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ANALYSIS OF THE REMOVAL OF BOD_5, COD AND SUSPENDED SOLIDS IN SUBSURFACE FLOW CONSTRUCTED WETLAND IN LATVIA

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ABSTRACT

This study aims to evaluate the performance of subsurface flow constructed wetland in Latvia which was established to receive storm water from surface runoff from a farmjard in agricultural area. As a part of this study, subsurface horizontal flow wetlands was monitored, in order to evaluate the changes in the efficiency of treatment depending on biological factors. The efficiency of horizontal subsurface flow constructed wetland was evaluated by comparing the concentration of total suspended solids (TSS), biochemical oxygen demand (BOD_5) and chemical oxygen (COD) at inlet and outlet of the wetland depending on temperature and pH. Since June 2014, water quality monitoring in a research site in the farm "Mezaciruli", Zaļenieku parish, Jelgava region has been carried out to treat the point source agricultural runoff from the impermeable pavements. The analysis of the data obtained in the monitoring allows to draw conclusions about the influence of certain factors in the subsurface flow constructed wetlands under the climate and environmental conditions in Latvia.

Key words: constructed wetlands, subsurface flow, BOD, COD, suspended solids

INTRODUCTION

Uncontrolled discharge of municipal waste water, particularly in rural areas, results in contamination of surface waters and groundwater, which are therefore not suitable for drinking water, crop irrigation, fish production and recreation. Pollution is usually spread due to infiltration and surface runoff, as well as poorly designed purification systems. Increasing the use of fertilisers and pesticides in agriculture contributes to diffuse pollution through runoff (Abou-Elela, Elekhnawy, Khalil & Hella, 2017). Constructed wetlands, artificially formed marshes, purses or ponds, can be used to purify contaminated water, such as municipal wastewater, agricultural runoff, and other polluted waters. Such structures can be designed to treatment of water pollution, mitigate flood impacts, and replenish groundwater stocks and recreation (Jansons & Grinberga, 2012). The wastewater treatment process is based on a sand filter saturated with micro-organisms or a shallow pond and it is not necessary to add any additional substances during the system operation. The treatment efficiency of the constructed wetland is supported by vegetation: plantations of reed or other moisture-loving plants planted above the surface of a sand filter or in a shallow pond.

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The purification process in constructed wetlands depends on a variety of performance and environmental factors (Tsihrintzis, Akratos, Gikas, Karamouzis & Angelakis, 2007) such as hydraulic loading rate (HLR), hydraulic retention time (HRT), pH level of the environment, temperature, dissolved oxygen, ect. Biotic (macrophytes (aquatic plants) and micro-organisms) and abiotic factors (environment) are responsible for the various waste water treatment processes (Varma, Gupta, Ghosal, Majumder, 2021). One of the main factors influencing macrophyte and micro-organism activity is temperature. Therefore, seasonal variation becomes a primary aspect affecting the efficiency of removal of nutrients and organic materials. Wetlands are affected by a climate that causes cyclic activity of evotranspiration, photosynthesis and micro-organisms (Varma et al., 2021).

A wide variety of studies have shown a marked difference in seasonal efficiency associated with temperature changes over different seasons. Akpor, Adelani--Akande and Aderiye (2013) reported that the nutrient removal was at an optimal temperature of 30°C. Song, Li, Lu and Inamori (2009) observed that the efficiency of removing chemical oxygen demand (COD) was higher during the summer and spring seasons (66.3 and 65.4%, respectively) than in the winter and autumn seasons (59.4 and 61.1%, respectively). Tunçsiper (2009) found that the average nitrogen removal efficiency in constructed wetlands was from 6 to 11% higher in summer than in winter. These studies have shown that there is a direct link between temperature and activity of microbes and their effects on the efficiency of pollution reduction (Varma et al., 2021).

One of the affecting operating factors is the hydraulic loading rate. Due to excessive loading rate, there is a higher load of pollutants and a shorter retention time that can lead to organic matter accumulation, a reduction in the effective pores, thereby reducing the purification efficiency (Maltais-Landry, Chazarenc, Comeau, Troesch & Brisson, 2007). In a studies conducted by García et al. (2005) and Trang et al. (2010), mean effluent COD, biochemical oxygen demand (BOD_5) and total nitrogen concentrations (Kjeldahl method) gradually increased with an increase in hydraulic loading rate and no significant effects on suspended solid removal were observed. Vymazal (2007) declared that the removal of nutrients for the surface of free water in constructed wetland is variable and, above all, depends on the hydraulic loading rate (Varma et al., 2021).

As the period of exposure to wastewater, microorganisms and rizosphere increases, the interaction between wastewater and constructed wetland components will increase, resulting in an improvement in the efficiency of discharge. Katayon, Fiona, Noor, Halim and Ahmad (2008) and Bakhshoodeh et al. (2020) observed that the increase in hydraulic retention time led to greater efficiency in removing BOD_5, COD and suspended solids. However, longer hydraulic retention time generally require larger areas and it results in higher costs. Akratos and Tsihrintzis (2007) concluded that hydraulic retention time exceeding eight days are sufficient to separate organic matter relatively (up to 91.9%). The hydraulic retention time played an important role in the efficiency of the removal of suspended solids and the eight-day hydraulic retention time was also sufficient to remove nitrogen from 80 to 90% (Varma et al., 2021).

The pH level of wastewater is an essential parameter affecting the efficiency of constructed wetlands, mainly regarding to the removal of nitrogen and organic matter. The chemistry and biology of wetland water are equally influenced by pH, such as a slower denitrification process at pH 5, while at pH < 4 there is a very limited denitrification (Vymazal, 2007). Denitrifying bacteria are known to survive at pH values ranging from 6.5 to 7.5, and if the pH of the effluent is not present in this range, the anaerobic degradation process is not complete and it results in the formation of volatile fatty acids and their increase in the system. In addition to regulating many biological processes, pH level is also a factor for a number of vital chemical reactions. Nitrification is favourable if the water pH is between 7.5 and 8 (Tchobanoglous, Burton, Stensel, 2004). In reference to the study of Vymazal (2007), the optimal pH range for nitrification is between 6.6 and 8. In the case of suspended solids, it was found that the coarse sand and the adsorption capacity of the broken stone was maximum at pH 7 and decreased at pH 5 and 9 (Seo et al., 2008; Varma et al., 2021).

Oxygen is an essential environmental variable governing nitrification and biodegradability. Artificial aeration is used to increase dissolved oxygen in wastewater. Artificial aeration is useful to separate BOD_5, COD and ammonia. However, aeration does not have a significant effect on phosphates, and nitrates retained in the presence of high dissolved oxygen. Nitrification – denitrification is generally recognised as the primary process for the removal of total nitrogen in wetlands (Vymazal, 2005). Insufficient oxygen availability in horizontal subsurface flow leads to delays in the nitrification process as well as the degradation of organic substances (Noorvee, Põldvere & Mander, 2007). The nitrification process is the most important phase of nitrogen removal in the constructed wetlands of the subsurface flow, as oxygen availability is low. A dissolved oxygen concentration of 1.5 $mg \cdot dm^{-3}$ and higher is assumed to be essential for nitrification (Ding, Song, Wang & Yan, 2012). The study found that high dissolved oxygen contributed to better degradation of organic compounds (Liang et al., 2020). Maintaining aerobic conditions is a key factor for removing high COD, ammonia and nitrogen (Li, Lu, Zheng & Zhang, 2014). Increased removal of organic substances, nitrogen and ammonia was achieved through artificial aeration (Dong, Qiang, Li, Jin & Chen, 2012; Al-Baldawi, Abdullah, Suja, Anuar & Mushrifah, 2013).

The objective of this study was to evaluate the changes in the efficiency of subsurface flow constructed wetland, depending on the environmental factors affecting the biological process.

MATERIAL AND METHODS

Study site

A horizontal subsurface flow constructed wetland has been established in a farm in Mezaciruli, Zaďenieku parish, Jelgava municipality, Latvia. According to the EU Nitrates Directive (Council Directive 91/676//EEC), the research site is located in a nitrate-sensitive area, as intensive agricultural activity is highly developed in the Zemgale region. Since August 2014, constructed wetland has been installed on the farm with a purpose to improve the water quality of rainwater collected from hard surfaces on the farm. The water treatment system involved in the study consists of a sedimentation basin, such as a pretreatment plant, a water pump, and a horizontal subsurface flow constructed wetland with a total surface area of 160 m^2. The filter part of the wetland is made of coarse sand and gravel layers up to a depth of 0.9 m. The filter is hydroinsulated from groundwater and common reeds have been planted on top of the wetland (Grinberga & Lagzdiņš, 2017).

Sampling and water quality analysis

To evaluate the treatment efficiency in a constructed wetland, water samples are collected in the inlet and outlet, twice or once a month, depending on the discharge of water. Water is collected in plastic bottles previously washed with distilled water. The monitoring period have been 73 calendar months from August 2014 to December 2020. In water samples, the concentration of total suspended solids ($mg \cdot dm^{-3}$) was analyzed in accordance with the Latvian standard determined by the Latvian Hydrochemology Institute. The concentration of BOD_5 and COD was determined in accordance with the Latvian standard (Grinberga, Lauva & Lagzdiņš, 2021).

Data processing

As part of the study, temperature and environmental pH parameters were observed to determine their impact on the reduction of BOD_5, COD and suspended solids following the treatment of wastewater in the constructed wetland. Temperature data are derived from the Jelgava Station of the Latvian Environmental, Geology and Meteorology Centre (LVĢMC) during the period from August 2014 to December 2020. At the Jelgava observation station, located 17 km from the study site, the average temperature (water sampling days from August 2014 to December 2020) for the growing season (April–September) is 14.02°C and the non-vegetation period (October–March) 1.62°C.

In order to determine the impact of temperature and pH on the wetland efficiency, a correlation analysis was applied to the reduction of BOD_5 and COD after effluent treatment in constructed wetland. For the purpose of evaluating the data obtained, the estimated value is compared to the critical value. The results have been analysed using the signifiance level – $p = 0.05$ and the number of actual observations.

RESULTS AND DISCUSSION

When evaluating the monitoring data, the average inflow concentration in the sedimentation basin for suspended solids is 94.54 mg·dm^{-3}, BOD_5 is 273.36 mg·dm^{-3} and COD is 421.94 mg·dm^{-3}. Table 1 summarises the mean values and standard deviation for water quality parameters at inflow and outflow, including the entire study period, vegetation and non-vegetation treatment efficiency. The standard deviation describes the variability of suspended solids, BOD_5, COD concentration in the inflow and outflow of constructed wetland. The decrease in concentrations of BOD_5 is up to 80% and the reduction in COD concentration is up to 74%, while the concentration of suspended solids increase on average by 33%.

Vegetation in constructed wetland have a number of benefits that has a positive impact on most biological processes. The growth and development of roots and corms ensure the development of micro-organisms, with a positive impact on microbiological processes. Figure 1 compares the treatment efficiency for suspended solids, BOD_5 and COD in the wetland during the vegetation and non-vegetation period. The concentration of parameters observed during the non-vegetation period varies more than during the vegetation period where the impact factor is climate. The seasonal observations, in particular BOD_5 and COD treatment efficiency are less variable, while concentrations of suspended solids shows more extreme data indicating that this water quality parameter is variable and unpredictable.

The studies identified significant temperature impacts on the efficiency of wastewater treatment and the activity of microbiological processes in constructed wetland. A correlation analysis for data from August 2014 to December 2020 showed that there was a weak correlation between suspended solids, BOD_5, no significant impact on the efficiency of COD retention (Table 2).

Table 1. Mean, standard deviation and efficiency values for water quality parameters

Water quality parameter	Mean inflow concentration [mg·dm^{-3}]	Average outflow concentration [mg·dm^{-3}]	Efficiency [%]	Effeciency in the vegetation period [%]	Non-vegetation efficiency [%]
Suspended solids	94.54 ±128.11	39.90 ±50.30	–33	–10	–41
BOD_5	273.36 ±228.61	15.00 ±12.65	80	79	81
COD	421.94 ±331.90	48.76 ±22.96	74	76	73

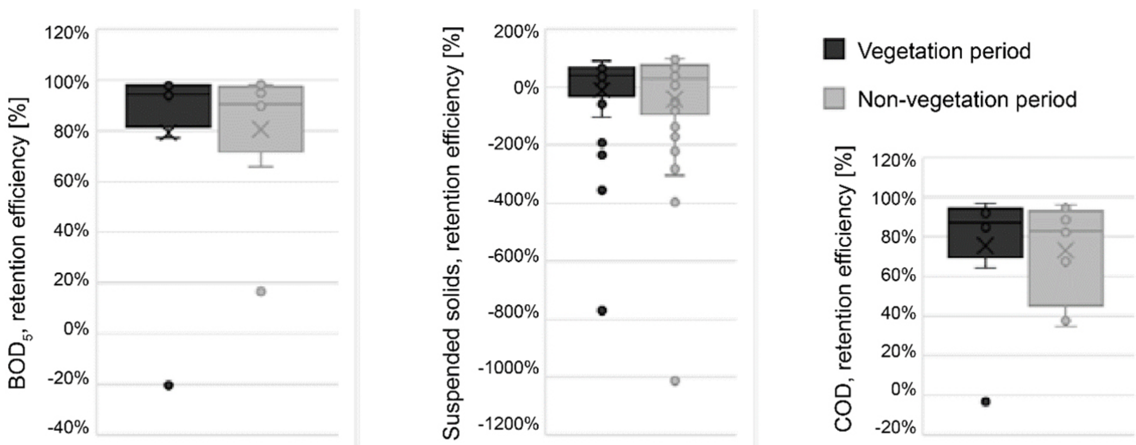

Fig. 1. Retention efficiency of suspended solids, BOD_5, COD during vegetation and non-vegetation period

Table 2. Correlation test: temperature impact on suspended solids, BOD_5, COD retention efficiency

	Correlation factor (r)	| t |	$t_{0.05;\,n}$
Suspended solids	0.119	1.07	1.99
BOD_5	–0.02	–0.08	2.12
COD	–0.067	–0.25	2.12

Air temperature data from the Jelgava meteorological station, located 17 km from the study site, have been used for the impact assessment.

The average pH in the study period is 7.27, during the vegetation period 7.30 and during the non-vegetation period 7.24, indicating that the pH of the environment in the wetland is neutral. Compared to the studies examined in the introduction, this pH range is optimal for the nitrification process (Tchobanoglous et al., 2004) and the results at pH 7 indicate that the adsorption capacity of coarse sand for suspended solids is appropriate (Seo et al., 2008).

Environmental pH values above 7.5 are observed during the beginning and end of the period of vegetation (April, September) and non-vegetation (March, October). The reason for such fluctuations may be related to the different economic activities and their effects, such as silage, mineral manure, agricultural machinery storege, etc. on hard surfaces.

In assessing the effects of the pH of the environment on the water quality parameters selected, the correlation test showed a weak correlation between pH and the purification efficiency of suspended substances ($r = -0.132$), while comparing the pH to the treatment efficiency of BOD_5, the correlation factor points to a close, moderate, negative, linear relationship, while examining the characteristics related to t-test for the comparison of average values with probability $p = 0.95$, it is concluded that the relationship does not exist (Table 3).

When assessing the effects of the pH on COD, it may be observed that the correlation factor indicates a negative, medium-close, linear relationship, but the t-test shows that because the t-factor value (–2.17) is greater than t-critical (2.12), there is a negative linear relationship or a decrease in the environmental pH increases the efficiency of COD treatment in a wetland.

Figure 2a linear relationship between the pH and the efficiency of COD treatment. When comparing the pH impact on the treatment efficiency of suspended solids during the vegetation period, it can be concluded that the relationship does not exist because the correlation is weak (see Table 3). There is a mean close correlation between the parameters during the non-vegetation period ($r = -0.737$) but after the t-test, a negative linear relationship was established between the pH and the efficiency of COD treatment.

Table 3. Correlation test: pH effect on suspended solids, BOD_5, COD purification efficiency

	Correlation factor (r)	Coefficient of determination (R^2)	Standard deviation (σ) [%]	| t |	$t^{0.05}$; n
Suspended solids	–0.132	0.017	200	–1.19	1.99
BOD_5	–0.465	0.216	34	–1.96	2.12
Vegetation period	–0.370	0.137	41	–0.98	2.31
Non-vegetation period	–0.487	0.237	28	–1.37	2.31
COD	–0.502	0.252	28	–2.17	2.12
Vegetation period	–0.330	0.109	33	–0.86	2.31
Non-vegetation period	–0.737	0.543	25	–2.67	2.31

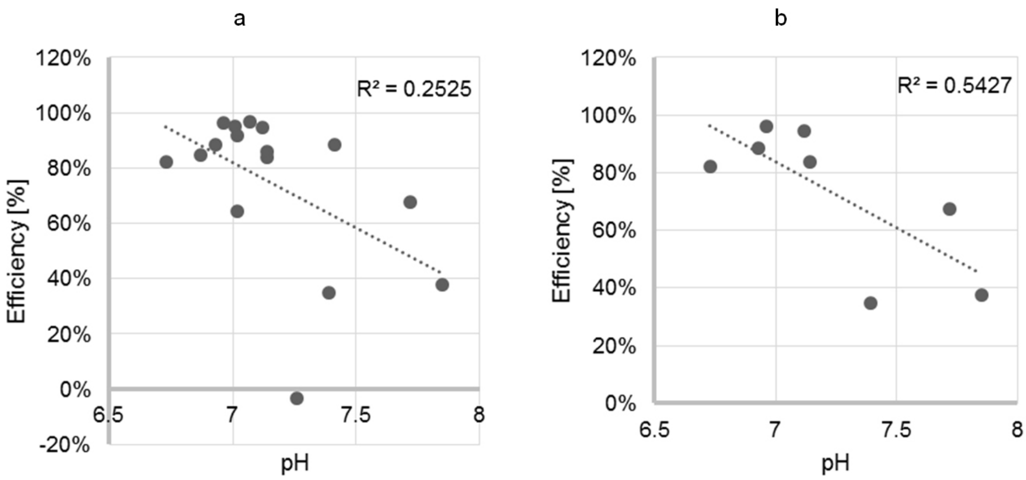

Fig. 2. Relationship between pH and COD treatment efficiency during vegetation (a) and non-vegetation period (b)

As shown in Figure 2b, the trend curve is negative, or the pH decreases, increases the efficiency of COD treatment.

The pH and air emperature are only a part of the many factors of the climate (e.g. precipitation, etc.) and the environment (e.g. economic load on hard surface, etc.) which may have an impact on the treatment efficiency in the subsurface flow constructed wetlands, which may also have affected the data obtained so far in the studies and also affect the results obtained here.

CONCLUSIONS

The air temperature does not significantly affect the reduction of BOD_5, COD and suspended solids in the effluent treated in the horizontal subsurface flow constructed wetland. Factor pH impacts on COD treatment efficiency (74%), particularly during the non-vegetation period (April–September) (73%). The treatment efficiency of BOD_5 and suspended solids is not affected by the pH. Vegetation impacts the reduction of BOD_5 and COD in the constructed wetland. Constructed wetland has a heat energy from bacterial activity inside the filter layer, reducing the effect of air temperature on purification processes.

The monitoring of horizontal flow subsurface flow constructed wetland should be continued in order to obtain as much data as possible over the longer term, thereby excluding the values of various extreme data resulting from different climate or environmental conditions.

Authors' contributions

Conceptualization: L.G. and D.G.; methodology: L.G.; validation: L.G. and D.G.; formal analysis: L.G. and I.G.; investigation: D.G.; resources: A.C.; data curation: D.L.; writing – original draft preparation: D.G.; writing – review and editing: I.G. and J.D.; visualization: D.L.; supervision: L.G. and A.C.; project administration: L.G.; funding acquisition: W.S. and A.G.

All authors have read and agreed to the published version of the manuscript.

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ANALIZA USUWANIA BZT_5, CHZT I ZAWIESINY OGÓLNEJ W SZTUCZNYM EKOSYSTEMIE MOKRADŁOWYM O POZIOMYM PRZEPŁYWIE PODPOWIERZCHNIOWYM, ZLOKALIZOWANYM NA ŁOTWIE

STRESZCZENIE

Celem pracy jest ocena wydajności sztucznego ekosystemu mokradłowego o poziomym przepływie podpowierzchniowym. Mokradło zostało utworzone do odbioru wody burzowej ze spływu powierzchniowego z podwórza gospodarstwa rolnego na Łotwie. W ramach badań monitorowano sztuczny ekosystem mokradłowy o poziomym przepływie podpowierzchniowym, aby ocenić zmiany w efektywności oczyszczania w zależności od czynników biologicznych. Efektywność stworzonego mokradła o poziomym przepływie podpowierzchniowym oceniano poprzez porównanie stężenia zawiesiny ogólnej (TSS), biochemicznego zapotrzebowania tlenu (BZT_5) i chemicznego zapotrzebowania tlenu (ChZT) na dopływie i odpływie mokradła w zależności od temperatury i pH. Monitoring jakości wody na stanowisku badawczym w gospodarstwie „Mezaciruli", parafia Zaļenieku, region Jelgava prowadzono od czerwca 2014 roku w celu oceny efektywności oczyszczania spływu zanieczyszczeń z punktowego źródła rolniczego z nieprzepuszczalnych nawierzchni. Analiza danych uzyskanych w ramach monitoringu pozwala na wyciągnięcie wniosków dotyczących wpływu niektórych czynników na funkcjonowanie sztucznego ekosystemu mokradłowego o przepływie podpowierzchniowym w warunkach klimatycznych i środowiskowych panujących na Łotwie.

Słowa kluczowe: sztuczne ekosystemy mokradłowe, przepływ podpowierzchniowy, BZT, ChZT, zawiesina ogólna