Assessment of Decentralized Wastewater Treatment Systems for Sanitation of Small Communities using A Qualitative Approach Methodology: A Case Study from Northern India

Pankaj Banyal, N Singh, A.A Kazmi

Abstract -To date different technologies based wastewater treatments have been actualized at full scale level over the world; however the integral elements for the determination of most suitable treatment framework are still obscure. The present study is fervent to the investigation of 11 decentralized sewage treatment plants in Northern India using a qualitative approach methodology in which distinctive focus was paid to economic indicator of these plants. A total of eight technologies i.e. Package type (including Anaerobic , Anaerobic +Aerobic treatment and Anaerobic +Aerobic treatment), and cluster type, i.e. Extended Aeration (EA), Moving bed Bio-film Reactor (MBBR), Sequencing Batch reactor (SBR), Membrane Bio reactor (MBR),Rotational Biological Contractor (RBC) were counted in this field review. As a component of the qualitative evaluation of these plants, land requirement, capital investments, operation and maintenance (O&M) costs and treatment efficiencies (in terms of BOD, COD, TSS removal) were selected as determining broader indicator in the cull of the felicitous wastewater treatment system in developing countries like India. An intensive field campaign was run and data obtained by conventional field visits + preset questionnaire format for analyzing results to gain insight into available technologies as per capacity wise classification of small scale plants. The study analyzed approximate cost of treatment in the range of 4.4 to 6.8 Rs/m3 (±15%) for On-site Package treatment plant and Rs (•) 3.0 to 10.1 (±15 -20%) for Cluster Type (< 5.0 MLD) as per design flow, Land usage for package type @ 4.0 to 40 m2 (±20%), 220.0 to 7630.3 m2 (±20%) for cluster type, Capital investment @ • 82.5 to 833.3 (±20%) Lacs/MLD for Package type and for cluster type @ 80.4 to 528.6 (±20%) Lacs/MLD; Specific power consumption @ < 0.7 (±10%) KW-h/m3 for design flow and 0.15 to 1.76 (±10%) KW-h/m3 for Actual Flow, technical performance was pragmatic with % BOD removal @ 65 to 98%, % COD removal 66 to 98 % and % TSS removal 65 to 97 % .These results give a test and an opportunity for the research community and market leader to choose a suitable option of similar regions. The results of this study allow users and engineer to choose the treatment system according to their resources available viz. –a- viz. requirement.

Keywords: Decentralized sewage treatment plants; Specific power consumption; Operation and maintenance; Economic analysis

I. INTRODUCTION

Expeditious advancement in masses, urbanization, industrial development, and exuberance of essentials in developing countries has drawn attention + responsiveness of various scholar towards the design of the suitable wastewater + treatment system. Ecological experts are furthermore highlighting now on suitable wastewater treatment systems to preserve the water environment and fresh water resources for certification the ingenuousness of imbibing water in little and prevalent manner [1] [2] [3].

In the most recent two decades, decentralized wastewater treatment frameworks (DEWATS) have been accounted for more proper answer for sanitation in creating nations[4] [5] [6]. Also a paramount part of the environmental engineer accept that DEWATS can be a perpetual answer for the wastewater administration in provincial and urban territories of developing countries [3].

The literature survey revealed that, to date a variety of technology options are available in the literature, including aerobic, anaerobic, natural and hybrid treatment systems, but selection of an appropriate wastewater treatment alternative in a decentralized context of developing countries is still a challenge for environmental engineer. A details collection of these systems has been polished recently by [4]. Previous studies suggested that the treatment efficiency of DEWATS plays major role in the selection of the appropriate treatment system, especially in developed countries, but surprisingly this is not true always as other constraints, such as land requirement, capital investment and operation & maintenance (O & M) cost limits the feasibility. Contrarily, in developing countries, selection was found to be more biased towards economic aspects and power consumption rather than their performance [7]. To best of the author's knowledge till date, In India, there is certainly not sufficient published work to assess the technical as well as economic efficiency of decentralized STPs based on all leading technologies of the market which could portray the actual status of the DEWATS. So it is extraordinarily anticipated from environmentalist that they should system monetarily and ecologically conceivable structures to propose a proper framework taking into account genuine practices either for traditional reasons or water need. Bearing this in mind, an intensive study was carried out in Northern India to assess the technical as well as economic efficiency of full scale DEWATS. The prime objectives of this study are as follows:

(i) To launch a ‘hand to hand’ on the selected plants to address a more incorporated assessment of the general maintainability of wastewater + treatment alternatives.

Manuscript Received on March 2015.
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(ii) Qualitative, technical and socioeconomic evaluation of existing DEWATS (capacity <5 MLD) across Northern India.
(iii) Consolidation of technical and economic data (collected via field visits, personal communication, and formal meetings with the working force) to contribute to the existing research/knowledge and to derive a comparative account based on economic parameter, discerning their efficiency.
(iv) Brings out key eccentricities at execution level, specific necessities for region, imperativeness and capital, O&M, and regular perspectives.
The upshots from this study can be time-honored as an issue for the general expense correlations of proposed treatment choices and will be helpful in arranging the imminent DEWATS in developing countries (like India). This study can also reference for different situations in this field.

II. MATERIAL AND METHODS

A series of athletic field visits was conducted from May 2014 to Mar 2015 and still on its approach, as an issue's task in ecological frameworks to understand economics & the subjective examination of DEWATS for review of planning, cost, condition, operation and upkeep of actually functional plants in Northern India.

2. 1. Description of study area

The DEWATS have been chosen with a varying capacity from 0.0006 MLD to up to 4.54 MLD by keeping in mind the capacity trend and of their adaptability. A total of 11 DEWATS was evaluated in this study, which was classified into two categories, i.e. package type and cluster type. Table 1 lists the description of each plant. Schematic layout of all plants is presented in figure 1 A & B.

Table 1 Description of DEWATS evaluated across Northern India

S NO	Plant Code	Technology	Capacity (MLD)	Year of Commissioning
1.	P1	On-site septic tank anaerobic filter	0.0006	2013
2.	P2	On-site contact aeration	0.006	2012
3.	P3		0.2	2012
4.	P4	Moving Bed Biofilm Reactor (MBBR)	0.4	2014
5.	P5	Rotating Biological Contactor (RBC)	0.45	2013
6.	P6	Extended Aeration (EA)	0.76	2005
7.	P7	Extended Aeration (EA)	1.35	2005
8.	P8	Sequencing Batch reactor (SBR)	3.0	2010
9.	P9	Extended Aeration (EA)	3.93	2005
10.	P10	Extended Aeration (EA)	4.44	2005
11.	P11	Membrane Bio Reactor (MBR)	4.54	2010

**** Installation of each plant was underground.***

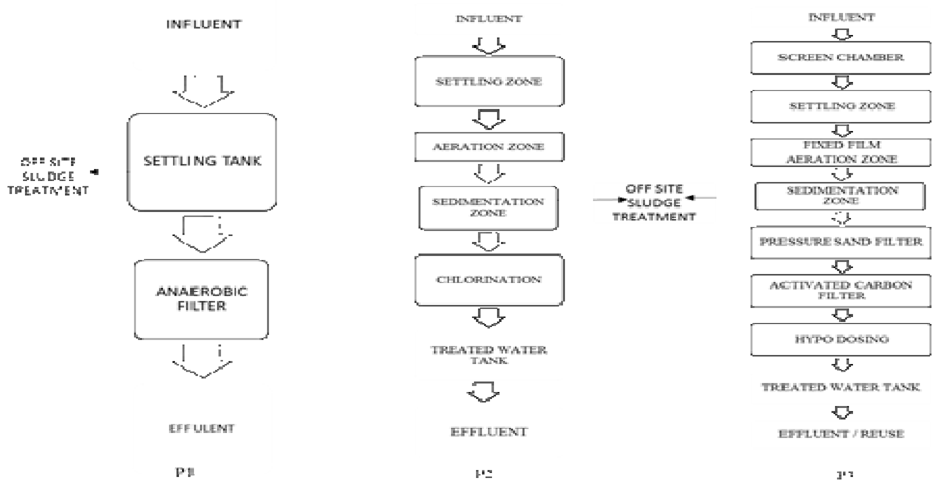

Fig. 1A Actual schematic layouts of plants visited during this study

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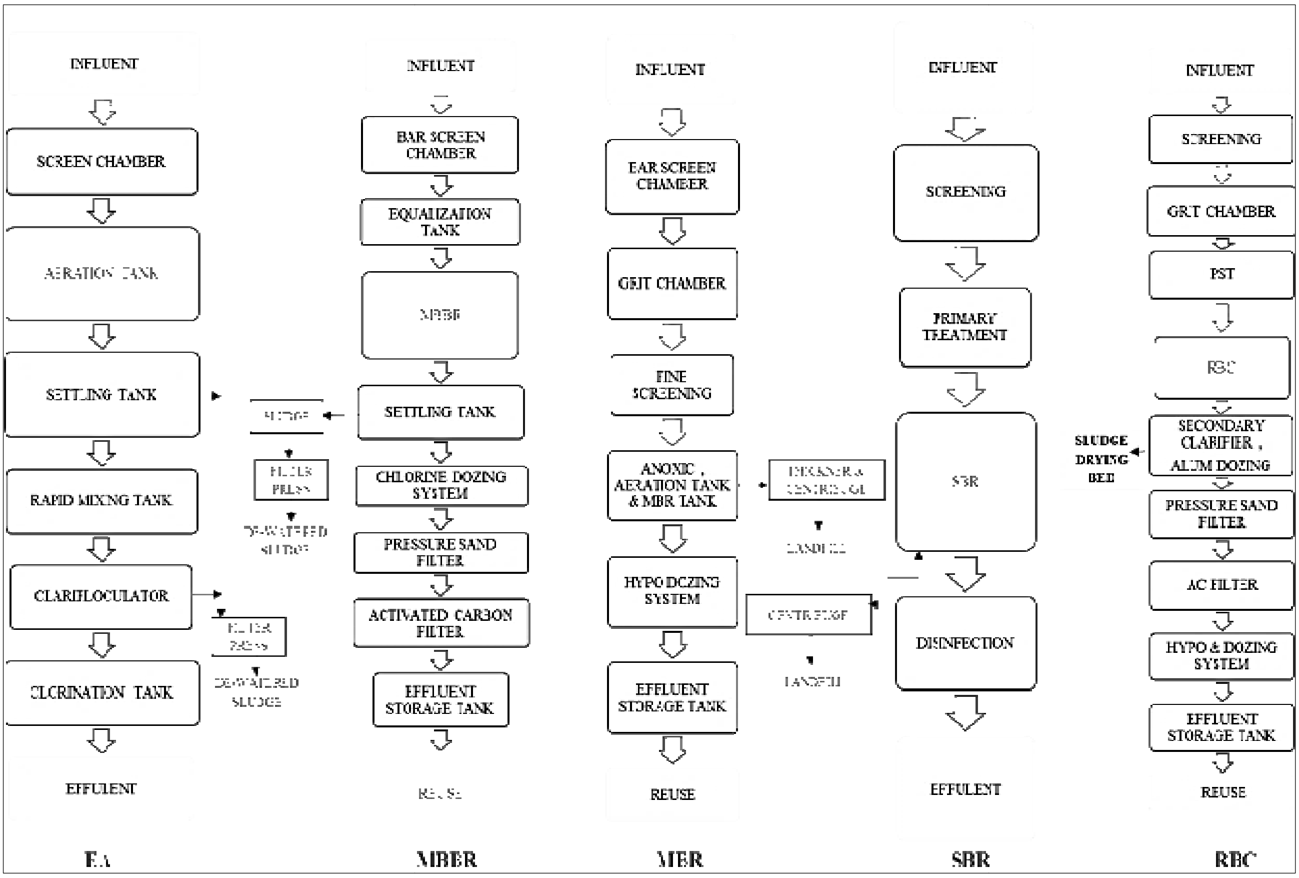

Fig. 1B Actual schematic layouts of plants visited during this study

2. 2. Assessment methodology

Three most common approaches for evaluation of wastewater treatment plants are known as expressive, instructive and investigative [8] [9]. Among these, the most reliable investigative methodology was utilized in this study, which can lead research community to assess the suitability and feasibility of a treatment system. For the purpose of field review, author fused a motivational study by a questionnaire (not with-standing specific parameter check) under five arrangements of physical inspection, grab sampling, on-site technical check, interaction with bodies, economic aspects and problems related to water treatment respectively. Some inputs are best appreciated/evaluated and further calculated as per factual prerequisite and constraints which necessitate to formalize these hypothesis. The author have also used multiple sources of data along with extensive field visits to complement the study with a broader perspective. Moreover, work force comments from respective plants were also taken into consideration before making any conclusive remarks.

2.3. Assortment of relevant data

2.3.1 Land usage

As one of the significant obstacles in the establishment of the sewage treatment plants in Indian urban areas, the Land data were measured and calculated (i.e. along the perimeter) and total area used for the STPs was generated.

2.3.2 Capital Investment and O & M cost

The capital investment (as per year of installation) and O&M Cost are two main parameter that need to be taken into account in economic examination of treatment plants. The collected data was analyzed and evaluated to draw a correlation between different capacities and re-occurring cost was explored in depth for establishing facts and figure.

2.3.3 Energy usage

Energy consumption data were compiled and evaluated based on data available from field records / working load / equipment inventories /monthly electricity bills / interaction with operator to analyze and formulate estimation for determine the working load and hour of run of the plants.

2.4 Environmental sample collection and analysis of performance parameter

Additional investigation of the major performance parameter like biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS) was furthermore directed for expected visits. The overall treatment efficiency of all plants was evaluated by analysis of influent and effluent samples of each plant. All samples had been stored in a deep freezer at the temperature of 4^0C and experiments have been carried out within two days of sample collection. All analysis was performed as per the method prescribed in standard methods **[10].**

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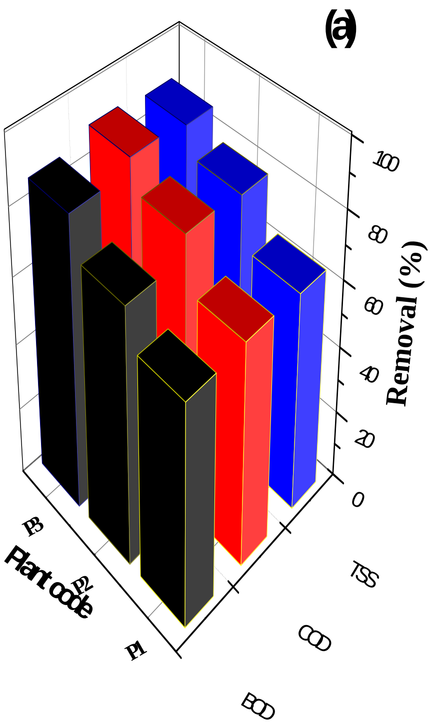
III. RESULTS AND DISCUSSION

3.1 Performance assessment of DEWATS

Figure 2 shows the results of BOD, COD and TSS removal efficiencies, according to their classification heads. Among the three evaluated package plants, P3 showed much higher treatment efficiency in terms of BOD, COD and TSS (86 - 90 %) as compared to P1 (65 - 66 %)and P2 (75-81%) as shown in figure 2.This can be attributed for P3 to anaerobic + aerobic nature of treatment + additional tertiary treatment unit, while P1 was completely anaerobic. Results of treatment performance of cluster type plants are also presented in figure 2. The removal efficiencies for BOD, COD and TSS of each plant in this category were observed above 90 % and gets matched with each other (±10%). This indicated that the treatment potential of these technologies based treatment system not much different with each other. Use of pre and post-treatment also made it possible so much higher efficiencies as shown in figure 1. These results proved that actual treatment practice (with incorporation of additional tertiary unit) may differ than reported ones. These differences can be attributed to the O & M practice of each plant which was also evidenced by personal visits and communication. From the field review it was seen that P11 technology reflects the removal efficiency up to 98% which was best among the selected plants. On the other side P4, P5 and P8 (up to 97 %) presented the bit lower performance than P11 based STP. The efficiency of all other plants can also be increased by adding an efficient tertiary treatment unit with the present treatment technology as evident from the plants like P3, P4, and P5 as shown in fig 2. The group of plants P6, P7, P9, and P10 has shown efficiencies of 90%, which is attributed to good skilled management.



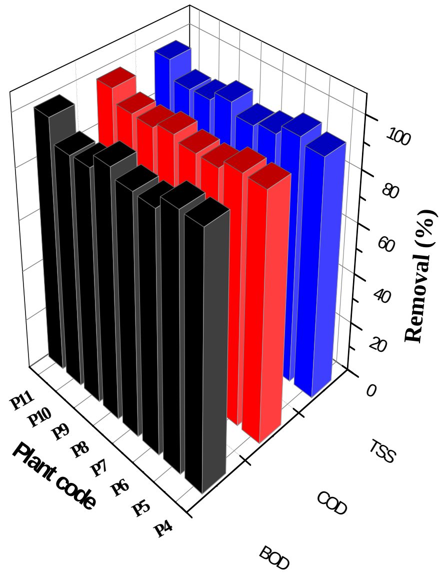


Fig. 2 Treatment efficiency of selected (a) onsite package and (b) cluster type DEWATS

This exercise clearly indicates that selected plants in this field review are well enough to achieve significant treatment efficiency and final selection may be independent from performance if one is not much concerned about performance i.e. below treatment efficiency less than 90 %.

3.2 Land usage &capital investment

Land availability and initial capital investment for a given size/capacity are two of the most important limitations, shaping the choice of DEWATS and future expansion for next coming generations may be taken into account for expansion of existing ones, ideally at many locations it was lacking. In general, the land required for a plant establishment generally relies upon the adopted technology, its treatment capacity and type of locality (rural, urban or peri-urban). In the last two decades, although the footprint required was same for a capacity, but increased cost of land again limiting the adaptability of that technology. While on the other side, due to technological advancement + variances of technologies, capital investment for a particular size of the plant has been with competitive rates and thus resulted in fluctuation of rates. Having these considerations in mind, the Land area & Capital Cost requirement has been appreciated based on field data collection for all selected plants. It is important to mention here that estimated land area was inclusive of minimum extra assets which are required to be constructed along with the treatment units.

Figure 3 shows the land usage and capital investment required for on-site package and cluster type treatment systems. The Capital costs reported in this study are the original values to the year of erection of the plant. These values can be further utilized for any project with a variation of (±10-15%) depending on the type of terrain, classification of the area and to which mass of the populace being subjected to. The approximate rough present cost effectiveness per MLD can be calculated based on the NPV valve (6%) compounding from the year of construction of the plant keeping in mind the particular technology has not gone obsolete and lost its credibility in the market.

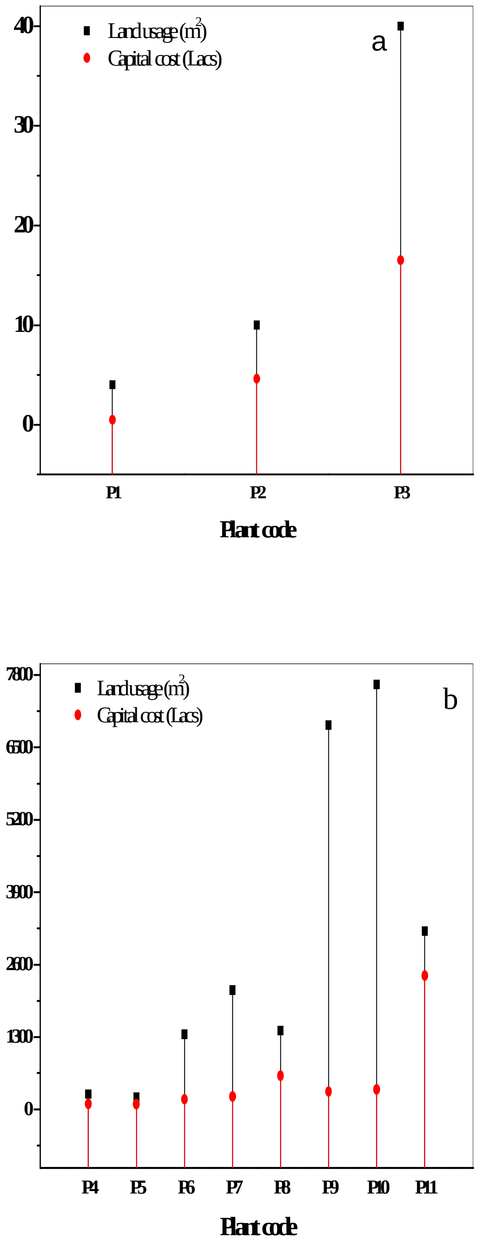


Fig. 3 Actual land usage and capital investment for selected DEWATS a) onsite package plants b) cluster type

Results of field campaigning suggests that, however capital investment and land requirement for on-site type DEWATS are dependent on field capacity but their relative contribution is constant and follow a linear relation with respect to capacity of plants. These results further suggest that if one has limitation of land availability, then capital investment supposed to be increased. It is important to mention here that the relative contribution of land and capital investment was found to be dependent of type of technology. On the other side, for cluster type plants, capital investment was found to be not following any significant relation with respect to capacity, except for P11. Also, for P11 these results suggest that capital investment was much higher as compared to other plants of this category. However the land requirement followed a decreasing trend. It was also observed that increasing the capacity of plants in the range of 0.4 - 4.54 MLD, land area requirement was related to capacity following a relation as shown in figure 4 for cluster type. Moreover, the relative contribution of land and capital investment (as per year of commissioning) for the plants in this category, followed a correlation same as for on-site package plants. Recent year correlation can be developed using above NPV as mentioned above.

Overall field gathering and discussion show that increasing the capacity of on-site plants decreases the land requirement significantly as compared to capital investment while in cluster type plants, capital investment was found to be almost same for P4, P5, P6, P7 and P8 (±10-20%) capacity plants. P9 and P10 showed the maximum footprint, but economical in terms of capital cost from year of establishment. Overall, as compared to other plants of cluster types, P11 was found to be more capital-intensive, but requires much less land even with increased capacity.

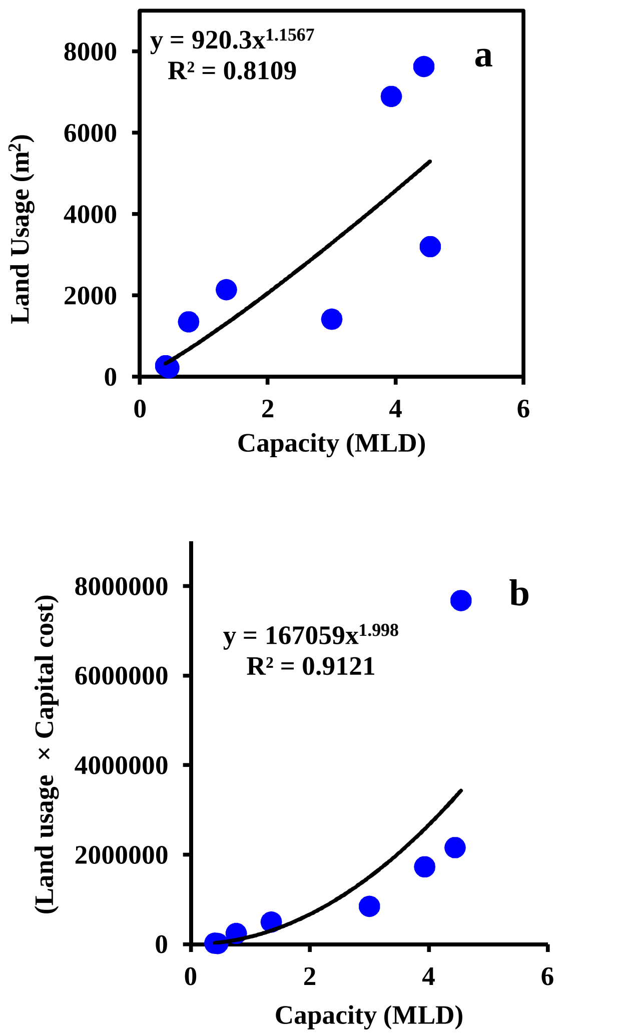


Fig. 4 Suitable fit for a) land requirement, and b) relative contribution (Land usage × Capital investment {as per year of commissioning}) with respect to capacity for cluster type plants

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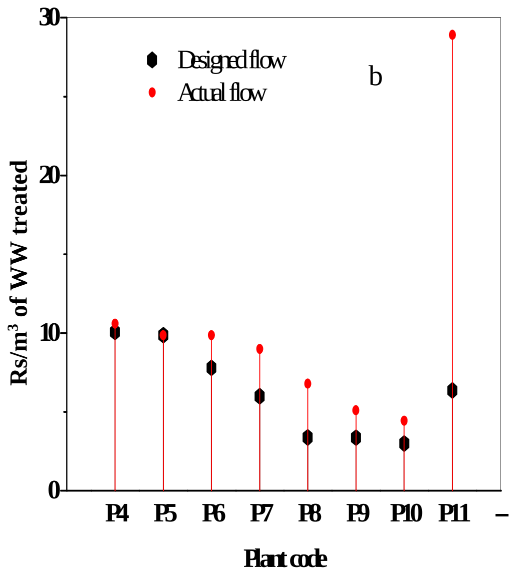
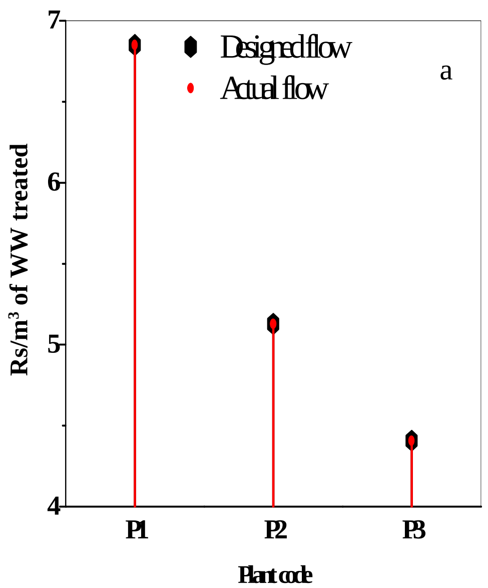
3.3 Cost of treatment

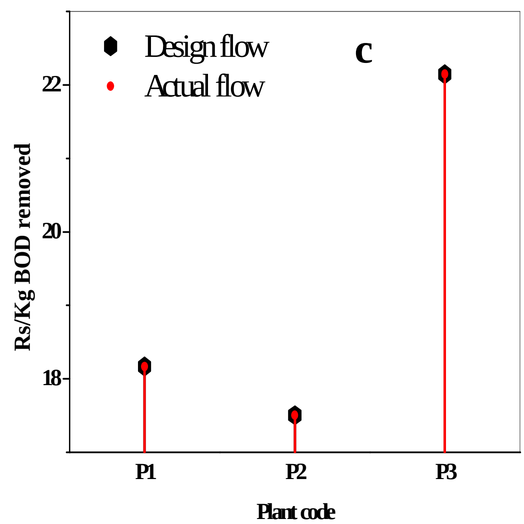
Reoccurring cost was considered as part of the qualitative assessment to draw sound results which are reassuring to improve a structure for assessment. Cost of treatment for each plant considered in this study was observed to be dependent on the O & M cost and was calculated on the basis of designed and actual flow. Field visit revealed that lack of skilled personal for operation resulted in variation of O&M cost which affected the cost of treatment significantly. During field visits it was observed that it is possible to have a lower value for O&M irrespective of having a higher value for all the above inputs. Further under mentioned values can be used further with a margin of (±15-20%) as per the geographical location and the economic growth of undeveloped lands. The cost of extra paraphernalia (i.e. for the substructure, office block, and site upkeep, organizational inputs) are excluded as these expenses will escalate the overall O&M Cost viz.- a wise cost of treatment and thus no relation could be justified.

The results of this exercise revealed that the cost of treatment for onsite plants decreases with respect to their capacity. A similar pattern was observed for cluster type plants except for P11 as shown in figure 5. Cost of treatment for on-site package plants was observed as ▪ 6.80 – 4.40 per cubic meter of treated wastewater. Cost of treatment for cluster type plants was observed in the range of ▪ 10.10–3.30 and ▪ 10.60 to ▪ 4.40 at designed and actual flow while for P11 plant were ▪ 6.40 and 28.90 at designed and actual flow. The cost of replacement of membrane for P11 plant not included in for reoccurring cost as it will form part of extra construction cost. This doesn't match the capacity trend line with treatment cost as ▪ 6.40 being highly mechanized plant. Thus, one line statement can be drawn these plants are for functional aspects, but not for study purpose as one cannot correlate many aspects and varies from plant to plant.



Overall no standardization could be established between the plants regarding fixed inputs, except but surely the decreasing trend line for the cost of treatment is observed in both categories with the increase in plant capacity and being independent of technologies except P11 being exceptional as it is fully atomized and gives the highest removal efficiency. In addition to the cost of treatment another techno-economic parameter, i.e. cost/Kg of BOD removed was assessed for all plants and was assessed three to five times the cost of treatment. These values for on-site package types were observed in the range of ▪ 17.50 to 22.10 (Figure 5c & d). Similarly for cluster type plants these values were found to be ▪ 33.90-11.0 and ▪ 35.40 - 16.50 (with P11 exceptionally higher ▪ 96.0 as plant may run with actual flow by year 2018) at design and actual flow, respectively.





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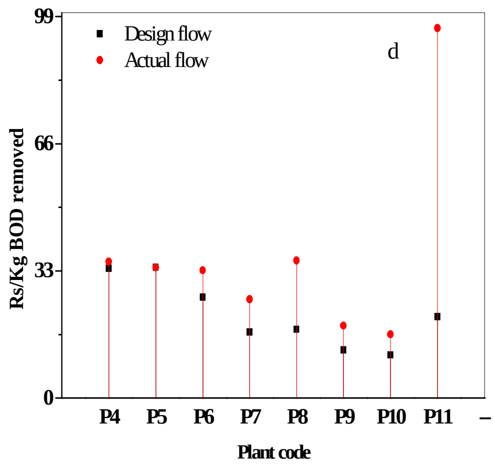
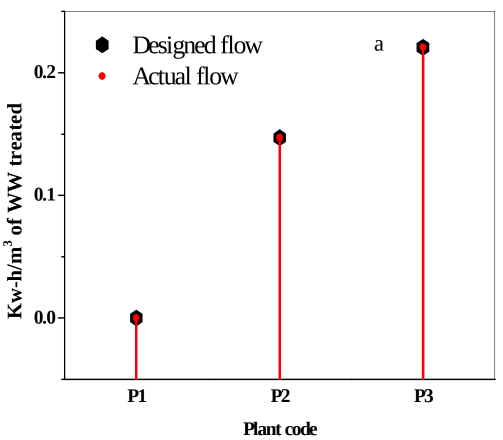
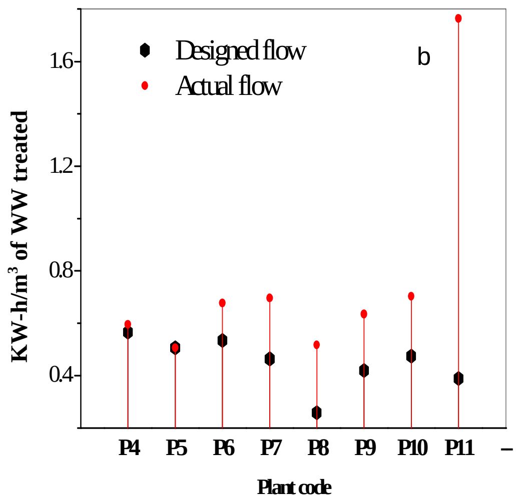


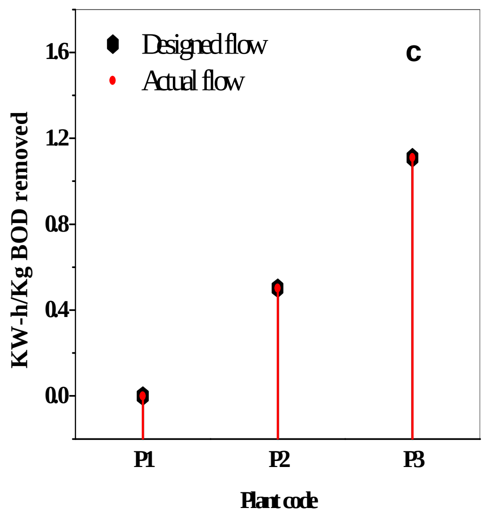
Fig. 5 Cost of treatment for a) onsite package plants and b) cluster category plants; ▪ /Kg of BOD removed for c) onsite package plants and d) cluster type plants

3.4 Power consumption

Power consumption is one of the most important contributor to the operational cost of wastewater treatment plants and generally presented as specific power consumption (SPC) i.e. power consumed for unit wastewater treatment. The SPC can vary wrt to many factors i.e. Drive make & classification, energy efficient drives and other integral electrical factors which can effect efficiency to the tune of 20 to 25% and overall effecting the reoccurring cost by additional 10-20%. The SPC for on-site package plants varied in the range of 0 - 0.22 kWh/m3 of WW treated, whereas for P1 it is 0.0 as being anaerobic treatment. Figure 6 shows SPC 0.6 - 0.3 for design flow with P8 the least SPC as integrated power management software ensures the correct functioning of this plant, also SPC for actual flow was 0.52 to 0.70 and P11 plant being exceptional higher with 1.76 as the plant is presently running under-utilized. P11 being accredited to more highly programmed treatment system and multifarious processes that necessitate extensive larger power inputs has shown good results as with the actual flow scenario also and can be further used with ±10% variation based on design flow parameter. These results broadly fits in the values as mentioned in the various reported literature [11].







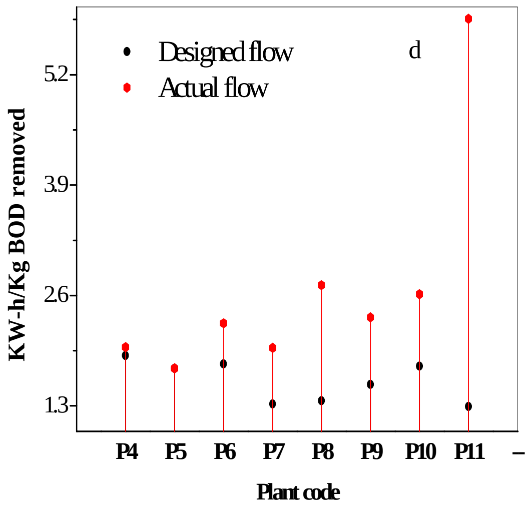


Fig. 6 Specific power consumption and power required for unit Kg BOD removed for onsite package and cluster type plants a) SPC for onsite b) SPC for cluster type c) power consumption for BOD removal of onsite package type d) power consumption for BOD removal of cluster type

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IV. CONCLUSIONS

Following upshots were drawn from this field campaign:

- This study has brought distinctive parameter for the user to assess the techno- economic indicator based predominantly on Land, Capital, Operative cost as per prerequisite and after that suitable technology can be chosen within a suitable range of (±10 - 20%) (Depending on the type of region classification) for developing countries like India. The financial criteria and confined communications had settled on a choice making prototypical for selecting the suitable little scale STPs elective. The broader information assimilated from field work narrowed to more or less realistic future useable values.
- Land usage was highest for an on-site package system which suggests that these systems are not suitable for plant having capacity more than 1 MLD with reference to planning for underground installation. Socio-economic evaluation of cluster type plants revealed that Land usage does changes much on increasing treatment capacity (0.76 - 4.44 MLD) while capital investment followed decreasing trend with increasing capacity for this technology types plants. The land requirement decreased as the capacity of the plants was in increasing order except for those plants installed in hilly terrains.
- As far as cost of treatment is concerned, it was found to be dependent on the capacity of STPs. Increasing the treatment capacity from 0.0006 to 4.54 MLD, the treatment cost varied in the range of ▪ 10.10 - 3.30 and ▪ 10.60 – 4.40 for designed and actual flow respectively with P11 plant was observed ▪ 28.90 (as ultimate constant utilization by 2021). The overall assessment based on study shows that the cost of treatment generally decreases with the increase in the capacity. The range of cost of treatment gives a broader perspective of the treatment cost for that capacity.
- As far as treatment efficiency is concerned, the performance potential of all plants having capacity in the range of 0.4 to 4.54 MLD was almost same and varied between 90% (±10%) for BOD, COD and TSS. Among these P11 based STP presented the best effluent quality system. Examination of on-site package system revealed that on-site contact aeration treatment systems are more efficient (up to 90% with tertiary unit) than on-site septic anaerobic filter package systems with removal efficiency ranging up to 66 %.
- All the plants selected in this study showed that power consumption was not so much different with each other except for P11 category. Specific power consumption as per design flow was averaged < 0.7 (±10%) kWh/m3 of treated wastewater with least of 0.15 KWh/m^3 for P2 package type plant and 0.3 kWh/m^3 for P8 cluster type. Overall power consumption was found to be inversely proportional to size of plants.
- The plant performance and further usability of values will be assessed based on design flow parameter as actual flow is of temporary nature and shows plants installation viz –a viz location being adequately assessed for taking load variations for years to come. Also, the selection of a process requires analysis of all factors, not just technical performance. The other qualitative economic parameter needs to be incorporated to reach a final recommendation.
- Closing remarks for this study was to look beyond the perspective of the performance evaluation and introspection the modalities which can be used in policy making pronouncements in emerging nation state like India. The author strongly likes to submit that results can vary according from place to place due to the actual working conditions, terrain implications and skilled/ unskilled manpower available for that area and it is hoped that this will facilitate policy makers/ officials, users, development/research organizations, government; local level partner make better investments in water management as per their constraints.

ACKNOWLEDGEMENT

The author wish to thank the Dept. of Civil Engineering, Indian Institute of Technology, Roorkee, India for providing the financial assistance and technical assistance for this project.

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