**Project Report on**

# Report on Multi-Criteria Assessment of the Natural Treatment Systems

As part of WP2: Decision Support Tool (DST) of

Sponsored Research Project

**Innovation Centre for Eco-prudent Wastewater Solutions**

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# 1. Introduction

The United Nations prioritize clean water and sanitation access under Sustainable Development Goal (SDG) 6. With the onus on the government to treat domestic sewage, it has become necessary for the governing bodies to invest in social infrastructure i.e., education, health, water supply and sanitation apart from advancing economic infrastructure. Apart from cities, the pace of development in adjoining peri-urban areas is also increasing rapidly. Peri-urban fringes will soon be on the frontline of economic development and become prominent development centres. Along with providing service to the citizens concentrated in urban clusters, the municipal authorities are obligated to supply water supply and sewerage infrastructure to the ever-growing population in the peripheries of cities.

## 1.1. Challenges of wastewater sector

The choice of sewage treatment technology varies for urban and rural areas due to a stark difference in the availability of land and funds, skill requirement, sewage quantity and characteristics. Sewage generation estimates available for India are typically carried out for cities where the authorities are obliged to provide sewerage facilities. On the other hand, sewage treatment until recently had not been a priority in rural areas. However, with greywater treatment and recycling coming up in national missions such as the Jal Jeevan Mission, both urban and rural areas urgently need to prioritize wastewater treatment. Although sewerage infrastructure exists in some cities, there is a large number of non-operational STPs. The underutilization of installed STPs and low nation-wide compliance are the barriers for sewage treatment (Vaidya et al., 2023). Moreover, citizens expect the sewage treatment services to be provided to them at free of cost, thus burdening the Urban Local Bodies (ULBs) with Operation and Maintenance (O&M) costs.

The recent regulatory order issued in 2019 by the apex regulatory body of India, the National Green Tribunal (NGT), demands wastewater treatment up to BOD < 10 mg/L irrespective of whether it is disposed of or used for any beneficiary purpose (NGT, 2019). In this regard, there is a need to plan future infrastructure of 40,527 MLD for new standards, while upgrade the existing STPs of capacity 31,841 MLD to tertiary treatment. The ULBs are inclined to adopt modern and advanced treatment technologies from western countries (Singhirunnusorn and Stenstrom, 2009). However, there is a lack of techno-economic feasibility studies of adopting such advanced technologies in a developing country such as India as the O&M in the long run is a serious concern. Thus, high-tech and advanced technologies implemented to attain the new norms might not sustain due to a lack of skilled personnel and technical expertise for operating the system; delayed maintenance in case of failures; or lack of funds for paying the energy bills (Asolekar et al., 2014).

## 1.2. Overview of Sewage Treatment Technologies

A plethora of sewage treatment technologies exist in the market. Several advancements have been achieved over the period due to growing research and significant number of variants in technologies are also available. However, the basic categorization of treatment remains the same, as illustrated in Figure 1.

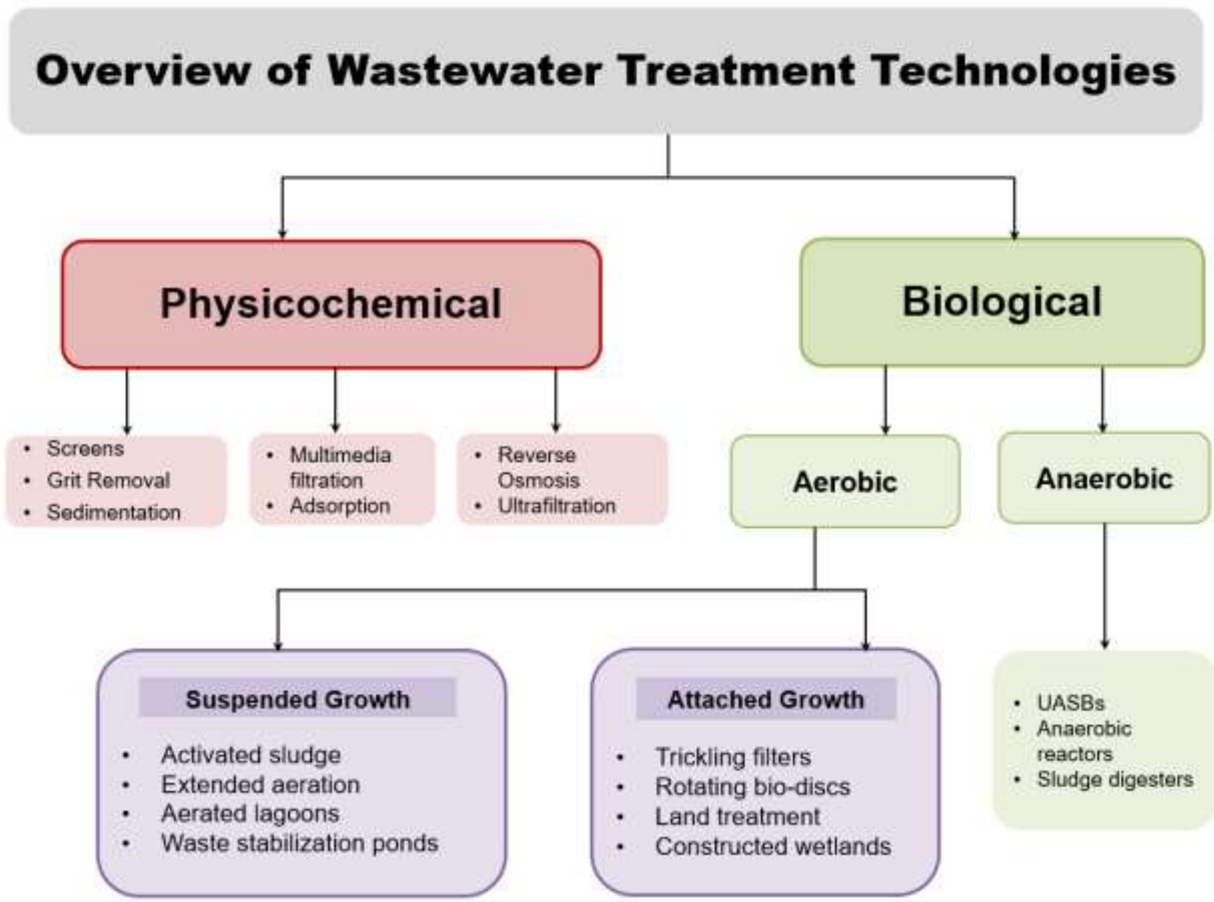



**Figure 1:** Overview of Wastewater Treatment Technologies (Adapted from Arceivala and Asolekar, (2017)

Broadly speaking, wastewater treatment technologies can be categorized as physicochemical and biological. Physicochemical treatment involves unit operations such as sedimentation, adsorption, and filtration. Biological processes can either be aerobic or anaerobic, depending on the presence or absence of oxygen. Aerobic processes are of two types. In suspended growth, the biomass remains in a suspended form in the wastewater, while in attached growth, the biomass gets attached to media used in the treatment systems. Many technology providers are prevalent in market for the commonly prevalent treatment technologies; however, the basis of treatment and the scientific principles are essentially the same, and any sewage treatment technology has to fall in one of the above classifications.

Typically, aerobic treatment requires continuous provision of oxygen for the microbial degradation to take place. On the other hand, anaerobic treatment functions in environments devoid of oxygen; however, in this case either the efficiency is compromised (for a similar detention period as of aerobic systems) or a larger capacity or treatment volume is required. The treatment technologies achieving good removal efficiencies are either costly due to the energy demand, or require large land, resulting in an increased land (capital) cost. Thus, wastewater treatment often involves a trade-off between energy and land. This tradeoff results in a broad classification of treatment technologies as Mechanized Treatment Systems (MTS) and Natural Treatment Systems (NTS). MTS such as Activated Sludge Process (ASP), Sequencing Batch Reactor (SBR), Membrane Bioreactor (MBR), Moving Bed BioReactor (MBBR), require less land area but higher energy whereas natural treatment systems are low-cost treatment alternatives requiring land. NTS such as Constructed Wetlands (CWs), Duckweed Ponds (DWPs) or Waste Stabilization Ponds (WSPs) are potential low-cost alternatives in this regard, which are not adequately explored due to relatively higher land requirements. The major points of differences between the two treatment approaches namely mechanized and natural, are depicted in Table 1.

**Table 5:** Differences between mechanized and natural treatment

| Sr. No | Point of difference | Mechanized | Natural |
|---|---|---|---|
| 1 | Land | Low | High |
| 2 | Energy | High | Low |
| 3 | Operating cost | High | Low |
| 4 | Nutrient removal | Inadequate | Adequate |
| 5 | Pathogen removal | Inadequate | Adequate |
| 6 | Heavy metal removal | Inadequate | Adequate |
| 7 | Suitability across geographic areas | Negligible effect | Dependence on climatic conditions |
| 8 | Guidelines and policies | Available and generally adopted | Clear guidelines policies mandating not available |

The engineered natural treatment systems have broadly been categorized under the heads of systems using phytoremediation (plants); bioremediation (microbes) and zoo-remediation (animals) (Chaturvedi, 2008). The term 'phyto' means plants. The wastewater treatment systems involving the use of plants for nutrient and metal uptake or those using algae are considered under phytoremediation. Bioremediation involves the use of microorganisms whereas zoo-remediation involves the use of animals such as fish or earthworms to carry out wastewater treatment. Considering the numerous advancements in treatment technologies and the rise in patented technologies, the above categorization of engineered natural wastewater treatment systems can be slightly modified to include a fourth category termed 'natural hybrid systems' in the classification as seen in Figure 2. Constructed wetlands also involve microbial action in the pollutant removal and can also be considered under the natural hybrid combination of 'phyto + bio'.

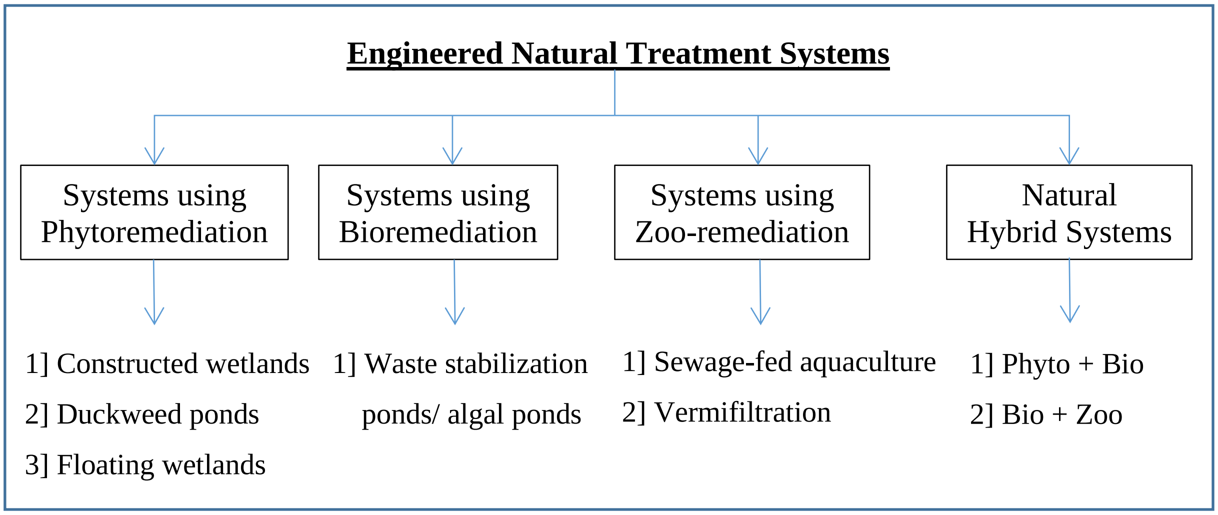



**Figure 2:** Categorization of Engineered NTS (Adapted from Chaturvedi, 2008)

The perilous balance between the growing water demands and supplies has led to a forceful adoption of recycling and reusing water. However, hardly any of the technologies produce an effluent of recyclable quality for high-end applications at an affordable cost. Each category of wastewater treatment i.e. mechanized and natural has its own advantages and disadvantages making it appropriate for different land settings. The land requirement mainly limits the full-fledged use of non-mechanized treatment technologies especially in urban areas, while it is the enormous operational cost limiting the adoption of mechanized treatment in rural and peri-urban areas. Hence, it is necessary to come up with intelligent combinations of treatment technologies to achieve effluent which can be reused and recycled in different scenarios. Amidst the stringent norms by regulatory authorities such as NGT, the challenge is to attain the required wastewater disposal norms while adhering to international commitments such as Sustainable Development Goals (SDG). To leverage the benefits of both MTS and NTS, strategically combining NTS with the conventional MTS to achieve sustainable water management has been put forth as an approach referred to as ‘Hybrid Treatment Systems’ (HTS) (Kalbar, 2021). The schematic of HTS is represented in Figure 3.

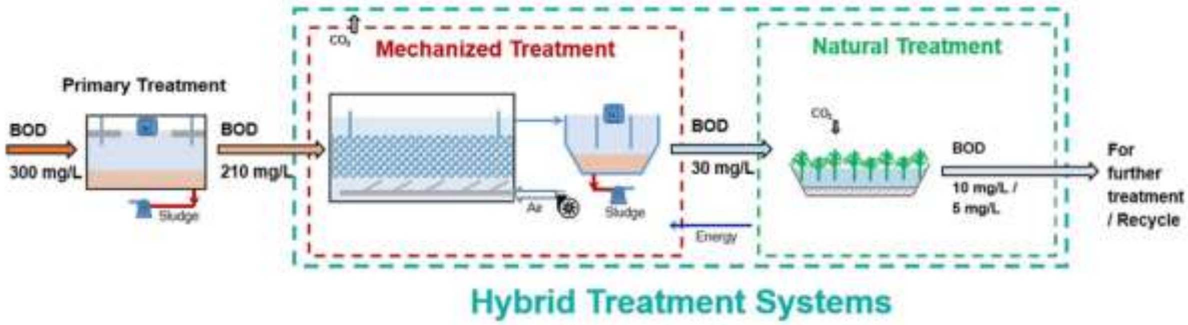



**Figure 3:** Concept of Hybrid Treatment Systems (Adopted from Kalbar, 2021)

## 1.3. Need for appropriate technology selection

Investments in infrastructure projects such as wastewater treatment are carried out for a long-time frame and are hence costly. The urban local bodies need to properly investigate the sewerage planning before making huge investments in sewage treatment facilities. A large number of treatment technologies have experimentally proved successful removal of various contaminants from wastewater. However, each experiment is carried out with specific treatment technologies and in a particular lab environment. Each technology has its own advantages and limitations, when scaled up on ground. Hence, despite the proven technology, it not necessarily functions to its desired standards in every scenario. There are technology providers in the market claiming for their technology to be innovative, unique and superior among all. In this scenario, there is confusion while choosing the technology among the Urban Local Bodies (ULBs), who often lack technical understanding regarding the same. Wastewater treatment before disposal is mandatory as per the Central Pollution Control Board (CPCB) and recently the discharges standards are made more stringent.

Mechanized sewage treatment systems are not adequately capable of removing nutrients nitrogen and phosphorus thereby causing high sludge production and eutrophication issues on disposal in water bodies. The conventional wastewater treatment technologies such as ASP and UASB, trickling filters only remove the biodegradable and carbonaceous pollutants. These complicated mechanized technologies however fail to reduce the nutrient load of nitrogen and phosphorus effectively (Kumar et al., 2015). Further, the mechanized systems also lack capacity of coliform removal (Rani et al., 2021). This makes the effluent unsuitable and poses a risk on its reuse. Even if some advanced treatment technologies are available, they are very costly and demand skilled technical expertise. However, natural treatment systems have the potential to achieve good nutrient as well as coliform removal at an affordable cost. It is of utmost importance to explore these wastewater treatment solutions to augment the existing sewage treatment capacity. In any case, it is important to identify and understand the context in which a particular treatment technology has to be adopted due to the tradeoffs in costs, performance efficiency, and resource requirement.

It is the situation, and not the technology, that decides the appropriateness of technology selection (Kalbar et al., 2012). The one-size-fits-all approach fails in managing the liquid waste, hence, it is important to analyze the location where wastewater treatment is to be implemented. The existing infrastructure, population density, awareness level of stakeholders, availability of skilled manpower, funds availability, end use of treated wastewater *etc*. are a few of the factors to be considered for decision-making. However, decision-making often lacks the inclusion of multiple criteria, and public utilities tend to create infrastructure on the basis of capital cost alone. Lack of consideration of O&M and planning infrastructure from a holistic perspective results in the failure of sustenance of treatment technologies.

A developing country such as India has a huge gap in sewage generation and treatment capacity. The Government has allocated funds for sewage treatment, and the focus should be on creating 'sustainable and resilient' sewage treatment plants (Kalbar and Lokhande, 2023). The infrastructure once created is difficult to dismantle and hence inappropriate technology selection unnecessarily results in wastage of financial and material resources (Kalbar et al, 2016). The treatment of wastewater generated by the rural community is not even addressed in India till date (Wintgens et al., 2016). Depending on the location of application and the end-use of the treated wastewater, it is necessary to go beyond the conventional approach of low-costs to integrate multiple dimensions of sustainability. Hence, in the wake of confusion and lack of awareness among decision makers and other stakeholders regarding technology selection, there is a need for a decision support tool to facilitate Urban Local Bodies select an appropriate technology based on the locality or the city, and ensures maximum sustainability and resilience with minimum costs.

# 2. Multi-Criteria Decision Making

A plethora of technologies are available in the market, each of them have certain advantages and disadvantages, making them suitable in certain localities or under certain contexts. The conventional approach of selecting technologies based on capital cost and a one-size-fit-all approach in planning has resulted in several problems and failures of municipal STPs due to multiple issues. Further, to overcome the challenges of wastewater sector, it is becoming increasingly important to address the decision-making from all dimensions of economic, environmental, social, technical essentially making technology selection and infrastructure planning a complex problem. The units and means of gauging various parameters are very wide and hence, simultaneous inclusion of different dimensions needs multi-criteria decision-making techniques to bring all parameters on a comparable level. Hence, the use of multi-criteria decision-making methods has gained importance in wastewater treatment.

Several communities are eager to improve the sanitation in their locality but either face budget issues or lack technical assistance. The water bodies in India are deteriorating due to disposal of untreated wastes. Elected representatives in developing countries taking measures to improve the conditions of water bodies require strong base to justify the investments (Kalbar et al., 2016). A decision support tool to facilitate the urban and rural local bodies select an appropriate treatment system could significantly contribute to improving the wastewater treatment infrastructure in India.

## 2.1. Decision Support for Wastewater Sector

The objective of a Decision Support System (DSS) is to find out a suitable technology that maximizes the quantity of treated water with minimal costs and environmental impacts. DSS have the advantage of presenting a comprehensive evaluation in days, for which ULBs would require months. The traceability of results and the ease of presenting them to persons lacking technical background makes DSS a popular choice (Laura et al., 2020). DSS helps the planners, decision makers and variety of stakeholders to tackle the concept of sustainability from multiple dimensions, rather than only focusing on treatment efficiency of technologies or capital cost of the infrastructure (Zhao et al., 2019). Moreover, the trade-offs associated with wastewater treatment demand techniques that can quantify the trade-offs, and DSS can essentially aid technology selection by accounting for the trade-offs. DSS have been used by researchers for the selection of appropriate wastewater treatment technologies (Kalbar et al., 2012b; Khattiyavong and Lee, 2019; Rezaei et al., 2019; Sadr et al., 2018). The evolution of decision support systems over the decades as depicted by Mannina et al. (2019) has been presented in Figure 4.

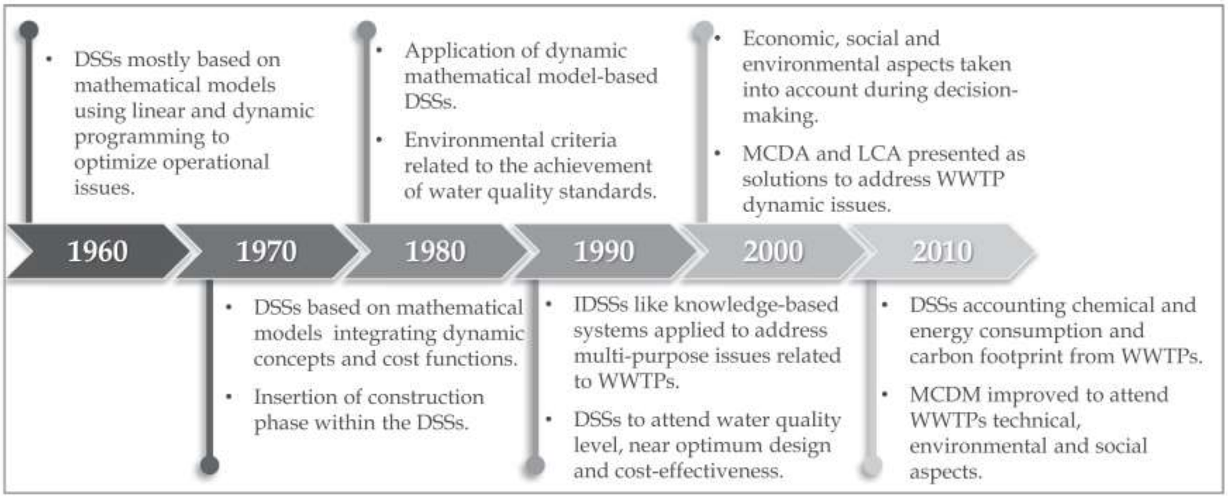



**Figure 4:** Evolution of decision support systems (Adopted from Mannina et al., 2019)

A systematic review of various decision support systems (DSS) applied for wastewater treatment plants conducted by Mannina et al. (2019) has reported life cycle assessment, mathematical models, multi-criteria decision making and intelligent DSS as the four commonly adopted approaches. The focus of different studies includes design, energy consumption, operational optimization, improved effluent quality and environmental sustainability. Although mathematical models were popular due to their widespread knowledge; however, Multi-Criteria Decision-Making (MCDM) approach is most reliable to achieve optimization of wastewater treatment plants (Mannina et al., 2019). In certain cases, hybrid models of decision-making have been applied (Sadr et al., 2018). AHP and its derivatives are useful approaches to deal with complexities involved in selection of wastewater treatment technologies (Arroyo and Molinos-Senante, 2018). Mathematical models have been coupled with TOPSIS in one study to optimize behavior of plant based on membrane bioreactors (Mannina et al., 2019). Application of five MADM methods has showed TOPSIS to be the suited for wastewater technology selection (Kalbar et al., 2016). Technique for Order of Preference by Similarity to Ideal Situation (TOPSIS) and Analytical Hierarchy Process (AHP) are reported to be the commonly used multi-criteria decision attribute tools. The use of LCA in combination with multi-criteria analysis is widely used for the evaluation of available alternatives (Kalbar et al., 2014; Rezaei et al., 2019). Table 2 summarizes the application of decision support systems in wastewater sector.

**Table 6:** Applications of decision support systems in wastewater sector

| Description/ Paper title | Methods/ approach | Scenarios/ criteria | Reference |
|---|---|---|---|
| Managing sludge from wastewater treatment plants | Multi-criteria analytical hierarchy process (AHP) | 3 main criteria, 9 sub-criteria, 5 alternatives | Qdais, 2019, (Jordan - only abstract available) |
| Sustainability assessment of tertiary wastewater treatment technologies: a multi-criteria analysis | 'triple bottom line' approach; multi-attribute rating technique exploiting ranks: only framework in this paper | 4 tertiary wastewater treatment technologies | Plakas et al., 2016 |
| Comparing multi-criteria decision analysis and integrated assessment to support long-term water supply planning | models used in multi-attribute value theory (MAVT)–to integrated assessment (IA) models | 13 system scale water supply alternatives; 4 future scenarios; 44 objectives | Scholten et al., 2017 (Switzerland) |
| Multi-objective performance assessment of wastewater treatment plants combining plant-wide process models and life cycle assessment | dynamic process models – including (GHG), detailed energy models and operational cost – and LCA | - | Arnell et al., 2017 |
| Collaborative Risk Informed Decision Analysis: A water security case study in the Philippines | Collaborative Risk Informed Decision Analysis (CRIDA) method – step by step bottom-up approach to risk assessment | recommendations for the selection of a strategy direction (i.e. flexible vs. robust); economic evaluation method; funding and governance requirements needed to complete planning | Gilroy and Jeuken, 2018 |
| Selecting appropriate wastewater treatment technologies using a choosing-by-advantages approach | | 7 technologies, mix of natural and mechanized are compared and analysed | Arroyo and Senante, 2018 |
| A scenario-based multiple attribute decision-making approach for site selection of a wastewater treatment | MADM TOPSIS (problem also included GIS and hydraulic analysis for site selection) | 15 practically feasible alternatives; 3 sustainability dimensions; 4 scenarios (equal; | Wondim and Dzwairo, 2018 |

| Description/ Paper title | Methods/ approach | Scenarios/ criteria | Reference |
|---|---|---|---|
| plant: Bahir Dar City (Ethiopia) case study | | higher weights to different sustainability dimensions) | |
| Decision support system for management of reactive nitrogen flows in wastewater system | Causal loop diagrams, stock model, scenario analysis | No nitrogen recovered; no N removal but advanced agricultural practices; N recovered from WWT; urine segregated and no N recovered; N recovered from treated wastewater, biosolids, and segregated urine; scenario 5 + policy for the stabilization of protein consumption | Nascimento et al., 2018 |
| A multi expert decision support tool for the evaluation of advanced wastewater treatment trains: A novel approach to improve urban sustainability | the mathematical model has been incorporated into the IMCMEDM tool (Multi-Criteria Multi-Expert Decision Making) | 1] WWT through advanced technologies (membrane technology) for industrial water reuse<br>2] WWT using membrane technologies for unrestricted agricultural irrigation in Herakleion, Greece | Sadr et al., 2018 |
| A decision support tool for selecting the optimal sewage sludge treatment | Multi-Attribute Value Theory (MAVT) | | Turunen et al., 2018 (Finland) |
| Multicriteria decision making model of wastewater reuse: a stakeholders' perspective in the context of India | AHP | | Das et al., 2019 |
| Performance Simulation and Assessment of an Appropriate Wastewater Treatment Technology in a Densely Populated Growing City in a Developing Country: A Case Study in Vientiane, Laos | Process simulation using Biowin and TOPSIS | Trickling filter and activated sludge process in centralized; on-site and decentralized scale – 6 scenarios; four environmental criteria: (1) land requirement, (2) electricity use, (3) sludge | Khattiyavong and Lee, 2019 |

| Description/ Paper title | Methods/ approach | Scenarios/ criteria | Reference |
|---|---|---|---|
| | | production, and (4) $CO_2$ emissions | |
| Multicriteria decision making model of wastewater reuse: a stakeholders' perspective in the context of India | AHP; face to face and web interviews | Economic, environmental, engineering, technological and social feasibility | Das and Radhakrishnan, 2019 |
| A multi-criteria sustainability assessment of water reuse applications: a case study in Lakeland, Florida | Concept of regret-based decision-making model is adopted | US EPA 2012 guidelines for water reuse used to design seven scenarios (diff end uses); economic, environmental and social indicators | Rezaei et al., 2019 |
| HIT.WATER scheme: An integrated LCA-based decision-support platform for evaluation of wastewater discharge limits | LCA system linked with Water Quality Model (WQM), Plackett–Burman (PB) design and Conjoint Analysis (CA) | | Bai et al., 2018 |
| Selecting sustainable sewage sludge reuse options through a systematic assessment framework: Methodology and case study in Latin America | | | Laura et al., 2020 |

## 2.2. Selection criteria for wastewater treatment

In any practical scenario, the problem of wastewater treatment technology selection involves decision making based on a finite number of alternatives and criteria. Researchers have identified a number of relevant criteria covering technical, economical, societal, and other aspects which can be either quantitative or qualitative in nature.

In Multi-Attribute Decision-Making (MADM), the preference for a particular alternative can be measured on an ordinal scale or on a cardinal scale. With ordinal scales, non-numerical properties, such as ratios or intervals, are used; the characterization of objects is purely relational, and objects are rank ordered. Intensity of preference is not apparent from ordinal scales. Ordinal scales can be expressed in terms of numbers or verbal rankings, e.g., 1, 2, 3, 4, etc. or as bad, good, and excellent. Cardinal scales assign numerical values (numbers, intervals, ratios, etc.) to objects. Attributes can be of the following three types:

1. Benefit attributes offering increasing monotonic utility i.e. greater the attribute value, higher is its preference. For example, fuel efficiency.
2. Cost attributes offering decreasing monotonic utility i.e. lower the attribute value, higher is its preference. For example, production cost.
3. Non-monotonic attributes offering non-monotonic monotonic utility i.e. the maximum utility is located somewhere in the middle of the attribute range. For example, room temperature in an office and blood sugar level in a human body.

To overcome the challenges of wastewater sector, it is becoming increasingly important to address the decision-making from all dimensions of economic, environmental, social, technical which essentially makes technology selection and infrastructure planning a complex problem. Each of these dimensions. Hence, the use of multi-criteria decision-making methods such has gained importance in wastewater treatment. The indicators outlined in Table 3 have popularly been considered in literature regarding decision-making related to wastewater treatment technology selection.

**Table 7:** Criteria for wastewater technology selection

| **Technical** | | |
|---|---|---|
| **Criteria** | **Unit** | **References** |
| Water quality/ parameter removal efficiency | % / 5-point scale | Plakas et al, 2016; Wencki et al, 2020; Arroyo et al, 2018 |

| | | |
|---|---|---|
| Sludge production | kg/day | Case et al, 2019 |
| Adaptability | 5-point scale | Spuhler et al, 2020; Wencki et al, 2020 |
| Flexibility/ Operability | 0 to 100 | Kalbar et al, 2012; Laura et al, 2020 |
| Reliability | 0 to 100; 0 to 1 | Kalbar et al, 2012; Spuhler et al, 2020; Plakas et al, 2016; Laura et al, 2020; Sadr et al, 2020; Turunen et al, 2018 |
| Integrability in existing infrastructure | 5-point scale | Spuhler et al, 2020; Wencki et al, 2020 |
| Technical complexity | 5-point scale | Wencki et al, 2020; Plakas et al, 2016; Wencki et al, 2020; Arroyo et al, 2018 |
| Operational safety | 5-point scale | Wencki et al, 2020 |
| **Economic** | | |
| **Criteria** | **Unit** | **References** |
| Life cycle costs | Rs. Lakh/ MLD | Kalbar et al, 2012 |
| Net energy costs annualized | | |
| Land requirement | M2/ MLD or m2 or m2/pe | Kalbar et al, 2012; Spuhler et al, 2020; Plakas et al, 2016; Sadr et al, 2020; Wencki et al, 2020; Arroyo et al, 2018; Laura et al, 2020; Case et al, 2019 |
| Construction cost/ capital costs/ Initial investments/ CAPEX | Rs. Lakh/ MLD or Euros/ p.e. | Spuhler et al, 2020; Plakas et al, 2016; Sadr et al, 2020; Laura et al, 2020; Rezaei et al, 2019 |
| O&M costs/ OPEX | Rs. Lakh/ MLD or Euros/ $m^3$ | Spuhler et al, 2020; Plakas et al, 2016; Sadr et al, 2020; Laura et al, 2020; Rezaei et al, 2019 |
| Cost for consumables annualized/ spare parts/ labour cost | | Sadr et al, 2020 |
| Willingness to pay | | Rezaei et al, 2019 |
| Total monthly profit from sludge commercialisation | | Laura et al, 2020 |
| Overall costs/ TOTEX | EUR/ m3 | Wencki et al, 2020; Sadr et al, 2020 |
| Market position/ competition | 5-point scale | Wencki et al, 2020 |
| Added local economic value | EUR/m3 | Wencki et al, 2020 |
| Opportunity costs | EUR/d | Wencki et al, 2020 |
| **Social** | | |
| **Criteria** | **Unit** | **References** |
| Human resources/ No of personnel required | Number/ 5 -point scale | Wencki et al, 2020 |
| Skilled/ unskilled labour | Number | Sadr et al., 2020 |

| | | |
|---|---|---|
| Odour impact | | Plakas et al, 2016; Arroyo et al, 2018; Lura et al, 2020 |
| Noise impact | | Plakas et al, 2016; Arroyo et al, 2018; Lura et al, 2020 |
| Visual impact | | Plakas et al, 2016; Arroyo et al, 2018 |
| Community/ public acceptance | 0 to 100; 5-point scale; 0 to 10 | Kalbar et al, 2012; Spuhler et al, 2020; Plakas et al, 2016; Sadr et al, 2020; Wencki et al, 2020; Arroyo et al, 2018; Turunen et al, 2018; Laura et al, 2020 |
| Public health benefits | 5 -point scale | Sadr et al, 2020; Wencki et al, 2020 |
| Reduced pathogen exposure/ ingestion risk; gas inhalation | | Spuhler et al, 2020; Laura et al, 2018 |
| Ease of use for consumer | | Sadr et al., 2020 |
| Community engagement | 0 to 100 or Employees/ pe | Kalbar et al, 2012; Plakas et al, 2016 |
| **Environmental** | | |
| **Criteria** | **Unit** | **References** |
| Global warming/ GHG emissions | kg $CO_2$-Eq/p.e.-year; kg $CO_2$-eq/$m^3$/year; kgC/$m^3$; ton/year; kg/day | Kalbar et al, 2012; Landa et al, 2020; Sadr et al, 2020; Turunen et al, 2018; Case et al, 2019; Rezaei et al, 2019 |
| Energy consumption/ Electricity use | kWh/$m^3$/year; KWh/$m^3$ | Spuhler et al, 2020; Landa et al, 2020<br>Plakas et al, 2016; Sadr et al, 2020; Wencki et al, 2020; Arroyo et al, 2018; Case et al, 2019 |
| Reliability of water supply | | Landa et al, 2020 |
| Transportation | km | Laura et al, 2020 |
| Consumption of process and operating resource | g/ m3 water produced | Wencki et al, 2020 |
| Low contamination of water resources and air | | Spuhler et al, 2020 |
| Durability of plant/ Process stability | 0 to 100 or years/ failure | Kalbar et al, 2012; Wencki et al, 2020 |
| Replicability | 0 to 100 | Kalbar et al, 2012; Spuhler, 2020 |
| Promotion of sustainable behaviour | 0 to 100 or 5-point scale | Kalbar et al, 2012; Wencki et al, 2020 |
| Potential for resource recovery | Ton/ year | Spuhler et al, 2020; Arroyo et al, 2018; Arroyo et al, 2018; Turunen et al, 2018; Laura et al, 2020 |
| Compatibility with ecological zones/ Ecosystem services | 0 to 3; 5-point scale | Spuhler et al, 2020; Turunen et al, 2018; Wencki et al, 2020 |

| | | |
|---|---|---|
| Sewage sludge production/ demand for usage | 1-10 scale | Arroyo et al, 2018; Turunen et al, 2018 |

## 2.3. TOPSIS

One of the most popularly used MADM method having applications in the wastewater sector is Technique for Order of Preference by Similarity to Ideal Situation (TOPSIS). The algorithm of TOPSIS can be readily implemented computationally and made available as a decision support tool for the end users. The target end users may be engineers from urban local bodies, officials from developmental agencies, policy makers, and planning officials. The method is based on a compensatory approach and the utility is estimated by comparing each alternative directly depending on data in the decision matrices and weights. The method assumes that each attribute has a monotonically increasing or decreasing utility. The non-monotonic indicators can be qualitatively converted to monotonic indicators through expert judgments. The best alternative is identified by considering both the positive ideal solution and negative ideal solution. The disadvantage or unfavourable value in one attribute is offset by an advantage or favourable value in some other attribute. This mimics human thinking where humans always think of both positive and negative qualities of the alternative to choose the best available option among all. The geometric concept of distance measurement is used in TOPSIS as a proxy for human preference, which is a suitable approach for the decision-making with regard to wastewater management. The step-by-step process followed while decision-making using TOPSIS is depicted in Figure 5. The advantages of TOPSIS over other MADM techniques are:

(i) a sound logic that represents the rationale of human choice;

(ii) a scalar value that accounts for both the best and worst alternatives simultaneously;

(iii) a simple computation process that can be easily programmed into a spreadsheet; and

(iv) the performance measures of all alternatives on attributes can be visualized on a polyhedron, at least for any two dimensions.

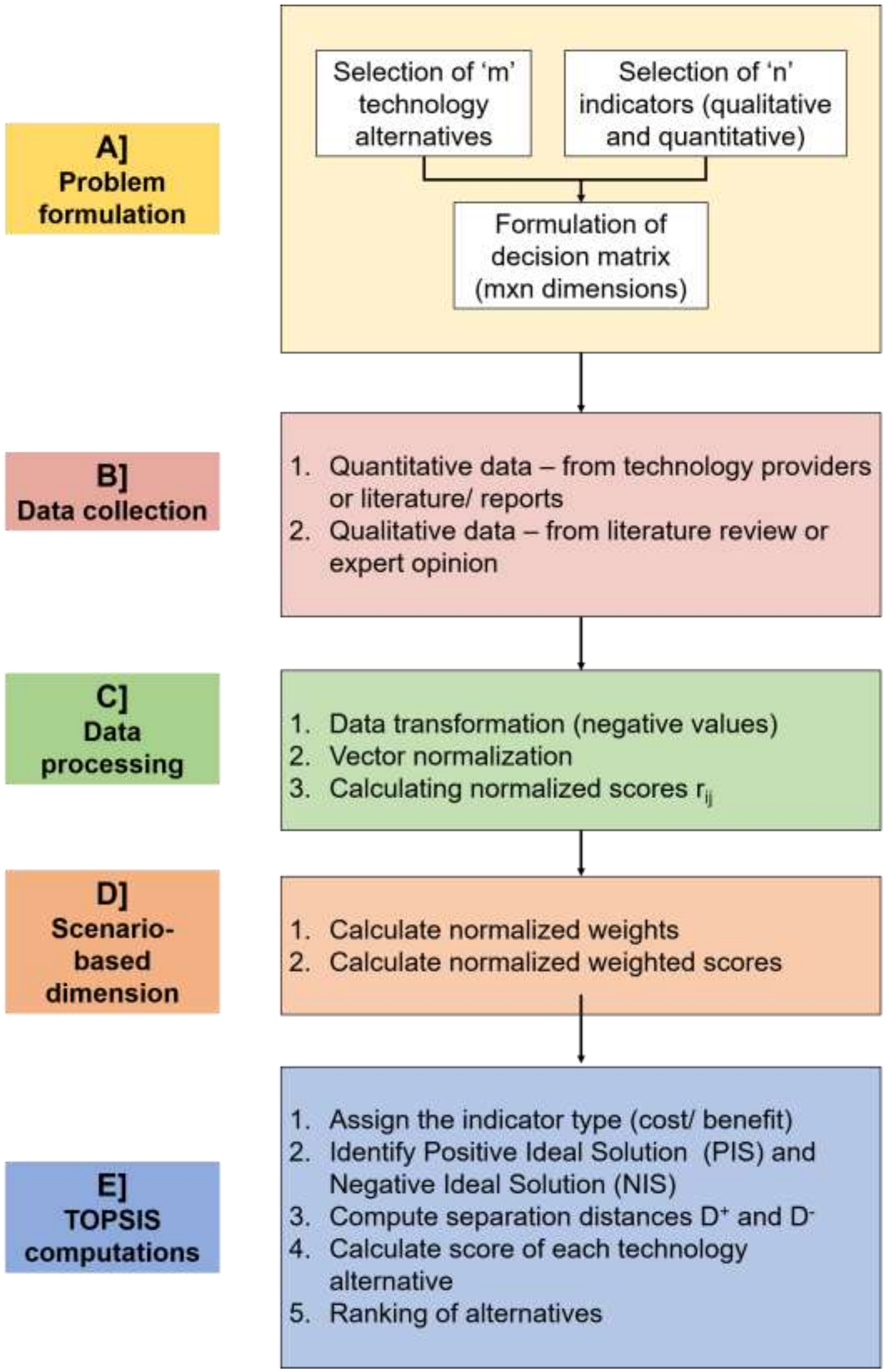



**Figure 5:** Steps involved in algorithm of TOPSIS

The first step is to shortlist the possible treatment technology alternatives for comparison. Next step is to choose the set of criteria and indicators that will be used to rationally prioritize the technology alternatives. Once this set of technology alternatives and indicators is in place, the decision matrix is formed. The information available Ai ¼ (A1, A2, ., Am), based on a set of attributes/criteria/ from the decision-makers can be represented in the form of matrix called a decision matrix which is shown in Figure 6. The data for relevant indicators can be obtained from technology providers in a standardized format, or can be compiled through secondary data sources and literature review. Once the decision matrix is completely filled with data regarding indicator values for the specified treatment technology alternatives, some preliminary operations such as data transformation (i.e. handling negative values) and normalization (i.e. vector normalization) are performed. There is also a provision to enter weights for different criteria, which gains significance in scenario-based decision-making (discussed in sub-section 2.4). TOPSIS ranks or scores a finite number of alternatives indicators, Xj ¼ (X1, X2, ., Xn).

$$
\begin{array}{llccccccc}
 & & & & \textit{Criteria/Attributes} & & & & \\
 & & X_1 & X_2 & X_3 & \cdots & X_j & \cdots & X_n \\
 & A_1 & x_1(a_1) & x_2(a_1) & x_3(a_1) & \cdots & x_j(a_1) & \cdots & x_n(a_1) \\
\textit{Alternatives/Options} & A_2 & x_1(a_2) & x_2(a_2) & x_3(a_2) & \cdots & x_j(a_2) & \cdots & x_n(a_2) \\
 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
 & A_i & x_1(a_i) & x_2(a_i) & x_3(a_i) & \cdots & x_j(a_i) & \cdots & x_n(a_i) \\
 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
 & A_m & x_1(a_m) & x_2(a_m) & x_3(a_m) & \cdots & x_j(a_m) & \cdots & x_n(a_m)
\end{array}
$$

**Figure 6:** A typical decision matrix in multi-criteria decision-making

## 2.4. Scenario based decision making

The approach of scenario based decision making for wastewater technology selection was introduced by Kalbar et al. ( 2012b). The need to expand the decision-making to include scenarios in rural areas was again reported by Sadr et al., (2018). Decision support software incorporate multi-criteria assessment tools which also include scenario based analysis, like those addressed for sludge handling by Laura et al. (2020). With a change in decision scenario, the evaluation emphasis of stakeholders is reported to get shifted (Bai et al., 2019). One study has evaluated from sustainability perspectives, the water reuse scenarios designed on the basis of guidelines (Rezaei et al., 2019).

The challenge in wastewater management is selection of the best available technology for the particular wastewater treatment objective at a particular site. A highly mechanized technology can be appropriate for a given situation, depending on the technological level of the community, labor and resource availability, and other factors. First level of information, as mentioned in Table 4, is often neglected due to lack of clarity, and specifying the scenarios can help overcome this limitation by including primary level information in the decision-making (Kalbar et al., 2012). Accordingly, depending on the context, in one scenario, an attribute can be a cost attribute, while in another scenario, the same attribute can be a benefit attribute due to the physical and/or economic conditions applicable to the scenario. For example, land requirement can be a cost indicator in urban and peri-urban areas where there is land constraint. However, in rural areas where land availability is not a major constraint, it can be a benefit indicator.

**Table 8:** Information levels for context-specific decision-making

| Level | Factor |
|---|---|
| First | such as the location of the plant, the objective of the treatment and land availability in the region |
| Second | number of alternatives available |
| Third | scores of the alternatives with respect to individual criteria or indicators |
| Fourth | weights associated with criteria or indicators, which can be assumed to be equal in the absence of information on how they should be weighted |

The methodology developed in this work effectively captures regional and local societal priorities in terms of weights for criteria for each scenario and translates them into the mathematical algorithms of the MADM methodology. The criteria and indicators need to be weighed, and scenario-based decision-making can help in better weighing by prioritizing appropriate indicators on a case-specific basis.

# 3. Life Cycle Costing for wastewater treatment

The common tendency of the ULBs is to adopt treatment technologies based on capital costs. However, the O&M aspect, which plays a significant role in the life cycle of the STP, is often ignored in this process, as a result of which, the systems tend to fail in the long run most of the times. Lack of consideration of O&M costs while planning infrastructure also leads to a failure due to the paucity of funds with the municipal corporations or ULBs to operate the systems. The extensive energy consumption leads to enormous electricity bills posing an economic burden. Failure in paying the bills during O&M of plants leads to MTS plants becoming defunct within a short span. Therefore, it becomes necessary to include O&M costs in the decision-making.

## 3.1. Methodology

To compare the treatment systems, it is necessary to account for Life Cycle Costs (LCC) being incurred during the entire lifetime of the wastewater treatment plant. In this tool, the present worth method of LCC is used. Present Value or the Present Worth is the sum of all possible costs incurred in the future, that are discounted to the present year of construction, and the initial investment costs. The detailed methodology can be found in IS 13174 Life Cycle Costing (Part 1 and 2). All the cash flows in the functional life of Wastewater Treatment Plants (WWTPs) are analyzed for a functional life of 30 years as STPs typically have a design life of 30 years. 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. Figure 7 shows a typical cash flow diagram for a wastewater treatment plant.

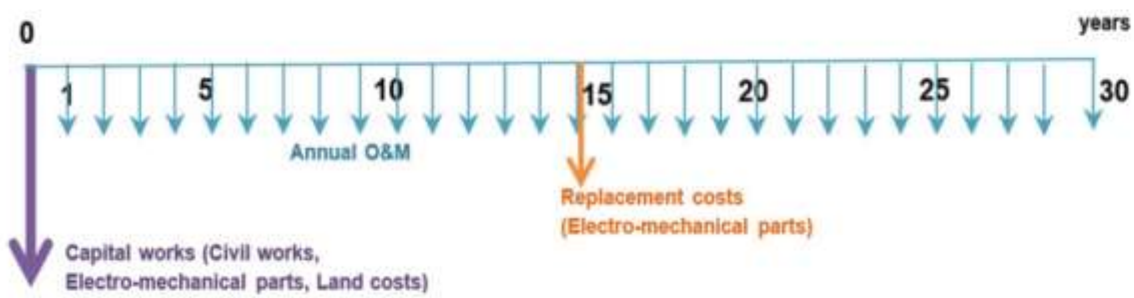



**Figure 7:** Cash flow diagram for LCC in wastewater treatment

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

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

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

The present worth of a uniform payment mode (A) compounded after 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 known as the uniform-payment series present worth factor.

**Cost components to be considered for analysis:**

1. Capital cost (includes land cost, civil and electromechanical costs)
2. O&M costs
    a. Energy
    b. Labour/ manpower
    c. Consumables (chemicals)
    d. Operation and maintenance
3. Replacement costs
4. Revenue generation

## 3.2. Significance of Life Cycle Costing

There exists a trade-off between O&M cost and land cost for MTS and NTS, which is distinctly seen in Figure 8. The O&M costs of MTS linearly increase with the BOD removal up to 30 mg/L. The escalation in costs is exponential as the outlet BOD crosses 30 mg/L due to the requirement of advanced technologies. However, as CWs are non-mechanized treatment systems, the O&M cost is not significantly impacted for BOD removal even beyond 30 mg/L. However, the land requirement for CWs increases exponentially with reduction in outlet BOD. This makes the use of CWs (and other NTS) for secondary treatment more suitable in rural and peri-urban settings in a decentralized manner, where land availability is not a major constraint. The land vs energy (or land vs O&M costs) trade-offs between MTS and CWs show that each of the systems if used individually is suitable for only a specific local condition. In this regard, the strategic combination of MTS and NTS to avails their trade-offs is suggested as an approach named HTS.

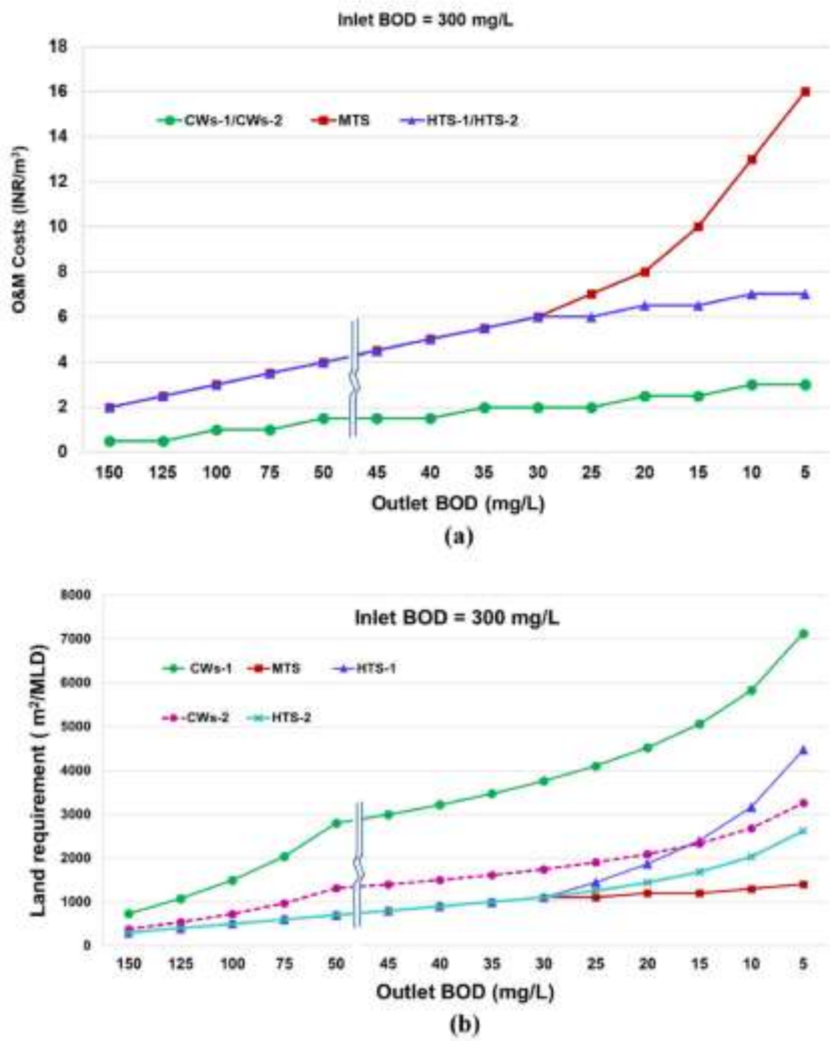



**Figure 8:** Trade-offs between land and O&M costs in wastewater treatment

The above-mentioned trade-offs necessitate the comparison of the two approaches from a life cycle perspective. Hence, LCC using the present worth method has been carried out by (Kalbar, 2022). The cost components considered in the analysis include capital costs (civil works, electro-mechanical equipment and land requirement), annual O&M costs (labor, energy, chemicals and routine maintenance) and replacement costs for the electro-mechanical components. The land cost is assumed as INR 0.04 Lakh/ $m^2$ in urban areas whereas $2/3^{rd}$ and ½ of this cost are assumed in peri-urban and rural areas respectively. The calculations are performed for 30-year design life of STP at an assumed discount rate of 10% for analysis.

The results of LCC show that consideration of land costs result in CWs being the most capital-intensive technology choice in urban, peri-urban, and rural settings. However, the consideration of

O&M costs for 30 years shows CWs to be the most economical option. This suggests the significance of O&M costs in the economic evaluation of the wastewater treatment technology selection as against the commonly adopted capital cost. Table 5 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. The results of Table 5 are graphically represented in Figure 9. The trend of capital costs shows MTS to be cheaper. However, O&M costs for NTS and HTS are substantially lower than MTS, and are significantly observed to impact the LCC. This analysis shows that the inclusion of LCC in analysis has potential to change the decision taken against short-term considerations.

**Table 9:** Life Cycle Costs in Urban, Peri-urban and Rural areas for different wastewater treatment technologies

| 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 |

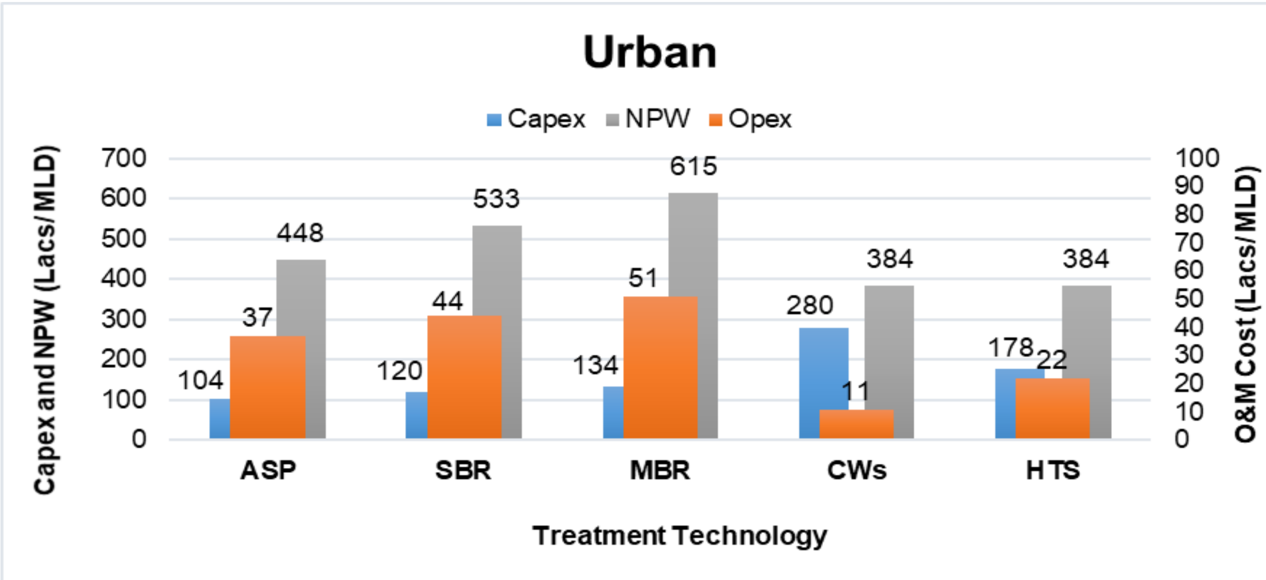



**Figure 9:** Capital, O&M and life cycle costs comparison for different treatment technologies

## 3.3. Life cycle costing framework in JalVishwa

The land and energy prices vary across the nation. Hence, for the same technology, land costs and O&M costs might differ. Considering this dynamism in the cost considerations, a dynamic life cycle costing module is developed for representative analysis of life cycle costs through the net present worth of the present as well as future investments. The cash flow diagram assumed for computations is as shown in Figure 10.

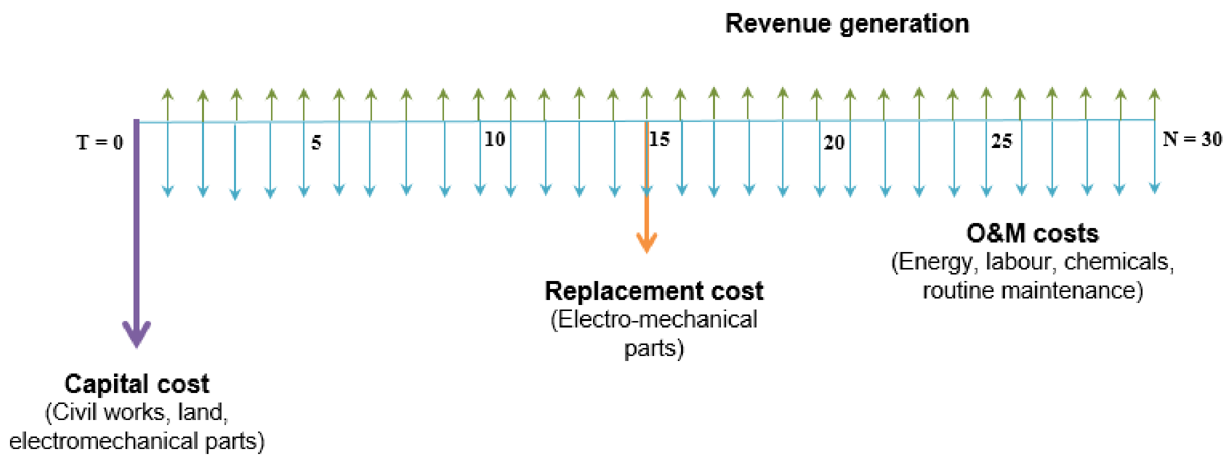



**Figure 10:** Cash flow diagram for LCC in wastewater treatment

# 4. Decision-making for wastewater treatment

Multi-Attribute Decision-Making (MADM) is majorly associated with decision-making problems involving a finite number of alternatives (known as discrete variable problems), whereas Multi-Objective Decision-Making (MODM) is concerned with decision-making problems with an infinite number of alternatives (known as continuous variable problems). Considering the application of treatment technology selection in the wastewater sector, MADM is suitable due to discrete technology alternatives. Technique for Order of Preference by Similarity to Ideal Situation (TOPSIS) and Analytical Hierarchy Process (AHP) are reported to be the commonly used multi-criteria decision attribute tools.

## 4.1. Criteria and indicators in framework

**Criteria and Indicator Selection:**

Six criteria are broadly considered in the decision support tool.

1. Economic
2. Social
3. Environmental
4. Technical
5. Circularity
6. Resilience

From the sustainability perspective, economic, social and environmental criteria form the pillars of sustainability. Additionally, technical criteria are also significant for ensuring the sustenance of plant by the operators. Further, amidst freshwater scarcity and resource constraints, circular economy is gaining significance in the wastewater sector. Hence, the circularity potential of a particular treatment technology is also significant in today's time. Lastly, in the wake of climate change and occurrence of extreme events, it is necessary for the STPs to be resilient enough to resume service without causing much damage through service disruption to the public. Figure 11 shows the various indicators that can be used to quantify each of the criteria considered for technology assessment.

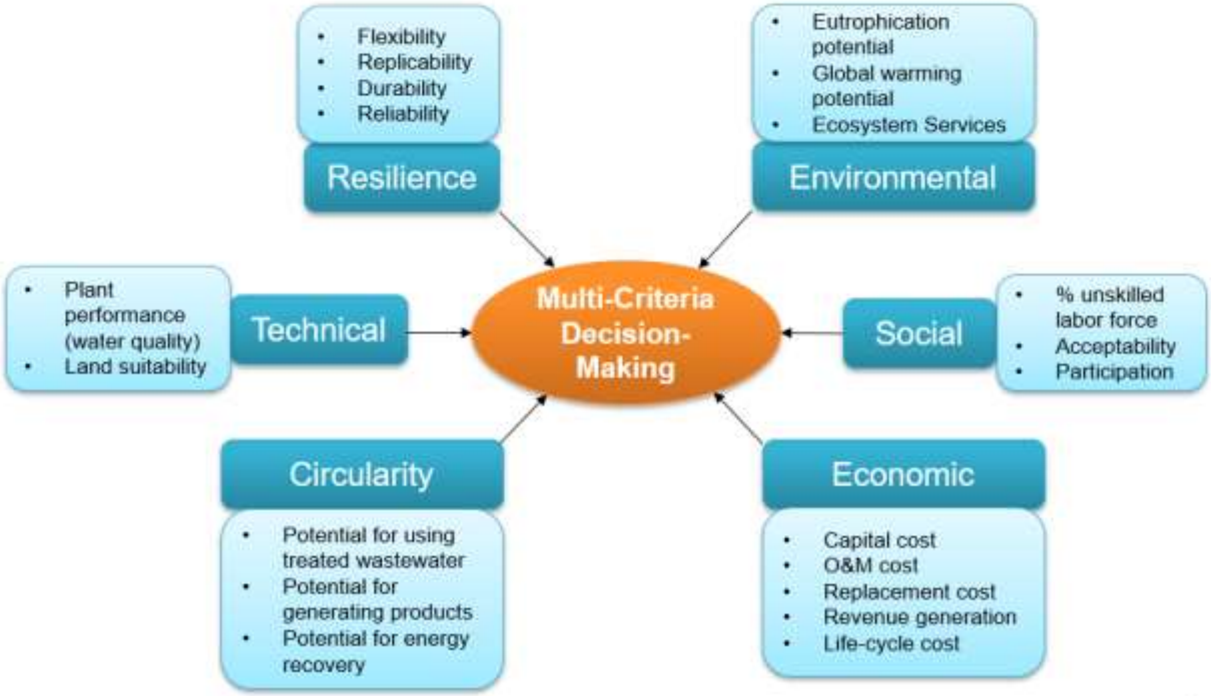



**Figure 11:** Proposed criteria and indicators for appropriate wastewater treatment technology selection

### 4.1.1. Economic

Capital cost includes the cost of electromechanical components and construction cost, and is the typical decision-making criteria. If land is not available with the urban local body, the land cost can be considered separately or might be included in capital cost. ***Capital cost*** often becomes the decision-making criteria particularly when an external funding agency is involved to support the creation of infrastructure.

After creation of STP facilities, the ULBs are responsible for operating and maintaining the treatment systems. The ***O&M costs*** substantially differ across the categories of treatment technologies due to the varying energy requirements. While mechanized treatment systems are energy-intensive, natural treatment systems have substantially lower energy requirements. O&M costs have been reported to be a dominant component in LCC of wastewater treatment technologies (Kalbar, 2022), the negligence of which in decision-making can lead to inappropriate technology selection.

Some technologies may be patented or might be from the developed countries. Over a period of time, certain parts or units may need replacement. In case of breakdown or failures, the service may be hampered and needs long waiting period till the replacement components are made available or the technical issues are resolved. In this regard, technologies demanding lower ***replacement costs*** will be favoured, or those technologies whose replacement can be managed locally.

Some technologies also have potential for revenue generation, alternatively, resource recovery or wastewater recycling can also be set up as a business model to ensure ***revenue generation*** from the STPs. Revenue generation can be given a higher priority in areas where ULB's are facing the challenges of inadequate funds or employment issues.

All the above-mentioned cost components play a vital role in technology selection; hence, they should be considered in decision-making. Instead of considering individual costs, ***life-cycle costs*** can account for all the costs simultaneously, and should be the ideal or preferred economic indicator for technology selection.

### 4.1.2. Environmental

Along with wastewater treatment, the effluent quality is of utmost relevance specially when the treated wastewater is disposed in nearby water bodies. An undesirable consequence of excess nutrients in water bodies is the emergence of aquatic plants at a growth rate exceeding the ecosystem balance. The presence of excess nutrients in water bodies has resulted in eutrophication in rivers and lakes across the globe. Hence, ***eutrophication potential*** is a useful environmental indicator in this regard. The eutrophication potential of wastewater treatment should be minimum to protect the aquatic ecosystems.

Some treatment technologies are energy-intensive and hence consume larger electricity. However, the nation has international commitments towards SDGs necessitating a check on energy consumption for wastewater treatment. Even if a particular technology has outstanding performance but requires substantial energy for treatment, it needs reconsideration. In this regard, the environmental indicator of ***Green House Gas emissions*** can be used to assess the treatment technology options.

Wastewater treatment has the primary target of contamination removal and improving the effluent quality. However, there are some natural treatment technologies that can provide secondary benefits apart from treatment such as aesthetically pleasing surroundings, temperature regulation, carbon sequestration etc. In this way, wastewater treatment using such systems can also provide ***ecosystem services***.

### 4.1.3. Technical

The performance of the treatment technology in terms of ***parameter removal efficiency*** is the crucial technical aspect. The organic removal, nutrient removal, fecal coliform removal should be such that the desired treatment standards are met. Moreover, if the wastewater treatment is oriented for recycling or reclamation, the cost aspects of tertiary treatment involving coliform removal play a key role. The additional expenses borne for advanced treatment using mechanized treatment systems are significantly higher than that incurred by using natural treatment systems. In this manner, the tertiary treatment cost as a fraction of secondary treatment might differ for various treatment technologies.

Apart from the water quality aspects, ***land requirement*** for a particular technology will also depend on the plant capacity to be designed, technology under consideration and the wastewater characteristics for the given context. Further, land suitability for wastewater treatment is also vital.

### 4.1.4. Resilience

Wastewater treatment plants are designed for a longer time frame of up to 30 years. Amidst the climate crisis and pressure to conserve environment and natural resources, there are growing mandates on stringent norms for effluent disposal or usage of recycled wastewater for various purposes. The STP designed for a particular standard might need upgradation in the due course of time or the end use of treated wastewater might change. For example, if an STP disposing treated wastewater in the river is now required to supply treated wastewater to a nearby residential colony, then the coliform removal needs to be ensured for safe recycling. Such changes in objectives are accounted by ***flexibility*** of a particular treatment technology to changes input or output design parameters.

If any ULB needs to implement wastewater treatment in a decentralized manner, it necessitates the installation of multiple STPs in the same region. If a particular treatment technology is deemed suitable in for a given locality or a city, then ease of ***replicability*** becomes crucial, that can facilitate better construction of STPs with requirement of technical expertise for only a few installations. After a process is set, the city engineers can manage the installation with minimum guidance or dependence on technology providers or consultants. These aspects can also help in scaling up the technology solutions. Fixing of set procedures or guidelines to implement, operate and maintain treatment technologies can aid in achieving scalability.

The treatment technology should be durable i.e. should sustain for a longer time period. The treatment units should be sturdy and not need frequent replacement, which can hamper the service provision. Higher ***durability*** of the technology with minimal maintenance and spare part requirements can ensure service provision even amidst extreme conditions.

Lastly, ***reliability*** is also an essential parameter for wastewater treatment to be resilient which can be assessed by: (1) the variability of treatment effectiveness under normal and emergency operation, (2) the probability of mechanical failures, and (3) the impact of failures upon effluent quality.

### 4.1.5. Circularity

Circular economy in wastewater sector has tremendous potential and is gaining attention in recent times. If substantial resources are utilized for treating ***wastewater*** to particular standards, its utilization for secondary or non-potable uses is desired as against disposal in water bodies. Hence, the treatment technologies should be capable of removing nutrient and microbial load adequately so that wastewater recycling does not pose any problems or health hazards. Secondly, some technologies generate ***byproducts*** such as algae, plants, sludge etc. that can be used for manufacturing products such as fertilizers, compost, bricks and thereby fetch revenue. Further, some technologies also have potential of generating ***energy*** through sludge or algae processing. Thus, the end-products are reused in the same or different loop, thereby facilitating circularity in wastewater treatment. This circularity is beneficial and can reduce the environmental burden on virgin resources, but the circularity potential is technology specific and varies for different technologies.

### 4.1.6. Social

The exclusion of relevant stakeholders in decision making regarding technology selection, particularly the end-users, often leads to failure in sustaining the sewage treatment facilities. Hence, ***public acceptance*** to the wastewater treatment technology is vital for the success of the STPs. Further, STPs need timely O&M and there should be willingness of end-users and other relevant stakeholders to actively participate in restoring the functioning of the STPs. Hence, ***public***

***participation*** to treatment technology is crucial, particularly in case of decentralized treatment systems that are relatively nearby the end-user or in a close vicinity.

The other social aspects that need consideration are regarding the manpower requirement and level of expertise for operating and maintaining the treatment systems. If the O&M costs are considered, it is better if a higher share of O&M costs comprise of human labour as against energy, which is detrimental for the environment. ***% Manpower to machine cost*** is a proposed social indicator in this regard that can capture the investment in human capital as against machines and energy.

Mechanized and advanced treatment systems require greater level of skill for running the treatment plants and are hence suitable in urban areas where adequately skilled labour can be readily available. Requirement of highly skilled personnel for plant operation can make the treatment systems highly dependent on single person, in the absence of which plant functioning and service provision to the desired levels might get affected. On the contrary, natural treatment systems are known to function with relatively low skill and semi-skilled personnel. Such technologies are preferred in rural areas or in communities and can also generate local employment. Empowering semi-skilled persons for wastewater treatment has greater potential for employment generation, as local labour can be provided necessary O&M protocols to be followed. Hence, if the salaries of human capital are considered, a greater ***cost fraction of semi-skilled/ unskilled labour to skilled labour*** can capture this aspect.

## 4.2. Framework for technology selection

The Figure 12 represents the decision-making framework for technology selection adopted in the decision support tool. Several wastewater treatment technology alternatives are prevalent. Depending on the context of decision-making, technology might be needed to be chosen from among few options. Apart from the commonly used technologies, any new technology can be added as an alternative, provided the technology details as per the technology fact-sheet template are entered by the user.

**Scenario selection**

Secondly, the scenario needs to be stated, which will help in criteria identification and their weighing. Two aspects are considered in scenario selection. The context of decision-making, whether the location of STP is in an urban, peri-urban or rural region. As this might affect land availability, land price, manpower availability, wastewater characterization etc. Accordingly, the weights for different criteria might vary for effective decision-making. The second factor for defining scenarios is the fate of the treated wastewater, whether it has an end use for irrigation or landscaping or gardening, or is used to cater non-potable water demands such as toilet flushing or for high-end industrial applications, or is disposed to sea or the river. The end use affects the water quality standards to be achieved at the STP. The scenarios will be defined as a combination of the context of decision-making and the end-use application.

**Criteria and indicators**

Third step is the identification of the criteria and indicators. The user should select maximum number of indicators that can address the technology selection from multiple dimensions. The dominance of indicators from a single criterion should be avoided. Further, for the selected technologies and the indicators, data collection should be conducted based on primary methods such as site visits to sewage treatment plants and technology providers. For the qualitative indicators (rated on scale of 1 to 100 or 1 to 10), help of experts or relevant stakeholders can be sought. Additionally, the data for qualitative indicators can be supplemented by secondary literature review.

**Scenario-based indicator weighing**

The provision of indicator weights is also embedded in the tool to facilitate scenario-based decision-making. Some indicators such as eutrophication play a decisive role in technology selection of the treated wastewater is to be disposed in rivers and oceans. In this case, a higher weight to eutrophication will penalize the technologies having higher tendency to cause eutrophication. Another example is that of coliform removal, which will have higher weight in case of wastewater recycling scenario as against wastewater disposal scenarios.

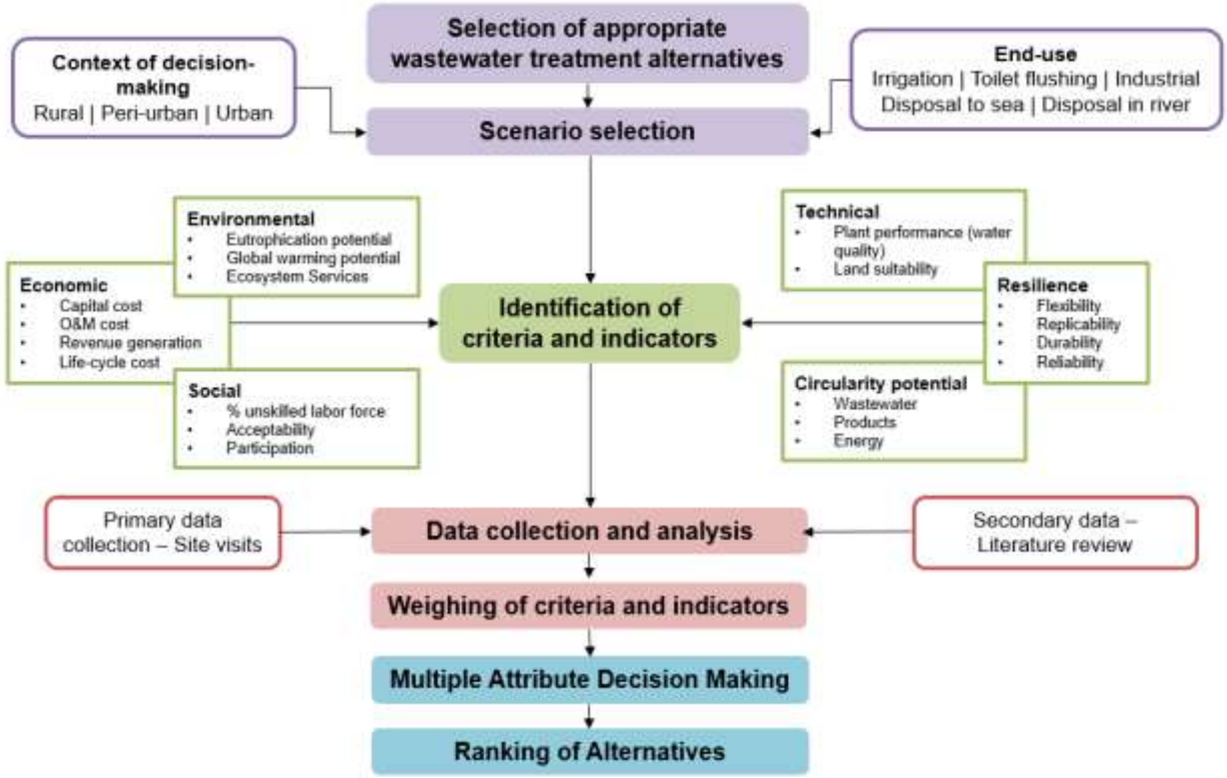



**Figure 12:** Decision-making framework for appropriate wastewater treatment technology selection

**Ranking of alternatives**

It is not possible to achieve the optimal solution for each scenario because there are a finite number of alternatives available. Therefore, the best available solution needs to be selected. TOPSIS is the MCDM technique whose algorithm is embedded in the decision support tool. Further, there is uncertainty involved in decision-making at various steps, particularly in data collection. A one-size-fit-all approach does not work in wastewater treatment. Thus, although the data for technologies is compiled through primary and secondary data collection, there might be variation in the actual plant performance. Hence, a small difference of 0.1 or 0.25 in the technology scores does not necessarily have a huge implication. Accounting for these uncertainties in analysis, the technology having comparable scores are clubbed as 'most preferred' alternatives.

# 5. JalVishwa 1.0

**Figure 13:** Logo of JalVishwa

The holistic aim of this decision support tool, named JalVishwa, is to ensure 'Water for the World, and Water for All'. Figure 13 denotes the logo for the tool. Amidst the scarcity of water in today's times, the treated and reused wastewater has the potential to divert the unused freshwater to other sectors or the poor people who are deprived of water access. Hence, it becomes necessary for the ULB's to plan the sewage treatment facilities wisely to ensure an optimal use of resources. The ***problems*** (urban water management and sewage treatment) of every region and city are different and hence the ***solution*** (choice of sewage treatment technology) should be customized to that situation. In this regard, JalVishwa is a ***decision support tool*** to select the ***most appropriate*** sewage treatment technology for ensuring ***sustainable and resilient*** sewage treatment in every city or at a specific location.

JalVishwa is a freely available tool, and the user only requires to register oneself before being redirected to the interface of the tool. Figure 14 shows the user registration form. After pressing submit, the user is redirected to the actual link of the decision support tool, clicking on which the user is redirected to the actual home page of JalVishwa as shown in Figure 15.

The link to the open access tool is given below:

[jalvishwa-iitb.github.io](jalvishwa-iitb.github.io)

The YouTube tutorials regarding usage of the tool can be found on the following link:

[https://www.youtube.com/playlist?list=PLhUEOeQI5cNuVk6ZwVWBmc4cMhBs1enPA](https://www.youtube.com/playlist?list=PLhUEOeQI5cNuVk6ZwVWBmc4cMhBs1enPA)

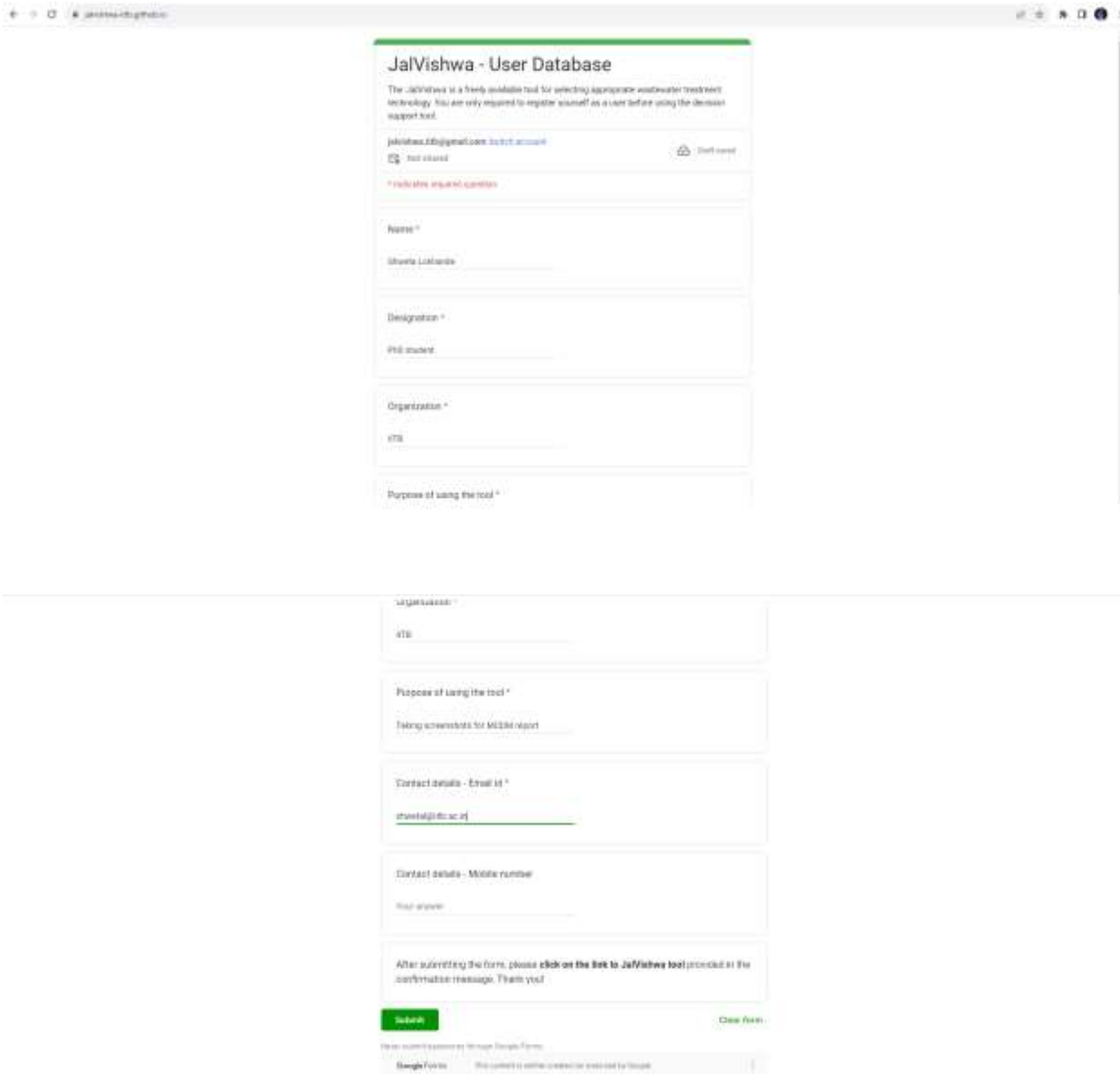



**Figure 14:** User registration form


**Figure 15:** User being redirected to link of tool after registration


**Figure 16:** Home page of JalVishwa

Figure 16 shows the home page of JalVishwa. There are five tabs arranged horizontally at the top. The first tab is that of 'Introduction' (refer Figure 17), which introduces the user to the significance and relevance of this technology selection tool for wastewater treatment. The second tab 'Overview of Wastewater Treatment Technologies' covers the various categories and classification of wastewater treatment technologies (refer Figure 18) and includes a brief technology fact sheet of the commonly used treatment technologies (refer Figure 19 for sample techno factsheet) .


**Figure 17:** Introduction tab

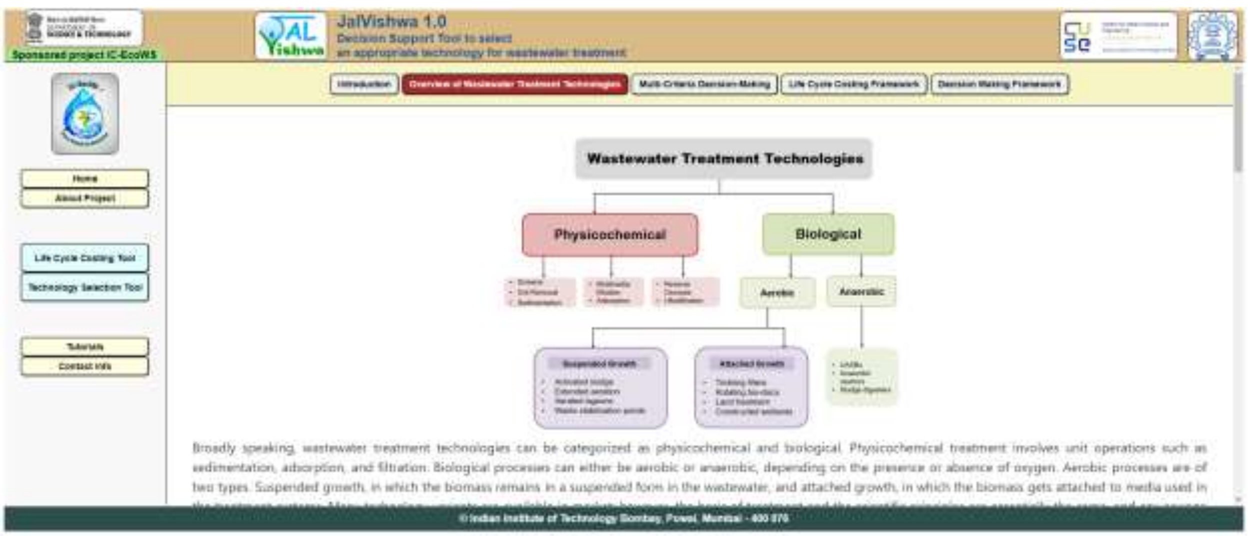



**Figure 18:** 'Overview of Wastewater Treatment Technologies' tab

# CONSTRUCTED WETLANDS

## Categorization of Technology

**BIOLOGICAL → AEROBIC → ATTACHED GROWTH**

Engineered Natural Treatment Systems using 'Phytoremediation'

## Technology Brief

Constructed wetlands are engineered systems artificially developed to function in natural processes along with coexisting microorganisms to aid wastewater treatment. The design of constructed wetlands has been adopted by mimicking the natural wetland systems that are known to treat wastewater. The wetland vegetation and the microbial population present in media are the key functional units in constructed wetlands whose natural mechanisms assist in the removal of the contaminants present in groundwater or surface water. Constructed wetlands are less expensive than the competitive mechanized treatment technologies, and are simple to operate. Further, plants have the advantage of nutrient removal, attractive biomass yield, and can generate revenue. A number of variants of CWs are developed which might be used as per the land availability on site.

**Figure 19:** Sample techno-factsheet

The third tab is of 'multi-criteria decision-making' (refer Figure 20). This has brief information about the multi-criteria decision-making techniques and some common terminology associated with the same. The fourth tab of 'Life Cycle Costing Framework' presents the need for life cycle cost considerations and the methodology adopted for the same (refer Figure 21). There is an option to navigate to LCC tool as denoted in Figure 22. The last tab of 'Decision Making Framework' comprises the list of indicators suggested for decision-making along with the MCDM technique used in the present algorithm of decision support tool (refer Figure 23). The option to navigate to technology selection tool is shown in Figure 24.


**Figure 20:** 'Multi-criteria decision-making' tab

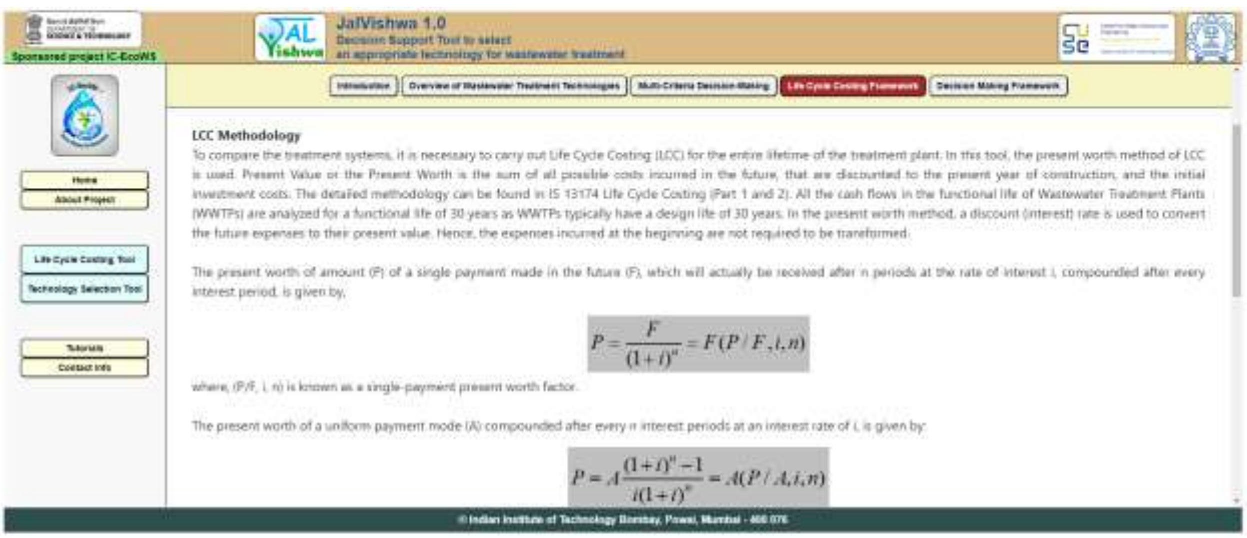



**Figure 21:** 'Life Cycle Costing Framework' tab

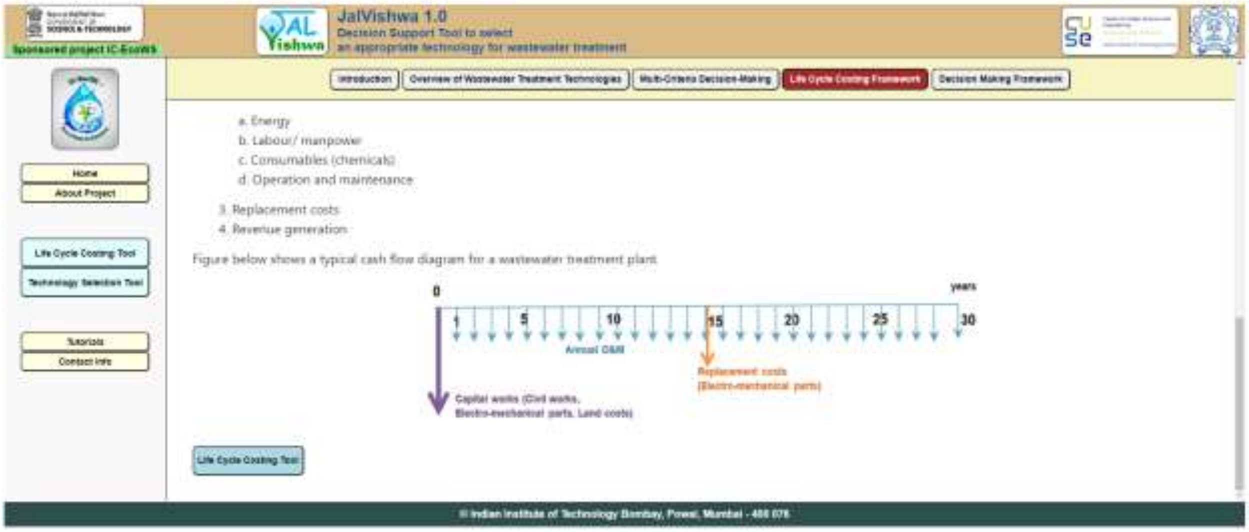



**Figure 22:** Option to navigate to LCC tool

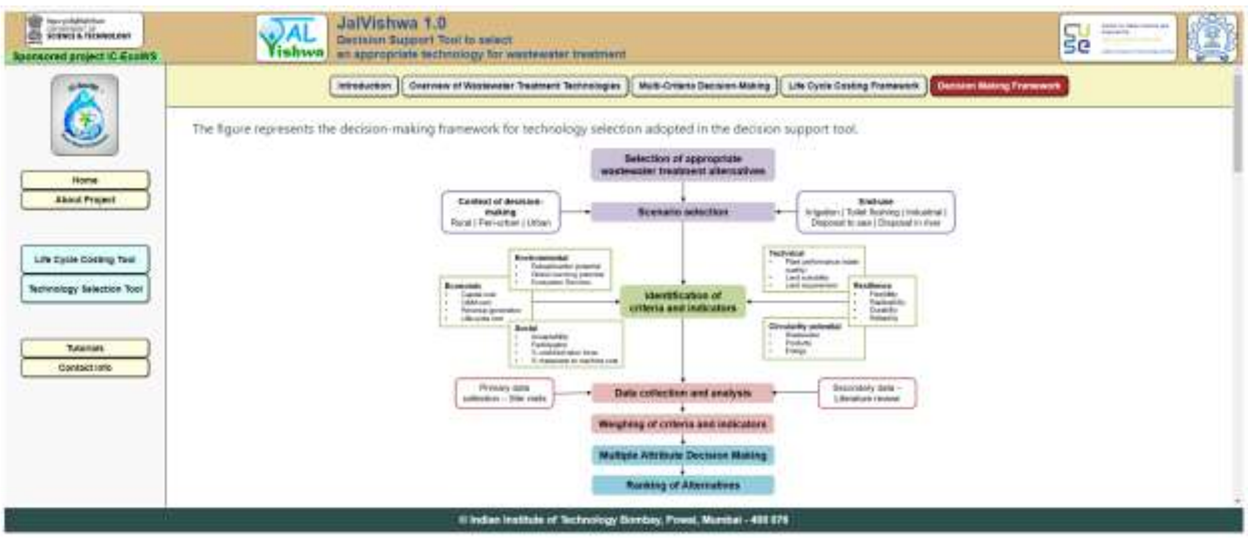



**Figure 23:** 'Decision Making Framework'

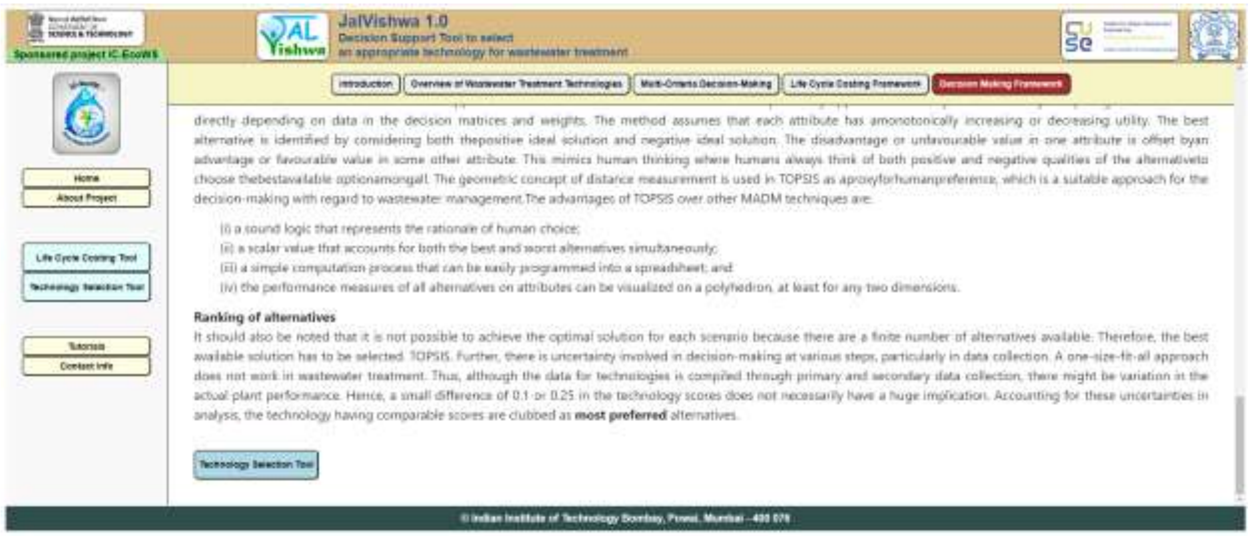
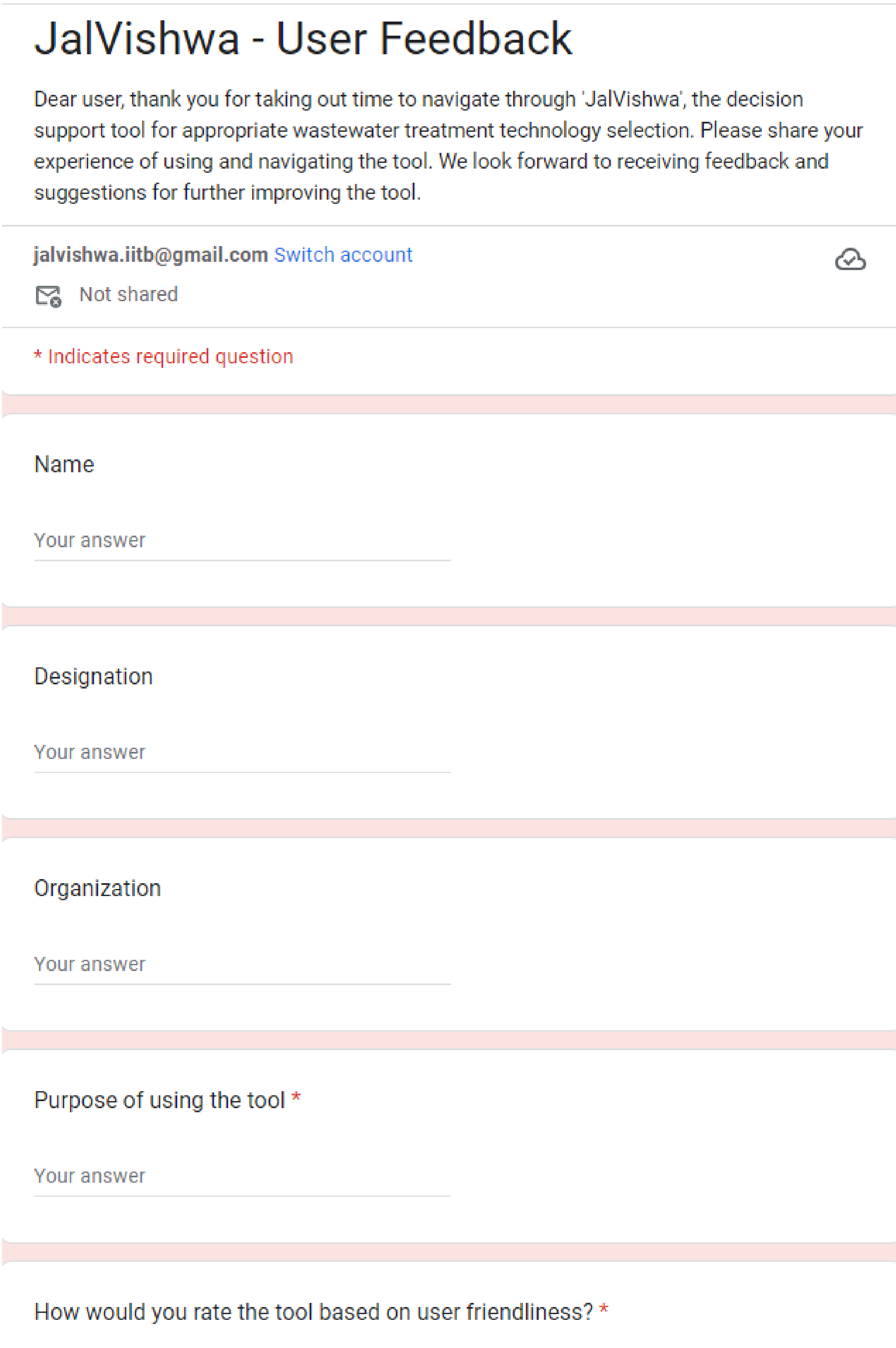



**Figure 24:** Option to navigate to Technology Selection Tool

On the left hand side, there are buttons for the Life Cycle Costing tool and Technology Selection tool, which are discussed separately in sub-sections 5.1 and 5.2 respectively. The section of tutorials includes links to four videos regarding navigation of the tool (refer Figure 25). Lastly, the contact information and link to the feedback form are provided (refer Figure 26 and Figure 27 respectively).


**Figure 25:** Tutorial videos


**Figure 26:** Contact details



# JalVishwa - User Feedback

Dear user, thank you for taking out time to navigate through 'JalVishwa', the decision support tool for appropriate wastewater treatment technology selection. Please share your experience of using and navigating the tool. We look forward to receiving feedback and suggestions for further improving the tool.

jalvishwa.iitb@gmail.com Switch account

Not shared

* Indicates required question

Name

Your answer

Designation

Your answer

Organization

Your answer

Purpose of using the tool *

Your answer

How would you rate the tool based on user friendliness? *

**Figure 27:** Screenshot of the feedback form

## 5.1. Life Cycle Costing Tool

Figure 28 shows the interface of the life cycle costing tool. The inputs are of two types – project details and technology details. Project details include life of project and interest rate to be considered for analysis. Additionally, location-specific inputs of land cost and energy price are asked from the user, as these might vary across the nation. However, for a given project in hand where technology selection is the goal, the basic project details will remain the same for all technologies since they are location specific.


**Figure 28:** Interface of the life cycle costing tool

The treatment technology cost details are divided as capital costs, replacement cost, O&M costs and revenue generation. Capital cost is considered as initial investment and includes land cost. For replacement costs, two options are provided. The user can either state the replacement cost (to be incurred after 15 years) as a fraction of the capital cost. In this case, the input for replacement cost is a percentage value (refer Figure 29).

**Figure 29:** Provision for entering replacement costs as part of capital costs

Alternatively, if a technology provider has detailed information regarding the life of various units or components of STPs which need replacement at differing time intervals, he can do so by choosing option of '*part-wise replacement'* as shown in Figure 30. In this case, the user needs to feed in the time span after which a particular part needs replacement, along with the replacement cost of the same. In the tool, cost details for maximum of five components can be entered for evaluation of LCC.

**Figure 30:** Provision for entering part-wise replacement costs in LCC tool

Figure 31 shows the sample report of Life Cycle Costing. The first page of the report includes all cost inputs fed by the user. The second page of the report shows the component wise life cycle cost analysis. The ultimate LCC, with and without revenue is also represented as a summary for that particular treatment technology, as shown in Figure 32.

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Decision Support Tool to select
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**INPUTS**

| | |
|---|---|
| **Project Details** | |
| Life of project ( Years ): | 30 |
| Rate of interest ( Percentage ): | 10 |
| Land Price ( INR/sq.m ): | 1600 |
| Energy Price ( INR/kWh ): | 5 |
| **Technology:** | **Membrane Bio-Reactor** |
| **Parameters for Capital Cost** | |
| Land Area Required ( sq.m ): | 200 |
| Civil Works ( INR Lakh/MLD/Year ): | 500 |
| **Parameter for Replacement Cost** | |
| Percent of Construction Cost: | 40 |
| **Parameters for O & M Cost** | |
| Energy Consumed ( kWh/KL/day ): | 60 |
| Labour/Manpower ( INR Lakh/MLD/Year ): | 2.4 |
| Chemicals ( INR Lakh/MLD/Year ): | 0.8 |
| Routine Maintenance ( INR Lakh/MLD/Year ): | 1.1 |
| **Parameters for Revenue Generation** | |
| Revenue Generation ( INR Lakh/MLD/Year ): | 0.3 |

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**Figure 31:** Inputs page in LCC report

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**OUTPUTS**

**Capital Cost**

| Description | Symbol | Rate | Ni | Factor | Present Worth (Lakh) |
|---|---|---|---|---|---|
| Land Acquisition Cost | C1 | 3.2 | 0 | 1.000 | 3.2 |
| Civil Works | C2 | 500 | 0 | 1.000 | 500 |
| | | | | **Total** | **503.20** |

**Replacement Cost**

| Description | Symbol | Rate | Ni | Factor | Present Worth (Lakh) |
|---|---|---|---|---|---|
| Replacement Cost | C3 | 200 | 15 | 0.239 | 47.88 |
| | | | | **Total** | **47.88** |

**Operation and Maintenance Cost**

| Description | Symbol | Rate | Ni | Factor | Present Worth (Lakh) |
|---|---|---|---|---|---|
| Energy Cost | O1 | 1095.75 | 30 | 9.427 | 10329.54 |
| Labour/Manpower | O2 | 2.4 | 30 | 9.427 | 22.62 |
| Consumables/Chemicals | O3 | 0.8 | 30 | 9.427 | 7.54 |
| Routine Maintenance | O4 | 1.1 | 30 | 9.427 | 10.37 |
| | | | | **Total** | **10370.07** |

**Revenue Generation**

| Description | Symbol | Rate | Ni | Factor | Present Worth (Lakh) |
|---|---|---|---|---|---|
| Revenue Generated | O5 | 0.3 | 30 | 9.427 | 2.83 |
| | | | | **Total** | **2.83** |

**Summary**

Technology: **Membrane Bio-Reactor**

Net Present Worth (without revenue): **INR 10921.15 Lakhs**

Net Present Worth (with revenue): **INR 10918.32 Lakhs**

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**Figure 32:** Output summary page in LCC report

## 5.2. Technology selection tool

The interface of technology selection tool is shown in Figure 33. As seen in Figure 34, the relevant indicators among the list can be opted for decision-making as per the user. Subsequently, the scenario needs to be selected, as seen in Figure 35. Then after the technology choices need to be selected, after which the *submit* button appears as illustrated in Figure xx.


**Figure 33:** Interface of technology selection tool

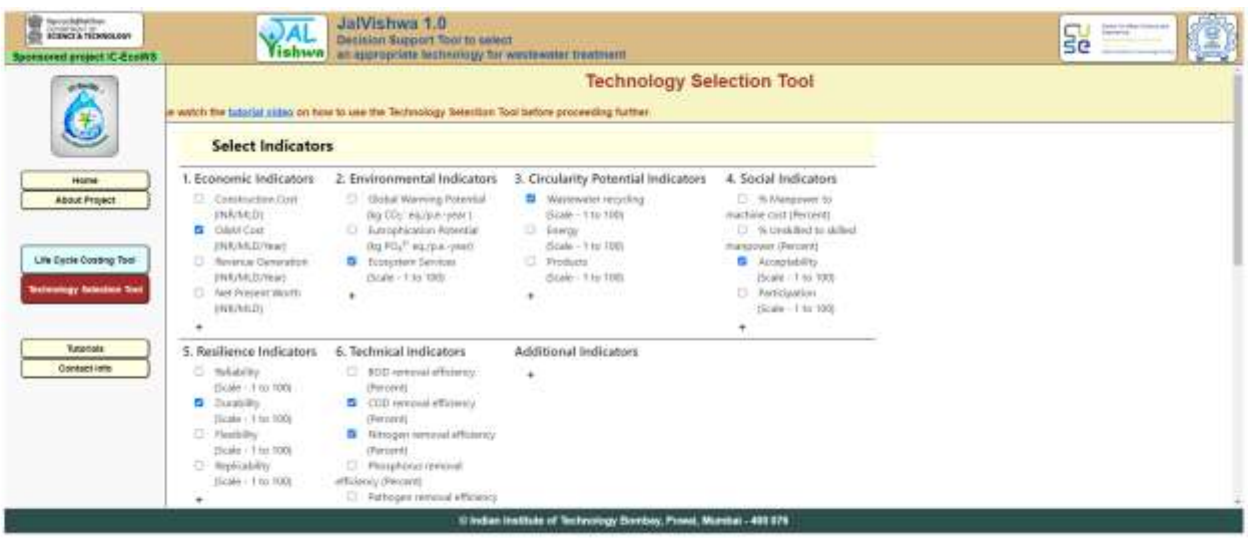



**Figure 34:** Choosing indicators in the tool


**Figure 35:** Scenario and technology selection in the tool


**Figure 36:** Decision matrix generated in JalVishwa

After pressing *submit*, the decision-making matrix appears (as seen in Figure 36), which lists the selected technologies and the selected indicators that need to be filled by the user. Additionally, the type of indicator needs to be selected (whether cost or benefit type), and the weightages to the scenarios should be given (refer Figure 37). Once this matrix is filled, the user can press on the '*Generate technology assessment report*' button. The PDF of the report will be generated as shown in Figure 38, in which the preference levels of the technologies considered will be indicated.

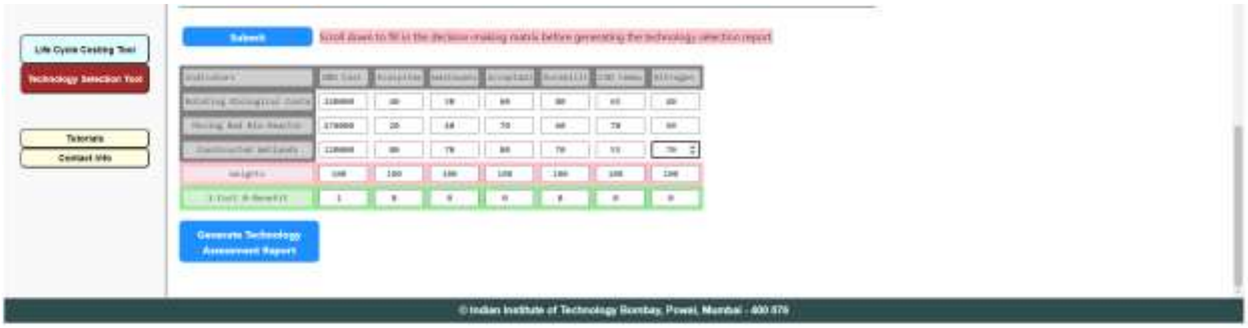
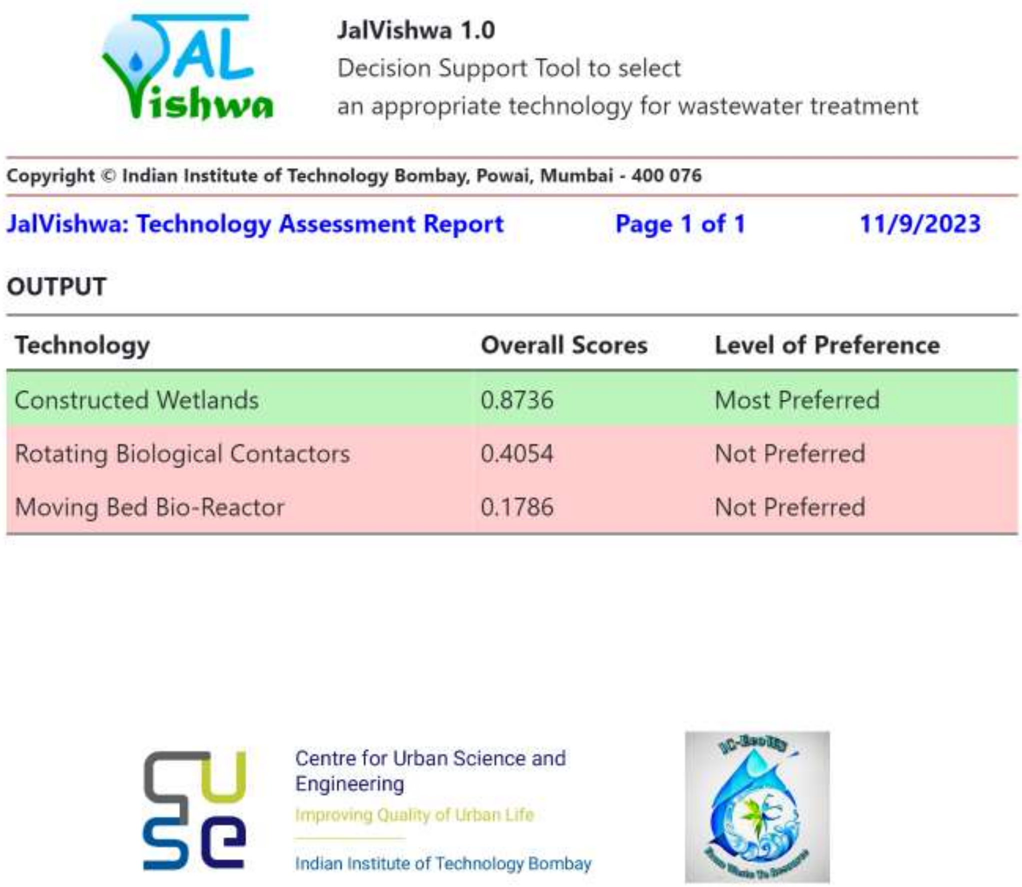



**Figure 37:** Data entered in decision matrix before generating report



JalVishwa 1.0

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OUTPUT

| Technology | Overall Scores | Level of Preference |
|---|---|---|
| Constructed Wetlands | 0.8736 | Most Preferred |
| Rotating Biological Contactors | 0.4054 | Not Preferred |
| Moving Bed Bio-Reactor | 0.1786 | Not Preferred |

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**Figure 38:** Sample report format of technology selection tool

In indicator selection, apart from the existing indicators, the tool provides the flexibility to the user to add any other indicator. For example, as seen in Figure 39, Toxicity is a new parameter added in environmental indicators. Similarly, there is an option to add new technology (refer Figure 40), which is not listed in the tool. As per modified inputs, the decision matrix will get reflected and necessary information can be filled.

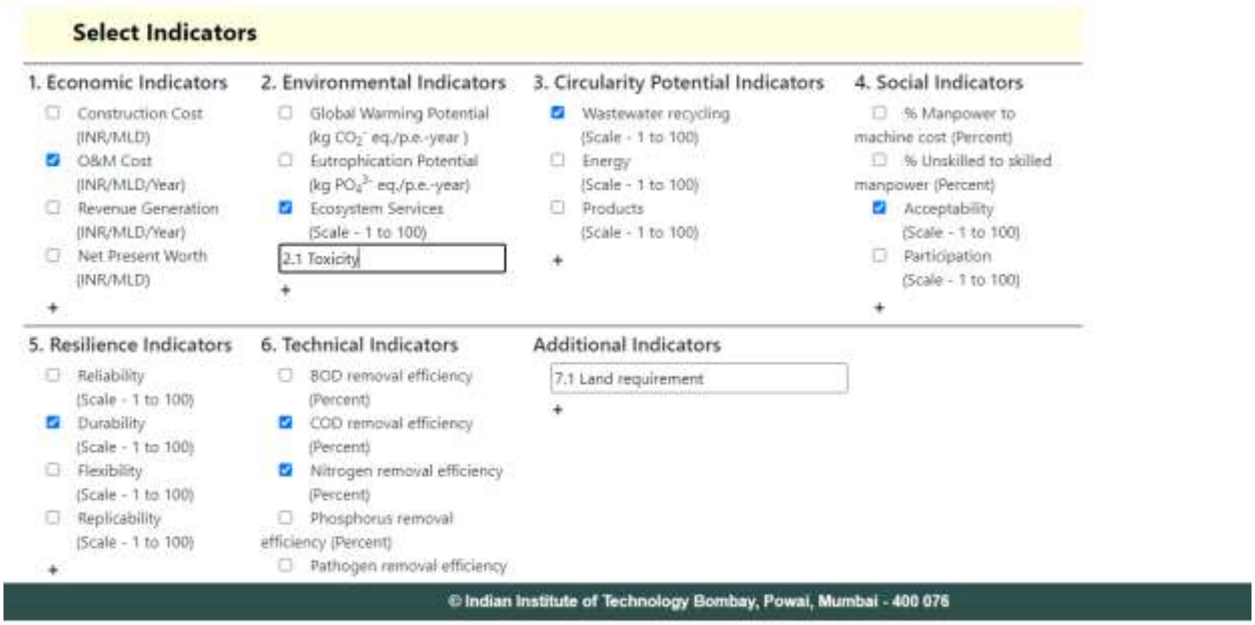


**Figure 39:** Flexibility in JalVishwa to add new indicators


**Figure 40:** Flexibility in JalVishwa to add new technologies

# 6. Summary

A novel multi-criteria decision support tool JalVishwa, is developed for appropriate wastewater treatment technology selection. A dynamic life cycle costing tool is embedded to facilitate representative decision-making.

The salient features of the tool are:

1. Multiple criteria inclusion facilitating holistic decision making.
2. Decision making framework encompassing indicators from life cycle thinking
3. Flexibility with respect to technology and indicator selection
4. Scope of including criteria weighs for scenario-based decision making
5. Dynamic life cycle costing tool facilitating location-specific economic assessment
6. Guidance to decision-makers towards achieving circular economy in the water sector sector

The decision-making framework can help urban local bodies in moving from conventional approach of basing technology selection on economics, but also include environmental, social and other dimensions for making sewage treatment facilities resilient and sustainable. Usage of this freely available tool can aid the urban local bodies in implementing national schemes such as Swacchha Bharat Mission, Jal Jeevan Mission, AMRUT 2.0 and accordingly plan for fund allocation. The tool can be used by urban local bodies, planners, practitioners and researchers, and help adhere to various sustainable development goals related to water, sanitation and cities. Further research regarding qualitative indicators for the decision-making framework can be taken up in future research.


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# Disclaimer

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