Water and Environment Journal
Promoting Sustainable Solutions
CIWEM

Water and Environment Journal. Print ISSN 1747-6585

Efficiency of a pilot hybrid wastewater treatment system comprising activated sludge and constructed wetlands planted with *Canna lily* and *Cyperus papyrus*

Euis Nurul Hidayah [1], Okik Hendriyanto Cahyonugroho [1], Ram Babu Pachwarya[2] & A. L. Ramanathan[3]

[1]Department of Environmental Engineering, Universitas Pembangunan Nasional Veteran Jawa Timur, Surabaya, Indonesia; [2]Department of Chemistry, Motilal Nehru College, University of Delhi, New Delhi, India; and [3]School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India

Keywords
activated sludge; *Canna lily*; constructed wetlands; *Cyperus papyrus*.

Correspondence
Euis Nurul Hidayah, Department of Environmental Engineering, University of Pembangunan Nasional Veteran Jawa Timur, Surabaya 60294, Indonesia.
Email: euisnh.tl@upnjatim.ac.id

doi:10.1111/wej.12658

Abstract

Combination of constructed wetland with activated sludge (AS) is one of the application of sustainable development for dealing with environmental pollution. The objective of this study was to compare the performance of three system of domestic wastewater treatment, namely AS, combination AS with constructed wetland containing *Canna lily* (AS-CWC), combination AS with constructed wetland containing *Cyperus papyrus* (AS-CWP) for treating domestic wastewater. Mini pilot scale of treatment system was built under continuous flow. Samples were taken at outlet in each unit for measuring water quality parameters, such as BOD, TSS, PO_4^{3-}, NH_4^+-N and NO_3^--N. The results indicated that AS-CWC performed a higher removal of BOD, PO_4^{3-} and TSS than AS-CWP and AS. AS-CWC and AS-CWP showed a statistically insignificant difference removal of NH_4^+-N and NO_3^--N, though the former performed a higher removal than the later. This study revealed that TOC increased in the highest percentage in AS and the lowest increasing in AS-CWP. Constructed wetlands should be integrated with primary treatment to enhancing effluent quality and reduce organic matter, a precursors of carcinogenic compound.

Introduction

Constructed wetlands have been increasingly used as an alternative treatment for wastewater, such as domestic sewage (Abou-Elela and Hellal, 2012; Yadav *et al*., 2018), industrial effluent (Haddis *et al*., 2019), agricultural (Kasak *et al*., 2018), polluted river water (Wei *et al*., 2020), landfill leachate (Dan *et al*., 2017) and storm water (Meng *et al*., 2018). Constructed wetlands have been developed based on ecological principles, plants in the constructed wetlands system could utilize organic and nutrient compound, such as nitrogen and phosphorus compounds, which are naturally needed by plants (Wu *et al*., 2015; Vymazal, 2018). Wastewater can be associated as natural liquid fertilizers, because wastewater contain nutrient and organic, which could be utilized for plant growth (Chazarenc *et al*., 2015). Previous studies have shown that wastewater treatment by using constructed wetlands can remove organic pollutants in high percentage (Haritash *et al*., 2017; Akizuki *et al*., 2018; Sandoval *et al*., 2019), remove inorganic pollutants (Abdel-Shafy and Al-Sulaiman, 2014; Boog *et al*., 2014), reduce pathogens (Abdel-Shafy and El-Khateeb, 2012; Donde *et al*., 2020) and metals including some heavy metals by vascular plants as well (Abdel-Shafy *et al*., 1994). If the constructed wetlands system is arranged properly then it can became a garden, which has an aesthetic benefit for environmental landscape. Effluent from constructed wetlands could be used for gardening, for recharging groundwater, for reclaimed water through the role of macrophyte under various mechanism of phytotechnology, such as phytodegradation, phytovolatilization and phytoextraction, and for more purposes (Wu *et al*., 2015; Vymazal, 2018). In addition, constructed wetlands is a natural treatment, without chemicals, with low-cost and easy for operation and maintenance (Vymazal, 2018; Ansari and Golabi, 2019).

Constructed wetlands have some issues that give limitation to its application for long-term process. Sludge accumulation due to high total suspended solid (TSS) and organic caused substrate blocking in the influent and pore bed spaces of constructed wetlands (Liu *et al*., 2015). Nitrification is often limited in constructed wetlands due to oxygen deficiency and creating predominantly anaerobic conditions in the wetland system. Thus, unsuitable conditions for nitrification can seriously limit the treatment potential of these systems (Akizuki *et al*., 2018; Su *et al*., 2018).

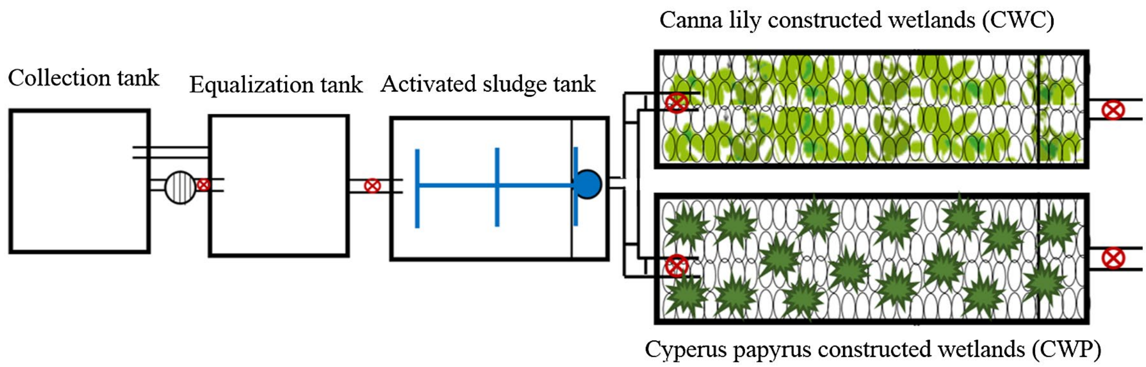

Fig. 1. Layout of mini pilot scale constructed wetlands. [Colour figure can be viewed at wileyonlinelibrary.com]

Therefore, combining constructed wetlands with other additional technologies, such as membrane bio-reactor (MBR) (Mutamim *et al*., 2012), electrochemical oxidation (Anglada *et al*., 2010) and microbial fuel cells (MFCs) (Mohan *et al*., 2008) have emerged in recent years for enhancing the individual advantages in terms of wastewater treatment. These technologies have been known to be powerful treatment for removing the specific pollutants and implementation an eco-green process for energy recovery, though these technologies have some limitations, regarding cost and maintenance system. A conventional activated sludge (AS) processes has been widely used technology in wastewater treatment for reducing organic pollutant, however, it needs to be upgraded to meet the effluent standards. A combination of AS system with constructed wetlands has a high potential to be applied in wastewater treatment. This will improve the treated water quality in order to meet effluent wastewater quality standard (Liu *et al*., 2015).

Different types of plants can be grown and easily for adapting in the system constructed wetlands. Aquatic macrophytes plants are known as the main source of oxygen in the constructed wetlands through the root zone. Many microorganism is existed in the roots of plants, because roots provide a source of microbial attachment, release carbon that supported to the denitrification process. Roots could reduce the velocity of wastewater flow rate on the constructed wetlands system as well (Vymazal, 2018; Sandoval *et al*., 2019). *Canna lily*, an ornamental plants that have an aesthetic value, has a large root system and strong enough to absorb organic matter, therefore, *C. lily* can absorb more nutrients for growth and store the excess nutrient in its tissue than other aquatic plants (Haritash *et al*., 2017; Wang *et al*., 2018; Yadav *et al*., 2018). *Cyperus papyrus* has the porous structure of the stems, does not develop deep roots and forms a kind of networks that helps a greater coverage of the root area, which in turn allows a greater oxygenation of the system (Abou-Elela *et al*., 2017; Haddis *et al*., 2019; Avila *et al*., 2019). Therefore, *C. papyrus* has a great efficiency in removing nutrient and organic pollutants. Many studies have reported the high performance of those plant for treating wastewater. Combination between AS with constructed wetland containing *C. lily* (AS-CWC) and combination AS with constructed wetland containing *C. papyrus* (AS-CWP) has been scarce information. The objective of this study was to compare the performance of three system of domestic wastewater treatment, namely AS, combination AS with constructed wetland containing *C. lily* (AS-CWC), combination AS with constructed wetland containing *C. papyrus* (AS-CWP) for treating domestic wastewater.

Materials and methods

The study was conducted in mini pilot scale of constructed wetlands in the area of Jawaharlal Nehru University (JNU) New Delhi during August–October 2019. The climate was generally warm with an average high temperature of 35°C and an average low temperature of 30°C. Domestic wastewater was taken from Sewage Treatment Plant (STP) JNU. The system of constructed wetland is comprised by: collection tank to stock domestic wastewater; AS tank, including aeration tank and clarifier (capacity 9L); two constructed wetlands with horizontal sub-surface horizontal (dimension: 0.6 m long × 0.6 m wide × 0.4 m deep) filled with 0.3 m gravel, as shown in Fig. 1.

Constructed wetlands was planted with *C. lily* (CWC) and the other was planted with *C. papyrus* (CWP) under considering density 4 plants/m^2 (Wu *et al*., 2015). Preliminary experiment was conducted in term of range finding test in 7 days, plant acclimation for 3 weeks (Vymazal, 2018) and microorganism acclimation. The AS was operated with 50% sludge recirculation from clarifier tank, under F/M = 0.05–0.1 kg BOD/kg and SVI = 50–100 mL/gr (Metcalf and Eddy, 2002). Domestic wastewater was fed continuously from collection tank to the AS 20 L/day. Further, treated effluent from clarifier was discharged into CWC and CWP at each flow rate 10 L/day and detention time 2 days. Detention time was measured at starting time inflow wastewater filled the CW for the first time, then, wastewater filled the CW, until wastewater passed through the CW to the outlet. Samples were collected in the effluent of each operation unit, including raw wastewater, AS, CWC and CWP unit twice per week.

Collected samples were analysed for NH_4^+-N, NO_3^--N and PO_4^{3-} by using 100 Bio UV-Visible Spectrophotometer, and total suspended solid (TSS) was determined by using gravimetric methods, all were following standard methods (APHA, 2012). BOD was measured after 5 days incubation at 20°C with DO metre (Hach, USA). Dissolved organic matter surrogates was quantified through total organic carbon (TOC) using TOC Analyser 5000A Shimadzu, ultraviolet absorbance at 254 nm (UV_{254}) using 100 Bio UV-Visible Spectrophotometer, and specific ultraviolet absorbance (SUVA) by dividing UV_{254} value to TOC concentration (Edzwald and Tobiason, 2011). Dissolved oxygen (DO) and pH were measured in situ using HQ40D portable (Hach, USA). Statistical data analysis, such as Kolmogorov–Smirnov, Analysis of Variance (ANOVA) and Kruskal–Wallis, was applied by using Minitab 16.1. (Minitab, LLC, Pennsylvania). Kolmogorov–Smirnov was used for testing normal distribution data, while ANOVA and Kruskal–Wallis were used for knowing differences mean efficiencies removal all parameters. ANOVA was applied if data follow the normal distribution, while Kruskal–Wallis was applied for failed normal distribution data. Further, statistical box plot analysis was performed using SigmaPlot 10.0 (Systat Software, Inc.) in order to present the performance of treatment efficiencies among three system of domestic wastewater treatment. Box plot is non-parametric analysis because it display variation in samples of a statistical population without making any assumptions about its population distribution. Box plot graph was used to compare the efficiency performance of AS, AS-CWC and AS-CWP in removing BOD, TSS, NH_4^+-N, PO_4^{3-}, TOC and NO_3^--N.

Results and discussion

Characteristic of raw and treated domestic wastewater quality

Characteristic of raw domestic wastewater and its treatment quality is shown in Figs 2 to 3. Figure 2a, the pH value, describe a decreasing trend of the pH in the effluent of treatment process, especially a significant decrease in effluent of AS-CWC. The pH values decreased is probably due to effect of nitrification, because during nitrification, H^+ ions will be released (Vymazal, 2018), as shown a consistency result with the decreasing NH_4^+-N in AS-CWC. Plants utilize nitrogen can cause to the pH lowering due to respiration and litter decomposition processes (Collins *et al*., 2004). In addition, effect of increasing metabolite microorganism in wetlands and in AS might cause the acidification of effluent (Chen *et al*., 2017). Heterotrophic microorganism existed in the AS, and probably these microorganism contributed in the constructed wetland. Therefore, decreasing of pH in that systems is might be due to production of lactic acid, acetic acid and butyric acid during degradation of organic matter by heterotrophic microorganism (Paredes *et al*., 2007).

The DO value in the AS increased significantly, and it shows the highest DO value among others, as shown in Fig. 2b, due to air was injecting to the system for aeration purposes. The air distributed to aeration tank by aerator allows the oxygen to be transferred from the air to the wastewater in term of liquid phase. It has been well known that DO concentration in the activated sludge process is an important parameter to achieve a high efficiency of treatment and system stability (Du *et al*., 2018). AS-CWC and AS-CWP indicates sufficient DO value in the systems, though it shows a lower DO value than that of AS processes. Oxygen supply in constructed wetlands are probably obtained from influent oxygen, radial oxygen loss (ROL) and atmospheric reaeration (AR) (Liu *et al*., 2016).

Influent oxygen in the constructed wetlands is supplied from AS process, as the figure shown an oxygen deficits after constructed wetlands. ROL mechanism is oxygen, which is produced by photosynthesis, goes through the aerenchyma from stems and plant leaves to plant roots, and then, released into the surrounding environment from the roots under wastewater logged conditions (Liu *et al*., 2016; Ejiri and Shiono, 2019). AR mechanism describes that oxygen transfer process between air and wastewater through molecular diffusion, though existing substrate and environmental factors probably hindered the mechanism (Boog *et al*., 2014).

Sufficient DO value in both constructed wetlands seems supporting microbial communities for degrading and uptaking organic pollutants, as in accordance with decreasing of BOD concentration (Fig. 2c). Domestic wastewater or RW showed a higher BOD because domestic wastewater mainly contains organic substances, such as carbohydrate, lignin, proteins and their decomposition products, nutrients and trace elements (Nath and Sengupta, 2016). There was a significant reduction of BOD in AS process, and slightly deficit BOD concentration in both constructed wetlands. It has been reported well that microorganism in AS process consume organic matter, in term of BOD, from the wastewater using oxygen for respiration. Microorganism existed as suspended growth in the aeration tank. Supernatant, which might has lower BOD than raw wastewater, was separated from the sludge in the settling tank, excessive settled sludge will be discharged according to the F/M and SVI value (Metcalf and Eddy, 2002). Microbial and biological degradation of BOD is a high possibility mechanism

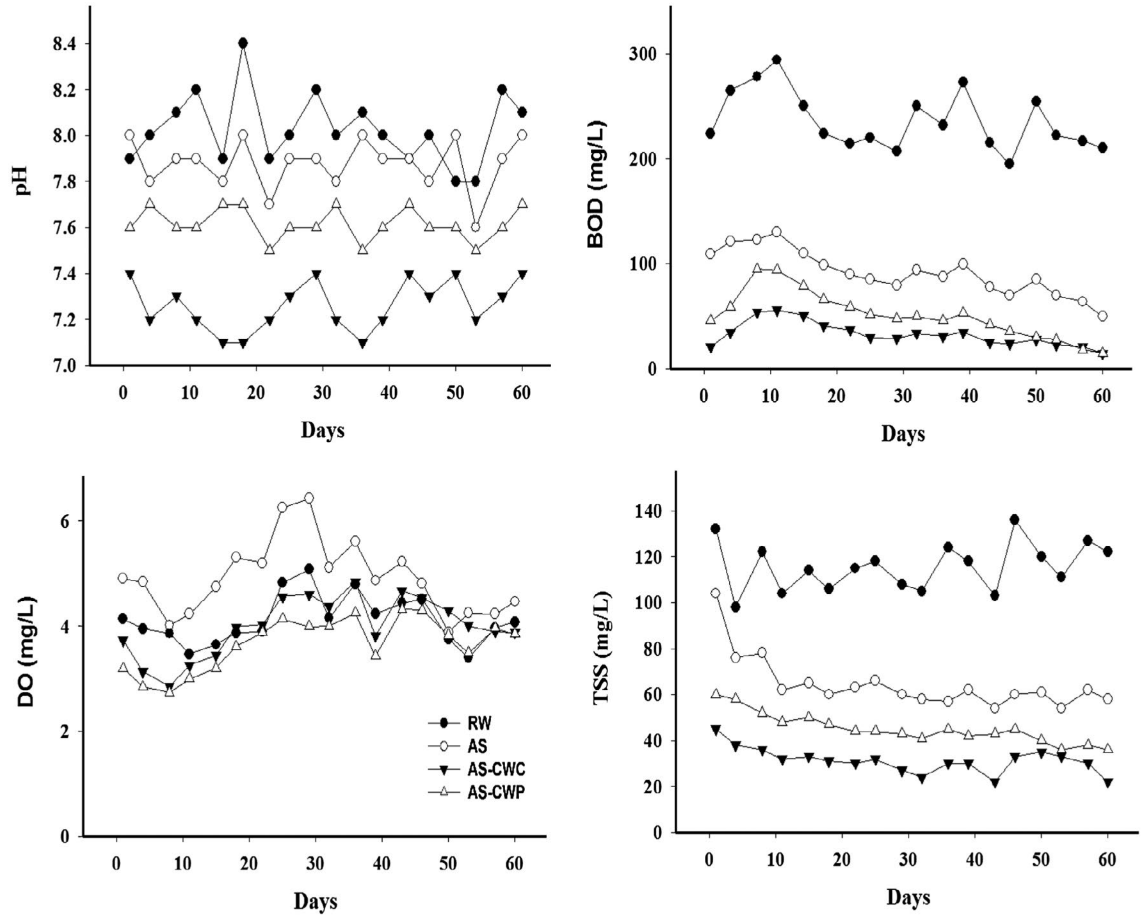

Fig. 2. Concentration of (a) pH, (b) DO, (c) BOD and (d) TSS of raw and treated domestic wastewater through activated sludge and combination of constructed wetlands with activated sludge.

in constructed wetlands. Microbial communities might be existed, in term of biofilm or attach growth, on the all surfaces of the plant including leaves, stems and roots (Vymazal, 2018; Clairmont and Slawson, 2019). Higher surface area of stems and root will produce high removal of organic. Substrate could be used as attached media growth for microbial, therefore, microbial allows to reduce BOD_5 concentration.

The concentration of TSS in the treated wastewater of all processes was higher than in the raw domestic wastewater, as shown in Fig. 2d. Significant removal of TSS in the effluent of activated sludge is due to effect of settling tank, which separated the sludge and supernatant. A slight decreasing of TSS in AS-CWP over to AS indicated that constructed wetlands system contributed to reduce TSS concentration. The lowest TSS concentration in AS-CWC indicated that the system has higher performance in removing TSS concentration. Constructed wetlands system are able to remove suspended solids due to adsorption on the submerged parts of the plant and wetlands media, sedimentation due to slow flow velocity, filtration mechanism through impaction of particles in the roots and stem of plants (Priya and Selvan, 2017; Avila *et al*., 2019). Substrate, such as gravel, plays the role of filtration, as the voids and media structure has remarkable impact on suspended solids and trapping suspended solid during the flow path. Low flow rate and longer hydraulic detention time could improve settling retention of suspended solid (Wu *et al*., 2015; Noh *et al*., 2016).

Figure 3 represents the concentration of nutrient, including NH_4^+-N, NO_3^--N and PO_4^{3-}, and dissolved organic (TOC) in raw and treated domestic wastewater. The results shows NH_4^+-N concentration decreased significantly after activated sludge, and a slightly decrease after constructed wetlands (Fig. 3a). Concentration of NH_4^+-N after AS-CWC and AS-CWP treatment results a similar reducing concentration. Activated sludge obviously shows an increasing NO_3^--N concentration (Fig. 3b), an opposite results with NH_4^+-N concentration. However, effluent of AS-CWC and AS-CWP shows a slightly reducing NO_3^--N concentration over raw wastewater and

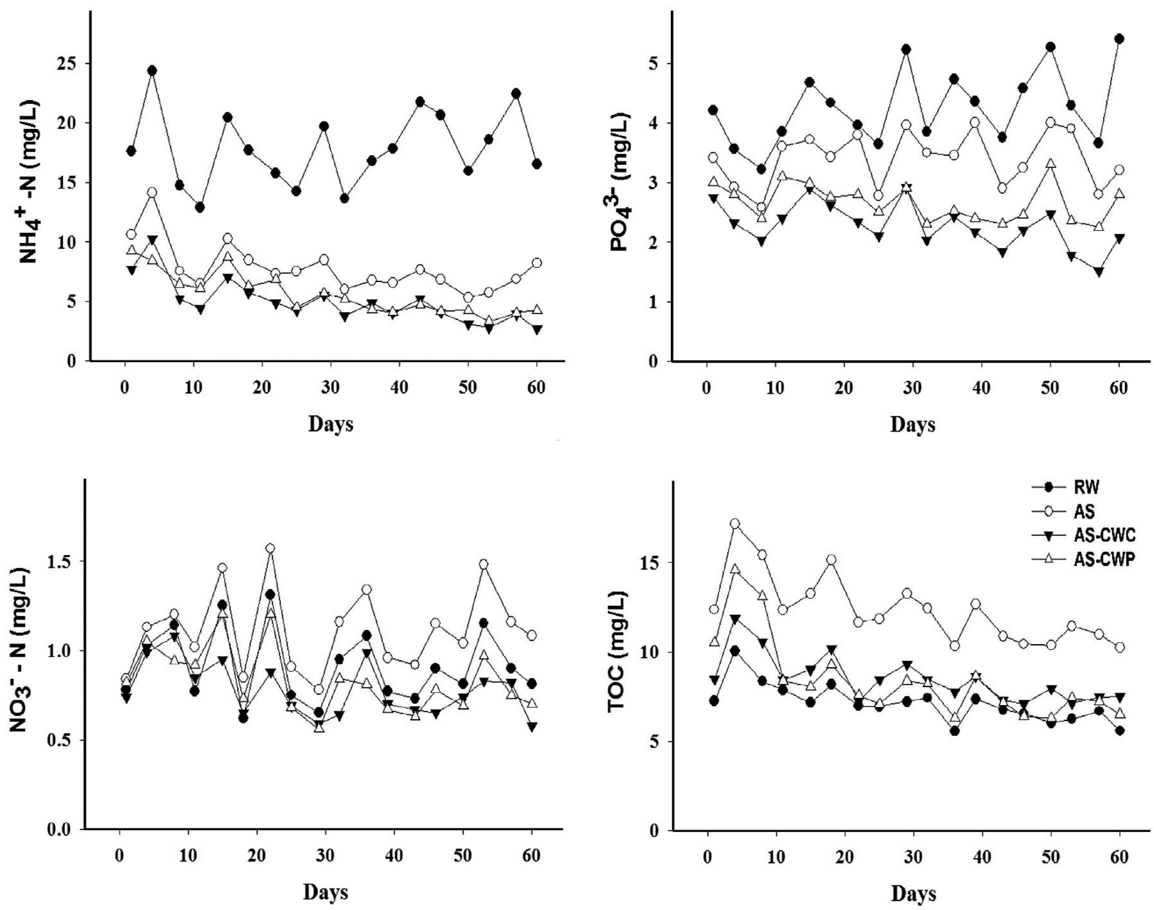

Fig. 3. Concentration of (a) NH_4^+-N, (b) NO_3^--N, (c) PO_4^{3-} and (d) TOC of raw and treated domestic wastewater through activated sludge and combination of constructed wetlands with activated sludge.

activated sludge. Comparison between concentration of NH_4^+-N and concentration of NO_3^--N reflected that conditions existed for nitrification (Wu *et al*., 2015; Su *et al*., 2018). In nitrification, NH_4^+-N is oxidized to NO_3^--N by nitrifying bacteria in aerobic zones, which have been proved by adequate dissolved oxygen in all systems (Fig. 1b). DO concentration greater than 1.5 mg/L are needed for nitrification to take place (Ye and Li, 2009), thus, denitrification might not be existed in the constructed wetlands system. Composition, structure and diversity of denitrifying bacteria is affected by organic carbon consumption and DO concentrations. It has been studied that variation of denitrifying community structure formed significantly at hypoxic (0–0.5 mg/L) and anoxic (0 mg/L) DO layers (Hong *et al*., 2020). Carbon utilization ability of different denitrifiers on each DO layers were generally different from each other. Further, this study conjectured that plant uptake could be a possible mechanism of reducing NH_4^+-N, NO_3^--N and PO_4^{3-} as well (Fig. 3c). Previous studies have reported that plants nutrients uptake accounted for a higher proportion of N removal and P removal in the wetlands system (Zheng *et al*., 2016; Avila *et al*., 2019). Presence of macrophytes could provide surfaces and oxygen for microorganism growth in the rhizosphere, and provide carbon from root exudates due to photosynthetically fixed carbon (Saeed and Sun, 2012).

Quantification of TOC are used to represent dissolved organic matter in raw and treated domestic wastewater (Fig. 3d). The result shows that raw wastewater contains of low level of TOC concentration, then, the value increased to the highest concentration in activated sludge process. Increasing TOC is probably due to effect of microbial activities, as identified into three components of fluorescence organic: fulvic acid-like, soluble microbial products-like and humic acid-like, in the previous study (Hidayah *et al*., 2020). It has been reported that microorganisms released its metabolite by-products during growth and decay or it is known as soluble microbial product and extracellular polymeric substances, which has been characterized in the biological processes (Xie *et al*., 2012; Xie *et al*., 2016; Ding *et al*., 2017). TOC concentration decreased in constructed wetlands system, though TOC concentration is still higher than that of raw wastewater. Decreasing TOC concentration in constructed wetlands is attributed to the refractory organic matter, which could be degraded by microorganism through mechanism phytodegradation and phytostabilization process in constructed wetland. Previous studies have mentioned that most of removed pollutants in wetlands has been attributed primarily to the existence of microorganism (Saeed and Sun, 2012; Su *et al*., 2018; Clairmont and Slawson, 2019). Those microorganisms could be characterized as refractory organic matter and recalcitrant organic matter, which is derived from microbial activities during growth and decay phase (Ni *et al*., 2010; Shon *et al*., 2012). In addition, root zone of plants could adsorbed and absorbed the organic contaminant through rhizofiltration and phytoextraction, which has occurred in the constructed wetlands (Wu *et al*., 2015; Vymazal, 2018).

Performance of activated sludge and its combination with *C. lily* and *C. papyrus* constructed wetlands

Kolmogorov–Smirnov was used to reveal the distribution data, and the results showed that distribution data of efficiencies removal for BOD ($P > 0.15$), PO_4^{3-} ($P > 0.15$), TSS ($P > 0.15$) and NH_4^+-N ($P > 0.15$) was normal. Efficiencies removal of TOC and NO_3^--N were failed to follow a normal distribution as $P < 0.01$ and $P < 0.01$, respectively. For normal distribution data, Analysis of Variance (ANOVA) testing was performed to know differences mean efficiencies removal of BOD, PO_4^{3-}, TSS and NH_4^+-N among three system of domestic wastewater treatment. The results showed that there was statistically significant differences mean efficiencies removal of BOD, PO_4^{3-}, TSS and NH_4^+-N among three system of domestic wastewater treatment, as P value = 0.000, respectively. Nonparametric Kruskal–Wallis testing was performed for failed normal distribution data, and the results indicated a statistically significant differences mean efficiencies removal of TOC and NO_3^--N. Further, performance of treatment efficiencies among three system of domestic wastewater treatment were presented by statistical box plot analysis. Figure 4 presents box plot of efficiency removal BOD, TSS, nutrients NH_4^+-N and PO_4^{3-}, while Fig. 5 shows box plot of efficiency removal and increasing of NO_3^--N and TOC in AS, and its combination with constructed wetlands, that is AS-CWC and AS-CWP processes. The results shows that combination of constructed wetlands with activated sludge showed a better performance than activated sludge for removing organic, TSS and nutrients. First, performance of AS process in removing of organic BOD, nutrients NH_4^+-N, PO_4^{3-} and TSS has been well known in wastewater treatment process (Fig. 4). Microorganism existed as suspended growth in the aeration tank conducted biodegradation of organic matter in the aerobic state

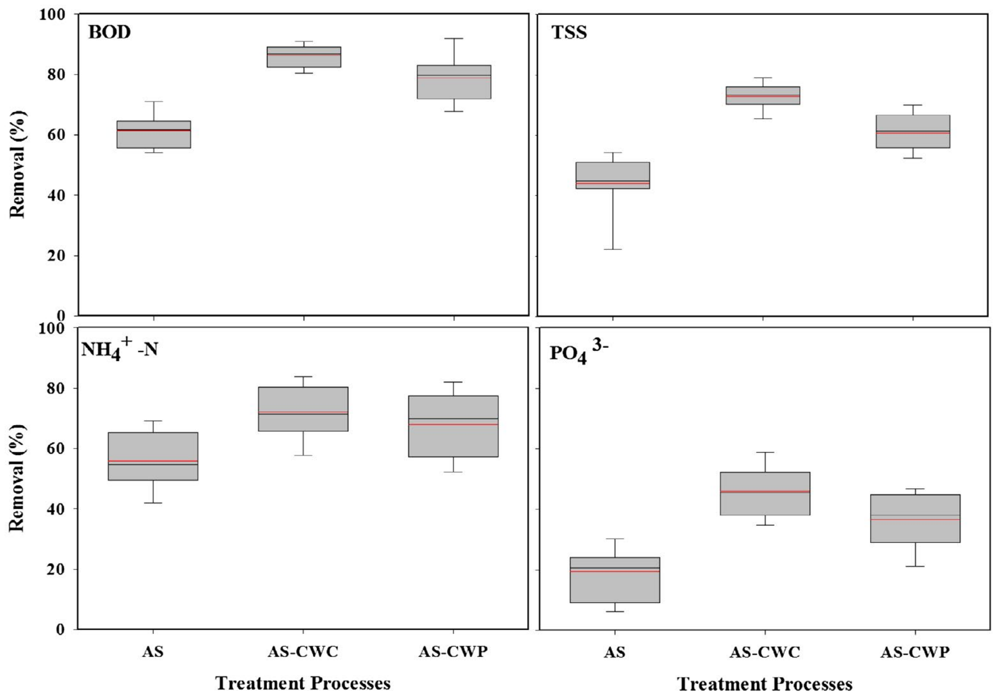

Fig. 4. Percentage efficiency of performance AS, AS-CWC and AS-CWP in treating BOD, TSS, nutrients NH_4^+-N and PO_4^{3-} (the red line indicates a mean percentage removal; the black line indicate a median percentage removal). [Colour figure can be viewed at wileyonlinelibrary.com]

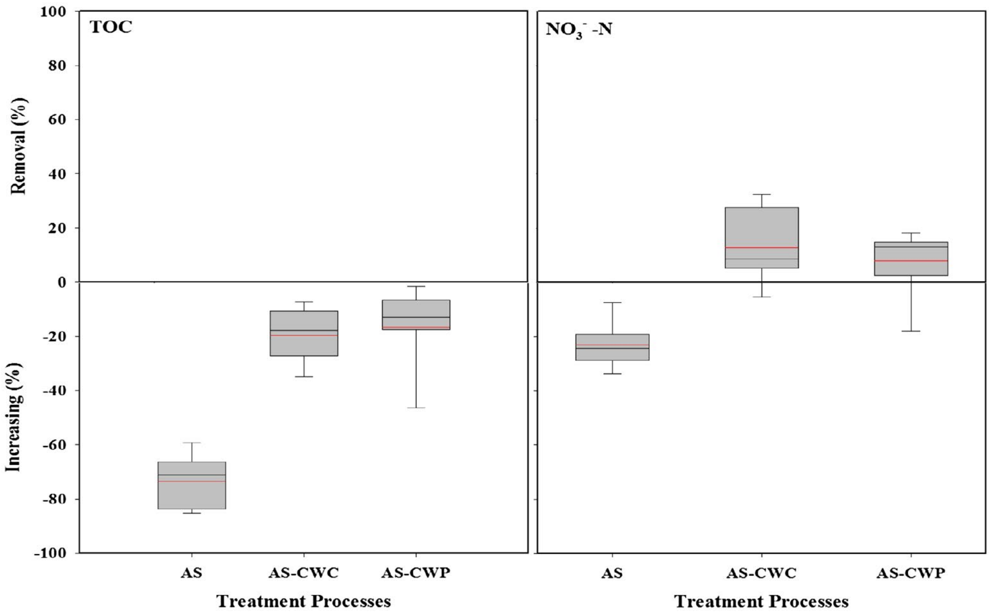

Fig. 5. Percentage efficiency of performance AS, AS-CWC and AS-CWP in treating NO_3^--N and TOC (the red line indicates a mean percentage removal; the black line indicate a median percentage removal). [Colour figure can be viewed at wileyonlinelibrary.com]

(Metcalf and Eddy, 2002). However, only biodegradable organic could be removed in the AS process, as indicated by BOD removal 61.50%. Another organic matter, such as refractory organic matter and recalcitrant organic matter might existed and accumulated in the system (Shon *et al*., 2012).

In addition, source of organic matter from metabolite products of microorganism will contribute to the quantity and quality of organic matter in the AS system (Ni *et al*., 2010; Xie *et al*., 2016). As the results shows a significant increasing of TOC concentration (73.49%) in the AS system (Fig. 5). Removal of NH_4^+-N (55.93%) in activated sludge indicates nitrification process, a biological oxidation of NH_4^+-N to NO_2^--N followed by oxidation of NO_2^- to NO_3^--N by nitrifying bacteria in aerobic zones (Wu *et al*., 2015; Su *et al*., 2018). Denitrification process, microbial process of reducing nitrate and nitrite to gaseous forms of nitrogen, might not be existed in the AS system due to aerobic state, thus, it caused an increasing NO_3^--N (23.01%) in the effluent of activated sludge, as shown in Fig. 5. The AS system is distinguished by clarifier tank, instead of aeration tank, to reduce TSS concentration in the effluent of AS (44.12%), as shown in Fig. 4. Clarifier tank is used to separate the suspended solid, which is a heavier biomass, and recycle amount of suspended solid into aeration tank (Metcalf and Eddy, 2002).

Second, the results shows that *C. lily* in AS-CWC system has a higher removal of organic BOD, TSS, nutrients PO_4^{3-} and slightly higher removal of nutrient NH_4^+-N and NO_3^--N than *C. papyrus* in AS-CWP, as shown in Fig. 5. Comparison between AS-CWC and AS-CWP is associated to the performance of *C. lily* and *C. papyrus*, which is depend on the morphology, structure and eco-physiology of its roots. Both emergent plants *C. lily* and *C. papyrus* are identified as fibrous-root plants (Lai *et al*., 2011). The fibrous-root plants had many fine and long lateral roots, a thin epidermis, higher root porosity, large cavities of aerenchyma, larger root biomass, longer root system and shorter root longevity, which were positively correlated with releasing oxygen through rhizosphere or it is known as radial oxygen loss (ROL) (Lai *et al*., 2012; Wang *et al*., 2018). These root properties were considered to enhance more oxygen transferring to the rhizosphere, be favourable in absorption of phosphorus, a greater attachment area for nitrifying bacteria and growth of organic-phosphorus, decomposing microorganism, and hence, support N and P removal. Nevertheless, it seems that *C. lily* has better anatomical and morphological traits that can promote higher efficiency removal of organic and nutrients. *Canna lily* has higher root longevity and below-ground biomass (i.e. various roots diameter) than *C. papyrus* (Lai *et al*., 2011). In addition, Abou-Elela and Hellal (2012) had proved that *Canna* could uptake more nitrogen 68.1 g/m^2 and phosphorus 32.55 g/m^2 than *Cyprus* due to *Canna* roots were distributed more widely in the constructed wetland bed, while Haritash *et al*. (2017) conjectured that *Canna*-based constructed wetland can be an effective tool for phosphate removal from wastewater under tropical conditions through plant uptake with average removal 167 mg/m^2 day for total phosphate.

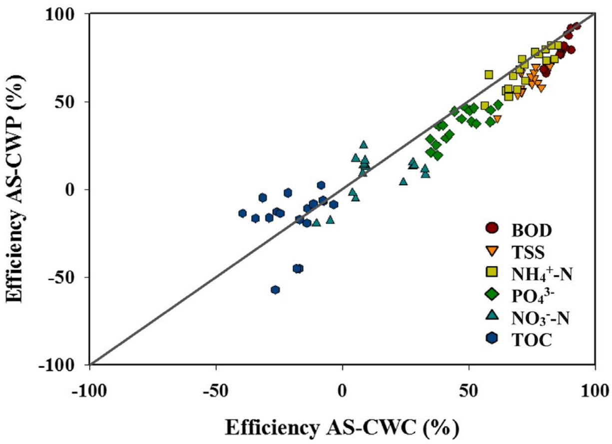

Fig. 6. Comparison of AS-CWC and AS-CWP performance in removing all organics, nutrients and TSS. [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 6 shows a comparison of efficiency performance of AS-CWC and AS-CWP for all parameters, including BOD, TOC, TSS, NH_4^+-N, NO_3^--N and PO_4^{3-}. The solid line drawn at a 1:1 slope represents an equal percentage removal of the all parameters. The figure shows that more parameters was removed by the AS-CWC than AS-CWP. This can be understood in combination with Figs. 4 and 5, which indicates that AS-CWC preferably removed most of all parameters over AS-CWP. It is thus conjectured that AS-CWC is suggested for further application emergent plants for constructed wetland. This study indicated that constructed wetland as post-treatment can undoubtedly improve the efficiency of domestic wastewater treatment, while the significant reduction of BOD, NH_4^+-N, PO_4^{3-} and TSS in the activated sludge process can reduce the risk of high organic loading and constructed wetland clogging.

Conclusion

(1) The performance among AS process, combination *C. lily* constructed wetland with AS (AS-CWC), and combination *C. papyrus* constructed wetland with AS (AS-CWP) for treating domestic wastewater has been compared according to its efficiency removal of organics, nutrients and TSS.

(2) The AS process gives a significant contribution in removing BOD, NH_4^+, PO_4^{3-} and TSS due to microbial activities for degrading organic carbon, for taking nutrient.

(3) However, TOC and NO_3^--N increased in the AS system due to metabolite by-product and lack of denitrification, respectively.

(4) AS-CWC and AS-CWP could enhance effluent of domestic wastewater quality, as indicated through removal of all organics, nutrients and TSS.

(5) AS-CWC demonstrates a higher performance than AS-CWP due to characteristic of morphology, structure and eco-physiology of its roots.

(6) This research reveal an insight that combining constructed wetlands with other additional technologies should consider the formation of by-products, which is generated from additional technologies, and post-treatment of constructed wetlands should be applied in order to meet effluent wastewater quality standard.

Acknowledgements

This work was financially supported by Department of Science and Technology (DST) and Federation Indian Chambers of Commerce and Industry (FICCI), India through ASEAN-India Research Training Fellowship Programme (AI-RTF) with file No: RTF/2018/000021

To submit a comment on this article please go to http://mc.manuscriptcentral.com/wej. For further information please see the Author Guidelines at wileyonlinelibrary.com

References

Abdel-Shafy, H.I. and Al-Sulaiman, A.M. (2014) Effeciency of degrasing/settling tank followed by constructed wetlannd for greywater treatment. *Egypt Journal Chemistry*, **57**(5–6), 435–446.

Abdel-Shafy, H.I. and El-Khateeb, M.A. (2012) Integration of septic tank and constructed wetland for the treatment of wastewater in Egypt. *Desalination and Water Treatment*, **51**, 3539–3546.

Abdel-Shafy, H.I., Hegemann, W. and Teiner, A. (1994) Accumulation of metals by vascular plants. *Environmental Management and Health*, **5**(2), 21–24.

Abou-Elela, A.I. and Hellal, M.S. (2012) Municipal wastewater treatment using vertical flow constructed wetlands planted with Canna, Phragmites and Cyprus. *Ecological Engineering*, **47**, 209–213.

Abou-Elela, S.I., Mohamed, A.E., Magdy, T.K. and Mohamed, S.H. (2017) Factors affecting the performance of horizontal flow constructed treatment wetland vegetated with *Cyperus papyrus* for municipal wastewater treatment. *International Journal of Phytoremediation*, **19**(11), 1023–1028.

Akizuki, S., Nagao, N. and Toda, T. (2018) A multifunctional single-stage process for the effective methane recovery and denitrification of intermittently discharged wastes. *International Biodeterioration and Biodegradation*, **127**, 201–208.

Anglada, A., Ortiz, D., Urtiaga, A.M. and Ortiz, I. (2010) Electrochemical oxidation of landfill leachates at pilot scale: evaluation of energy needs. *Water Science and Technology*, **61**(9), 2211–2217.

Ansari, A. and Golabi, M.H. (2019) Prediction of spatial land use changes based on LCM in a GIS environment for Desert Wetlands – a Case study: Meighan Wetland, Iran. *International Soil and Water Conservation Research*, **7**(1), 64–70.

APHA. (2012) *Standard Methods for the Examination of Water and Wastewater*. Washington, DC: American Public Health Association.

Avila, F.G., Chavez, J.P., Chimbo, F.Z., Moscoso, S.D., del Pino, L.F. and Anazco, A.A. (2019) Performance of *Phragmites australis* and *Cyperus papyrus* in the treatment of municipal wastewater by vertical flow subsurface constructed wetlands. *International Soil and Water Conservation Research*, **7**(3), 286–296.

Boog, J., Nivala, J., Aubron, T., Wallace, S., van Afferden, M. and Müller, R.A. (2014) Hydraulic characterization and optimization of TN removal in an aerated vertical subsurface flow treatment wetland. *Bioresource Technology*, **162**, 166–174.

Chazarenc, F., Gagnon, V. and Korkusuz, E.A. (2015) Treatment of pollution in constructed wetlands: from the fundamental mechanisms to the full-scale applications. *Environmental Science and Pollution Research*, **22**(17), 12775–12778.

Chen, S.C., Jan, M.Y., Lin, K.L., Chao, S.L. and Liao, C.S. (2017) Sustainability of constructed wetland under the impact of aquatic organisms overloading. *Sustainability*, **9**, 863–875.

Clairmont, L.K. and Slawson, R.M. (2019) Contrasting water quality treatments result in structural and functional changes to wetland plant-associated microbial communities in lab-scale mesocosms. *Microbial Ecology*, **79**, 1–14.

Collins, B., McArthur, J.V. and Sharit, R.R. (2004) Plant effects on microbial assemblages and remediation of acidic coal pile runoff in mesocosm treatment wetlands. *Ecological Engineering*, **23**(2), 107–115.

Dan, A., Fujii, D., Soda, S., Machimura, T. and Ike, M. (2017) Removal of phenol, bisphenol A, and 4-tert-butylphenol from synthetic landfill leachate by vertical flow constructed wetlands. *Science of the Total Environment*, **578**, 566–576.

Ding, Z., Bourven, I., van Hullebusch, E.D., Panico, A., Pirozzi, F. and Esposito, G., *et al*. (2017) Quantitative and qualitative characterization of extracellular polymeric substances from Anammox enrichment. *Journal of the Taiwan Institute Chemical Engineers*, **80**, 738–746.

Donde, O.O., Makindi, S.M., Tian, C., Tian, Y., Hong, P., Cai, Q., *et al*. (2020) A novel integrative performance evaluation of constructed wetland n removal of viable bacterial cells and related pathogenic, virulent and multidrug resistant genes from wastewater systems. *Journal of Water Process Engineering*, **33**, 101060.

Du, X.J., Wang, J.L., Jegatheesan, V. and Shi, G.H. (2018) Dissolved oxygen control in activated sludge process using a neural network-based adaptive PID algorithm. *Applied Science*, **8**, 261–282.

Edzwald, J.K. and Tobiason, J.E. (2011) Chemical principles, source water composition, and watershed protection. In: Edzwald, J.K. (Ed.) *Water quality and treatment: A Handbook on Drinking Water*. New York, NY: AWWA McGraw-Hill, pp. 1–76.

Ejiri, M. and Shiono, K. (2019) Prevention of radial oxygen loss is associated with exodermal suberin along adventitious roots of annual wild species of Echinochloa. *Frontiers in Plant Science*, **10**, 254–267.

Haddis, A., der Bruggen, B.V. and Smets, I. (2019) Constructed wetlands as nature based solutions in removing organic pollutants from wastewater under irregular flow conditions in a tropical climate. *Ecohydrology & Hydrobiology*, **20**(1), 38–47. https://doi.org/10.1016/j.ecohyd.2019.03.001

Haritash, A.K., Dutta, S. and Sharma, A. (2017) Phosphate uptake and translocation in a tropical *Canna*-based constructed wetland. *Ecological Processes*, **6**(12), 1–7.

Hidayah, E.N., Pachwarya, R.B., Cahyonugroho, O.H. and Ramanathan, A.L. (2020) Characterization of molecular weight-based fluorescent organic matter and its removal in combination of constructed wetland with activated sludge process. *Water, Air, & Soil Pollution*, **231**(41), https://doi.org/10.1007/s11270-020-4405-5.

Hong, P., Gong, S., Wang, C.B., Shu, Y., Wu, X., Tian, C., *et al*. (2020) Effects of organic consumption on denitrifier community composition and diversity along dissolved vertical profiles in lake sediment surface. *Journal of Oceanology and Limnology*, **38**, 733–744.

Kasak, K., Kill, K., Parn, J. and Mander, U. (2018) Efficiency of newly established in-stream constructed wetland treating diffuse agricultural pollution. *Ecological Engineering*, **119**, 1–7.

Lai, W.L., Wang, S.Q., Peng, C.L. and Chen, Z.H. (2011) Root features related to plant growth and nutrient removal of 35 wetland plants. *Water Research*, **45**, 3941–3950.

Lai, W.L., Zhang, Y. and Chen, Z.H. (2012) Radial oxygen loss, photosynthesis, and nutrient removal of 35 wetland plants. *Ecological Engineering*, **39**, 24–30.

Liu, H.Q., Hu, Z., Zhang, J., Ngo, H.H., Guo, W.S., Liang, S. *et al*. (2016) Optimizations on supply and distribution of dissolved oxygen in constructed wetlands: a review. *Bioresource Technology*, **214**, 797–805.

Liu, R., Zhao, Y., Doherty, L., Hu, Y. and Hao, X. (2015) A review of incorporation of constructed wetland with other treatment processes. *Chemical Engineering Journal*, **279**, 220–230.

Meng, Z., Chandrasena, G., Henry, R., Deletic, A., Kolotelo, P. and McCrthy, D. (2018) Stormwater constructed wetlands: A source or a sink of Campylobacter spp. *Water Research*, **131**, 218–227.

Metcalf and Eddy. (2002) *Wastewater engineering: treatment and reuse*. Dubuque, IA: McGraw-Hill Education.

Mohan, S.V., Saravanan, R., Raghavulu, S.V., Mohanakrishna, G. and Sarma, P.N. (2008) Bioelectricity production from wastewater treatment in dual chambered microbial fuel cell (MFC) using selectively enriched mixed microflora: effect of catholyte. *Bioresource Technology*, **99**(3), 596–603.

Mutamim, N.S.A., Noor, Z.Z., Hassan, M.A.A. and Olsson, G. (2012) Application of membrane bioreactor technology in treating high strength industrial wastewater: a performance review. *Desalination*, **305**, 1–11.

Nath, K.J. and Sengupta, A.K. (2016) An alternative approach for municipal wastewater management: technology options for small and medium towns. *Water Practice and Technology*, **11**(1), 157–165.

Ni, B.J., Zeng, R.J., Fang, F., Xie, W.M., Sheng, G.P. and Yu, H.Q. (2010) Fractionating soluble microbial products in the activated sludge process. *Water Research*, **44**, 2292–2302.

Noh, T., Jeon, J. and Kim, L.H. (2016) Simulation of various baffle types in a constructed wetland sedimentation tank using CFD. *Journal of Wetlands Research*, **18**(3), 324–329.

Paredes, D., Kuschk, P., Mbwette, T.S., Stange, F., Müller, R.A. and Koandser, H. (2007) New aspects of microbial nitrogen transformations in the context of wastewater treatment – a review. *Engineering in Life Science*, **7**(1), 13–25.

Priya, E.S. and Selvan, P.S. (2017) Water hyacinth (*Eichhornia crassipes*)-an efficient and economic adsorbent for textile effluent treatment – a review. *Arabian Journal of Chemistry*, **10**, S3548–S3558.

Saeed, T. and Sun, G.Z. (2012) A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: dependency on environmental parameters, operating conditions and supporting media. *Journal of Environmental Management*, **112**, 429–448.

Sandoval, L., Zamora-Castro, S.A., Vidal-Álvarez, M. and Marín-Muñiz, J.L. (2019) Role of wetland plants and use of ornamental flowering plants in constructed wetlands for wastewater treatment: a review. *Applied Science*, **9**, 685–701.

Shon, H.K., Vigneswaran, S. and Snyder, S.A. (2012) Effluent organic matter (EfOM) in wastewater: constituents, effect, and treatment. *Critical Review Environmental Science Technology*, **36**(4), 327–374.

Su, Y., Wang, W., Wu, D., Huang, W., Wang, M. and Zhu, G. (2018) Stimulating ammonica oxidizing bacteria activity drives the ammonium oxidation rate in a constructed wetland. *Science of the Total Environment*, **624**, 87–95.

Vymazal, J. (2018) Constructed wetlands for wastewater treatment. In: Fath, B. (Ed.) *Encyclopedy of ecology*. Oxford: Elsevier.

Wang, Q., Hu, Y., Xie, H. and Yang, Z. (2018) Constructed wetlands: a review on the role of radial oxygen loss in the rhizosphere by macrophytes. *Water*, **10**(6), 678–689.

Wei, D.B., Singh, R.P., Li, Y.K. and Fu, D.F. (2020) Nitrogen removal efficiency of surface flow contructed wetland for treating slightly polluted river water. *Environmental Science and Pollution Research*, **27**, 24902–24913.

Wu, H.M., Zhang, J., Ngo, H.H., Guo, W.S., Hu, Z., Liang, S. *et al*. (2015) A review on the sustainability of constructed wetlands for wastewater treatment: design and operation. *Bioresource Technology*, **175**, 594–601.

Xie, W.M., Ni, B.J., Seviour, T., Shen, G.P. and Yu, H.Q. (2012) Characterization of autotrophic and heterotrophic soluble microbial product (SMP) fractions from activated sludge. *Water Research*, **46**, 6210–6217.

Xie, W.M., Ni, B.J., Sheng, G.P., Seviour, T. and Yu, H.Q. (2016) Quantification and kinetic characterization of soluble microbial products from municipal wastewater treatment plants. *Water Research*, **88**, 703–710.

Yadav, A., Chazarenc, F. and Mutnuri, S. (2018) Development of the «French system» vertical flow constructed wetland to treat raw domestic wastewater in India. *Ecological Engineering*, **113**, 88–93.

Ye, F. and Li, Y. (2009) Enhancement of nitrogen removal in towery hybrid constructed wetland to treat domestic wastewater for small rural communities. *Ecological Engineering*, **35**, 1043–1050.

Zheng, Y.C., Wang, X.C., Dzakpasu, M., Zhao, Y.Q., Ngo, H.H. and Guo, W.S., *et al*. (2016) Effects of interspecific competition on the growth of macrophytes and nutrient removal in constructed wetlands: a comparative assessment of free water surface and horizontal subsurface flow systems. *Bioresource Technology*, **207**, 134–141.