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Using Analytical Hierarchical Process for Selection of Macrophytes in Constructed Wetlands for Dairy Wastewater Treatment

Devvrat Tripathi

M.Tech., Department of Civil Engineering, National Institute of Technology, Agartala, Tripura India

Email: devvrattripathi@gmail.com

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Abstract:**Constructed wetlands are nature based cost effective solution for wastewater treatment. Selection of macrophytes is tricky and a much needed skill to gain maximum output from constructed wetlands. Selection of macrophyte can have multiple criteria involved with different significance. However, no article could be found which discusses different criteria simultaneously and their relative importance for dairy wastewater treatment. This article intends to fill this gap by proposing a model considering environmental, tolerance and economic criteria for selection of macrophytes for dairy wastewater treatment. Analytical hierarchy process (AHP) was used to develop decision making model and for preliminary screening of macrophytes. Six commonly used macrophytes (*Phragmitesaustralis, Typhalatifolia,EichhorniacrassipesArundodonax, Lemna minor, Pistia stratiotes*) were selected and ranked via model. Final rankings were in order of *Typhalatifolia*>*Phragmitesaustralis*>*Arundodonax*>*Eichhorniacrassipes*>*Lemna minor* >*Pistia stratiotes.Typhalatifolia* was the most preferred macrophyte and performed best in environmental as well as tolerance criteria. Further, it was found that rankings of plants were exactly same for tolerance and environmental criteria. In other words, the plants which showed higher tolerance also showed better treatment performance in the exact same sequence in rankings.**

Keywords**:Macrophytes, constructed wetlands, dairy wastewater, Analytical Hierarchy process, MCDM**

I. INTRODUCTION

Constructed wetlands are nature based cost effective solution for wastewater treatment. The initial experiment on constructed wetlands started in 1950s in Germany (Seidel,1955) and since then has been an area of interest for many researchers. Water treatment occurs via phytoremidiation through interaction between substrate, microorganisms and macrophytes. Molinos-Senate at al. (2014) mention that constructed wetlands are most sustainable treatment option when compared to other wastewater treatment system. Conventional wastewater treatment systems maybe expensive or sometimes incapable of removing contaminants (such as emerging contaminants). This creates a research gap and hence constructed wetlands are being actively explored. Other benefits of using constructed wetlands are low operation and maintenance cost, easier operation, providing habitat for wildlife, economical and aesthetic advantages.

Constructed wetlands can treat discharges from point as well as non point sources. Promising results have been shown for treating industrial, domestic as well as municipal wastewater. Among industrial wastewater they can treat wide variety of wastewater such as textile, pharmaceuticals, acid mine drainage, agro food industry, petrochemicals, tannery, paper and pulp etc.

The dairy industry is considered as largest wastewater source among agro-food industries. The dairy industry is increasing at the rate of around 2.8% annum. This growth is further high in countries such as India where the per annum milk production rose by around 6.4% for the past few years (National Dairy development board, n.d.). The dairy industry includes variety of products such as raw/pasteurized/ sour/condensed milk, ice cream, cheese, butter, yogurts, whey powders, different types of deserts etc. However, dairy wastewater can contains high level of biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients (Nitrogen, phosphorus etc) and hence may breach the regulatory requirements for effluent disposal. High BOD and COD may lead to rapid utilization of dissolved oxygen (DO) by microorganisms, if disposed in water bodies. This may causedepletion of DO for fishes and aquatic organisms in water bodies and may result in their mortality. Similarly excess nutrients may lead to conditions of eutrophication, loss of species, habitat etc in aquatic ecosystem. Hence treatment is necessary and needs to meet regulatory standards. The regulatory requirements as per CPCB guidelines have been described in the table below.

TABLE 1
Effluent standards as per CPCB
(Central Pollution Control Board, 2021)

Parameter	Concentration not to exceed in mg/L, except pH	Quantum per product processed
pH	6.5-8.5	-
*BOD at 27^{O}C, 3 days	100	-
**Suspended solids	150	-
Oil and grease	10	-
Wastewater generation		3 m^3 / KL of milk

Constructed wetlands have often shown success in meeting these requirements. The performance/efficiency of constructed wetlands can be further optimized by working on its 3 essential components i.e. plants, substrate and microorganism. Selection of suitable/best macrophytes can lead to increased pollutant removal, increased resilience/recovery of wetland system.

Role of macrophytes have been debated with some studies concluding planted constructed wetlands, did not have any improvement over treated water compared with unplanted wetlands while majority of studies finds planted wetlands increased efficiency and treatment capacities compared to unplanted ones. Brix (1997) made a detailed study for role of plants. He mentions that physical effects of plants is most important as leads to erosion control, filtration, provides surface area for attachment of microbes. Uptake of nutrients and release of oxygen are most important functions of plant. Major components in treatment are microorganisms and inducing oxygen provides them aerobic conditions to degrade pollutants. Other functions of plants are providing habitat for wildlife and giving aesthetic appearance (Brix,1997). Hence macrophytes play a key role.

On considering the different species for same system it was found that efficiency did not changed or changed marginally. Hence after reviewing many articles, species in wetland may not enhance treatment efficiency considerably. However selection is of utmost importance as intolerant species cannot survive toxic contaminants. Moreover, some commonly used macrophytes can be weeds in some locations. For instance, *Phragmitesaustralis* are considered weeds in United states (Martin & Blossey,2013). Also in some scenario native species can be easily available and prove to be tolerant to industrial effluents. Considering heavy metals, plant selection is very crucial as removal efficiency of a specific heavy metal varies with type of plant used and hence is highly plant specific. Thus selection of macrophytes is a much needed skill to gain best results for wastewater treatment in constructed wetlands.

MCDM (Multi Criteria Decision Making) is a sub-discipline under operation research which can help us to make decisions for real life problems, often having several conflicting criteria and objectives to be considered simultaneously. There are many types of MCDM methods such as analytical hierarchical process (AHP), analytical network process (ANP), decision making trial and evaluation laboratory (DEMATAL), evaluation based on distance from ideal solution (EDAS), technique of order preference by similarity of ideal solution (TOPSIS), data envelopment analysis (DEA) and fuzzy decision-making (Khan et al., 2015).Each method has its own merits and demerits in area of application.

AHP is one of the most popular techniques for complex decision making (Rakshit et al.,2021). It decomposes complex decision making process into a system of objectives criteria and alternatives. AHP can be used in scenarios where there are multiple decision makers and/or subjective judgment is required. However pairwise comparison can make decision making very large and complex. Other disadvantage is decision maker may find it difficult to assign weightage on a 9 point scale. For instance, he may find it difficult to distinguish between one alternative is 6 times or 7 times more important than other (Rakshit et al.,2021).However AHP is convenient, flexible and can check inconsistency. Evaluation of subjective as well as objective parameters can be made (Rakshit et al.,2021). Such features make it popular.

MCDM have been used across different domains such as environmental science, transportation science, economics, management etc. for material selection, demand forecasting, industrial site location, manpower management, ethics, supply chain management and logistics etc. Among environmental engineering, applications are in selection of appropriate water treatment technologies, selection of waste disposal site, selecting solid waste treatment technology, evaluating traffic reducing policies etc. However no article could be found of using AHP for selecting macrophytes for treating dairy wastewater. This article aims to fill this research gaps and help engineers/ designers in selecting best suitable macrophytes via considering different criteria, weightages etc. for constructed wetlands.

II. MATERIALS AND METHODS

Identification of Macrophyte Option

Out of extensive literature review, 6 common macrophytes to treat dairy wastewater in constructed wetlands were selected. They have been described as options below-

Option 1- *Phragmitesaustralis*- Common name of *Phragmitesaustralis* is common reed. They belong to family poacae and are classified under emergent macrophytes. They have been most extensively researched in constructed wetlands for wastewater treatment. They can grow upto 6 meters tall. They can reproduce sexually as well as asexually. They can tolerate saline stress.

Option 2 – *Typhalatifolia-Typhalatifolia* belongs to family Typhaceae. These are monocotyledons flowering plants and have height 1-7 meters tall. Their common name is broad leaf cattail. They have spongy, strap-like leaves. They have starchy, creeping stems. They have unisexual flowers

Option 3- *Eichhorniacrassipes* – Their common name is water hyacinth and belong to family Pontederiaceae. They are free floating macrophytes. They reproduce by vegetative reproduction by means of slender runners called stolons.

Option 4- *Arundodonax- Arundodonax* common name is giant reed and belong to family Poaceae. They are also emergent macrophytes. They are tall, perennial and can grow even in drought areas. Their reproduction is mainly vegetative.

Option 5- *Lemnaminor*- In general terms known as common duckweed. These are free floating aquatic macrophyte. Duckweeds are classified as separate family- Lemnaceae, but someworksconsider them under family Arceae.

Option 6- *Pistia stratiotes*- Common name of *Pistia stratiotes* is water lettuce. They are floating macrophyte and belong to family Araceae. They have leaves upto 14 cm long and have no stem. Flowers are dioecious and hidden in middle part of plant leaves. They reproduce via asexual reproduction.

AHP

Saaty developed AHP in 1980 **(**Saaty,1980**)**. In this method intuition and logic of decision maker plays a key role. The relative difference/importance between criteria and sub-criteria is determined via extensive literature reviews (Review articles, original research articles, conference proceedings and handbooks for wastewater treatment) and expert opinions.

The main steps in AHP process are-

The problem is broken down into 4 steps

1. Identification of decision, options and criteria
2. Carry out pair-wise comparison
3. Calculate importance weight of each criterion
4. Identify the best option by calculating utility

Pair-wise comparison has to be done on a scale of 1 to 9. As per table 2higher values means increasing importance.

Consistency Ratio (CR) = Consistency index/Random consistency index (see table 3)

Consistency index (CI)= **(**λmax-n)/ (n-1)

TABLE 2
Preference & Numerical ratings (Saaty,1980)

Scale	**Numerical rating**
Extremely preferred	9
Very strongly to extremely preferred	8
Very strongly preferred	7
Strongly to very strongly preferred	6
Strongly preferred	5
Moderately to strongly preferred	4
Moderately preferred	3
Equally to moderately preferred	2
Equally preferred	1

Consistency index greater than 0.10 tells results are inconsistent. Hence comparisons have to be performed again. Higher value of CI shows lack of information/understanding.

III. Results and Discussions

For selection of macrophytes, firstly three different criteria were considered i.e. environmental, tolerance and economic benefits based on extensive literature review and expert opinions. The 3 criteria were further divided into 9 sub-criteria (Figure 1) for which pair-wise comparison among macrophytes were made (see Appendix A). For pair-wise comparison, literature cited was primarily for dairy wastewater and/or wastewater with similar characteristics/ synthetic wastewater. The weightages assigned for criteria and sub-criteria have been shown in table 4 (see Appendix A). Table 5 shows relative weights for pairwise comparison among macrophytes for 9 sub-criteria. Table 5 is an outcome of pairwise comparison made under Table A.4-A.12 in Appendix A

Rankings for sub-criteria

Organic matter removal has been assessed via BOD/COD reduction. BOD is biochemical oxygen demand required by microorganism for decomposition of organic matter under specified conditions (United States Geological survey, n.d.). While COD is chemical oxygen demand which is amount of oxygen needed for chemical oxidation of total organic matter. For organic matter removal for treating dairy wastewater, *Typhalatifolia* outperformed other macrophytes . While *lemna minor* ranked last for organic matter removal. However on assessing inorganic matter / nutrient removal it was found that *Pistia stratiotes* ranked last. *Typhalatifolia* ranked first for nitrogen as well as phosphorus removal. The priority of other macrophytes were *Phragmitesaustralis*>*Arundodonax*>*Eichhorniacrassipes*>*Lemna minor* >*Pistia stratiotes* for nitrogen removal. While preference for phosphorus removal had following sequence *Typhalatifolia*>*Phragmitesaustralis*>*Arundodonax*>*Eichhorniacrassipes*>*Pistia stratiotes*>*Lemna minor*. Hence for nutrient removal ranking for top four macrophytes remained constant while *Pistia stratiotes and Lemna minor* finished last for nitrogen and phosphorus removal respectively. Sooknah and Wilkie (2004) studied nutrient removal of water hyacinth and water lettuce among 3 floating macrophytes for nutrient removal in anaerobically digested flushed dairy manure wastewater and found that water hyacinth performed better than water lettuce for nutrient removal. Water hyacinth reduced total Kjeldahlnitrogen by 91.7%, ammonium by 99.6% and total-phosphorus by 98.5%.

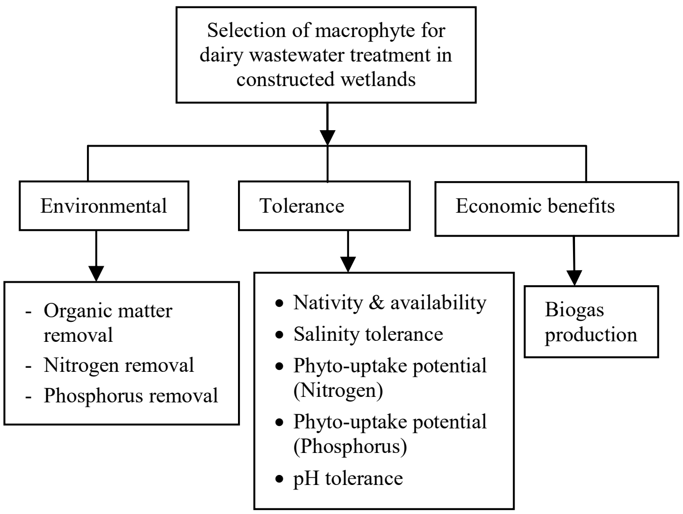

Figure 1: Decision Model for selection of macrophytes for dairy wastewater treatment

TABLE 4
Weightages for criteria and sub-criteria

Criteria (Weightages)	Sub-criteria	Weightage of sub-criteria
Environmental (0.199)	Organic matter removal	0.064
	Nitrogen removal	0.699
	Phosphorus removal	0.237
Tolerance (0.733)	Nativity and availability	0.530
	Salinity tolerance	0.062
	Phyto-uptake potential-Nitrogen	0.240
	Phyto-uptake potential-Phosphorus	0.138
	pH tolerance	0.03
Economic (0.068)	Biogas production	1.000

Among 6 macrophytes studied, *Typhalatifolia* has been rated highest for nativity and availability for being native as well as widely available compared to other macrophytes. On the same scale, water hyacinth has been rated low as it has been considered as one of the worst aquatic weed across world as well as India. In India, it is estimated that 20-25% of total utilisable water is infested with water hyacinth. While in state of West Bengal, Assam, Orissa and Bihar it was 40% (Thamkeand Khan, 2021). Reddy et al. (2008) mentions *Eichhorniacrassipes* among invasive species in India.

Salt content in dairy wastewater may fluctuate and may be high sometimes (specially in case of whey) ranging from 1-3% (Slavov,2017). Hence it is advisable to use plants with salinity tolerance. Halophytes are the plants which can grow in saline conditions. *Phragmitesaustralis* is most tolerant among the selected macrophytes for dairy wastewater conditions. It can grow in saline soils. Sooknah and Wilkie (2004) studied water hyacinth and water lettuce among 3 floating macrophytes. In undiluted anaerobically digested flushed dairy manure wastewater, growth of water hyacinth was inhibited while water lettuce failed to grow. The study mentions high salinity appears to be reason for inhibition.

Phyto-uptake potential is ability of plant to uptake high level of pollutant from influent dairy wastewater. Phyto-uptake potential for nutrients was considered for this study. This is because nutrients when discharged into aquatic bodies may lead to conditions of eutrophication. Eutrophication can cause algal bloom resulting in rapid utilization of oxygen and blockage of sunlight (USGS, n.d.). Algal blooms can reduce the ability of fish and other aquatic life to find food and can cause entire populations to leave an area or even die (Environmental Protection Agency,2021). Nitrogen and phosphorus are primarily responsible for eutrophication.

Brix (1997) mentioned nutrient uptake potential for 7 macrophytes in a study. As per publication, *Eichhorniacrassipes* can uptake upto 350 kg $ha^{-1}yr^{-1}$ of phosphorus. Based on literature review, *Eichhorniacrassipes* was ranked first and *Lemna minor* was ranked last. *Pistia stratiotes* acquired penultimate rank and performed poorly for phyto-uptake potential for phosphorus. On analyzing Phyto-uptake potential for nitrogen it was found that *Arundodonax* performed the best (0.374) followed by *Phragmitesaustralis* (0.259) .*EichhorniaCrassipes* outperformed *Typhalatifolia* by a good margin while *Lemna minor* and *Pistia stratiotes,* as in phyto-uptake potential for phosphorus, ranked again in the bottom two.

Influent dairy wastewater can have fluctuation in pH and it can be acidic as well as basic (Joshiba et al.,2019). Thereforemacrophyte selected should be able to withstand fluctuations in pH of influent wastewater. Among pH tolerance studied for different macrophytes, *Phragmitesaustralis* outperformed other macrophytes with a good margin. *Phragmites* scored 0.438 as compared 0.255 by *Typhalatifolia.Typhalatifolia* was followed by *Arundodonax* and *Eichhorniacrassipes* . While *Lemna minor* and *Pistia stratiotes* finished in the last two for pH tolerance.

Biogas originates via anaerobic microbial degradation of organic material. In principle, all organic materials can be digested/fermented. However, only liquid and homogenous materials are considered for biogas production. The main and most significant advantage of biogas is that it can be used as an alternative fuel produced from renewable energy. Also biogas mostly contain methane (50-75%), hence its exhaust emissions will be similar to natural gas (Zvirin, 1998 p.547). Other components in biogas are carbon dioxide (25-50 %), Nitrogen (0-10%), Hydrogen (0-1%), Hydrogen sulphide (0-3%), Oxygen (0-2%).Methane gas plants can be used as a source of fertilizer too. Biomass is also termed as organic combustible matter, it is stored solar energy in plant mass. Production of biogas is affected by temperature, pH, volatile fatty acids, inoculums-substrate ratio, effect of microbial population etc. Singhal and Rai (2003) and Chanakya et al. (1998) studied production of biogas via water hyacinth getting promising results. Dipu et al. (2011) studied biogas production of *Typha* sp., *Eichhornia*sp. ,*Lemna* sp., *Pistia* sp. and *Azolla* sp. and found that biogas production was low in initial days but increased later on. This study concluded that gas produced via plant biomass was more than traditional cow dung slurry.

TABLE 3
Random consistency index (RI)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

TABLE 5
Weightages for different sub-criteria on pairwise comparison among macrophytes

Sub-criteria	Organic matter removal	Nitrogen removal	Phosphorus removal	Nativity and availability	Salinity tolerance	Phyto-uptake potential-N	Phyto-uptake potential-P	pH tolerance	Biogas production
Phragmitesaustralis	0.161	0.230	0.235	0.266	0.474	0.259	0.086	0.438	0.30
Typhalatifolia	0.383	0.445	0.479	0.436	0.150	0.071	0.242	0.255	0.118
Eichhorniacrassipes	0.251	0.098	0.081	0.025	0.033	0.221	0.480	0.090	0.054
Arundodonax	0.103	0.154	0.135	0.080	0.244	0.374	0.126	0.151	0.424
Lemna minor	0.034	0.046	0.025	0.155	0.075	0.024	0.025	0.038	0.025
Pistia stratiotes	0.067	0.027	0.044	0.039	0.024	0.049	0.04	0.027	0.079

TABLE 6
Composite scores and ranking for criteria's

	Environmental		**Tolerance**		**Economic benefits**	
	Score	**Rankings**	**Score**	**Rankings**	**Score**	**Rankings**
Phragmitesaustralis	0.227	2	0.258	2	0.30	2
Typhalatifolia	0.449	1	0.298	1	0.118	3
Eichhorniacrassipes	0.104	4	0.137	4	0.054	5
Arundodonax	0.146	3	0.169	3	0.424	1
Lemna minor	0.040	5	0.097	5	0.025	6
Pistia stratiotes	0.034	6	0.040	6	0.079	4

Composite ranking

The composite ranking is the ranking for three criteria (i.e. environment, tolerance & economic benefits) considering all sub–criteria and weightages. Environmental criteria basically dealt with treatment efficiency. More weightage has been assigned to nitrogen removal as relative role of plant is higher for nitrogen removal as compared to phosphorus removal in constructed wetlands for dairy wastewater treatment. The primary mechanism for phosphorus removal for treating dairy wastewater in constructed wetlands is via substrate. Addition of Iron / Aluminium etc. to substrate is done for phosphorus removal in constructed wetlands treating dairy wastewater. *Typhalatifolia* outperformed among all macrophytes. While *Lemna minor* and *Pistia stratiotes* were bottom two performers. The scores and ranking for environmental criteria is given in table 6**.**

Tolerance criteria includes different stress parameters which could retard growth and/or cause death of macrophytes in constructed wetlands for dairy wastewater treatment. Stress/death of macrophytes could reduce treatment performance or make constructed wetlands dysfunctional. It includes parameters for nativity and availability, salt tolerance, phyto-uptake potential for nitrogen, phyto-uptake potential for phosphorus and pH tolerance.

Tolerance criteria has been assigned maximum weightage as it would ensure optimum functioning of constructed wetlands. Under tolerance criteria, *Typhalatifolia* outperformed. The overall sequence was *Typhalatifolia>Phragmitesaustralis>Arundodonax>Eichhorniacrassipes>Lemna minor >Pistia stratiotes*. It was found that ranking of macrophytes for tolerance as well environmental criteria remained same i.e. as per evaluation, macrophytes performing better on treatment parameter, also performed comparatively better for tolerance in exactly same sequence. The ranking for tolerance has been shown in table 6**.** Guittonny-Philippe et al. (2015) mentions that native macrophytes should be selected for industrial wastewater, preferably growing in the vicinity of discharge of industrial influents. At the same time macrophyte selected should not be invasive or be potential weeds in the given locality. Hence native species should be preferred over exotic species as it can pose a threat to ecosystem if invasive **(**Tanner and Kloosterman,1997).

Economic benefits can be a very useful parameter as constructed wetlands are extensive technologies and needs large area of land. Hence this may be a deterring factor to adapt constructed wetlands technology specially in urban areas. For economic benefits ranking differed, *Arundodonax* outperformed other macrophytes. *Phragmitesaustralis* and *Typhalatifolia* followed next. While *Pistia stratiotes*, *Eichhorniacrassipes* and *Lemna minor* performed the least. Giant reed has outstanding results in terms of yield, irrigation needs, water use efficiency and fertilizer use even in less favourable conditions (Pulighe et al, 2016). Zema et al. (2012) studied three energy crops i.e. *Phragmitesaustralis, Arundodonax*and *Typhalatifolia* and found that *Arundodonax* has increased biomass yield and highest energy yield per unit of cultivated area in a two year long study.

For computation of final ranking the weightages for individual criteria were multiplied with their relative scores for criteria as shown in Figure 2**.** As scores are now normalized, the final ranking is simply the sum of normalized scores of all three criteria. The rankings & scores of macrophytes are in following order *Typhalatifolia (0.320) >Phragmitesaustralis (0.254) >Arundodonax(0.182) >Eichhorniacrassipe (0.125) >Lemna minor(0.081) >Pistia stratiotes (0.042)*

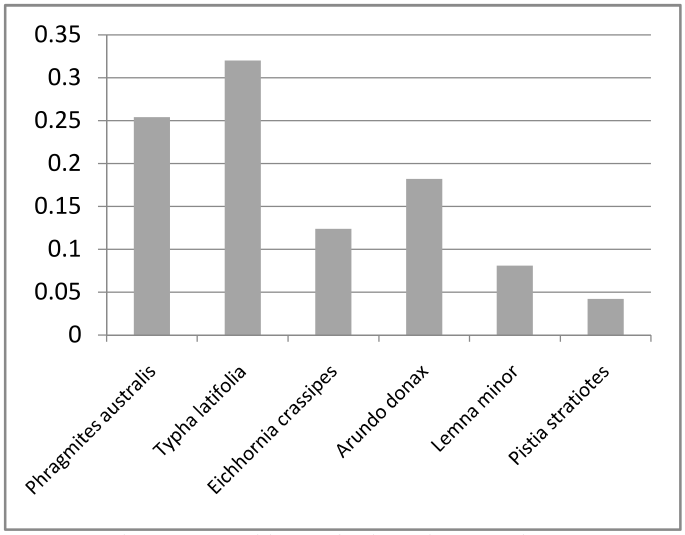

Figure 2- Rankings of selected macrophytes

IV. CONCLUSION

This article made a comprehensive evaluation for selection of macrophytes based on 9 sub-criteria among six macrophytes for dairy wastewater treatment. A model has been developed for selection of macrophytes based on 3 criteria which was further divided into 9 sub-criteria. To the best knowledge, no article could be found of which talks of multiple factors in decision making for selection of macrophytes in constructed wetlands and their relative importance. This work could ease the decision making for selection of macrophytes in constructed wetlands for dairy wastewater treatment. It aims to give reader a comprehensive understanding of different factors involved in macrophyte selection for treating dairy wastewater. Reader can further refine the model based on his requirement for the criteria of prime concern. Selection of macrophyte is a case of complex decision making and includes multiple criteria. Hence this study made a comparative analysis and developed a model for comprehensive evaluation to select macrophyte in constructed wetlands for dairy wastewater treatment.

On evaluation of criteria, *Typhalatifolia* was most preferred alternative for environmental as well as tolerance criteria. While *Pistia stratiotes* and *Lemna minor* were ranked lowest in environmental as well as tolerance criteria. After analysis, it was found that ranking of macrophytes followed the exact same sequence for tolerance as well as environmental criteria. However ranking deferred significantly for realizing economic benefits, under which *Arundodonax* ranked best followed by *Phragmitesaustralis*. *Eichhorniacrassipes* and *Lemna minor* were the bottom two performers for economic benefits criteria. Hence after decision making model and rankings, it was found that *Typhalatifolia* is most preferred option for dairy wastewater treatment with a score of 0.32 followed by *Phragmitesaustralis* (0.254). For studies using combination of macrophytes, *Typhalatifolia* can be used along with *Phragmitesaustralis* for dairy wastewater treatment in case of constructed wetlands, since these two are most preferred option. Further, more studies need to be made on *Arundodonax* for biogas potential, as successful implementation could turn constructed wetlands into profitable ventures and would attract investments and further research. Based on the above assessment, *Lemna minor* and *Pistia stratiotes* are not recommended among the six macrophytes because of their very low score for dairy wastewater treatment.

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APPENDIX

APPENDIX-A

TABLE A.1
Assigning weightages for criteria

	Environmental	Tolerance	Economic benefits
Environmental	1	1/5	4
Tolerance	5	1	8
Economic benefits	¼	1/8	1

Consistency ratio= 9.8%

TABLE A.2
Assigning weightages for sub-criteria (environmental)

	Organic matter removal	Nitrogen removal	Phosphorus removal
Organic matter removal	1	1/8	1/5
Nitrogen removal	8	1	4
Phosphorus removal	5	1/4	1

Consistency ratio= 9.8%

TABLE A.3
Assigning weightages for sub-criteria (tolerance)

	Nativity and availability	Salt tolerance	Phyto-uptake potential - Nitrogen	Phytouptake potential-Phosphorus	pH tolerance
Nativity and availability	1	7	4	5	9
Salt tolerance	1/7	1	1/5	1/4	4
Phyto-uptake potential – Nitrogen	1/4	5	1	3	7
Phyto uptake potential-Phosphorus	1/5	4	1/3	1	6
Soil pH tolerance	1/9	1/4	1/7	1/6	1

Consistency ratio= 9.8%

TABLE A.4
Assigning weightages to macrophytes for organic matter removal

	Phragmitesaustralis	*TyphaLatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	1/3	1/2	2	5	3
TyphaLatifolia	3	1	2	4	7	5
Eichhorniacrassipes	2	1/2	1	3	6	4
Arundodonax	1/2	1/4	1/3	1	4	2
Lemna minor	1/5	1/7	1/6	1/4	1	1/3
Pistia stratiotes	1/3	1/5	1/4	1/2	3	1

Consistency ratio= 2.6%

TABLE A.5

Assigning weightages to macrophytes for nitrogen removal

	Phragmitesaustralis	*Typhalatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	1/3	3	2	6	7
Typhalatifolia	3	1	5	4	7	9
Eichhorniacrassipes	1/3	1/5	1	1/2	3	5
Arundodonax	1/2	1/4	2	1	5	6
Lemna minor	1/6	1/7	1/3	1/5	1	3
Pistia stratiotes	1/7	1/9	1/5	1/6	1/3	1

Consistency ratio= 4.8%

TABLE A.6

Assigning weightages to macrophytes for phosphorus removal

	Phragmitesaustralis	*Typhalatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	1/4	4	3	7	6
Typhalatifolia	4	1	6	5	9	7
Eichhorniacrassipes	1/4	1/6	1	1/3	5	3
Arundodonax	1/3	1/5	3	1	6	4
Lemna minor	1/7	1/9	1/5	1/6	1	1/3
Pistia stratiotes	1/6	1/7	1/3	1/4	3	1

Consistency ratio= 8.1%

TABLE A.7

Assigning weightages to macrophytes for nativity and availability

	Phragmitesaustralis	*Typhalatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	1/3	8	5	3	7
Typhalatifolia	3	1	9	6	4	8
Eichhorniacrassipes	1/8	1/9	1	1/5	1/6	1/3
Arundodonax	1/5	1/6	5	1	1/4	4
Lemna minor	1/3	1/4	6	4	1	5
Pistia stratiotes	1/7	1/8	3	1/4	1/5	1

Consistency ratio = 8.9%

TABLE A.8

Assigning weightages of macrophytes for salinity tolereance

	Phragmitesaustralis	*Typhalatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	5	8	4	6	9
Typhalatifolia	1/5	1	6	1/3	4	7
Eichhorniacrassipes	1/8	1/6	1	1/7	1/4	2
Arundodonax	1/4	3	7	1	5	8
Lemna minor	1/6	1/4	4	1/5	1	5
Pistia stratiotes	1/9	1/7	1/2	1/8	1/5	1

Consistency ratio = 9.8%

TABLE A.9

Assigning weightages to macrophytes for phyto-uptake potential -Nitrogen

	Phragmitesaustralis	*Typhalatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	5	2	1/3	8	6
Typhalatifolia	1/5	1	1/4	1/6	5	2
Eichhorniacrassipes	1/2	4	1	1/4	7	5
Arundodonax	3	6	4	1	9	8
Lemna minor	1/8	1/5	1/7	1/9	1	1/4
Pistia stratiotes	1/6	1/2	1/5	1/8	4	1

Consistency ratio = 7.1%

TABLE A.10

Assigning weightages to macrophytes for Phyto-uptake potential –Phosphorus

	Phragmitesaustralis	*Typhalatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	1/5	1/6	1/2	5	4
Typhalatifolia	5	1	1/4	3	7	6
Eichhorniacrassipes	6	4	1	5	9	8
Arundodonax	2	1/3	1/5	1	6	5
Lemna minor	1/5	1/7	1/9	1/6	1	1/3
Pistia stratiotes	1/4	1/6	1/8	1/5	3	1

Consistency ratio = 8.8%

TABLE A.11

Assigning weightages to macrophytes for pH tolerance

	Phragmitesaustralis	*Typhalatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	3	5	4	8	9
Typhalatifolia	1/3	1	4	3	6	7
Eichhorniacrassipes	1/5	1/4	1	1/3	4	5
Arundodonax	1/4	1/3	3	1	5	6
Lemna minor	1/8	1/6	1/4	1/5	1	2
Pistia stratiotes	1/9	1/7	1/5	1/6	1/2	1

Consistency ratio = 6.5%

TABLE A.12

Assiging weightages to macrophytes for biogas production

	Phragmitesaustralis	*Typhalatifolia*	*Eichhorniacrassipes*	*Arundodonax*	*Lemna minor*	*Pistia stratiotes*
Phragmitesaustralis	1	4	6	1/2	8	5
Typhalatifolia	1/4	1	3	1/5	6	2
Eichhorniacrassipes	1/6	1/3	1	1/7	4	1/2
Arundodonax	2	5	7	1	9	6
Lemna minor	1/8	1/6	1/4	1/9	1	1/5
Pistia stratiotes	1/5	1/2	2	1/6	5	1

Consistency ratio = 5.5%