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Need for Adopting Hybrid Treatment Systems to Reduce O&M Costs of Sewage Treatment and Recycling in India

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Abstract: *In this study, Mechanized Treatment Systems (MTSs) and Natural Treatment Systems (NTSs) for Wastewater Treatment (WWT) and recycling are compared. Based on the comparison of land requirement and O&M costs, the novel approach of Hybrid Treatment Systems (HTSs) is proposed. The HTSs approach overcomes the limitations of the MTSs and NTSs by combining these treatment systems at an appropriate level. The study shows that significant operational energy savings and additional benefits such as nutrient and emerging contaminant removal can be achieved by adopting the HTSs approach. The life cycle cost analysis shows that HTSs are more economical than MTSs in urban, peri-urban, and rural settings. Hence, there is a need to adopt HTSs by central and state government in their river rejuvenation and clean water missions.*
Keywords*: Wastewater treatment; Recycling; Natural treatment systems; Hybrid treatment; Sustainability; India*

1. INTRODUCTION

Domestic wastewater (sewage) is continually increasing in India due to population growth and rapid urbanization. There exists a considerable gap between sewage generation and Wastewater Treatment (WWT). Out of around 72,368 MLD wastewater generated, 44% of the wastewater receives treatment (ENVIS, 2021). The gap of 40,527 MLD in sewage treatment needs to be effectively planned on an urgent basis.

To fulfill the existing sewage treatment gap, the Government of India is taking tremendous efforts in creating new sewage treatment infrastructure through various programmes such as Namami Gange, Atal Mission for Rejuvenation and Urban Transformation, and Smart Cities. To achieve the targets of these programmes it is necessary to adopt sustainable solutions of sewage infrastructure.

Conventionally, Mechanized Treatment Systems (MTSs) such as the Activated Sludge Process, Moving Bed Bio Reactor, Sequencing Batch Reactor have been used for sewage treatment. However, the MTSs consume significant energy during the operational phase of Sewage Treatment Plants (STPs), which results in high O&M costs. Whereas, the engineered Natural Treatment Systems (NTSs) also exist that can be used for WWT. **Figure 1** shows the classification of NTSs. Although NTSs have very high potential of creating sustainable infrastructure, their use has not been scaled up (even if there is ample land available at the location) due to the following reasons:

- No guidelines from policymaking bodies on NTSs usage
- Lack of appropriate design guidelines
- Lack of practitioners with an in-depth understanding of the NTSs

2. MTSs VERSUS NTSs: COSTS AND LAND REQUIREMENT COMPARISON

The above discussion on MTSs and NTSs shows that there exists a trade-off between these treatment approaches. As shown in Table 1, the MTSs have very high O&M costs but low land requirements. The O&M costs are majorly contributed by the energy required (about 50-60%) to operate the plant. On the other hand, the land requirement for NTSs is substantially higher, and is proportional to the organic load to be removed. However, NTSs incur minimal O&M costs.

Thus, both the MTSs and NTSs cannot be used individually as a full-fledged solution in most cases. Considering the trade-offs in the operational costs and land requirement, combining the two systems at an appropriate level is necessary. Considering the costs and land variation with respect to BOD removal (refer to Figure 3), moving from MTSs to NTSs for achieving BOD removal level beyond 30 mg/L will drastically bring down the O&M costs.

3. HYBRID TREATMENT SYSTEMS

Hybrid Treatment Systems (HTSs) is an appropriate combination of MTS with NTS to achieve the best performance with reduced overall costs (Kalbar, 2021). Constructed Wetlands (CWs) is the most commonly used NTS in India (Asolekar et al., 2014). The land required for CWs can be calculated as given in Crites et al. (2014).

$$A_s = \frac{Q(\ln C_0 - \ln C_e)}{K_T.y.n}$$

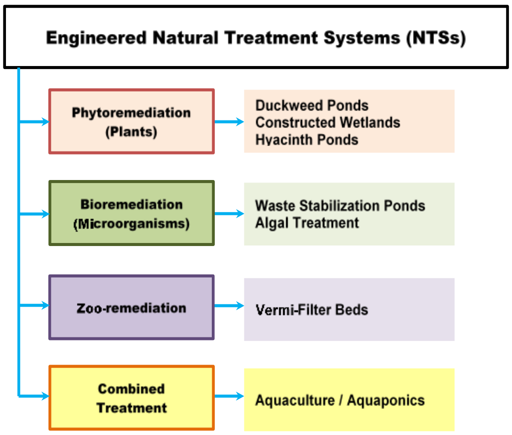
Where,
A_s = wetland surface area (m^2)
Q = average design flow (m^3/d)
C_0 = influent BOD concentration (mg/L)
C_e = effluent BOD concentration (mg/L)
K_T = rate constant = 1.1 d^{-1} at 20°C
y = design depth of wetland bed (m)
n = porosity of media
Two types of HTSs are possible using shallow bed (depth less than 0.9 m) or deep bed CWs (depth about 2 m) as shown in Figures 3a and 3b. The land requirement varies according the chosen depth of the wetland.

The costs and land requirements of MTS and CWs is shown in Figure 3a and 3b. The results from these figures show that MTS can effectively be used for the bulk organic load removal, whereas BOD can be brought down from 30 mg/L to required level with moderate O&M costs and land requirement using NTSs. However, if MTSs are used for further treatment, the O&M costs are significantly high. Hence, CWs can be used for any additional treatment (outlet less than 30 mg/L) required to meet the prevailing standards/recycling purpose. This shows that HTSs effectively combines the advantages of MTSs and NTSs.

Table 1: **Cost comparison of MTSs and NTSs (assuming inlet BOD removal of 300 mg/L) (adapted from Kalbar, 2021)**

System	Parameter	BOD removal up to 30 mg/L	BOD removal up to 10 mg/L
Mechanized Treatment Systems	Land requirement (m^2) per MLD	1100	1300
	O&M costs (INR/m^3)	5 - 6	12 -14
Natural Treatment Systems	Land requirement (m^2) per MLD	4000	6000
	O&M costs (INR/m^3)	1 - 2	2 - 3

4. LIFE CYCLE COSTING OF DIFFERENT SYSTEMS



The above calculations depict that HTSs have clear advantages over MTSs or NTSs being used individually. Although the use of HTSs brings down the O&M cost and land requirement, there is still a greater land requirement as compared to MTSs. Hence, it is necessary to carry out a comparison of the two approaches using the following cost components:

1. Capital costs
   1.1 Civil works
   1.2 Electro-mechanical equipment
   1.3 Land requirement
2. Annual operation and maintenance costs
   2.1 Labor/man power
   2.2 Energy
   2.3 Chemicals
   2.4 Routine maintenance
3. Replacement costs (Electro-mechanical components)

To compare the treatment systems, it is necessary to carry out Life Cycle Costing (LCC) for the entire lifetime of the treatment plant. All the cash flows in the functional life of Wastewater Treatment Plants (WWTPs) are shown in Figure 4. WWTPs typically have a design life of 30 to 50 years. To estimate the LCC, a functional life of 30 years can be considered. As shown in cash flow diagram in Figure 4, WWTPs typically incur land costs, construction costs (civil works and electro-mechanical equipment), electro-mechanical equipment replacements after 15 years, and annual O&M costs as mentioned above.

In this work, the present worth method of LCC is used. Present Value (Present Worth) is the sum of all future costs, discounted to the year of initial construction, and initial investment costs. The detailed methodology can be found in IS 13174 Life Cycle Costing (Part 1 and 2).

In the present worth method, a discount (interest) rate is used to convert the future expenses to their present value. Hence, the expenses incurred at the beginning are not required to be transformed.

The present worth of amount (P) of a single future payment (F), which will be received after n periods at an interest rate of i, compounded at the end of every interest period, is given by,

$$P = \frac{F}{(1+i)^n} = F(P/F, i, n)$$

where, *(P/F, i, n)* is termed as a single-payment present worth factor.

The present worth of a uniform payment mode (A) compounded at the end of every 'n' interest periods at an interest rate of i, is given by:

$$P = A\frac{(1+i)^n - 1}{i(1+i)^n} = A(P/A, i, n)$$

where, *(P/A, i, n)* is called a uniform-payment series present worth factor.

***Fig. 1**: Classification of natural treatment systems (adapted from Asolekar et al., 2014)*

In this study, the data on O&M costs and land requirement for WWT technologies is derived from secondary literature pertinent to Indian cases (Sato et al., 2007; Tare and Bose, 2009; GRBMP, 2010; Kalbar et al., 2012a, 2012b; Chauhan, 2017; Singh and Kazmi, 2016; Singh and Gupta, 2018) and author's personal communication with experienced practitioners. The land cost is assumed to be INR 0.04 Lakh per m^2 in urban areas and 2/3rd and 1/2 of this cost is considered in peri-urban and rural areas respectively. The land requirement for this cost analysis is calculated for shallow bed CWs i.e., HTS-1 in Figure 3, since they are most commonly found/ are popular in India. The discount rate considered for the analysis is assumed to be 10%.

Using the equation and the costing described above, the LCC of different WWT technologies have been calculated as outlined in Table 2.

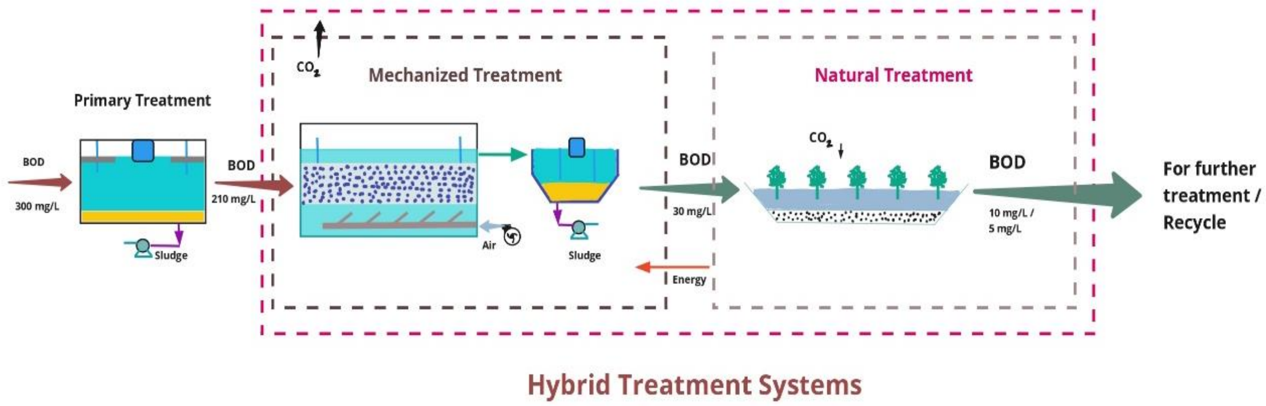
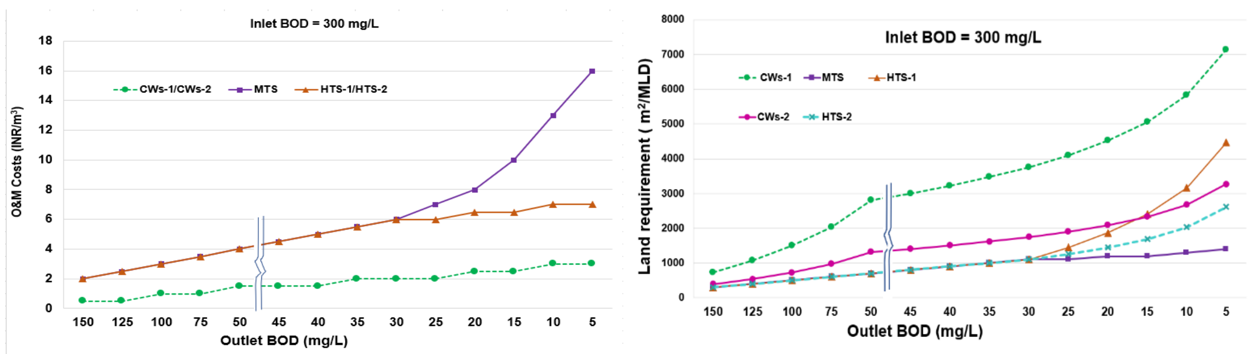


***Fig. 2**: Hybrid Treatment System Approach (adapted from Kalbar, 2021)*



(a) (b)

Fig. 3: *O&M costs and Land requirements of different treatment systems (MTS – Mechanized Treatment System; CWs-1 – Shallow Bed Constructed Wetlands; CWs-2 - Deep Bed Constructed Wetlands; HTS - Hybrid Treatment System) (adapted from Kalbar, 2021)*

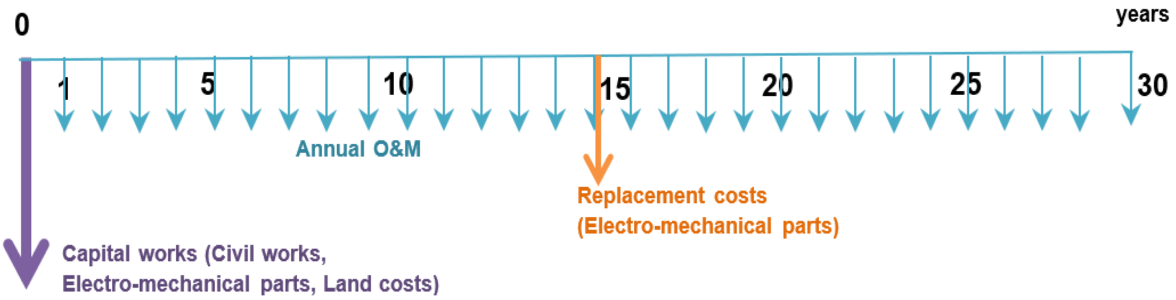


Fig. 4: *Cash flow diagram of WWTPs considered for LCC*

5. COST-EFFECTIVE TREATMENT SYSTEMS IN DIFFERENT SCENARIOS

The results of LCC in Table 2 show that if land costs are considered then, CWs turns out to be the most capital cost intensive technology choice in urban, peri-urban, and rural settings. However, if we consider the O&M costs over 30 years, CWs are the most economical option based on Net present Worth (NPW). *This suggests that in the economic evaluation of the treatment technologies, O&M costs play a significant role and not the capital costs.*

CWs are the most preferred option wherever land is available without any constraint. However, in peri-urban and urban areas, land availability may pose a challenge for adopting CWs. Hence, HTSs may become a prospective alternative instead of completely moving to MTSs as shown in Figure 5.

Table 2: Life cycle costs of different wastewater treatment systems considering 30 yrs of functional life

Cost Comparision for BOD removal up to 10 mg/L		Capital Costs	Annual O&M Costs	Net Present Worth (30 yrs)
		Rs. Lacs/MLD	Rs. Lacs/MLD	Rs. Lacs/MLD
Urban	ASP	104	37	448
	SBR	120	44	533
	MBR	134	51	615
	CWs	280	11	384
	HTS	178	22	384
Peri-urban	ASP	91	37	435
	SBR	109	44	522
	MBR	126	51	607
	CWs	200	11	304
	HTS	136	22	342
Rural	ASP	84	37	428
	SBR	104	44	517
	MBR	122	51	603
	CWs	160	11	264
	HTS	115	22	321

Table 2 shows that, in any type of setting, MBR followed by SBR and ASP are most expensive treatment systems based on the NPW. HTSs and CWs both have lowest NPW in urban settings. However, if land availability is a constraint then HTSs can be adopted. In peri-urban and rural settings CWs are most preferred followed by HTSs system.

6. SIGNIFICANCE OF USING HTSS AND ADDITIONAL BENEFITS

There is a huge gap in sewage generation and treatment capacity available in India which has put tremendous pressure on the governing bodies to control the pollution of rivers and lakes. This has led to progressive discharge standards, as shown in Table 3.

Table 3: Existing and new sewage discharge standards (NGT, 2019)

Sr. No.	Parameters	Old Norms 1986	NGT Order dtd. 30th April, 2019
1	Biochemical oxygen demand (BOD) (3 days at 27ºC (mg/L)	<30	<10
2	Chemical oxygen demand (COD), mg/L, max	<250	<50
3	Total Suspended solids (SS), mg/L, max	<100	<20
4	Total Nitrogen (mg/L)	<100	<10
5	Ammoniacal Nitrogen (mg/L)	<50	No limit
6	Total Phosphorous	No limit	<1
7	Fecal Coliform (MPN/100 ml)	No limit	<230

In April, 2019, the National Green Tribunal (NGT) had ordered all STPs (including existing) to match the discharge standard of 10 mg/L for effluent BOD. This order has created a demand for low cost and affordable wastewater treatment systems. As per this new order by NGT, there is a need to upgrade the existing STPs to treat BOD up to 10 mg/L and construct upcoming STPs considering these standards.

The MTSs solely is not an appropriate solution catering to the challenges posed by these progressive regulations due to the high O&M costs and a lack of revenue available with the Urban Local Bodies (ULBs) and utility boards to pay for the same. Hence, the role to be played by the HTSs becomes critical.

The existing STPs having 30 mg/L standard can be upgraded using the HTSs approach, meaning, the additional treatment required can be achieved using the CWs, thus converting the overall system to HTSs.

For the upcoming STPs, HTSs approach can be adopted, which needs planning right from the project inception so that the overall O&M costs of STPs can be lowered. Decentralized infrastructure approach along with Circular Economy framework can be adopted for the wider implementation of HTSs (Kakwani and Kalbar 2020).

The additional benefits of using HTSs include their ability of removing nutrients at lowered operational costs and emerging contaminants that the conventional MTS are incapable of removing (Kalbar, 2021). Also, the substantial savings in the operational energy by using HTSs, will reduce the greenhouse gas emissions thereby contributing to climate change mitigation.

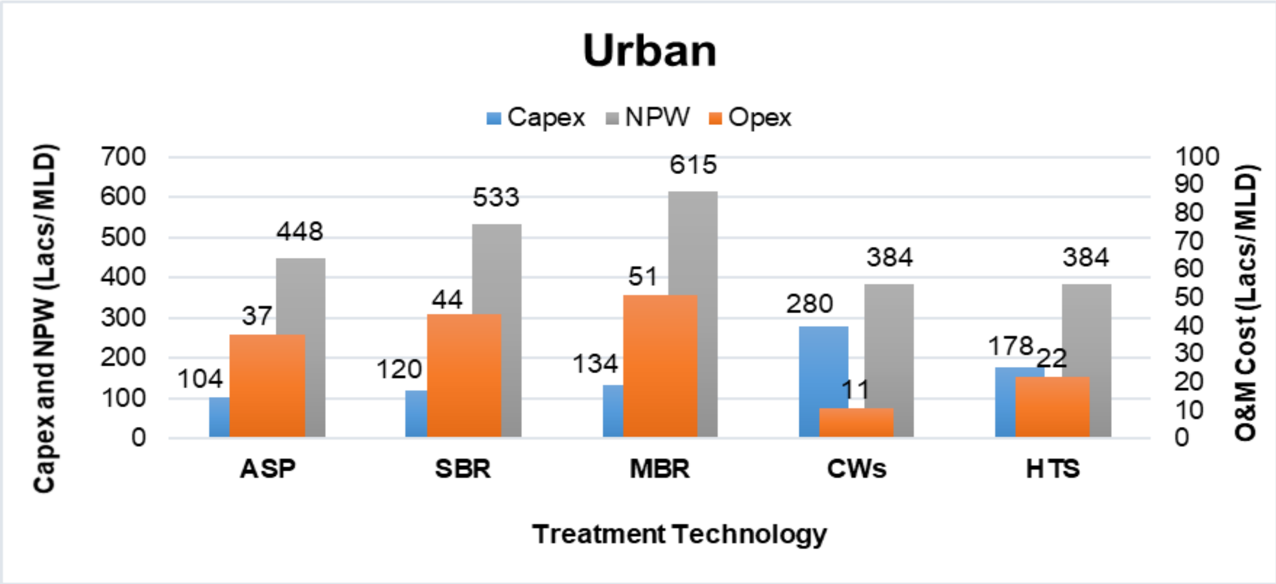


Fig. 5: *Different costs of treatment systems (for BOD removal up to 10 mg/L) along with Net Present Worth*

7. CONCLUSIONS

The present study proposes Hybrid Treatment Systems as a promising alternative approach for reducing the O&M costs of sewage treatment and recycling in India. The HTSs approach will help in saving significant operational energy in the treatment and recycling of sewage. The study also shows that the HTSs approach proves to be economical compared to MTSs in any of the settings, even after accounting for land cost.

The study highlights that it is the O&M cost and not the capital cost that dominates the economic evaluation of treatment technologies over the life cycle of the plant. Hence, the decisions pertaining to the technology selection should be taken based on the overall life cycle costs calculated for 30 years.

NTSs such as CWs can first be adopted wherever possible. However, the HTSs approach can be adopted if there is a constraint on land availability so as to leverage on the benefits of NTSs.

There is a need to develop guidelines and policies on the use of NTSs and HTSs. The wide application of these low-cost treatment systems is currently restricted due to lack of guidelines regarding their usage. Hope this study will help policymakers and practitioners to bring the usage of NTSs and HTSs to the forefront of sewage treatment.

8. ACKNOWLEDGEMENT

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