

Influence of aquatic plants and flow rate on physico-chemical characteristics of sewage effluent treated through constructed wetland technology

ABSTRACT

Aims: To evaluate the influence of aquatic plants and flow rate on physico-chemical properties of sewage effluent with constructed wetland technology.

Study design: Randomized block design

Place and Duration of Study: Sewage Treatment Plant (STP), Near staff quarters of Tamil Nadu Agricultural University, Coimbatore - 03.June 2021 – Dec 2021

Methodology: Constructed wetland (CW) model was designed and three different aquatic plants viz., *Canna indica*, *Arundo donax*, and *Xanthosoma sagittifolium* were used for the study. Two different flow rates viz., 5ml/min and 10 ml/min were compared for assessing their influence in treating sewage effluent in the constructed wetlands.

Results: Among the aquatic plants, the BOD, COD, TDS and TSS were declined to 25, 13.8, 42.2 and 71.4 percent in *Canna indica* and to 21, 11.9, 37.2 and 68.9 percent in *Xanthosoma sagittifolium* and 29, 8.4, 32.4 and 65.9 percent in *Typha angustifolia* utilized treatments at flow rates 5 ml/min. Whereas BOD, COD, TDS and TSS were declined to 22.2, 24.5, 34.5 and 63.2 percent in *Canna indica* and to 18.2, 20.3, 32.5 and 60.4 in *Xanthosoma sagittifolium* and 15.5, 19.4, 28.6 and 58.1 in *Typha angustifolia* utilized treatments at flow rates 10 ml/min.

Conclusion: Based on the study, it was evident that constructed wetland (CW) with *Canna indica*, *Xanthosoma sagittifolium* and *Typha angustifolia* seems to perform better under flow rate of 5 ml/min.

INTRODUCTION

Sewage is wastewater that is released from homes as well as commercial, institutional, and public institutions in the area. Wastewater that is not properly treated can have serious consequences for the environment and human health. Fish and wildlife populations may be affected, oxygen levels may be depleted, beach closures and other restrictions on recreational water use, fish and shellfish harvesting restrictions, and drinking water contamination may occur. Hence, treatment of sewage effluent by using an eco-friendly, viable technology is needed for effective recycling and therefore, constructed wetlands (CWs) will be the best option. CWs are complex, integrated systems that include water, plants, animals, microorganisms, and the environment. Wetlands provide a variety of purposes, including water purification, water storage, carbon and other micro and macronutrient digestion and recycling, shoreline

stabilisation, and plant and animal support. CW is a shallow manmade basin filled with substrate (typically soil or gravel) and flora that can withstand saturated conditions. Water is then directed into the system from one end and flows over the surface (surface flow) or through the substrate (subsurface flow) before being released from the other end at a lower position through a weir or other device that regulates the water depth in the wetland [1]. Surface flow wetlands, subsurface flow wetlands, and hybrid systems that include surface and subsurface flow wetlands have all been classified under constructed wetlands [2][3]. Constructed wetland systems can also be used in conjunction with traditional treatment methods to improve treatment efficiency [4]. The selection of constructed wetland types depends on the prevailing environmental conditions and also the type of wastewater to be treated such as domestic wastewater, agricultural wastewater, coal mine drainage, and stormwater [2]. The present study aims to assess the efficiency of various aquatic plants with different flow rates under CW in treating the sewage effluent.

MATERIALS AND METHODS

Sewage effluent for the study was collected at the Sewage Treatment Plant (STP) located near staff quarters of Tamil Nadu Agricultural University, Coimbatore. Three different aquatic plants namely Indian shot (*Canna indica*), Giant reed (*Arundo donax*), and Arrow leaf elephant ear (*Xanthosoma sagittifolium*), were collected from Muthanangulam, Nagarajapuram, Telungupalayam in and around lakes of Coimbatore district. The collected plants are authenticated and certified by Botanical Survey of India (BSI), Coimbatore and then plants utilized for the research studies.

A lab scale model constructed wetland was designed with horizontal flow system. All the six reactors were in uniform size of 45x21.5x30 cm (LxBxH). The media used in the experiment was gravel, coarse sand and garden soil. The size of gravel 20 mm and the porosity of sand 50% and soil was 32% for each reactor. Inlet was arranged manually with saline tubes to optimize the average flow rate passing through constructed wetland system. Outlet for the treated effluent collection was arranged at bottom of the reactor with silica tubes. Total of six model constructed wetlands was designed with two different flow rates for each of three selected aquatic plants was planted. Aquatic plants like *Canna indica*, *Xanthosoma sagittifolium* and *Typha angustifolia* of uniform sizes was selected and washed thoroughly. The initial weight of the plants was recorded and later, (3 nos.) of plants of each species were placed in the model constructed wetland. The collected sewage effluent was placed at an elevated position and the effluent was passed with average flow of 5 ml/min and 10 ml/min in each of two constructed wetlands. The sewage effluent was passed into the model constructed wetland system for a period of (1, 2, 3, 4, 5, 6, and 7) retention time with the average flow being maintained in each constructed wetland. The treated effluent was collected after the retention time of 1st, 2nd, 3rd, 4th, 5th, 6th and 7th day. The collected treated effluent was subjected to various water quality analysis following the standard analytical procedures.

RESULT AND DISCUSSION

The initial sewage effluent used for model constructed wetland was alkaline with a pH of 7.77 and an Electrical conductivity (EC) of 3.03 dS m^{-1} . The redox potential (Eh) of the effluent was -691 mV. The total dissolved solids in the effluent were 2328 mg L^{-1} and the total suspended solid was 400 mg L^{-1} . The Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of the initial sewage effluent were 580 and 2180 mg L^{-1} respectively. The total nitrogen and total phosphorus in the effluent were 0.25 and 0.21 % respectively. Heavy metals observed were Nickel (4.81 mg L^{-1}), Lead (8.01 mg L^{-1}), chromium and Cadmium was below detectable level in the sewage effluent. The total coliforms were 1600 MPN/100 ml.

The effect of the plants on pH of the sewage effluent after treatment in model constructed wetland was showed in Table1. pH shows a decreasing trend on increasing the retention time. *Canna indica* recorded a mean minimum pH of 6.79 and 7.05 at flow rates 5 ml & 10 ml/min respectively followed by *Xanthosoma sagittifolium* with respect to the retention time, 1st day recorded as mean pH of 7.46 and 7.52 at flow rates of 5 ml and 10 ml/min which declined to 6.29 & 6.90 on 7th day for flow rate 5 ml and 10 ml respectively. The present investigation to access the influence of plants, retention time and two different flow rates in the pH of the sewage effluent, through the model constructed wetland, reveal that the pH got decreased from D₁ and D₇. The flow rate 5ml/min performed well compared to flow rate 10 ml/min. Among the aquatic plants, *Canna indica* was significantly superior to other plants. The decrease in the pH in the lower HLR may be due to more contact time of the effluent with the plant and the medium used in the study. [5] also reported that HRT plays a major role in the reduction of pH based on the plants and substrate utilized for the study.

Table 1. Effect of plants and flow rate on pH of sewage effluent in model constructed wetland

Plants	Flow rate 5 ml/min							Mean
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	
<i>Canna indica</i>	7.24	7.12	7.02	6.95	6.66	6.40	6.12	6.79
<i>Xanthosoma sagittifolium</i>	7.49	7.21	7.14	7.08	6.82	6.59	6.22	6.94
<i>Typha angustifolia</i>	7.65	7.47	7.29	7.16	6.92	6.77	6.54	7.11
MEAN	7.46	7.27	7.15	7.06	6.80	6.59	6.29	
	P		D		P*D			
SE (d)	0.01		0.01		0.02			
CD (0.05)	0.02		0.03		0.05			
Plants	Flow rate 10 ml/min							Mean
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	

<i>Canna indica</i>	7.36	7.32	7.13	7.01	6.92	6.87	6.79	7.06
<i>Xanthosoma sagittifolium</i>	7.62	7.53	7.36	7.17	7.14	7.07	6.93	7.26
<i>Typha angustifolia</i>	7.59	7.49	7.37	7.22	7.18	7.12	6.98	7.28
MEAN	7.52	7.45	7.29	7.13	7.08	7.02	6.90	
	P		D			P*D		
SE (d)	0.01		0.01			0.02		
CD (0.05)	0.02		0.03			0.05		

D₁- 1st Day of retention time; D₂- 2nd Day of retention time; D₃-3rd Day of retention time; D₄- 4th Day of retention time; D₅- 5th Day of retention time; D₆-6th Day of retention time; D₇- 7th Day of retention time

The Electrical conductivity of the sewage effluent collected from two different flow rates *i.e.*, 5 ml/min and 10 ml/min showed a declining trend from D₁ (1st day of sampling) to D₇ (7th day of sampling). The value of the EC of the sewage effluent after treatment in constructed wetland is showed in Table 2. Among the aquatic plants, *Canna indica* recorded a minimum EC of 2.02 and 2.06 dS m⁻¹ for flow rate of 5 ml & 10 ml/min respectively which was significantly better than all the plants. The EC of the sewage effluent after treating through the model CW using the three aquatic plants *viz.*, *Canna indica*, *Typha angustifolia*, *Xanthosoma sagittifolium* seems to follow the same trend as that of pH of the effluent. Sorption is a process which involves the transfer of ions or charges from aqueous phase to solid-phase. Here, in this study, soluble salt responsible for EC may get adsorbed to the medium and roots of the plant growth in the model CW. *Canna indica* is a plant with good medicinal property along with the capacity to treat industrial wastewaters was reported by [6].

Table 2. Effect of plants and flow rate on EC (dS m⁻¹) of sewage effluent in model constructed wetland

Plants	Flow rate 5 ml/min							
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	Mean
<i>Canna indica</i>	2.47	2.32	2.25	2.07	1.92	1.66	1.47	2.02
<i>Xanthosoma sagittifolium</i>	2.49	2.36	2.3	2.11	1.99	1.74	1.57	2.08
<i>Typha angustifolia</i>	2.63	2.42	2.29	2.2	2.02	1.88	1.6	2.15
Mean	2.53	2.37	2.28	2.13	1.98	1.76	1.55	

	P		D		P*D			
SE (d)	1.15		1.76		3.04			
CD (0.05)	2.39		3.66		6.34			
Plants	Flow rate 10 ml/min							
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	Mean
<i>Canna indica</i>	2.49	2.36	2.27	2.1	1.96	1.7	1.54	2.06
<i>Xanthosoma sagittifolium</i>	2.53	2.39	2.34	2.15	2.01	1.77	1.59	2.11
<i>Typha angustifolia</i>	2.65	2.45	2.33	2.24	2.05	1.92	1.63	2.18
Mean	2.56	2.4	2.31	2.16	2.01	1.8	1.59	
	P		D		P*D			
SE (d)	0		0		0.013			
CD (0.05)	0.01		0.01		0.028			

Redox potential (Eh) of the sewage effluent was observed throughout the experimental period of 7 days. Eh values decreased from D₁ to D₇ at both flow rates of 5 ml/min and 10 ml/min. The mean Eh values ranged from -663 to -682 @ flow rate of ml/min and -667 to -685 @ flow rate of 10 ml/min (Table 3). The initial redox potential of the effluent is -691mV. *Canna indica* outperformed with -686 mV (Day 1) which on increasing retention time improved to -640mV whereas *Typha angustifolia* recorded a redox potential of -672mV (Day 7) for the flow rate of 5ml/min. This fluctuation on increasing the retention time might be due to the release of oxygen to the rhizosphere by plant roots [7].

Table 3. Effect of plants and flow rate on Eh (mV) of sewage effluent in model constructed wetland

Plants	Flow rate 5 ml/min							Mean
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	
<i>Canna indica</i>	-686	-686	-670	-666	-656	-640	-640	-663
<i>Xanthosoma sagittifolium</i>	-691	-690	-684	-684	-676	-650	-648	-675
<i>Typha angustifolia</i>	-690	-690	-687	-682	-680	-674	-672	-682
MEAN	-689	-689	-680	-677	-671	-655	-653	
	P		D		P*D			
SE (d)	1.15		1.76		3.04			
CD (0.05)	2.39		3.66		6.34			
Plants	Flow rate 10 ml/min							
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	Mean
<i>Canna indica</i>	-690	-689	-672	-670	-660	-645	-644	-667
<i>Xanthosoma sagittifolium</i>	-691	-690	-687	-688	-679	-654	-653	-677

<i>Typha angustifolia</i>	-691	-690	-689	-687	-684	-677	-675	-685
MEAN	-691	-690	-683	-682	-674	-659	-657	
	P		D		P*D			
SE (d)	18.46		28.2		48.85			
CD (0.05)	38.4		58.66		101.6			

The effect of plants on TSS (total suspended solids) of the sewage effluent after treatment in model constructed wetland was analysed (Table4). *Canna indica* seems to have greater influence in significantly reducing the TSS from D₁ (174 & 196 mg L⁻¹ at flow rates of 5 ml and 10 ml/minute respectively) to D₇ (22 & 54 mg L⁻¹ at the flow rate of 5 ml and 10 ml/min respectively). *Xanthosoma sagittifolium* & *Typha angustifolia* followed the similar trend next to *Canna indica*. TSS of the effluent reduced from the retention time of 1 to 7 days at the flow rate of 5 ml/min and 10 ml/min. The percent reduction was 58%, 55% and 46% at the D₁ *Canna indica*, *Xanthosoma sagittifolium* and *Typha angustifolia* respectively @ 5 ml/min (HLR 0.00516 /day) whereas at D₇, the percent reduction was 95%, 88%, 80% by *Canna indica*, *Xanthosoma sagittifolium* and *Typha angustifolia*. There was clear evidence in the reduction of TSS at flow rate of 5 ml/min than 10 ml/min at the 7th day of retention time. This might be because of filtration, interception or flocculation of suspended particles in the medium i.e. sand, gravel and pebbles and aquatic plants used in the study. [8] also observed the positive effect of TSS removal of the effluent by aquatic plants *Typhalatifolia*. EWRC (2017) also stated *Colocasia esculenta* can be used for a constructed wetland. *Xanthosoma sagittifolium* belongs to the same family of *Colocasia esculenta* i.e., Araceae seems to have the same property in removing solids and other particles in a constructed wetland. [9] also reported that TSS production was above 90% in the constructed wetland.

Table 4. Effect of plants and flow rate on total suspended solids (mg L⁻¹) of sewage effluent in model constructed wetland

Plants	Flow rate 5 ml/min							
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	Mean
<i>Canna indica</i>	174	162	154	124	96	70	22	115
<i>Xanthosoma sagittifolium</i>	186	170	160	134	122	64	36	125
<i>Typha angustifolia</i>	200	188	164	146	124	86	48	137
MEAN	187	173	159	135	114	73	35	
	P		D		P*D			
SE (d)	0.23		0.35		0.61			
CD (0.05)	0.48		0.73		1.27			
Plants	Flow rate 10 ml/min							Mean
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	
<i>Canna indica</i>	196	210	182	154	130	104	54	147

<i>Xanthosoma sagittifolium</i>	224	204	190	170	156	92	72	158
<i>Typha angustifolia</i>	234	214	192	184	160	118	70	167
MEAN	218	209	188	169	149	105	65	
	P		D		P*D			
SE (d)	0.28		0.43		0.74			
CD (0.05)	0.58		0.89		1.55			

The effect of plants on total dissolved solids (TDS) of the sewage effluent with varied retention time and flow rates in model constructed wetland was presented in Table 5. The TDS of the effluent ranged from 666 to 2126 mg L⁻¹ for flow rates of 5 ml and 10 ml/min respectively. Among the aquatic plants, *Canna indica* recorded a mean minimum TDS value of 1346.4 & 1452 mg L⁻¹ at flow rates of 5 ml and 10 ml/min respectively. With respect to retention time similar trend was observed as that of pH. The percent reduction of TDS in the sewage effluent used in the model constructed wetland was shown in the figure 1. The HLR of 0.00516 cm/day (5 ml/min) seems to be superior compared to (0.01033 cm/ day- Flow rate 10 ml/min) at all the retention time of D₁ to D₇. The removal percentage was 75%, 60%, 58% and 60%, 50%, 40% by *Canna indica*, *Xanthosomasagittifolium*, *Typhaangustifolia* respectively at the flow rate of 5 ml per minute and 10 ml per minute at the retention time of D₇. [10]also observed that the two-stage hybrid ecological wastewater treatment systems can be used to improve the quality of wastewater thereby using them for irrigation purposes (Fig 1).

Table 5. Effect of plants and flow rate on total dissolved solids (mg L⁻¹) of sewage effluent in model constructed wetland

Plants	Flow rate 5 ml/min							Mean
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	
<i>Canna indica</i>	1984	1856	1520	1334	1142	923	666	1346
<i>Xanthosoma sagittifolium</i>	1986	1888	1668	1524	1284	1023	866	1463
<i>Typha angustifolia</i>	2126	1956	1772	1684	1364	1140	964	1572
MEAN	2032	1900	1653	1514	1263	1029	832	
	P		D		P*D			
SE (d)	2.6		3.97		6.87			
CD (0.05)	5.4		8.26		14.3			
Plants	Flow rate 10 ml/min							Mean
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	
<i>Canna indica</i>	2044	1950	1700	1512	1680	1002	776	1523

<i>Xanthosoma sagittifolium</i>	2050	2056	1820	1686	1372	1106	912	1572
<i>Typha angustifolia</i>	2218	2014	1874	1796	1494	1240	994	1661
MEAN	2104	2006.67	1798	1664.67	1515.33	1116	894	
	P		D		P*D			
SE (d)	2.79		4.26		7.38			
CD (0.05)	5.8		8.86		15.35			

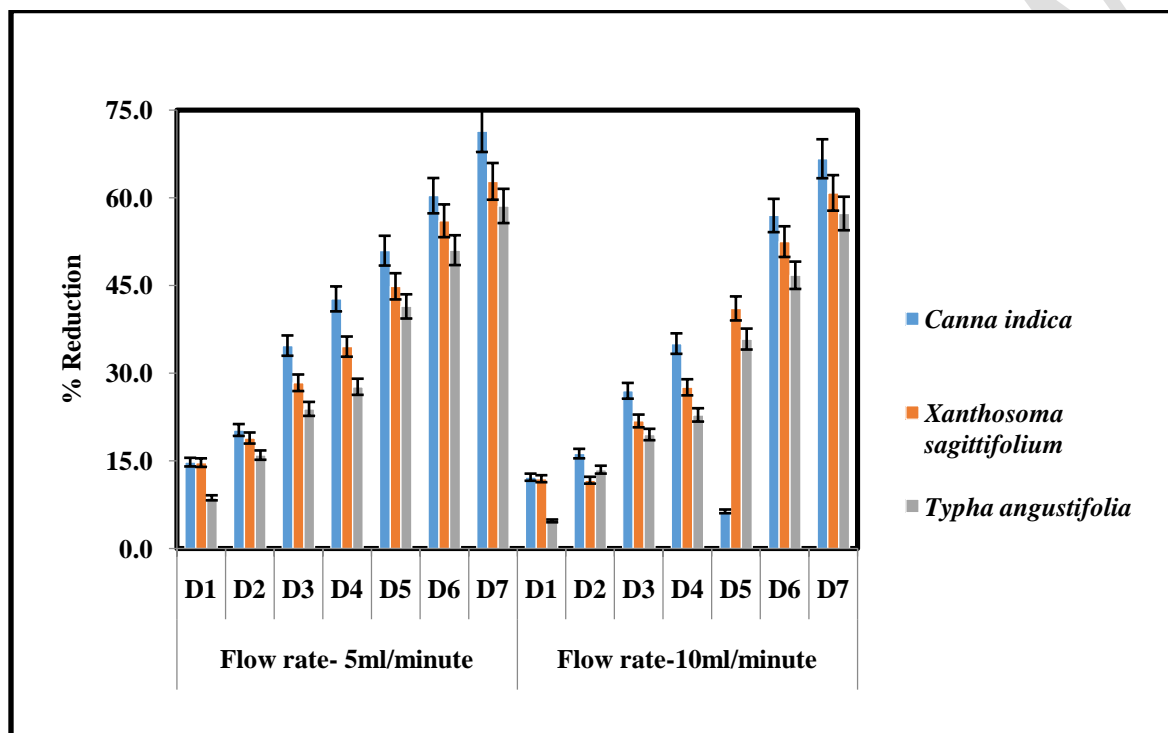


Fig 1.Effect of plants and flow rate on total dissolved solids (mg L^{-1}) of sewage effluent in model constructed wetland

An increase in biochemical oxygen demand (BOD) removal efficiency was observed in the model constructed wetland with the flow rate of 5ml/min using three aquatic plants. At the retention time of 7days, the percent reduction was found to be 45%, 40% and 36% @ flow rate of 5ml/min and 42%, 38% and 34% at the flow rate of 10ml/min by the plants viz., *Canna indica*, *Xanthosoma sagittifolium* and *Typha angustifolia* respectively (Fig 2).

The organic matter in the effluent may undergo hydrolysis and converts into a soluble form and enters the media and attach to biofilm and then further decomposed. Aerobic bacteria in the biofilm release oxygen through the roots of plants which in turn supports organic pollutant degradation [7]. The root system of the aquatic plants gives a larger surface area for microorganism which will facilitate the decomposition of organic matter. The decrease in BOD after treating with aquatic plants is corroborated

with the findings of [11]. The aquatic plants used in the study especially *Canna indica* possess thick leaves and large surface area for gas diffusion and in turn, helps in reduction of BOD. These findings are supported by [12]. *Xanthosomasagittifolium* is significantly on par with *Canna indica*. [13] also reported that utilization of *Colacasiaesculenta* has higher BOD and COD reduction during domestic wastewater treatment. Morphologically, *Xanthosomasagittifolium* is similar to *Colacasiaesculenta* and hence it may also have attributed to BOD removal in constructed wetland.

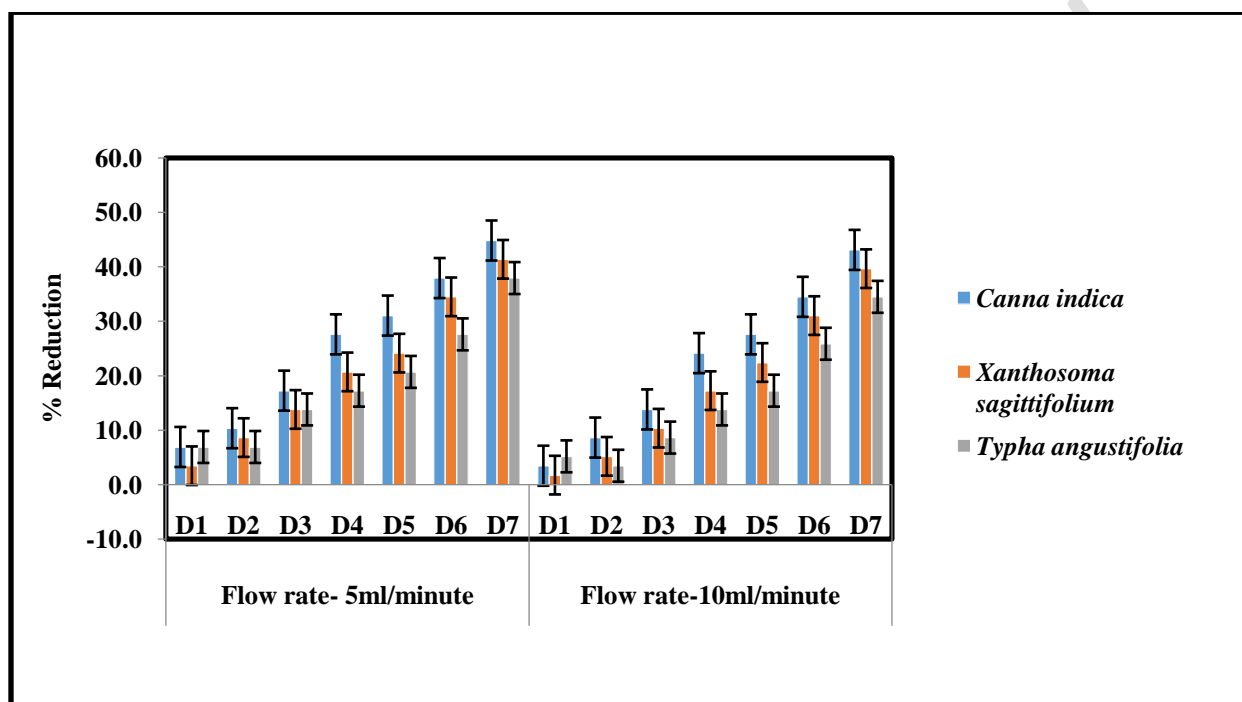


Fig 2. Effect of plants and flow rate on biological oxygen demand (BOD) of sewage effluent in model constructed wetland

The chemical oxygen demand (COD) of the treated sewage effluent ranged from 800 to 2560 mg L⁻¹ in treated effluent with respective of retention time (Table 6). The lower mean COD of 1666 mg L⁻¹ was reported in *Canna indica* followed by *Xanthosoma sagittifolium* (1783 mg L⁻¹). Similar declining trend in COD with incremental retention time. Mean COD value of 2476 mg L⁻¹ on 1st day to 1016 mg L⁻¹. The COD of the effluent gradually showed declining trend as the retention time increased from D₁ to D₇. COD can be decomposed by aerobic and anaerobic microbial processes and also by physical processes such as sedimentation and filtration. The percentage removal of COD at D₇ at the flow rate of 5ml/min and 10 ml/min was 44%, 37.6%, 36.7% & 41%, 35.7 %, 34.4% by *Canna indica*, *Xanthosoma sagittifolium* and *Typha angustifolia* respectively. The flow rate of 10ml/min was found to have lesser performance than 5ml/min. All the three plants used comes under the category of emergent macrophytes which would have an extensive lacunar system that includes 60% of plant tissue helping in substantial oxygen release to the rhizosphere thereby reducing the oxygen demand for decomposition. These findings corroborated with the results of [12] who

stated that *Canna* plants has higher COD removal efficiency at lower HRT of seven days in treating sewage wastewater through CWs.

Table 6 Effect of plants and flow rate on chemical oxygen demand (mg L⁻¹) of sewage effluent in model constructed wetland

Plants	Flow rate 5 ml/min							
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	Mean
<i>Canna indica</i>	1880	1840	1760	1660	1520	1440	1220	1880
<i>Xanthosoma sagittifolium</i>	1920	1860	1820	1700	1620	1530	1360	1920
<i>Typha angustifolia</i>	1920	1880	1840	1720	1640	1560	1380	1920
MEAN	1907	1860	1807	1693	1593	1510	1320	
	P		D		P*D			
SE (d)	2.87		4.39		7.61			
CD (0.05)	5.98		9.13		15.82			
Plants	Flow rate 10 ml/min							
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	Mean
<i>Canna indica</i>	1920	1880	1800	1560	1580	1500	1280	1646
<i>Xanthosoma sagittifolium</i>	1980	1900	1880	1760	1660	1570	1400	1736
<i>Typha angustifolia</i>	1960	1940	1900	1780	1680	1600	1430	1756
MEAN	1953	1906	1860	1700	1640	1556	1370	
	P		D		P*D			
SE (d)	47.00		71.79		124.36			
CD (0.05)	97.75		149.31		25.62			

CONCLUSION

The efficiency of constructed wetland is greatly influenced by the aquatic plants, and different retention time in reducing the salt and pollutant load of the sewage water. All the sewage water quality parameters showed a decreasing trend on increasing the retention time and regarding the plants with it followed the order *Canna indica* > *Xanthosoma sagittifolium* > *Typha angustifolia*. There was a significant reduction in the redox potential, EC, TDS, TSS, BOD and COD of the sewage water @ 5 ml/min followed by 10 ml/min. Based on the study it was evident that CW with *Canna indica*, *Xanthosoma sagittifolium* and *Typha angustifolia* seems to perform better under flow rate of 5 ml/min.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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