concentration was reduced from 7.653mg/l to 5.642mg/l outflow, non-harvested wetlands percentage of NO₃-N were lower compared to harvested wetlands (22.2%) as the inflow concentration were lowered from 7.875mg/l to 5.954mg/l.

There was a relationship between amount of NO₃-N removed and outflow temperature in wetlands (r = 0.532, P < 0.001) this association was direct proportion, the increase of one variable was affecting another in positive way and in this association NO₃-N removed in wetlands were depending on the temperature on that specific wetland (r²=0.283, F= 70.332, P<0.001). There was weak association between NO₃-N removed and flow rate in wetlands (r = -0.21, P = 0.05), this association was in a relation that the decrease in flow in some wetlands increased the chance of TN retention, also it was observed that amount of TN removed in some wetlands were depending on flow rate (r²=0.004, F= 8.2, P = 0.005).

Table 6. Average amount of NO₃-N removed in each wetland throughout the entire experiment period and when each season compared separately.

<table>
<thead>
<tr>
<th>Type of wetland</th>
<th>Average amount of NO₃-N removed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>Non-harvested</td>
<td>1.699</td>
</tr>
<tr>
<td>Harvested</td>
<td>2.011</td>
</tr>
<tr>
<td>P- value</td>
<td>0.005</td>
</tr>
</tbody>
</table>
Figure 2. Showing amount of NO$_3$-N removed by wetlands for the entire experiment period.
4. DISCUSSION.

The results and findings from wetland experiment are similar to those obtained from most of previous experiment done about effect of plant harvesting in constructed wetlands. Results from wetlands experiment and those obtained from literature review, all showed that, plant harvesting in wetland has a significant effect in nutrients removal, non-harvested wetland had lower NH$_4$, TN and TP removal efficiency compared to harvested wetlands.

Results from experimental wetland done during this study showed that there are no significant differences between harvested and non-harvested wetlands in terms of nutrients removal when each season were considered separately, these results are similar to those obtained in the studies done by Alvarez and Becares (2008) as well as Zheng et al. (2015). NH$_4$, TN, and TP concentrations were continuously higher throughout experimental period in the non-harvested wetland effluent, this could be due to the reason that plants in wetland were decaying during winter season and release nitrogen and phosphorus to the wetland effluent according to Bojcevska and Tonderski (2007).

Also, it was found out that, in the harvested wetland sunlight was promoting periphyton productivity, which mainly lead to an increase in nutrient uptake within the harvested wetland, that’s why the harvested wetland showed high efficiency removal of nutrients according to Yang et al. (2016). Similarly, both results from wetlands experiment and Alvarez and Becares (2008) show that, vegetation influenced temperature (T) and pH variables of the wetland in winter and it influenced T, pH, and OD parameters throughout all operation periods.

Results from wetlands experiment indicated and confirmed likewise that of study done by Yang et al. (2016) that harvesting of biomass (plants) in wetlands has positive effects on contaminant removal and microbial abundance during summer. Therefore, harvesting of biomass during summer was suggested as the best way to improve contaminant removal in wetlands, however, it was found that plant harvesting can change the microbial community by reducing the comparative abundance of proteobacteria, hence the harvesting practice should take into consideration microbial activities in the wetland (Healy et al. 2007).

There is no difference in terms of nutrients removal between two wetlands with different multi harvesting schemes at the same place with same temperature and light in a single year (Zheng et al. 2015), this was also same to results obtained from wetlands experiment. Only harvesting in summer time was observed having positive effects in nutrients removal according to
Vymazal and Jaroslav (2010). This could be due to reason that, plant harvesting in summer improved convection conditions and enhanced reaeration rates, which enhanced the breeding of facultative or bacteria aerobic. Harvesting in late summer reduce the shading effect, this provides better light environments that maybe stimulates the breeding of photosynthetic bacteria and Cyanobacteria which offer heterotrophic bacteria with oxygen and this establishes a stable ecological symbiosis which is better for microbial activities in wetland (Yang et al.2016).

According to Wang et al. (2014) and results obtained from experiment, both shows that there is significant association between microbial activities and vegetation in wetlands, this was observed when the cleared wetland performance was poor compared to harvested and non-harvested wetland due to low population density of microbes, this could be due to luck of nitrogen supply source for anaerobic bacteria as well as surface area for microbial attachment according to Healy et al. (2007).

Also results from experiment indicate that harvesting plants in wetland decreased the COD and NH$_4^+$-N removal rate during the winter compared to other parameters. Due to that, harvesting plants in wetland must be done on the top parts only not on the roots that provides the attachment for microbial colonies (Healy et al.2007).

Results from literature reviewed show that the best harvesting time for plants in the wetlands is summer (Wang et al.2014), also results from experimental wetlands comply with these results as it was found out that the best nutrients removal was observed during summer, this could be associated with temperature and sunlight according to Davis (1995). Therefore, for areas that does not experience winter season it is recommended during time where there is no rainfall, this time provides the wetland with better space and light conditions for microbial activities as well as plant regeneration (Yang et al. 2016).

Results from the experimental wetlands show that, there were significant differences in TN and NO$_3$-N removed, between the harvested and nonharvested wetland effluent when the entire operation period was taken it account (P=0.005), also the same results like this were obtained in the study done by Wang et al.(2014), but when each season was considered separately statistical differences were only observed during first summer after harvesting for TN removal, for NO$_3$-N difference between were observed in first summer and winter only.
Results from experiment showed that, for summer harvested wetlands performed better than non-harvested wetland, but in winter non-harvested wetlands performed better than harvested in terms of NO$_3$-N removal, these results are similar to that obtained by Wang et al. (2014). For winter this can be explained by the fact that during winter time some of plants parts decay and provided denitrification bacteria with a carbon source which accelerates denitrification process (Shelef et al. 2013), however this need more study since not all plants decay in winter, there some plants which do not decayed during winter time according to Alvarez and Becares (2008).

Harvesting annually, it didn’t show any significant different effect to TN removal during second summer according to results obtained from wetlands experiment, as it was observed in next summer the efficiency of these wetlands were the same, these results comply with those obtained by Alvarez and Becares (2008). This could be due to the reason that in the second summer there was negligible amount of biomass in wetland and this reduces microbial activities that depends on amount of biomass as the source of energy (Shelef et al. 2013), also there was a constant hydraulics in wetland due to plant harvesting, which made the two seasons to have nearly same retention time which has association with TN removal, longer water retention time high TN removal and vice versa is true (Healy et al. 2007).

Plant harvesting practice in wetland has a positive effect as it improves the efficiency of nitrogen, phosphorus, COD, and BOD removal in the wetlands in summer season according to Yang et al. (2016), Alvarez and Becares (2008) as well as results from wetland experiment. It was observed that harvested plant showed high removal rate compared to non-harvested wetlands, in winter season this practice has a negative effect on NO$_3$-N removal as the non-harvested wetland showed high removal rate compared to harvested wetlands.

In general, plant harvesting has positive effect in nutrients removal in wetlands when the whole year is taken into consideration, and it can be very efficient more in tropical regions where there is no winter season (results from experiment, Yang et al. 2016). Moreover, further study is recommended to investigate the damage of vegetation due to plant harvesting such as destruction of plant defensive mechanism (root exudates) (Healy et al. 2007, Groudeva et al. 2001). After harvesting process plants roots parts are constantly exposed to a variety of natural enemies, such as bacteria pathogenic fungi, nematodes, viruses, oomycetes, and root-feeding arthropods. Also, to investigate the effect multiple harvests in single year in high temperate regions such as in Tanzania (Yang et al. 2016).
5. CONCLUSION

Results from this study indicates that, plant harvesting in constructed wetland has effects in removal of nutrients, harvested wetland showed the high performance for TN and NO$_3$-N removal in summer compared to non-harvested wetlands, and that the difference between these wetlands were statistically significant. Also, another difference between these wetlands were observed in winter where non-harvested wetland performed better in NO$_3$-N removal compared to harvested wetland.

It was confirmed under this study that, TN and NO$_3$-N removal in wetlands depends on flow rate and temperature, temperature was directly proportional with nutrients removal while flow rate was inversely proportional to nutrients removal, this means that, how often can plants be harvested in wetland depends on temperature and nutrients concentration (results from wetlands experiment). In cold areas harvesting must be done once per year (summer season or early summer) while in in tropical areas this may depend on temperature and nutrient concentration (Shelef et al. 2013).

Plant harvesting also has significant effect to microbial abundance and activity in wetlands, therefore before implementation of this wetland management strategy, the microbial abundance factor should be taken into consideration to avoid disturbance of microbial activities in the wetland (Healy et al. 2007). In additional to that, some precautions should be taken before plant harvesting in some loaded wetlands to avoid the accumulation of total suspended solids in outflow since in many wetlands plants acts like physical filters for TSS (Wang et al. 2015).

In general, plants harvesting in constructed wetland has significant effect in terms of nutrients removal especially TN, TP, COD, and BOD, therefore, this practice could be recommended as the best wetland plants management to improve and maintain nutrient removal in constructed wetlands. Nevertheless, it needs more experiments particularly at different hydrodynamic conditions and weather.
6. REFERENCES.


Elvanus Kapira, a Masters Graduate at Halmstad University 2017, From Tanzania.