Water is needed in all aspects of life and hence forms an essential part of human well-being. Nationally and internationally organizations and institutions are making efforts to provide adequate supply of potable water to every one as it is ‘Right to life’ and proper handling of this resource would lead to sustainable development. But present day conditions with increasing water demand, urbanization and improper disposal of wastewater pose harm to this process of development. The conditions in cities are worse. Therefore, policy-makers and designers must consider these challenges as opportunities and develop systems which will help in conserving the depleting freshwater resources and use water efficiently and effectively.

The residential sector in cities has seen a major increase in water demand in recent years. Water consumption is expected to grow from 30 billion m$^3$ to 111 billion m$^3$ (Source: TERI Presentation dated June 10, 2010) and with the increase in high-rises, water demand is increasing at a much rapid pace. India, therefore, needs to rethink on new water treatment approaches and investigate which technique is appropriate today. While conventional centralized aerobic and anaerobic technologies exist in large set-ups, they have been found to be operational-energy intensive, require high maintenance and incur high capital cost (Table 1). Keeping this in mind, the present research is focused on developing a decentralized biological wastewater treatment system for tall residential buildings using a patented ‘Phytorid’ technology developed by National Environmental Engineering Research Institute (NEERI), Mumbai. This technology uses no electricity, requires minimal manpower and uses natural plants in a manner that they achieve the desired treatment levels; and reuse the treated water while becoming part of the landscape and aesthetics.

Phytorid for Wastewater treatment:

Phytorid uses natural mechanisms to treat the wastewater and is a low cost, natural and efficient alternative to the conventional energy intensive options. Earlier, this technology has been tested and used to treat the lakes, nallas, domestic wastewater, industrial effluents but has not been tested for its application on tall residential buildings making this research unique. The study included the application and feasibility of Phytorid system and its integration into one of the tall residential building in Mumbai, a growing urban center of India.

The treatment bed (Figure 1) is made up of media zone viz., bricks, sand and stone in which aquatic or semi-aquatic plant species such as cattails (Typha sps), elephant grasses (Pennisetum purpurem) canny lily (Canna sps.), dwarf palm (Cyperus alternifolius), arrow arum (Peltandra virginia), elephant ear (Colocasia esculenta), sweet flag (Acorus calamus), woolgrass (Scirpus sps.), yellow flag iris (Iris pseudocorus), soft rush (Juncus effuses), and horsetail (Equisetum hyemale) are grown which help in treating the wastewater with following treatment efficiency. Biochemical oxygen demand and total suspended solids removals averaged between 75-90% and 68-86% respectively while fecal coliform removal about 85-97% in the treatment cells is obtained (NEERI). Nitrogen reductions in the range 50-69% and phosphorus between 45-59% can be obtained.
The system consists of three zones: (i) inlet zone composed of crushed bricks and different sizes of stones, (ii) Treatment zone consist of same media as in inlet zone with plant species and (iii) Outlet zone.

The system is efficient to remove major effluents through the various physical, chemical and biological processes that take place due to the presence of the media and the plants in the treatment bed.

**Integrated System design approach:**

The design of such systems becomes more effective when an integrated approach is followed. Integrated systems here refers to systems that are well integrated in the building itself and which considers all aspects of treatment and organization put together in different combinations according to the needs and financial budgets of users into one complete framework becoming a unified whole. Hence in planning and designing such a system, all the technical, environmental, social and economic aspects should be considered.

**Design Concept:**

Domestic Wastewater is basically obtained in two forms - black water and grey water which vary in their contaminants content and hence should practically have different systems for treatment which is not a practice usually. Although dual plumbing is a common practice now-a-days in many residential towers, the wastewater is combined together and then treated or disposed-off. Hence the research revolved around having different treatment systems for grey and black water. Also, black water requires pre-treatment before entering the treatment bed which is not necessary for grey water in this kind of treatment system.

Once, the water is segregated the system is identified to be possibly designed in four major typologies these typologies may work better for grey water treatment than black water as black water requires pre-treatment and hence an additional area has to be provided. So, black water ideally should be treated centrally. The design typologies are:

1. **Individual unit.**

These units (Figure 2) can be installed at individual level and can serve small volume of water which can be designed in the form of flower bed units or small planter units.

2. **Intermediate unit.**

These units (Figure 3) can be installed at intermediate floor levels in the tall buildings like the refugee floor area or intermediate level green spaces like sky courts; open to sky terraces, etc.

In this case, the system can be designed to work on gravity where the water from the above floors is treated at the intermediate level and the treated water could be reused and send to the lower units through gravity.

3. **Centralized unit.**
This unit (Figure 4) is one which treats the wastewater in a centralized manner i.e. they collect the wastewater at one level and then supply it back to the system after the whole water is treated. The treated water is then pumped up to the required place as done in a conventional system.

4. Hybrid unit:

In this it can either be a combination of above two units/systems or it can be combined with another wastewater treatment system appropriately clubbed to give the required results.

One could decide from the above design typologies which typology is best suited for a particular use and develop the technology further. Some of the factors which are responsible for the selection of the design typology and the comparison between the typologies can be seen in Figure 5. The typology selection is the essential step for having an integrated system installed in any tall residential building.

Design Parameters:

After the typology is selected one needs to understand the design parameters which will lead to the design of such systems.

- **Design Volumes:**
  For design of any wastewater treatment system, the design volume is the most important parameter. The total water consumption in a residential building is the water used for various purposes like kitchen, toilet, bathing, wash basins, etc. The wastewater generated from all this gives the design volume. This can be calculated separately for black water and grey water. (Table 2)

- **System Design:**
  There are various spaces like the refugee floors, flower beds, podium areas, intermediate green spaces or any area common area where there is sunlight and appropriate surface area required in a residential tower which can potentially be used for the design of such systems. (Figure 6 and 7)

- **Sizing of the bed:**
  Surface area required to treat the wastewater depends upon the Retention time which is the time required to treat the wastewater to required standards. Typically the retention time required for treatment with this technology varies from 16-24 hours. Simple calculations could be done for calculating the surface area when the retention time is known (Table 2).

**Variations in the design of Phytorid bed:**
A number of variations are possible in the design of the system (Figure 8) as the technology is simple, uses basic materials and increases the scope of design, some of which are listed below:
- Variation in the depth of the bed (0.3 - 1m deep).
- Variation in the surface area/ shapes (Rectangular, Circular, Free flow, Pipe (Cylinder), Polygonal.
- Variation in the Assembly of the whole unit.
- Variation in the Position.
- Variation in the flow.
- Variation in the plant species used.
- Variation in the Construction material.
- Variation in the medium of treatment bed.

**Design and installation:** As the integrated system proposal focuses on productive use of treated wastewater, so the design and installation needs to look into a number of aspects like the technical, environmental, economic and social. These aspects could be the uncertainty in flow; issues like rain/droughts, winds; right to use the treated water; regulatory and legal framework for planning; disposal of waste after treatment; cost analysis; investments; operation and maintenance of the system; etc. All these aspects should be kept in mind while designing of the treatment system.

**Cost Benefit:** For any system to be installed effectively and efficiently, it is important to analyze the cost benefit of that system over a conventional sewage treatment plant now mandatory for high rise buildings. Cost benefit analysis helps to prove whether a particular technology is financially viable and economically beneficial. The research showed that the Phytorid technology is low cost as it uses minimal materials and no operational energy as it is uses natural techniques to treat the wastewater compared to the conventional energy intensive options (Table 3).

**Limitations to the use of the technology:**

Any system may have its own limitations to its use which could be tackled if properly designed and known. The limitations to this technology are:

Clogging of the solids near the inlet of the treatment bed

The time required for treatment of the wastewater is more compared to the conventional system

The Phytorid system is limited by the natural growth rate of plants and length of growing seasons. So the initial few months for the system an alternative system has to be thought of

Maintenance costs are often lower than conventional systems but the monitoring costs could be higher. The plants require timely harvesting and proper disposal of contaminants this may not be a tedious job but only requires supervision and monitoring.

High concentration of toxic materials could be hazardous to the growth of plants but as it used for treating domestic waste water in this case the toxic contaminants are relatively less.

The use of it in the landscape areas adds to the aesthetics but with that also introduces it to the human contact of the wastewater treatment bed. Proper care has to be taken in the rainy seasons when the storm water is mixed with the systems and the systems usually fail in providing the required results. In the above case and in any other uncertainties there needs to be a provision for other back up system so that the water level is maintained.
The land required is more than the conventional systems but this can be overcome by potentially dividing the systems in smaller units and strategically placing them in the negative spaces of the building like the Refugee floors, flower beds etc.

The depth of treatment is limited by the penetration depths of the specific plants used. If the contamination is deeper than the root zone than additional remediation may be needed.

Conclusion:

Through the study it is apparent that a low cost, low maintenance and energy efficient alternative is viable and feasible for use in the urban residential sector and even more suitable than the conventional decentralized options thus fulfilling the purpose of the study. An essential aspect for the use of such systems over the conventional decentralized (when compared to electro-mechanical solution) systems was the cost benefit analysis of the proposed design with the existing example where it showed significant economic benefits. Although the system showed some limitations or constraints to its use, they could be tackled with timely supervision. The design could be fully utilized and will be successful only if the integrated design approach is used which considers all the aspects necessary for the designing of the wastewater treatment system.

Phytoremediation systems are a low cost, energy efficient, natural and low maintenance systems compared to the conventional treatment systems and could be potentially used in the design of treatment of wastewater in Tall Residential building.

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