The Seasonal Dynamics of Removal of Nitrogen in Free Water Surface Constructed Wetlands in cold climate

Applied Environmental Science, 60 credits

Halmstad 2019-06-03
Chang Ge
The Seasonal Dynamics of Removal of Nitrogen in Free Water Surface Constructed Wetlands in cold climate

Chang Ge

Halmstad University, School of Business, Engineering and Science, Master’s Program in Applied Environmental Science

Supervisor: Stefan E.B. Weisner

Date: 29th May, 2019

Abstract

In Sweden and other Nordic countries, Free Water Surface (FWS) constructed wetlands are widely used for advanced sewage treatment. This study was performed in an experimental wetlands system in order to research the seasonal dynamics and interferences in N removal under cold climate condition. According to the result of study, as expected, N removal in FWS wetlands is strong related to temperature, the removal rates are higher in late summer and autumn than in spring and early summer. Removal at similar temperatures are quite different when they are in different months. For instance, in the study, the average N removal in June is significant different from N removal in September (P < 0.001), indicating that there are other factors affecting the N removal, different treatment wetlands have different situations. N removal in two different periods (March to July & August to December) were extracted for covariance analysis, it indicated that they are significant different. Besides that, the r²-value of correlation test showed that total N removal rate in FWS constructed wetlands is higher in relation to temperature in autumn and winter (r²-value is 0.4449) than in spring and summer (r²-value is 0.3857). Generally speaking, the dynamics of N removal in FWS wetlands is not steady and variable even at similar temperatures. Finally, I find the temperature of excess heating from district heating which has been used by the residents’ house in Sweden is high enough to heat up the temperature in FWS wetlands. That is a valuable improvement to be put forward.

Keywords:

Temperature, Variation, Sewage, Denitrification, Carbon source
1. Introduction

1.1 The Background of Nitrogen Removal

Nitrogen (N) is an imperative element of the biosphere, and essential for the growth and development of all organisms (Bachand et al., 2000). For instance, the production of grains usually depends on the content of nitrogen in fertilizers. Nitrogen is widely used in chemical industries and agricultural production. In China, over 53.2 million tons of urea, which mainly contains N, were used and 8.8 million tons of urea were exported in 2017 (Wang et al., 2017). In Europe, N is usually used in agricultural fertilizers and for industrial purposes. Consequently, sewage from human activities would contain N, resulting in a serious environmental problem and ecological pressure in natural freshwaters and marine waters (Frankenbach et al., 1999).

Massive inputs of N into freshwater and marine ecosystems, due to anthropogenic activities such as agriculture, industrial production, urbanization and mining, have become a major concern for human water security and degradation of global aquatic biodiversity. Therefore, it is essential to decrease these inputs into natural freshwaters, so more efforts should be taken in wastewater treatment plants (WWTPs) to remove nitrogen from the sewage (Uusheimo et al., 2018). In Sweden, scientists put emphasis on the problem of eutrophication due to the excessive N which is discharged into freshwaters, and the Baltic Sea (Fleischer et al., 1991). Obviously, we cannot rely only on the conventional technology of primary and secondary treatments through treating facilities in WWTPs. For instance, in Helsinki, the removal of N in some WWTPs is varying in a range from 8%~92%, this shows not only possibly low removal of N but also the lack of stability in removal efficiency (Uusheimo et al., 2018). My thesis topic will focus on the use of constructed wetlands as an advanced treatment technology after the conventional treating process in WWTPs.

1.2 Role of Wetlands

A wetland is an ecological environment form between land and waters, it can be regarded as a kind of buffer strip. Water can be retained in wetlands, an appropriate environment for many kinds of organisms to reside, for instance, in China, there are some specific natural wetlands for birds during their migration (Zhang et al., 2017). Wetlands have numerous functions, they could supplement the underground water, flood and desertification could be effectively controlled. Even in some countries, the governments use wetlands as an appropriate place for entertainment and outdoor activities (Zhang., 2006). In general, the wetlands play an important role in our daily life.

On the other hand, the thesis focuses on the capacity of sewage treatment. Based on the previous studies, the pollutants suspended in sewage (e.g. suspend solids, N, heavy metals, phosphorus) can
be effectively removed in wetlands through physical, chemical and biological mechanisms (Reuter et al., 1992). The vegetation is able to absorb the nutrients by their roots, which could constitute intersected nets to filter sediments (Fan et al., 2016). During the process of releasing and transferring oxygen by roots, aerobic and anaerobic conditions will appear, promoting nitrification and denitrification, which could remove N (Vymazal., 2013).

1.3 Nitrogen Removal in Constructed Wetlands

Treated wastewater still contains high concentrations of N before discharging to recipient waterbodies, wetlands are used to further treatment on N (Usheimo et al., 2018). Vegetation in wetlands have a capacity to absorb N by roots, but N removal by this process is small (about 8%–16%) of total N removal (Bachand et al., 2000). An efficient removal of nitrogen in wetlands is generally dependent on denitrification, but if N occurs mainly as ammonia it must be oxidized to nitrite (NO$_3^-$) by nitrification bacteria before denitrification can take place (Andersson et al., 2005). The denitrifying bacteria will transform NO$_3^-$ to gaseous N$_2$ and it will be released into atmosphere (Bastviken et al., 2004). Wetlands have some oxidation zones, facultative anaerobic zones, and anaerobic zones, so that the processes of nitrogen removal are achieved by their internal cooperation (Svedin et al., 2008). Nitrification and denitrification are the main mechanisms for nitrogen removal in wetlands (Du et al., 2014; Kujala et al., 2019).

1.4 Application of Constructed Wetland in Cold Climate

Constructed wetlands in Nordic countries aimed at advanced treatment in removal of N, and the removal of other pollutants (like COD, BOD and so on) can be negligible in wetlands (Kadlec et al., 2009). Removal of N and phosphorus (P) are affected apparently in constructed wetlands. However, removal of P was very considerable in the last 30 years in the Swedish WWTPs because of effective technologies have been taken in order to prevent eutrophication (Andersson et al., 2005).

Sweden and Nordic countries located in cold climate regions, the relatively low temperature would be the strongest interference to seasonal N removal dynamics. Anderson et al (2005) found that the removal of N will decrease when temperature in wetlands decreases. For instance, the Magle constructed wetland in Hässleholm had a 63% N removal in August but only 1% in December. In China, Du et al (2017) did some research on the functions of constructed wetlands in Tibet with cold climate and high latitude, indicating that the efficiency of nitrification would be severely restricted at below 10 degrees and almost stopped at 4 degrees, meanwhile, the efficiency of denitrification would sharply decrease at 15 degrees. (Du et al., 2017).

In this study, two hypotheses are proposed:
a. In a cold climate, the N removal in FWS constructed wetlands is strongly affected by temperature.

b. N removal rate in FWS constructed wetlands is higher in relation to temperature in autumn and winter than in spring and summer.

2. Methods and materials

2.1 Study Sites

The study was performed in experimental wetlands near Halmstad in the south of Sweden. The experimental wetlands were constructed in 2002 and consist of 18 similar Free Water Surface (FWS) constructed wetlands locating in the experimental area of 76 x 32m (Fig. 1A). The FWS wetlands were covered by vegetation and there are no trees besides them guaranteeing the open space in the fields. The six wetlands (1, 6, 9, 12, 15, 18) are covered with emergent vegetation, six wetlands (4, 5, 7, 10, 14, 17) are covered with submersed vegetation, the remaining six wetlands are control sites which are unplanted letting the wetlands develop by themselves (Weisner & Thiere., 2010). The soil in the area is heavy so that it can prevent water exchange between the wetlands and the surrounding ground. Each wetland system is rectangular basin and has a side slope of 45 degrees In addition, the wetlands are divided into shallow wetlands and deep wetlands, the shallow wetlands (3, 5, 10, 11, 13, 17) are 0.38 deep in average and the depth of deep wetlands (1, 2, 4, 6, 7, 8, 9, 12, 14, 15, 16, 18) are 0.55 in average. The incoming water going to wetlands was divided into 3 tanks, and then the water was distributed to corresponding six wetlands through pipes underground (Fig. 1A). Water entered the wetlands through the inlet pipes and baffles which could keep water being distributed in the short side of the wetland (Fig. 1C). And then water flowed straight to the outlet pipes which were perpendicular to the button of wetlands for guaranteeing wetlands’ depth (Fig. 1B).
Incoming water to wetlands has a relatively high concentration of Total N ranging from 7~9 mg/L, which is almost equal to the concentration of nitrite nitrogen in the incoming water. There are also outlet pipes which let the drainage flow into the stream nearby the wetlands. According to our topic, the concentration of nitrogen in inlet and outlet water should be focused on, so the study was based on the measurement of the concentration of nitrogen. The concentration of nitrogen in wetlands has been being measured since 2002. Data from 2015 to 2018 were extracted for research, data include the concentration of total nitrogen and nitrite nitrogen, water temperature and water flow.

2.2 Analysis Method

According to content above, the measurement were extracted for analysis. Concentration of total N, nitrite N and temperature are available in the study. In the process of study, two research ways were held. The data were calculated to average values among 18 wetlands in each measuring day as well as the temperatures. On the other way, the statistical analysis would be made and the data would be generalized in every month when compared with temperatures on account of seasonal dynamics. In
the data provided, 18 wetlands have 55 groups of data on the concentration of Nitrite N and Total-N. The average value of them in each date was calculated and analyzed by specific methods.

Statistics of N removal and temperature are average values among 18 wetlands and P value of them showed they are normally distributed (P>0.05). I investigated the differences in N removal under almost the same temperature, the measurement of N removal in 18 wetlands in average among 55 samples at similar temperature were extracted for Paired T-test. Pearson correlation test was used for analyzing if there is a correlation is between N removal in 55 samples and temperature because they are normal distributed data (P>0.05). Basic principle of covariance test is combining linear regression and variance analysis to adjust each group average error term and F test experiment for testing of two or more adjustment averages have significant differences. The covariance test is used to test if there is a significant difference in two different periods in experimental wetlands in the study. Finally, the curves of dynamics are made in Excel.

3 Results

The concentration of nitrite N from inflows are almost 8 mg/L or even lower. The concentration of total N in the inflows are almost equal to the concentration of nitrite N. The concentration of nitrite N and total N in the outflow from the 18 wetlands is 5 to 7 mg/L in average (Fig 2), and Fig 2 also roughly shows that absolute N removal is higher in summer and lower in winter according to the variation from 2015 to 2018 (Fig 2).

In summer, the absolute removal is relatively higher than that in winter. Total N removal was highest at 0.36 g/m2*d in August and lowest at 0.06 g/m2*d in February. According to the monthly variable curve of N removal and temperature, there is a discrepancy in the shape of curves (Fig 3). From the seasonal dynamics of N removal with temperature from 2015 to 2018 (Fig 4). In Fig 4, the absolute N removal in every month are distinct, and it has similar variation with temperature., the Pearson test shows they are significant correlation (P<0.001) in both nitrite N ($r^2=0.825$) and total N ($r^2=0.833$) removal. Therefore, I could make the conclusion that N removal in FWS constructed wetlands is strongly affected by temperature.

However, the figures above also indicate that it is not only temperature but also other factor affecting the removal of N. The N removal in June is lower than in May when the temperature is higher (Fig 3). Besides that, removal is quite different in different months even if the temperatures are almost similar, for instance, the average temperature in wetlands are almost same in June and September, but the removal of N is quite different from each other. The Fig 3 also shows the N removal variation from August to December more consistent with temperature change than in any other seasons (Fig 3).
MONTHLY INLET AND OUTLET OF NITRITE NITROGEN IN WETLANDS
(FROM 2015 TO 2018)

Average Outlet (mg/L) — Average Inlet (mg/L)
Fig 2. Inflow and outflow concentrations of total-N in average in experimental wetlands from Apr 2015 to Mar 2018
The average temperature in June and September are almost the same, but the N removal are quite different, and the same occasion occurs in July and August (Fig 3). In the next study, the N removal in different occasions in June and September (July and August) were extracted for analyzing, the N removal (including Nitrite N and total N) of every measurement from June to September should be calculated to average. The result of Paired T-test indicates that P-value is 0.000188 in June & September (t-value is -4.743), and 0.002 in July & August (t-value is -3.636) in nitrite N removal. On the other hand, P-value is 0.000054 (t-value is -5.342) in June & September and 0.001 (t-value...
is -3,928) in July & August in total N removal (Table 1). That shows the N removal difference is quite significant between June and September (July and August) even if the temperature in two months are similar.

Fig 4. The dynamics of nitrogen removal in wetlands with temperature from Apr 2015 to Mar 2018

Experimental wetlands also performed an apparent difference on N removal between two different
period, from March to July and from August to December (Fig 3). Therefore, the relation between N removal and temperature where compared between the two periods with analysis of covariance (ANCOVA). The first thing should be made sure was that if interaction of temperature and period would affect removal.

The result of test showed that P-value was 0.68 in total N removal and 0.948 in nitrite N removal (both of them are much bigger than 0.05, there is no significant difference), so the interaction of temperature and period has almost no effect on N removal in experimental wetlands. Finally, the ANCOVA test showed the P-value 0.081 in total N removal and 0.07 in nitrite removal. Consequently, I can make the conclusion that N removal in spring and summer is almost significant different from that in autumn and winter on account of the P-values of them are not much bigger than 0.05 (Table 1).
The result of analysis also indicated that differences of N removal between two periods can be shown in one figure (Fig 5). It shows that N removal is related to temperature, N removal goes up as well as temperature goes up. In addition, the regression line for Aug-Dec is above the line for Mar-Jul, that indicates removal is higher in Aug-Dec than in Mar-June even if they are at similar te-

Table 1. The results of statistical analysis on nitrogen removal

<table>
<thead>
<tr>
<th></th>
<th>Periods</th>
<th>Statistical Parameters</th>
<th>Nitrite Nitrogen Removal</th>
<th>Total Nitrogen Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation Test of Nitrogen Removal with Temperature</td>
<td>Every month from 2015 to 2018</td>
<td>P-value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>r²-value</td>
<td>0.825</td>
<td>0.833</td>
</tr>
<tr>
<td>Paired T-test of Nitrogen Removal in Different Months</td>
<td>June vs September</td>
<td>P-value</td>
<td>0.000188</td>
<td>0.000054</td>
</tr>
<tr>
<td></td>
<td></td>
<td>t-value</td>
<td>-4.743</td>
<td>-5.342</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Df</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>July vs August</td>
<td>P-value</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>t-value</td>
<td>-3.636</td>
<td>-3.928</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Df</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>ANCOVA Test of Nitrogen Removal in Two Different Periods</td>
<td>(Mar to Jul vs Aug to Dec)</td>
<td>P-value (Interaction Test)</td>
<td>0.948</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P-value (Significant Test)</td>
<td>0.07</td>
<td>0.081</td>
</tr>
</tbody>
</table>
-mperatures. This relation is however different in the two periods which indicates that another factor is also important. On the other hand, the $r^2$ -value also indicates that how strongly N removal is affected by temperature, $r^2$-value of N removal in Aug to Dec (autumn to winter) is bigger than in Mar to Jul (spring to summer) (Fig 5). Therefore, it shows that N removal rate in FWS constructed wetlands is higher in relation to temperature in autumn and winter than in spring and summer.

4 Discussion

In Fig 2, the N removal fell down sharply when temperature went down from August to December, even if the dead plants in wetlands are able to provide the organics (carbon sources) for denitrification. Other factors affect the removal of N apparently in spring and summer than in autumn and winter. N removal in June and September is significant different (more significant than in July and August). Consequently, it is not only temperature which affects the N removal in wetlands. In spring and summer, emergent plants were growing. They support denitrification by supplying organic carbon to denitrifying bacteria, released from plant litter and from living macrophytes (Weisner et al., 1994). On account of the growth of vegetation, the N removal from January to March increased slowly which is not suitable with the growth of temperature in wetlands (Fig 2).

The significant difference between the N removal in June and September can be attributed to the lower intensity of light in September, because denitrification is restricted during the daytime due to the relatively high oxygen production (Svedin et al., 2008). Some studies show that emergent macrophytes provide appropriate attachment for denitrifying bacteria, or stimulate denitrification indirectly by contributing to a lower redox potential (Weisner et al., 1994). I can make a debatable conclusion that interference by higher light intensity limiting the denitrification and insufficient attachment for denitrifying bacteria due to the immature vegetation resulting in a lower removal in June even if water in wetlands is warm enough.

The dynamics of total N removal in 2010 in Magle wetland in Hässleholm was similar with the situation in experimental wetlands, relatively higher in summer and lower in winter. The more important thing is that N removal was quite different even if at same temperatures. The submerged vegetation dominated the majority of the area and depth of water is shallow, resulting in a high concentration of dissolved oxygen (DO) in the water which could resist denitrification. Another practical situation in Magle is that the vegetation was also regularly harvested, meaning that organic matter which was an essential energy for denitrifying bacteria was removed (Andersson et al., 2005). In practical cases, denitrifying bacteria are not able to obtain enough carbon source for
denitrification when harvest in Magle. The variation of temperature in Magle may be not a quite different from that in the previous experimental wetlands, consequently, kinds of vegetation, light and hydraulic conditions might be the main interferences.

According to my description before, temperature is an important factor which affects the N removal most. The most direct measurement to improve N removal in wetlands is heating up the water in wetlands. On account of that propose, heat energy support may be the biggest problem.

In Sweden, the cities have specified facilities to guarantee the heat supply for residents, the hot water is transferred by pipes which are connected to houses and apartments, in that case, the heat is transferred in hot water (About 70~100°C) from energy power plant then it would be transferred back after satisfying the residents’ requirement. However, the situation shows that it still has relatively high temperature (About 40~50°C) after being transferred back to the energy power plants. According to the situation I have expressed, the most appropriate temperature would be around 15 degrees. Obviously, the excess heating will be available for heating up the water according to its abundant heat.

According to that assumption, two improvements are provided, a) heating up the water in inlet pipe before entering into wetland; b) laying the heating pipes in wetland in order to transfer heat everywhere. From the perspective of engineering cost, plan a is more feasible than plan b, because plan b lead to a considerable cost when wetland area is large. However, the temperature in wetland is likely not to be maintained if plan a is implemented. Therefore, this will be a valuable topic for further researching.

5 Conclusion

According to the study, nitrogen removal in FWS wetlands is strongly affected by temperature just as the previous hypothesis, and N removal rate in FWS constructed wetlands is higher in relation to temperature in autumn and winter than in spring and summer. And in different periods, the nitrogen removal would be quite different even if under the similar temperatures. In general, FWS wetlands can efficiently treat waste water from WWTPs under cold climate condition if appropriate measurements are able to be put forward, especially researchers could find the internal regulations and improve them.
References


My name is Chang Ge, I am from China, I graduated from Halmstad University. My major is Applied Environmental Science. From 2018 to 2019, I studied in Sweden for my master's degree.