Efficiency of Constructed Wetland Microcosms (CWMs) for the Treatment of Domestic Wastewater using Aquatic Macrophytes with Special Reference to Nitrate and Phosphate Removal

SUMMARY

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The presence of excess nutrients in wastewater causes eutrophication within the receiving waterbody by excess algal growth resulting into algal blooms. However, HMs within the environment are priority contaminants amongst the huge number of harmful elements due to their persistence and bioaccumulation ability. HMs, with high densities, are originating naturally from construction materials, agriculture activities, industrial processing and transportation. However, in DW they originate from household activities, small industrial operations and urban runoff. The majority of the HMs pose toxicity even at lesser fractions and their concentrations in tissues over some time could be harmful to ecosystems and human health. The excess concentration of these HMs in the environment may cause toxicity to living beings that can disrupt metabolic functioning. The concentration of these HMs within DW varies among cities or even for the same city depending upon residential and commercial locations and runoff. CWMs are well recognized eco-friendly, sustainable and cost-effective solution for the treatment of DW especially in decentralized settlements where traditional treatment methods are not practicable. Several environmental and working parameters are vital for the smooth functioning of CWMs. It is also observed that macrophytes and substrate materials also play a critical role in the elimination of wastewater contaminants. Consequently, selection of suitable macrophytes and substrate material is necessary**.** However, microbial communities present in the rhizosphere zone attached as biofilms help in the breakdown of several pollutants.

Removal efficiency of several wastewater parameters including HMs

HMs are among the most distressing contaminants present in the environment, mainly due to their toxicity and bioaccumulation properties. They act as a precursor to many bio-chemical reactions in the environment. In this study, the removal efficiency of several wastewater parameters including HMs were studied at different retention times. For that, eight CWM units in a single as well as in combinations were designed with three macrophytes and different substrate materials. The exclusion efficacy of all selected wastewater parameters such as BOD, TP, SRP, NO_2^--N NO_3^--N, and NH_4^+-N and various HMs with their removal rates were studied at three HRTs. The HMs uptake capacity of selected macrophytes was also evaluated in terms of BCF, TF, ATCF and RCF. CWM unit designed using free-floating *Pistia stratiotes* and emergent macrophyte *Phragmites karka* expressed higher removal ability with

advanced reaction rate for most of the wastewater contaminants including HMs. However, the highest reaction rate was recorded for Cr, Cd and Mn respectively throughout the experiment. The elimination percentages of all selected HMs in different CWM units extended from 43.80 to 63.67%, 75.92 to 92.07% and 82.17 to 98.58 % for 3, 7 and 14 d HRTs respectively. Maximum TF and BCF were expressed by *Pistia stratiotes* and *Phragmites karka* for Zn (0.69 and 1.69 respectively). However, the maximum RCF and ATCF were observed in *Pistia stratiotes* for Cu and Zn (0.35 and 0.10 respectively). The correlation studies between removal efficiencies of HMs and several other parameters for this most efficient CWM unit also exhibited significant variation depending upon retention time. All selected HMs expressed a significant positive correlation with As.

Interspecific competition among macrophytes and their impacts on the removal of contaminants

Interspecific competition among macrophytes to acquire nutrients, space and light is one of the most important aspects to determine their growth responses. Nevertheless, due to high inconsistency in competition among several macrophytes, the growth of various macrophytes planted in mixed culture during field scale application is still not clear. Hence, it is also desirable to assess the interspecific competition and relative growth rate among macrophytes and their impact on the performance of CWMs. Several growth-related parameters of macrophytes such as the number of macrophytes, the total number of macrophytes, total dry biomass production, AGB, BGB and root length were also studied to distinguish the dominant nature of the macrophytes. *Typha latifolia* was recognized as a superior competitor in competition with both *Phragmites karka* and *Pistia stratiotes* due to their aggressive competitor nature that constrains the growth and development of adjoining macrophytes in mixed culture. *Phragmites karka* was identified as the superior competitor when planted with *Pistia stratiotes* and inferior competitor with *Typha latifolia*. However, *Pistia stratiotes* observed as a weak competitor against both macrophytes. The negative CV of *Pistia stratiotes* with *Phragmites karka* and *Typha latifolia* explained that the overall biomass of *Pistia stratiotes* in monoculture was higher as compared to mixed culture with these macrophytes. Similarly, *Phragmites karka* displayed negative CV with *Typha latifolia*. It is also due to the higher biomass of *Phragmites karka* in monoculture as compared to mixed culture. The relative growth rate of *Typha latifolia*

was approximately two times greater than that of *Phragmites karka* among all experimental CWM units. The CWM unit having *Pistia stratiotes* and *Phragmites karka* in mixed culture exhibited more efficient removal of almost all selected water quality parameters most of the time throughout the experimental period.

Activity of different extracellular enzymes within soil substrate and their relation with contaminants removal

Activity of enzymes within soil substrate is suggested as a significant formative factor to enhance water quality in CWMs. In this study, the activity of different extracellular enzymes was assessed in two soil substrate layers for different CWM units. The vertical and temporal variations among the activity of different enzymes and their relationship with contaminants removal efficacy within several CWM units were also studied. The outcome of this work exhibited that the enzymes activity and contaminants elimination efficacy differ greatly depending upon retention time, substrate depth, type of contaminants and CWM units. The vertical variation among the enzyme's activity exhibited that the top layer (0-10 cm) of CWM units have significant activity of all selected enzymes and varied significantly from the lower layer. However, temporal variation exhibited significant variations over time with higher activity in the months of May, June, and October for most of the enzymes. CWM unit planted with *Phragmites karka* and *Pistia stratiotes* showed higher values of enzymes activity in the top as well in the deeper layer for most of the enzymes. The correlation results showed that phosphatase activity was significantly linked with the exclusion of TP and SRP in most of the CWM units. The activity of urease was significantly and positively correlated with NH_4^+-N removal in CWM units Pi+Ph+T and Pi+Ph. The activity of urease was also observed to have both negative and positive associations with the exclusion efficacy of NO_2^--N and NO_3^--N in various CWM units. However, the activity of the DHA enzyme expressed a negative association with the removal efficiency of BOD excluding CWM units Pi+Ph and Pi+Ph+T. Elimination of BOD and (MBC) exhibited a negative association with each other in the majority of the CWM units. However, a moderate positive and negative relationship was observed between BOD removal and FDA. CWM units revealed significant differences in enzyme activities depending upon treatment time and the presence of macrophytes.

Integration of CWMs with other available treatment technologies as a post treatment facility

The major wastewater treatment technologies utilized for the treatment of domestic wastewater throughout the world are UASB and FAB based STPs. About 80% of total worldwide installed UASB reactors for municipal wastewater treatment are present only in India. However, both processes alone cannot be seen as 'complete' ecological solutions as their effluents always do not fulfill the required discharge standards mainly for nutrients residual carbon, pathogens and heavy metals. In this study, the treatment performance of UASB reactors in single as well as in integration with CWM technology for the treatment of DW was studied. It is also observed that the removal efficacy of UASB reactors for several wastewater contaminants is enhanced significantly by integrating them with CWMs as a post-treatment facility. The concentration of BOD in the effluent of different CWM units after three days retention time successfully meets the discharge criteria of inland surface water. However, the maximum removal performance of several contaminants was expressed by the CWM unit Pi+Ph. The maximum removal of BOD via UASB reactor was recorded in Noida (79 ± 0.89%) having the treatment capacity of 34 MLD followed by the Kanpur (72 ± 1.41%). From the study, it is observed that the UASB or FAB-based reactors alone have not achieved water quality up to discharge standards. Nonetheless, the removal capability of the UASB reactor in integration with constructed wetlands in terms of BOD reached the highest (upto 98%) as compared to other available treatment technologies from DW. However, the removal of COD (90%), TSS (92%), TN (89%), NH_4^+-N (70%) and TP (88%) were also observed optimum.