Potential of Decentralised Wastewater Treatment Systems Applicable to India

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ABSTRACT

Appropriate sanitation facilities are still a challenge in many parts of the world, particularly in developing countries. With regard to almost 950 million people defecating in the open, the question arises whether the existing treatment facilities are sufficient to provide for a healthy sanitation in the world. This paper mainly emphasizes on developing countries (particularly, India) where cost is generally a very important parameter of judgment for choosing the appropriate system. This makes decentralized treatment systems much more suitable for installation as they are easier to build and operate, both financially and technically. This paper includes basic differences and fundamental explanations about the processes involved in different decentralized treatment systems and their comparison on the basis of installation cost carried out by using a technology ranking method. It is concluded that waste stabilisation ponds would be most cost effective solution from capital investment point of view. However, Multi Criteria Analysis (MCA) should be carried out for appropriate technology selection in different scenarios on the basis of different criteria. New developments in sanitation technologies can play an important role in selecting appropriate sanitation technology for a particular scenario.

Keywords: Decentralized wastewater systems, installation cost, sanitation technology, technology selection.

INTRODUCTION

Access to proper sanitation is a challenge that the world needs to tackle right now. Open defecation is a very serious problem for the world. According to WHO/UNICEF JMP report 2015, 2.4 billion people globally have no access to improved sanitation facilities of which, around 946 million people defecate in the open. Open defecation does not only affect the environment but also causes diseases like cholera, typhoid, hepatitis, polio, diarrhea, worm infestation, under nutrition and many more.

Therefore, it is quite perceptible from the numbers that this is a problem which needs attention and should be taken under control. Although this problem is being identified of in most of the countries, for example, Ethiopia has shown an average reduction of 4% over a period of 25 years reducing their number to 28 mn people. Also, in India there has been a reduction of 31 percentage points, representing 394 mn people. But still, there is a dire need of ameliorating the sanitation facilities in the world, specifically in developing countries in general, where rapid urbanisation and population growth is eminent. Improvement in sanitation would have a direct positive impact on environmentally sustainable of urban settlements in countries such as India (Sarkar and Bhattacharyya, 2015).

Also, we know that it is a herculean task to connect each and every part of the world to the existing centralized wastewater treatment plants. This means that we need to build more treatment plants in order to eradicate the aforementioned problem. Building centralized wastewater treatment plants in every part of the world lacking this facility does not seem to be a very logical step considering the budget requirement and technical expertise of these systems. These factors also result in inadequate operation of centralized wastewater treatment plants in developing countries (Paraskevas et al., 2002). Moreover, decentralized wastewater treatment plants are simpler and cost-effective for small and isolated villages/ settlements with low population (Butler and MacCormick, 1996; Paraskevas et al., 2002). There are several reported studies attempting to justify the use of specific type of sanitation practices, but it may not be considered universally applicable, even if certain attributes of sustainable environmental sanitation can be acknowledged (Mangkoedihardjo, 2014). When deciding about the treatment system, there are a lot of factors which must be considered, but in the case of developing countries cost seems to be the most cardinal factor of them all (Sadr et al., 2015). The reason behind the perceptible popularity of decentralized treatment systems is that it is very cost effective and requires fewer resources compared to the centralized system (Lens et al., 2001).

Considering all the above mentioned factors in mind, it is very important to have the knowledge of different decentralized wastewater treatment technologies and what are the different criteria on which they differ the most. The present review and analysis work has been carried out at the University of Surrey (UK) in collaboration with Sukriti Foundation (India) to outline the current situation and project the future developments in sustainable decentralised sanitation technologies and practices, particularly applicable to India. This paper is a review of some decentralized technologies which have made its way to practice in some or the other part of the world and a generic comparison of the technologies according to different criteria which seem to affect the selection criteria the most.

Decentralized Wastewater treatment systems

Wastewater treatment systems can be centralized where large volumes of water is treated with huge pipes, major excavations and big manholes (Fisher, 1995) it can be onsite treatment systems where wastewater from a single household or a colony is treated with small excavations and generally involves reusing the effluent. Decentralized treatment systems correspond to systems which ensure collection, treatment and reuse/recycle/ disposal of the waste generated from toilets near the

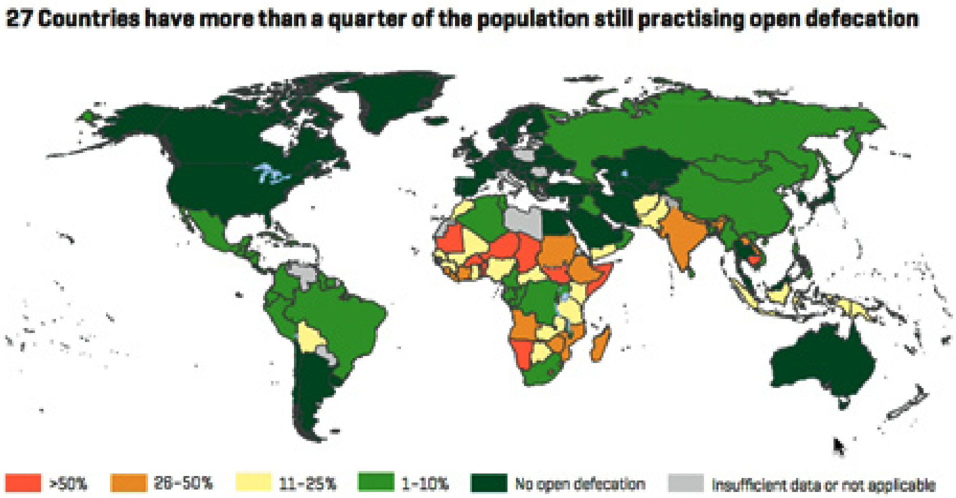


Fig. 1: Percentage of population practicing open defecation (United Nations, 2011)

generation point which makes decentralized systems an appropriate fit (Christ, 2003).

Decentralized systems are designed to operate at small scale (USEPA 2004). Decentralized wastewater treatment systems generally have 2 units, one primary treatment and the other, secondary treatment. Primary wastewater treatment refers to the water treatment involving settlement where heavy solids converted to flocs get settled at the bottom of the tank and other particles like grease and oil can float to the surface. The settled and floating materials are removed to get partially treated water. Secondary treatment is done to get a better quality effluent by removing dissolved and suspended solids.

As we have discussed earlier, Decentralized treatment systems are the best choice when it comes to areas such as small villages and settlements with low population. These are mainly rural areas which need the treatment plants the most seeing the numbers from the WHO/UNICEF JMP report which says that 82% of the global urban population uses proper sanitation facilities compared to 51% of the rural population. The report also states that at current rates of reduction, open defecation will not be eradicated among the poorest in rural areas by 2030. Not only in rural areas, Decentralized systems are also more suitable than centralized in peri-urban areas in low income countries (Parkinson and Tayler, 2003; Wilderer, 2005).

Fig 1 below shows variation of percentage of population practicing open defecation, where it can be clearly seen that open defecation practices in North America, South America, Europe, Australia

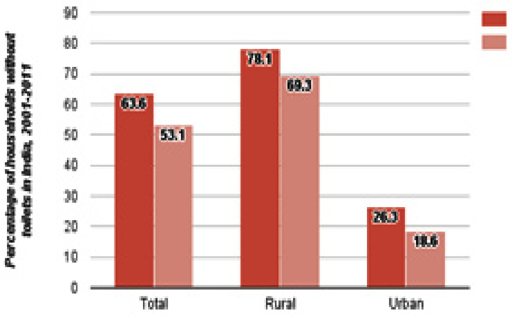


Fig. 2: Comparison of percentage of households in India without toilets, 2001-2011

and Northern Asia is negligible. Open defecation is mostly practiced in Africa and Southern Asia with some regions of Africa having more than 50% of the population practicing open defecation. Within African continent, Chad, Niger Burkina Faso and Mauritania are the countries with the biggest fractions of population practicing open defecation. Although the percentage is higher in African regions, but the absolute number is maximum in India, which is around 600 million people practicing open defecation (United Nations, 2011). Although one of the reasons for this number is perhaps India's large population but still the number is colossal and terrifying. Considering this, the main focus of this paper will be India and the solutions being posed are suggested keeping in mind the conditions prevailing in India.

Decentralized treatment systems in India

India is the country with the highest number of people practicing open defecation. Around 600 million people in India defecate in the open which is more than the next 13 countries combined. India counts for 90% of the people in south Asia and 59% of the 1.1 billion people in the world who practice open defecation (Unicef, 2015). As can be seen from the image, almost 3/4th of Indian states have 50% or more households without toilets. This explains the extent of improvement needed for the country. It is pretty evident from the image that the north, southwest and northeast parts of India are better than the rest of the country. The central part of India which includes Chhattisgarh, UP, Bihar, Jharkhand and many other neighboring states are the main contributors towards this substantial number of 600 mn. Fig 2 is made using the data gathered from Census of India which shows the variation of percentage of households without toilets over a period of 10 years, 2001-2011. As can be seen, the total number of households in India without toilets has decreased from 53.1% to 63.6%.

As discussed earlier, the major part of rural India, almost 70% rural India households still lack proper toilet facilities whereas only around 20% urban Indian households are living without toilets. These numbers give a clear picture that the need of the hour is to work on improving sanitation and toilet facilities in rural parts of India. When Indian states were compared, according to the data collected by Census of India, Chhattisgarh, Odisha, Bihar, Jharkhand and MP are the states which need the most attention because of their high percentage of households without toilets. Fig 3 shows the 12 states with the highest percentage of households without toilets in 2001. The red bars represent the decrease in the percentage from 2001 to 2011 and the blue bars represent the percentage in 2011. Although all of these 12 states are in bad conditions but the 5 aforementioned states are at maximum threat as can be seen from the chart. But there are states that have understood that this is an alarming problem and started working on it. There are programs run by government of India like *swachh bharat abhiyan (in Hindi)*, which has an objective of making 12 crore toilets by the end of 2019 (Sharma, 2015). This also explains the decrease in percentages of different states. For example, Himachal Pradesh has shown a decrease of 35.7%, highest decrease among all the states. Following Himachal Pradesh is Haryana with a decrease of 24.1%.

Different decentralized wastewater treatment systems and Technologies

Different decentralized wastewater treatment technologies and systems have been developed and implemented around the world. Table 1 shows some of the Decentralized Wastewater treatment plants being implemented in India and other countries (Sadr et al., 2016; Sadr et al., 2015; Tilley et al., 2014). A comprehensive literature review was carried out as the main approach, designed to list down and compare the various parameters of different Decentralized Wastewater Treatment (DWWT) plants. The main focus was put on collection plus treatment plants rather than collection plus

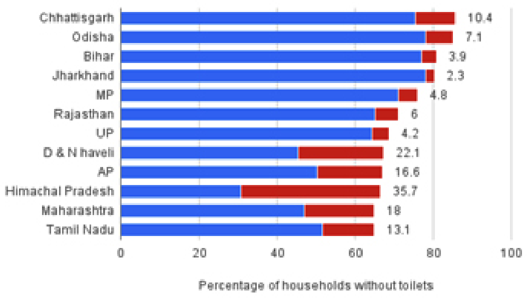


Fig. 3: Change in percentage of households without toilets from 2001-2011

discharge plants. Further the treatment plants were analyzed according to different criteria.

All the mentioned systems/technologies have been tested in one or more than one countries. The basic differences between the systems were studied from the existing literature and compiled in this paper so that the technologies can be compared on a very rudimentary level. The processes for each of the technologies are shown in Table 2 and the basic ideologies behind the systems are mentioned below.

T1: Ecosan Systems-Nepal

ECOSAN (short for ECOlogical SANitation) toilets, properly tested in Nepal, focuses on using human waste as a resource for agricultural purposes and food security (Wateraid Report). UDD toilets are used to separately collect urine and faeces and reuse them using different technologies.

T2: Compost Toilets

The main ideology behind these toilets is that it transforms the human waste into compost underneath the toilet which results in a low-cost supply chain requirement. The urine collected in these toilets is disposed in the nearest sewerage.

T3: Septic Tank and Absorption fields

It involves a basic septic tank which acts as a settlement tank providing a condition of dormancy for the sludge settlement. After the settlement, the water free from settleable and floating solids goes through a perforated pipe covered with media for secondary treatment (Lesikar, 1999). A very cost effective approach, removes more than 90% BOD_t with BW and about 80% with DPWW and a removal of above 90% with both the wastewaters (Luostarinen et al., 2005).

T4: MBBR system

Moving Bed Biofilm Reactor uses a tank volume for biomass growth with simple media carrying biofilms suspended in the tank which makes it a moving bed. This treatment is very efficient in removal of BOD as well as nitrogen and phosphorous.

T5: MBR systems

Membrane Bioreactors are the treatment processes which include membranes and an extraction pump for ultrafiltration of the wastewater. This being a technical process gives a high quality effluent but requires above average cost.

T6: Anaerobic Baffled reactor

These reactors contain alternate baffle walls with microorganisms in the compartments responsible for anaerobic digestion of organic pollutants. The effluent contains high amount of nutrients with a BOD removal of around 70%-80% as mentioned by Dama et al.(2002). The effluent also meets the guideline for agricultural reuse (Foxon et al., 2004).

T7: Upflow anaerobic sludge blanket

Wastewater flows from bottom of the tank upwards to be treated by a suspended sludge blanket. The bacterium in the sludge anaerobically digests the organic pollutants. Tilley et al. 2014 stated that it removes about 70-95% BOD, 80-90% TSS for an HRT of 1-3 days.

T8: Integrated Fixed Film activated sludge

This can be used as an upgrade for the existing treatment plants (Brentwood, 2009). It is basically an integrated form of Activated sludge and biofilm reactors. The MLSS is responsible for BOD removal and biofilm takes care of the oxidation of nitrogenous load (NH_4+). It requires very high construction, maintenance and electricity consumption cost.

T9: Rotating Biological Contactors

Rotating discs mounted on a shaft carry fixed biofilms which are alternately exposed to wastewater and atmosphere, allowing both aeration and assimilation of organic pollutants. It can be

Table 1: List of different decentralized wastewater systems and technologies

Tech No.	Technology	Water usage (Flushing)	Collection	Treatment	Reuse/ Recycle
T 1	Ecosan Systems-Nepal	No	✓	✓	✓
T 2	Compost Toilets	No	✓	✓	✓
T 3	Septic Tank and Absorption fields	Yes	✓	✓	✓
T 4	MBBR systems	Yes	✓	✓	✓
T 5	MBR systems	Yes	✓	✓	✓
T 6	Anaerobic Baffled reactor	Yes	✓	✓	✓
T 7	Upflow anaerobic sludge blanket	Yes	✓	✓	✓
T 8	Integrated Fixed film activated sludge	Yes	✓	✓	✓
T 19	Rotating Biological Contactors	Yes	✓	✓	✓
T 10	Terra Preta Toilets	No	✓	✓	✓
T 11	Blue diversion toilets	No	✓	✓	✓
T 12	MBBR + ASP	Yes	✓	✓	✓
T 13	MBBR + DAF	Yes	✓	✓	✓
T 14	Dynamic Aerobic and Anaerobic System	Yes	✓	✓	✓
T 15	Waste stabilization Pond	Yes	✓	✓	✓

used as a decentralized treatment technologies but requires high land area, high installation and operation cost and continuous electricity supply.

T10: Terra Preta Toilets

It includes urine diversion, addition of a charcoal mixture and is based on lactic-acid-fermentation with subsequent vermicomposting (De Gisi et al., 2014). The storage tank needs to be emptied weekly and taken to a common composting facility in the area which means high supply chain requirement.

T11: Blue diversion Toilets

Blue diversion toilets are toilets with inbuilt facility of storage of faeces and urine. The waste is collected and transported to a common composting facility and the urine is subjected to partial nitrification and distillation for the extraction of nutrients (Larsen et al., 2015).

T12: MBBR + ASP

It is an integrated system of two very efficient systems, Moving Bed Biofilm Reactor and Activated Sludge Process. MBBR is responsible for the reduction of organic load in a short retention time (small footprint) and the ASP creates a high quality effluent.

T13: MBBR + DAF

This is another integrated system with Dissolved Air Flotation instead of ASP. DAF can be used before or after the MBBR system. The former arrangement provides better quality influent to the MBBR system and the latter ensures proper removal of biosolids coming out of the MBBR system.

T14: Dynamic Anaerobic and Aerobic System

It is a 2 floor system with the lower floor acting as an anaerobic reactor and the upper floor as an aerobic reactor (MBBR). The waste enters the anaerobic reactor and the effluent is passed into the aerobic chamber. The biogas from the lower chamber is extracted there itself.

T15: Waste stabilization Pond

This treatment facility involves a very large footprint, having 3 ponds with different facilities, namely, Anaerobic, Facultative and Aerobic ponds (Kumar and Padhy, 2015). The second phase is anoxic in nature, where the top layer receives oxygen from the atmosphere and the lower layer is deprived of oxygen.

These were the basic definitions of the different technologies which would give the reader an idea about the fundamental differences between the processes. Table 2 shows the process outlays for each of the systems/technology so as to give a better idea about the processes involved and the fundamental differences in them.

Comparison on the basis of Installation Cost

Installation cost is a very crucial parameter for judgment because when we talk about developing countries, cost is always a bottleneck point of the discussion. This is the reason why comparison on the basis of installation cost is being given importance over other criteria. First step of a Multi Criteria Analysis was employed as the main approach for the comparison. The score is calculated by using the following formula:

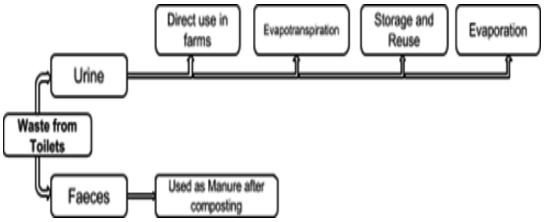
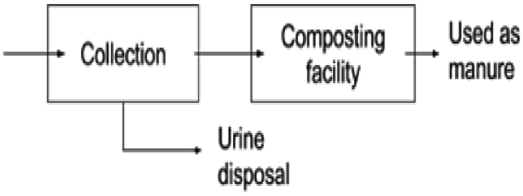
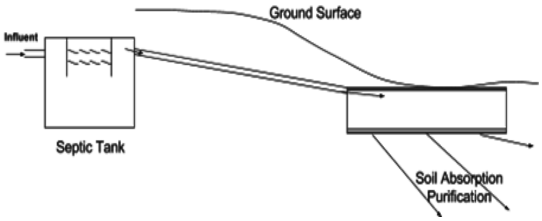
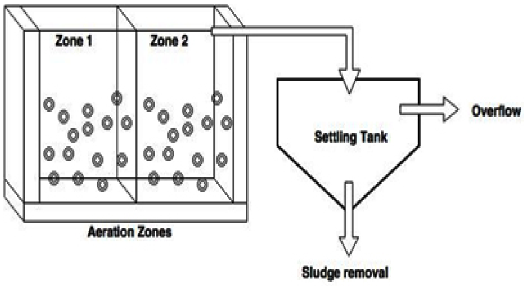
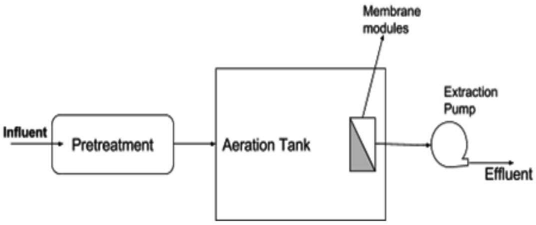
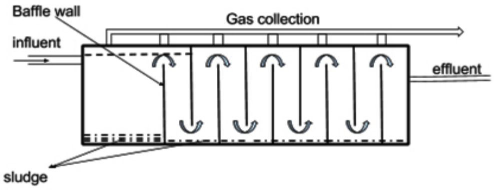
S_i = Number of times T_i appeared in the i^{th} row

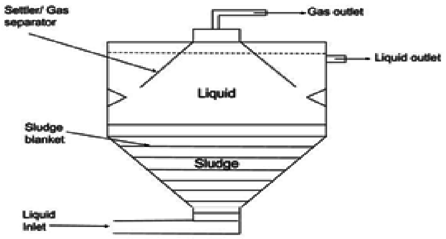
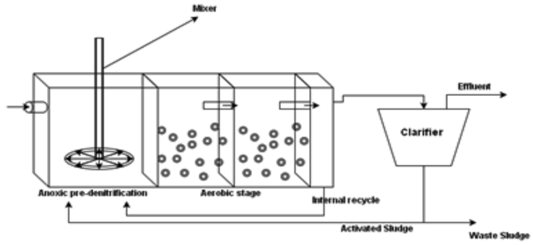
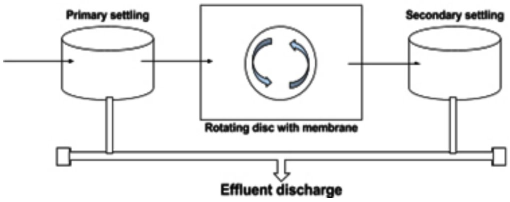
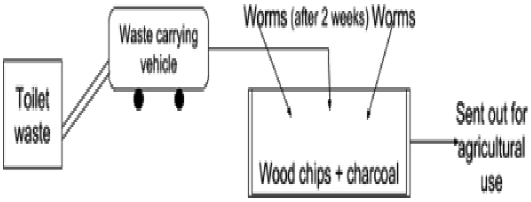
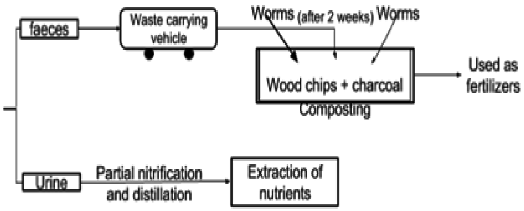
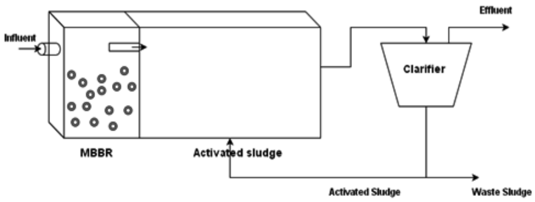
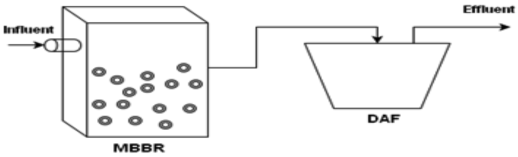
For the pair-wise comparison of the technologies, individual technologies are compared with one another and the more expensive one is placed in the respective cell. So, the score for a particular technology actually represents the number of technologies cheaper than the technology under consideration.

This approach was taken from the published thesis of Sadr (2014).A comparison matrix was first made (Table 3) and filled after consulting proper literature so that scores can be assigned to different technologies and they can be compared. All the one-one comparisons are made after reviewing appropriate literature corresponding to the technologies.

The score was evaluated by one-one comparison of the technologies with each other as shown in the table (Table 3). This score gives us an idea about the relative comparison of the installation cost for each of the systems. Although this is a very

Table 2: Process outlays of different Technologies

	Technology	Process Outlay
T 1	Ecosan Toilets- Nepal	
T 2	Composting Toilets	
T 3	Septic Tank and Soil Absorption	
T 4	MBBR	
T 5	Membrane Bioreactor	
T 6	Anaerobic Baffled Reactor	

T 7	Upflow Anaerobic Sludge blanket	
T 8	Integrated Flow Activated Sludge Reactor	
T 9	Rotating Biological Contactors	
T 10	Terra Preta Sanitation	
T 11	Blue diversion Toilets	
T 12	MBBR + ASP	
T13	MBBR + DAF	

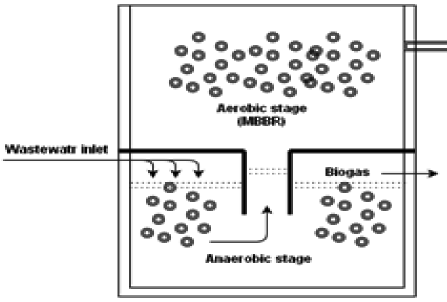
T 14	DANA	
T 15	Waste Stabilization Pond	

Table 3: One-One comparison matrix for score evaluation

	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12	T 13	T 14	T 15	Score
T 1	-	T 1	T 3	T 4	T 5	T 1	T 1	T 8	T 9	T 10	T 1	T 12	T 13	T 14	T 1	5
T 2	T 1	-	T 3	T 4	T 5	T 2	T 2	T 8	T 9	T 10	T 2	T 12	T 13	T 14	T 2	4
T 3	T 3	T 3	-	T 4	T 5	T 3	T 3	T 8	T 9	T 10	T 3	T 12	T 13	T 3	T 3	7
T 4	T 4	T 4	T 4	-	T 4	T 4	T 4	T 8	T 4	T 4	T 4	T 12	T 13	T 4	T 4	11
T 5	T 5	T 5	T 5	T 4	-	T 5	T 5	T 8	T 5	T 5	T 5	T 12	T 13	T 5	T 5	10
T 6	T 1	T 2	T 3	T 4	T 5	-	T 7	T 8	T 9	T 10	T 6	T 12	T 13	T 14	T 6	2
T 7	T 1	T 2	T 3	T 4	T 5	T 7	-	T 8	T 9	T 10	T 7	T 12	T 13	T 14	T 7	3
T 8	T 8	T 8	T 8	T 8	T 8	T 8	T 8	-	T 8	T 8	T 8	T 12	T 13	T 8	T 8	12
T 9	T 9	T 9	T 9	T 4	T 5	T 9	T 9	T 8	-	T 9	T 9	T 12	T 13	T 9	T 9	9
T 10	T 10	T 10	T 10	T 4	T 5	T 10	T 10	T 8	T 9	-	T 10	T 12	T 13	T 14	T 10	7
T 11	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	-	T 12	T 12	T 14	T 11	1
T 12	T 12	T 12	T 12	T 12	T 12	T 12	T 12	T 12	T 12	T 12	T 12	-	T 13	T 12	T 12	13
T 13	T 13	T 13	T 13	T 13	T 13	T 13	T 13	T 13	T 13	T 13	T 13	T 13	-	T 13	T 13	14
T 14	T 14	T 14	T 3	T 4	T 5	T 14	T 14	T 8	T 9	T 14	T 14	T 12	T 13	-	T 14	7
T 15	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12	T 13	T 14	-	0

important parameter for judgment but is in no way sufficient to make an informed decision about what technology to use for a particular scenario. The final ranking, given in Table 4 were assigned according to the scores evaluated from the evaluation matrix.

These comparisons are made keeping in mind a scenario in which the cost of land or any other effecting parameter does not affect the overall construction cost in any way. Although, detailed studies have been employed for comparison, but this comparison only caters the installation cost parameter and no other.

T 12: MBBR + ASP, is the most expensive of them all and T 15: Waste stabilization pond, is the cheapest of all the mentioned technologies. This in no way means that this ranking holds for all the circumstances. It keeps on changing as the surrounding conditions change. For example, if the land costs increase, T15: Waste stabilization pond will no longer be cheapest to install as it requires a large land area.

A point is to be noted here that this ranking is not always like this. It changes with the scenario under consideration. According to a study conducted

Table 4: Ranking according to Installation Cost

S No	Technology	Score	Rank
T 1	Ecosan Systems-Nepal	5	10
T 2	Compost Toilets	4	11
T 3	Septic Tank and Absorption fields	7	7
T 4	MBBR systems	11	4
T 5	MBR systems	10	5
T 6	Anaerobic Baffled reactor	2	13
T 7	Upflow anaerobic sludge blanket	3	12
T 8	Integrated Fixed film activated sludge	12	3
T 9	Rotating Biological Contactors	9	6
T 10	Terra Preta Toilets	7	8
T 11	Blue diversion toilets	1	14
T 12	MBBR + ASP	13	1
T 13	MBBR + DAF	13	2
T 14	Dynamic Aerobic and Anaerobic System	7	9
T 15	Waste stabilization Pond	0	15

by Tsagarakis et al (2003), waste stabilization ponds are only cost effective if the land cost is under $30 per m^2.

A way forward in sanitation technology ranking

Fig 4 is a representation of the relative ranking of different technologies according to the installation cost. To completely compare all the alternatives for a particular scenario, ranking can be done for a particular scenario and after assigning proper weight to different parameters, the scores can be combined to form the overall ranking for a scenario.

In order to fully compare these technologies according to a particular scenario, different criteria with complete data for each technology must be collected and a proper MCA study must be carried out. Also, a point is to be noted that the list of criteria chosen will have some correlation which should be taken care of, for example, installation cost and land requirement according to the above discussion. Therefore, these two criteria cannot be treated independently. Keeping these points in mind, a Multi Criteria Analysis can be carried out for these technologies for complete comparison.

The way forward would be to convey to technology developers, industry, and government and

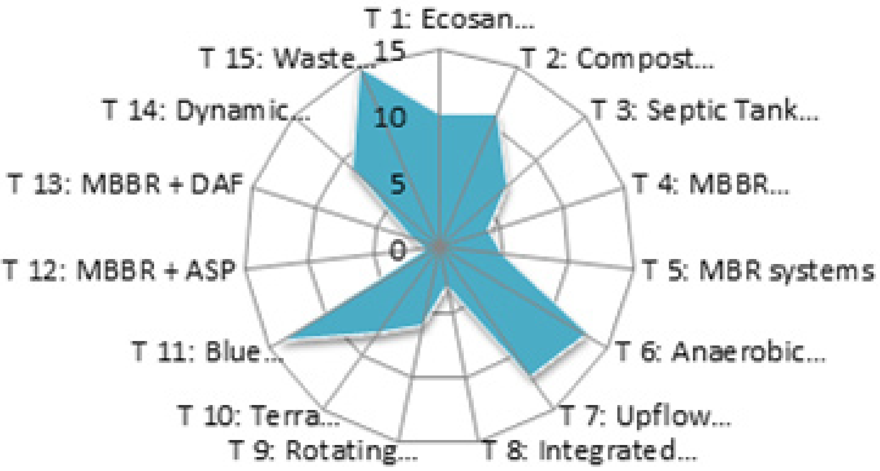


Fig. 4: Ranking of different technologies according to installation cost

non-government bodies that right sanitation system should be selected in order to get tangible benefits. New start-ups can play a vital role in providing novel and innovative sanitation technologies which would rank high in a MCA study. For example, Sukriti Social Foundation, a not for profit company (India), has come up with a practical, low-cost, financially self-sustainable and stand-alone toilet model - Eco Toilet that consumes the small quantity of water, requires no sewer infrastructure, uses renewable energy, and relies on little manual intervention for maintenance. The process incorporates intelligent integration of different components in the whole sanitation system for which there is fully or partially developed knowledge available in open literatures or market. The system is designed for urine and black water treatment on site which accounts for the lack of proper sewer infrastructure in countries like India. Moreover, greywater is recycled on site and reused for automatic flushing. Such systems should be studied in detail for their potential impact on sustainable sanitation in long term. Once their operational data are available, an MCA can be carried out for a detailed comparison and relative ranking.

CONCLUSION

In order to completely eradicate the problem of open defecation and sanitation, the areas which lack proper wastewater treatment facilities or toilets should adopt decentralized treatment facilities as they are not only efficient but cost-effective too which is the major point of consideration for developing countries like India. Although the choice of treatment plant for a particular area depends on a lot of factors and the factors in turn are dependent on the scenario taken under consideration.

In this study, the factors which were generally seen to affect the choice of technology are installation and operational costs, ease of deployment, maintenance, acceptance, comfort, performance, energy requirement, supply chain requirement, environmental impact, odour and health aspects. In order to decide on the best alternative for a particular scenario, Multi Criteria Analysis should be carried out on these technologies and the comparison should be done on the basis of the aforementioned factors. A term called weight of the criterion decides the importance factor for each parameter and is a variable which depends only on the scenario under consideration. Further work on applying weighted MCA should be carried out to improve the technology ranking methodology used in this study.

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