Project Report on

Existing Natural Treatment Systems Installations in India and Their Performance

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

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Improving Quality of Urban Life

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1. Background

The increasing population coupled with lack of techno-economical solutions, are the prominent catalysts expediting the deterioration of quality of water resources in India. Despite the prevalence of regulations on wastewater treatment in India, the quality of aquatic environment in all three settings of urban, rural and peri-urban, continues to decline. Out of the many reasons contributing to water scarcity in India, uneven distribution of surface water bodies, extensive abstraction of groundwater and its contamination, persistent droughts, deteriorating surface water quality are a few factors (Khalil, 2017). It is reported that around 2.5 billion South Asians will be victims of water scarcity by 2050. The 'Accelerated Irrigation Benefit Program' is a watershed development scheme launched to reach out irrigation to the drought-prone rural areas (Das and Bokshi, 2017). Moreover, the Government of India has increased the drinking water supply from 116 km^3/year (in 2010) to 174 km^3/year (in 2025) indicating the need of an economically viable treatment technology to cater to the increased wastewater generation by 2025 (Sonkamble et al., 2018).

The sewage generated in major Indian cities is estimated to be 38,354 MLD out of which treatment capacity exists for 11,786 MLD. Thus, 26,568 MLD of surplus sewage is directly responsible for water pollution (Datta et al., 2016). A significant gap, in the wastewater generation and the treatment capacity in Indian Sewage Treatment Plants (STP's), has been reported due to which Government of India has taken assorted initiatives to establish STP's for sewage treatment. However, the conventional technologies have major challenges such as high energy for operation and maintenance of the system (Kalbar et al. 2012a; 2012b). For class I cities, Activated Sludge Process (ASP) and Up-flow Anaerobic Sludge Blanket (UASB) reactor are the dominant treatment choices (accompanied by suitable primary and tertiary treatment) comprising of 59.5% and 26% of the total installed capacity in India (Khalil, 2017). The choice of technologies is seen to vary drastically for class II towns. Waste stabilization ponds and UASB constitute 71.9% and 10.2% of the total installed capacity (Khalil, 2017). Sometimes, illegal dumping of untreated or partially treated wastes in the sewer network makes the sewage composition fairly complex and varied. This is one of the reasons for failure of STP's in India, since they are designed to treat neither municipal solid waste nor additional industrial pollution load (Saha et al., 2015). The greatest challenge to be tackled in the coming decades is that of implementing wastewater treatment at a low cost which also allows selective reuse of treated effluents for industrial and agricultural purpose (Das and Bokshi, 2017).

1.1. Need for appropriate technology selection

Investment in infrastructure for wastewater treatment is costly and the urban local bodies have to investigate properly before investing in this sector (Khalil, 2017). A large number of treatment technologies have been experimentally proven to remove the various contaminants from wastewater. Each technology has its own advantages and limitations. 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 among the Urban Local Bodies (ULBs) while choosing the technology. Wastewater treatment before disposal is mandatory as per the Central Pollution Control Board (CPCB) and recently the discharges standards are made more stringent. Also, industries are not only forced to treat their own wastewaters but to reuse/ recycle it in their own premise. However, such mandates have created confusion due to the lack of awareness among stakeholders. Despite the proven technology, it not necessarily functions to its desired standards in every scenario. It is the situation, and not the technology, that decides the appropriateness of technology selection (Kalbar et al., 2012). It is important to analyze the location where wastewater treatment is to be implemented. The existing infrastructure, population density, awareness level, availability of skilled manpower, availability of funds, end use of treated wastewater *etc*. are few of the factors to be taken into account for decision making. The decision making pertaining to environmental problems lacks in inclusion of multiple criteria. A developing country like India has a huge gap in sewage generation and the treatment capacity. The Government has allocated funds for sewage treatment; however, technology selection is done considering limited factors which lead to failure of treatment systems. The infrastructure for sewage treatment if once created is difficult to dismantle and hence inappropriate technology selection unnecessarily results in a wastage of financial and material resources (Kalbar et al, 2016).

1.2. Natural vs Mechanized Treatment Systems

The performance of a number of treatment technologies is discussed in the 'Compendium for Sewage Treatment Technologies' by Tare and Bose, (2009). The comparison is done on the basis of two important parameters, land requirement (m^2/MLD) and cost requirement (INR/ KL). The technologies achieving good removal efficiencies are either costly due to the energy component or have a large land requirement. It is always a trade-off between energy and land.

The ASP and UASB process are reported to constitute 62% and 83% of total capacity of STP's in the Ganga Action Plan and Yamuna Action Plan respectively (Tare and Bose, 2009). In addition, Moving Biological Bed Reactor (MBBR) and Sequential Batch Reactors (SBRs) are the popular technologies. However, none of the technological options were found to achieve effluent of recyclable quality for high end applications. The perilous balance between the growing water demands and supplies has led to a forceful adoption of recycling and reusing water. 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.

Conventional sewage treatment systems are incapable to remove nutrients nitrogen and phosphorus thereby causing high sludge production and eutrophication issues on disposal in water bodies. Further, the mechanized systems also lack capacity of coliform removal. This makes the effluent unsuitable and poses a risk on its reuse. However, natural treatment systems have the potential to achieve good nutrient as well as coliform removal. It is of utmost importance to explore these wastewater treatment solutions for existing challenge of inadequate sewage treatment capacity.

1.3. Towards decentralization

Centralized systems collect the sewage from the entire town or city and collectively treat the same in one place. However, the conveyance of sewage needs to be carefully planned and is often a neglected factor in economic considerations. From financial perspective, 80-90% capital costs are attributed to the pumps, huge pipes and energy component (Capodaglio, 2017). Moreover, life cycle assessment of conventional wastewater treatment systems has showed the construction of sewer network in itself to cause an environmental impact of magnitude greater than both the construction as well as operation-maintenance cost. Decentralized systems are also less vulnerable to power cuts, extreme events such as natural calamities and accidents. Thus, adopting centralized systems for the rural or peri-urban communities having low income is bound to attract economic burden for the population. The conventional mechanized treatment options are not sustainable due to their complexity and high expenditure (Massoud et al., 2009).

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). In today's scenario of mandatory recycling of wastewater, centralized systems are not beneficial since <5% of effluent is recycled in centralized systems. On the contrary, decentralized treatment are reported to facilitate up to 30-100% reclaimed water, thus reducing the dependency on freshwater (Capodaglio, 2017).

A decentralized wastewater management may be defined as the collection, treatment and either disposal or reuse of treated wastewater from decentralized infrastructure such as individual households or cluster of houses, isolated communities, institutes or industries (Crites et al., 2010). The basic objectives behind adopting a decentralized wastewater management system is to ensure public health, protect the environment from degradation or contamination and reduce conveyance costs by treating the water and solids near the point of generation itself. Achieving complete sewerage network in any country is almost impossible due to economic as well as geographical reasons. Therefore, a combination of centralized and decentralized systems in accordance with population density should always be preferred. Decentralized systems can be relevant under the following circumstances:

- Remote location of community or distant sewers
- Inadequate wastewater generation due to limited water supply
- Reuse/ recycle options are feasible
- Expansion of existing treatment infrastructure is not possible
- Cost of wastewater transport is high
- Easy availability of low cost land in the premises of the community

1.4. Natural Treatment Systems (NTSs) to achieve decentralization

Decentralized NTS are reported to be best suited for cities which are unable to maintain pace with rapid increase in population. However, due to exorbitant land prices in urban and peri-urban areas, NTS are suitable primarily in rural settings (Starkl et al., 2013). Constructed wetlands (CW) are gaining popularity in developing countries and have also been implemented successfully in the urban regions of India by joint initiative of European Union and Department of Science and Technology under the project 'SWINGS' (Safeguarding Water Resources in India with Green and Sustainable Technologies) (Khalil, 2017). Constructed wetlands are capable of improving the water quality as well as enhancing the biodiversity in a region thus making it as an attractive option for urban planners (Nandkumar et al., 2019). Constructed wetlands with water hyacinth are reported to require only 13% of the energy in comparison to conventional sewage treatment thus making it a feasible option in developing countries (Datta et al., 2016). A CW developed in the middle of the wastewater channel in Mahakal Commercial area (Ujjain, Madhya Pradesh) is an example of on-site treatment plant eliminating the use of valuable city land domestic wastewater treatment (Billore et al., 2013). Natural treatment system models were developed for different scenarios after the efficiency of wetland was integrated with engineered interventions. Accordingly, a single outlet system, minimized community wetlands and CW were found to be the suitable options for rural, peri-urban and urban areas respectively (Sonkamble et al., 2018).

Village ponds (natural ponds receiving rainwater) which are an integral part of rural India, if integrated with scientific treatment methods like duckweeds and aquaculture, can prove to be effective measure for wastewater management. The potential of ponds in India is not utilized fully, hence the socio-economic as well as environmental benefits of the same need to be reached out to the villagers. Moreover, the utilization of nutrients nitrogen, phosphorus and potassium (N, P, and K) from village ponds and recycling them in some way for agriculture is an added benefit in today's scenario where the use of fertilizers is causing pollution of water bodies (Ansal at al., 2010). The eutrophication in ponds can thus be effectively converted to generation of organic fertilizers with these natural treatment methods that might reduce the use of fresh chemical fertilizers.

In one study, rapid sustainability assessment of NTS was done using four parameters health, environmental, institutional, social and economic for twelve case studies situated throughout India. The significance of institutional and organizational involvement is highlighted in this study, which should be considered in planning (Kumar at al., 2015).

2. Natural Treatment Systems

Despite the advanced removal efficiencies obtained in mechanized treatments, they have certain drawbacks. The aeration requirement in secondary treatment demands significant cost and energy. Also, these technologies require skilled personnel for operation, in the absence of which the wastewater treatment installations are a complete failure. Due to these limitations, mechanized treatment technologies cannot be adopted universally. In these circumstances, natural treatment systems which are simple and reliable can be adopted.

Natural treatment systems are based on processes taking place in nature and mimic the same resulting in effective removal. It minimizes or even eliminates the energy requirement for treatment. However, natural processes take place slowly and at their own pace. Thus, NTS requires longer detention times and demand more land area. Wastewater treatment systems involve the trade-off of land vs. energy. It is important to note that the natural component of NTS make the technologies dependent on the latitudinal location of plant, the availability of sunlight, temperature and other climatic factors (Sonkamble et al., 2018).

2.1. Categorization of NTS

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). In this report, the above categorization of engineered natural wastewater treatment systems is slightly modified to include a fourth category termed 'natural hybrid systems' in the classification, which is represented in Figure 1 below.

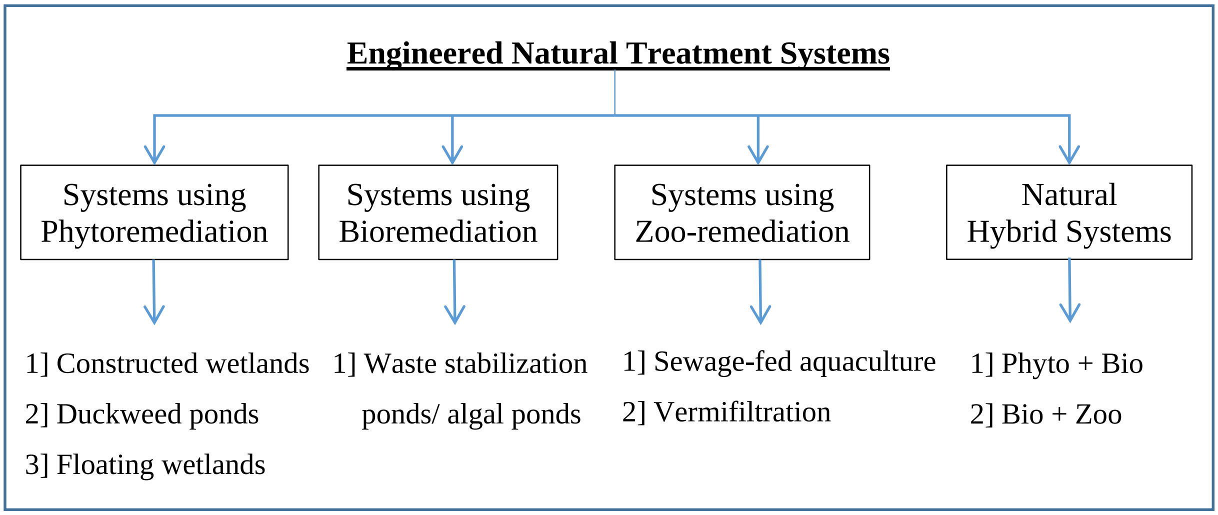


Figure 1: Classification of engineered natural treatment systems

Arceivala and Asolekar, (2017) have considered the following natural treatment systems:

1. Classical Algal Ponds (WSP's)
2. Hyacinth and Duckweed plants, Fish ponds
3. Natural and Constructed wetlands
4. Vermiculture
5. Sewage-fed aquaculture

2.2. Systems using phytoremediation

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 in this section.

2.2.1. Constructed wetlands

2.2.1.1. Basic description

Constructed wetlands are engineered systems artificially developed to function natural processes along with coexisting microorganisms to aid wastewater treatment (You et al., 2019). The wetland vegetation and the microbial population present in media are the key functional units in constructed wetlands whose natural mechanisms assist in removal of the contaminants present in groundwater or surface water. Constructed wetlands are necessarily affected by climatic conditions, native plant species and substrate materials used. They are known by various names such as planted soil filters, reed bed treatment systems, artificial wetlands or vegetated submerged beds. The design of constructed wetlands has been adopted by mimicking the natural wetland systems which are known to treat wastewater.

Constructed wetlands are less expensive than the competitive mechanized treatment technologies, and are simple to operate and maintain. It is also claimed to require lesser land compared to other NTS. However, the large area requirement makes it economical to adopt CW only where land is available at a cheap rate. Also, the design criteria of CW are yet to be systematically developed for various scenario and climatic conditions.

2.2.1.2. Flow diagram

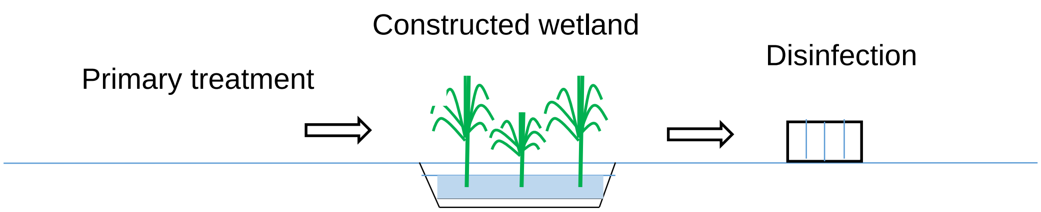


Figure 2: Schematic diagram of constructed wetland

2.2.1.3. Application

Constructed wetland is considered to be a viable, sustainable, and cost-effective solution for treating greywater from small communities. It is also found to be economical for treatment of municipal wastewater, effluent from textile industry and leachates from landfills (Ramprasad et al., 2017). Constructed wetlands have also been used to treat industrial effluents from pharmaceuticals, textiles, sugarcane molasses, tanneries, electroplating, pulp and paper mills as well as landfill leachates (Rana and Maiti, 2018). If the design of a constructed wetland resembles a natural wetland, it may also provide habitat for those species of birds, insects or animals (such as mice and snakes) which thrive in wetland environment (Reenu et al., 2015). Apart from secondary or tertiary treatment of wastewater, the use of construction wetlands has now been extended to habitat development, storm water treatment and flow attenuation.

2.2.1.4. Wetland flow patterns

There are two flow patterns commonly used in wetlands, horizontal and vertical flow. The characteristics of both flow patterns are summarized in Table 1 below:

Table 1: Comparison between horizontal and vertical flow patterns in wetland

Sr.	Horizontal flow	Vertical flow
1	Limited oxygen supply	Sufficient oxygen supply
2	Enhanced nitrification is not achieved	Almost complete nitrification achieved
3	Efficient denitrification	Nitrogen remains in the form of nitrate

It is suggested by Goswami et al., (2019) to operate the vertical and horizontal flow wetlands in in batch and continuous mode respectively. The distribution of roots in case of horizontal flow wetland needs to be maintained uniformly throughout the filter bed height, but in case of vertical flow wetland it is important to ensure the uniform root distribution only in the upper layers (top 10 cm). The higher oxygen transfer capacity in vertical wetlands, efficient nitrification and BOD removal has led to a growing interest in the same (Hoffmann et al., 2011). However, lesser efficiency of solids removal might lead to early clogging of the system. The limitations of both vertical and horizontal configurations have led to the concept of hybrid wetlands consisting of both horizontal and vertical wetland is series. The nitrogen can be completely nitrified in the initial vertical flow CW whereas it can subsequently be denitrified in the succeeding horizontal CW (Ramprasad et al., 2017).

2.2.1.5. Classification of wetlands

Based on the level of water flow, wetlands are classified as follows:

Free water surface CW: (FWS)

Surface flow CW has partial wastewater flow through leaves and stem that may encourage algal production, odors, and mosquito breeding. The stems and submerged leaves in wetland, to an extent serve as media supporting the bacterial growth. The leaves shade the water surface preventing algal growth to some extent. However, the algal growth is inevitable and results in early clogging of the system. The oxygen is transported from leaves to roots thereby supporting the growth of plants. The suggested pre-treatment for these wetlands are rotary disc filters, imhoff tanks, septic tanks or stabilization lagoons.

Sub-surface flow CW:

Sub-surface flow has higher wastewater flow area so less land area is needed, making it suitable for urban neighborhood (Goswami et al., 2019). Sub-surface CW are less sensitive to extreme winter conditions of frost and snow, and have considerably lesser foul odor, mosquitoes and algal formation problems thus facilitating its universal adoption all over the world compared to surface flow CW (Khalil, 2017). However, the increased cost due to gravel media and construction volume are the disadvantages of these systems.

Unlike free water surface CW, sub-surface wetlands do not have any exposed water surface. The wastewater being protected from the effect of wind currents and re-suspension thus enables an effluent with lower concentration of suspended solids. Also, the evaporation rates are low for sub-surface wetlands. Nitrogen removal in sub-surface CW primarily occurs due to nitrification-denitrification. As we know, the nitrification step requires oxygen whereas the sub-surface wetlands have limited aerobic zone. For this reason, often aeration is supplemented by using surface tubes to provide oxygen to intensify nitrification. The systems fail if they receive algal loaded wastewater from a facultative pond. The trapping of algae at the inlet and further decomposition of it adds to the organic load.

2.2.1.6. Removal principles

The wastewater treatment in a constructed wetland occurs due to an interaction between various zones such as the sediments, media pores, plant and plant roots, biomass zones associated with plants as well as media. An in-depth understanding of the removal mechanisms of various parameters is vital to develop performance prediction models. The carbon and nutrient cycles are the basis of constituent transformations occurring in the wetlands and aquatic systems. Since the aerobic as well as anaerobic conditions co-exist in FWS systems, both the carbon as well as nutrient cycles are operative. However, the relative contribution of both cycles varies throughout the year and is difficult to predict.

Wetland plants have a unique coping strategy to operate in an anaerobic environment. They widespread aerenchyma tissue formed provides low resistance to the oxygen, enabling it to pass from aerial parts of plants to the roots. Constructed wetland surpass the conventional technologies in this regard and are capable of removing metals without substantial costs and energy (Rana and Maiti, 2018).

The removal of contaminants takes place through a combination of mechanisms namely sedimentation, precipitation, adsorption, filtration, plant uptake, cation exchange, oxidation-reduction, bacterial degradation *etc*. Table 2 below illustrates the details of mechanisms contributing to the removal of a particular pollutant.

Table 2: Removal mechanisms in constructed wetland (Crites et al., 2010)

Sr.	Pollutant	Removal mechanisms
1	Biodegradable organics	Bioconversion by facultative and anaerobic bacteria on plant and debris surfaces
2	Suspended solids	Filtration, sedimentation
3	Nitrogen	Nitrification-denitrification, plant uptake, volatization
4	Phosphorus	Filtration, sedimentation, plant uptake
5	Heavy metals	Adsorption of plant roots and debris surfaces, sedimentation
6	Trace organics	Adsorption, biodegradation
7	Pathogens	Natural decay, predation, sedimentation, excretion of antibiotics from plant roots

The kinetics and mechanisms involved in the removal of soluble, particulate and colloidal solids is different. Due to multi-size particles, modelling of BOD (Biochemical Oxygen Demand) and TSS (Total Suspended Solids) becomes complicated. The BOD removal rate constant is known to vary as the wastewater flows across the wetland, adding to the complexity of modelling. The removal of larger particles (by flocculation, sedimentation, straining and entrapment) affects the removal rate of smaller particles and results in decreased removal rate coefficient. Sediments having a hydraulic conductivity of 12-15 m/d, comprising of medium to coarse grain soil and 30-39% porosity are reported to be of potential use in wetlands (Sonkamble et al., 2018).

The water soluble substances from plants after its death are transferred to the liquid. They are primarily constituted by amino acids and sugars which readily metabolize within the wetland. Due to this reason, the effluent from wetland typically has values ranging from 2-10 mg/L, (3-5 mg/L normally) which is often mistook as residual influent BOD.

2.2.1.7. Design guidelines

For the design of wetlands, ideal plug flow is assumed. However, preferential flow channels are observed to develop in practice. It is best to model the performance of a wetland (designed as an ideal plug flow reactor), as a series of 4 to 6 completely mix reactors. In case of natural systems, the bacterial population gets acclimatized to cold climate to maintain the mass despite slow activity rates. The design guidelines for constructed wetlands are described in Table 3, Table 4 and Table 5 below.

Table 3: Design guidelines for constructed wetlands, adopted from (Arceivala and Asolekar, 2017)

Sr. No	Parameters	Typical values	
		European literature	**Recommended for India**
1	Area required, m^2/person	2.0 – 5.0	1.0 – 2.0
2	BOD_5 loading rate, g/m^2-day	7.5 – 12.0	17.5 – 35.0
3	Detention time, days	2-7	2 – 3
4	Hydraulic loading rate, mm/day	< Hydraulic conductivity of bed	-
5	Depth of bed, m	-	0.6 – 0.9
6	Porosity of bed, % (typical)	-	30 – 40
7	1st order reaction constant, K_T/ day	-	0.17 – 0.18
8	Evapotranspiration losses, mm/day	10 - 15	>15

Table 4: Area requirement for constructed wetland (Hoffmann et al., 2011)

Area	**Cold climate** (average temperature < 10℃)		**Warm climate** (average temperature > 20℃)	
Flow pattern	Horizontal flow	Vertical flow	Horizontal flow	Vertical flow
m^2/ person	8	4	3	1.2

Table 5: Design parameters for constructed wetland (Crites et al., 2010)

Sr.	Design Parameter	Unit	FWS	SS CW
1	Organic loading rate	kg BOD/ha-day	<110	<112
2	Aspect ratio	-	2:1 to 4:1	<4:1
3	Detention time	days	8-14	3-4 (BOD); 6-10 (N)
4	Water depth	mm	100-450	450-1000
5	Gravel size	mm	-	3-32

2.2.1.8. Species used in CW

A number of species such as *Typha angustifolia, Phragmites australia*, *Typha capensis, Brachiria mutica*, *Typha latifolia*, *Colocasia esculenta*, *Phragmites karka*, *Canna indica etc.* have been used as constructed wetland species in Indian context. Table 6 describes the properties of some of the commonly used species.

Table 6: Properties of some common species used in constructed wetlands

Sr.	Name of species	Properties	Reference
1	*Phragmites australis*	Increased residence time of water leads to sedimentation of suspended particles. The plants also provide a physical site for bioremediation. Suspended solids, nutrients, heavy metals, bacteria and toxic organic compounds have been efficiently removed.	Reenu et al., 2015
2	*T. latifolia*	Intensive gas transfer through convection make it suitable for CW; found in a variety of climates as well as all water bodies including brackish and freshwater, flowing and stagnant water bodies	Rana and Maiti, 2018
3	*C. esculenta*	Metal uptake ability makes it common choice for bioremediation	Rana and Maiti, 2018

2.2.1.9. Studies conducted on constructed wetlands

The evolution of constructed wetland in central India and the first conference on wetlands is discussed by (Billore et al., 2013). This study also describes few CW's and reports it to be a promising option to combat the growing pollution in India. Due to lack of nutrient standards for disposal, earlier CW's were not designed for nutrient removal, however nutrient removal efficiency has also been talked about in this study (Billore et al., 2013).

Described below are some of the lab-scale studies conducted on constructed wetlands.

1. The potential of *Canna lily* to treat high strength wastewater (carbon, nitrogen and phosphorus) was evaluated in a study conducted in sub-tropical conditions. Remarkable efficiency in carbon removal was observed for wastewater having COD: BOD ratio as high as 24.4, which is considered to be difficult to degrade (Haritash et al., 2015).
2. The performance evaluation of Green Roof-top Water Recycling System (GROW) in Indian scenario for varying design parameters was the focus of study conducted by Ramprasad et al., (2017). The promising results positively suggest the application of GROW as a cost-effective and reliable system in tropical countries like India.
3. A mass balance has revealed that the metal loss from wastewater was equivalent to the sum of natural transformation of metals and net accumulation in plants (Rana and Maiti, 2018).

4. A satisfactory removal of phosphates through Brachiaria based CW in all the seasons was observed and it indicates the ability of CW's to absorb shock loads. Plants were observed to remove phosphate from wastewater even after the saturation of sites leading to increased removal efficiency even at a later stage of experiment. Excess of nitrogen either in the form of nitrate or ammonium was found to improve the phosphate removal efficiency. During the trials the phosphate removal efficiency was observed to increase with excess phosphate concentration (Nandakumar et al., 2019).
5. The efficiency of coconut biochar (as an adsorbent) mixed in the substrate of CW was evaluated and found to remove the color as well as chromium concentration of tannery wastewater (You et al., 2019).

Described below are some of the field-scale studies conducted on constructed wetlands.

1. The effectiveness of sub-surface flow CW the suitability of plant species *Typha angustifolia* and *Canna indica* for treating the effluents of pulp and paper mills has been evaluated, in which the plants are found to be well adapted to hydraulic retention time (HRT) of 3.5 days (Rani et al., 2011).
2. A CW designed as per Darcy's law and based on Environment Protection Act (EPA) and CPCB guidelines was set up in SRM University and six field trials were carried out (Reenu et al., 2015).
3. A technology variant 'OLAND' (Oxygen-limited autotrophic nitrification-denitrification), which is a biological process for nitrogen removal from wastewater, contributed to almost 60% savings through decreased aeration costs (Saha et al., 2015).
4. Residence time distribution is a classical approach to measure mean residence time in constructed wetland, on the basis of which the optimum wastewater level and flow of 0.6 m and 2.3 m3/s were reported (Goswami et al., 2019).

The overall efficiency of pollutant removal by constructed wetlands from literature is documented in Table 7 below.

Table 7: Efficiency of parameter removal in constructed wetlands

Sr.	Treatment	Parameter	Efficiency (%)	Reference and place of study
1	Constructed wetland	COD BOD TDS Nitrate Phosphate Potassium	75.99 76.16 57.34 62.08 58.03 57.83	(Reenu et al., 2015), SRM University
2	Constructed wetland	Organic content Nutrients Microbes	77-78 77-97 99.5-99.9	(Sonkamble et al., 2018), Hyderabad
3	Constructed wetland	EC COD TKN Copper Cadmium Manganese Chromium Cobalt Zinc Lead Nickel	67.8-71.4 70.7-71.1 63.8-72.3 75.3-83.4 73.9-83.1 74.1-74.5 64.8-73.6 82.2-84.2 63.6-66.1 71.4-77.9 76-80	(Rana and Maiti, 2018)
4	Constructed wetland	pH, COD, BOD, TSS, TN, NO3–N, TP, FC	>82	(Ramprasad et al., 2017), IIT Madras
5	Constructed wetland	BOD Cobalt Copper Iron	52 78.78 28.9 23.42	(Patil, Dhulap, & Kaushik, 2016)
6	Constructed wetland	TSS BOD NH_4-N TKN	62-82 40-75 67-78 59-78	(Billore et al., 2013), Central India
7	Artificial Floating Island	TSS NH_4-N NO_2-N TKN BOD	46.6 45-55 33-45 45-50 40-50	(Billore et al., 2013), Central India
8	UASB + SSF CW	COD	87-98	(Saha et al., 2015)
9	FUP-CW	COD NH_4-N PO_4-P Suspended solids Fecal coliform	68.5+/- 13 68+/-3 38+/-5 97.6+/-5 97+/-13	(Saha et al., 2015)

Sr.	Treatment	Parameter	Efficiency (%)	Reference and place of study
10	Free surface CW	Ammoniacal nitrogen	35-40	(Datta et al., 2016)
11	Constructed wetland	BOD COD	69.8-96.4 63.6-99.1	(Haritash et al., 2015), Delhi
12	Constructed wetland	TS (summer) COD (summer) BOD (summer) Color (summer) TS (winter) COD (winter) BOD (winter) Color (winter)	87.6+/-1.1 86.6+/-2 80+/-0.1 89.4+/-0.6 72.15+/-0.71 70.94+/-2.3 72+/-2.2 74.9+/-0.47	(Rani et al., 2011)

2.2.2. Duckweed ponds

2.2.2.1. Basic description

Duckweed systems are suggested in case of further treatment required to be given for algal pond effluents or enhanced denitrification to be achieved before discharging wastewater to lakes and rivers. The duckweeds have varied advantages such as high protein content, high productivity, significant nutrient uptake, easy handling and harvesting, low fiber content and tendency to reduce development of mosquitoes (Ghangrekar et al., 2007). The harvested duckweed is rich in proteins and can be used as fish feed or poultry feed after passing certain tests. Duckweed treatment is thus a wastewater treatment system which can generate revenue to pay for its own operation and maintenance. However, in the circumstances of wastewater containing heavy metals, the duckweed cannot be used as fish feed as heavy metals are also removed by duckweeds. Also, duckweeds can effectively be used as pellets for fish feeds after sun-drying, since the wax coat on their upper surface prevents fungal growth, thereby facilitating longer storage periods (Ansal et al., 2010).

Features of duckweed plants are as follows:

- Freshwater plants with fronds (leaves) 1-3 mm wide and roots <10 mm
- Grow at a rate 30% faster than water hyacinth with better nutrient accumulation and easy harvesting
- Surface mat of biomass has the potential to double its surface area in 2-4 days depending upon wastewater content and climatic condition
- Anoxic effluent as oxygen is not transferred to the water

- More cold tolerant than water hyacinth minimum operating temperature of 7° C and maximum up to 33° C. However Indian climate is mostly suitable for duckweeds
- More responsive to wide range of pH ranging from 5-9 (6.5-7.5 considered as optimum)
- Ability to control over mosquito breeding and bad odor problems that may be caused in other open pond systems
- Potential for community based job creation and revenue generation when coupled with fish ponds

2.2.2.2. Flow diagram

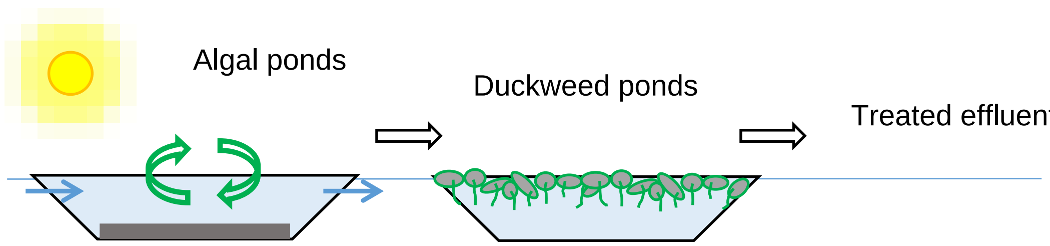


Figure 3: Flow diagram of duckweed pond treatment

2.2.2.3. Duckweed species

The duckweeds are classified as macrophytes, belonging to the botanical family '*Lemnaceae*'. This family consists of four genera: *Lemna*, *Spirodela*, *Wolffia* and *Wolffiella*. However, the use of mixed culture is known to elucidate maximum output. The uses, nutrient content and nutrient removal capacity of the commonly used duckweed species are mentioned in Table 8 below.

Table 8: Characteristics of duckweed species (Ramachandra et al., 2017)

Scientific name	Common name	Uses	Nutrient content (% dry weight)		Nutrient removal capacity (kg/ha-day)	
			N	P	N	P

Lemna minor	Common duckweed	1] Important food source for fish and birds, hence grown in dams 2] Valuable indicator of nutrient levels 3] Fish enthusiasts grow it as live food for goldfish and native fish	2.5-5.9	0.4-1.8	2.92	0.87
Spirodela	Giant/ big duckweed	1] High protein food source (ducks, geese, certain fish) 2] Harvested as feed for cattle and pigs in Asia and Africa	2.5-5.1	0.5-1.4	-	-
Wolffia	Common water meal	1] Variety of duck and geese including mallard can consume it 2] The dense canopy controls mosquito larvae	-	-	-	-

2.2.2.4. Removal principles

Duckweed species are small floating aquatic plants. The duckweed ‘fronds’, which are suitable for floating, do not have any stem or leaf. This reduces the fiber requirement of duckweeds, in comparison to other terrestrial plants. The ponds with a single duckweed layer form a continuous mat on the water surface, which inhibits the penetration of light as well as transfer of oxygen. Therefore, a very thin layer of aerobic bacteria and algae (below 10 cm) is observed around the tiny duckweed roots that cause limited aerobic digestion. As we go deeper, the water column below the duckweed surface is devoid of oxygen and algae, making the anoxic-anaerobic conditions favorable for denitrification. The quiescent conditions also facilitate the settling of solids. The tender mat of duckweed is susceptible to break under the wind or wave action. In these circumstances, the exposure of water surface to sunlight promotes the growth of algae which in turn will increase the suspended solids. Hence, it is of utmost importance to install ‘wind barriers’ so as to keep the duckweed layer intact. Growing dense vegetation around the operating pond is an alternative to wind barriers. In case of very low or freezing temperature, duckweeds tend to sink at the bottom in a dormant condition and starts functioning automatically when favorable temperature is achieved. This self-rejuvenating property makes the treatment process much easier. The mechanisms by which various pollutants are removed in a duckweed pond system are mentioned in Table 9 below.

Table 9: Mechanisms occurring in duckweed ponds for removal of various pollutants (Verma and Suthar, 2015); (To et al., 2020); (Willett, 2004)

Sr.	Pollutant	Removal mechanisms
1	Biodegradable organics	Bioconversion by aerobic microorganisms attached to duckweed fronds, digestion by anaerobic and anoxic bacteria that forms sediments
2	Suspended solids	Sedimentation, biodegradation into organic matter, absorption for duckweed growth
3	Nitrogen	Plant uptake, denitrification, volatilization of free ammonia
4	Phosphorus	Plant uptake for growth
5	Heavy metals	Uptake by plant fronds, adsorption on tiny roots and bacteria, sedimentation
6	Toxins	Lipophilic toxins and accumulated by duckweeds cells through their lipids in cell membrane
7	Pathogens	Natural decay due to long detention times

There is a tendency for oxidation ponds to become eutrophic in the absence of control systems like those in engineered aerobic treatment units. Despite faster removal of nitrates and phosphates in duckweed ponds in comparison to oxidation ponds, the dissolved oxygen (DO) levels were observed to be too low so as to sustain fish cultivation. The floating duckweed biomass hindering the penetration of sunlight is the main reason for reduced DO levels. Hence, duckweed treatment is only effective for removal of nutrients present in large amounts. Along with it, duckweed pond can also remove algae effectively from the effluent of oxidation ponds (Ghangrekar et al., 2007).

About 99.8% removal efficiency of fecal coliform was reported through treatment by Lemna gibba. This high removal of coliform makes it a promising tertiary treatment with great potential in developing countries and rural areas (Ansal et al., 2010).

2.2.2.5. Design guidelines

Duckweed ponds are the simplest of all wastewater systems if design constraints are considered. They are constructed in many ways such as simple pond, sheltered pond (pond divided in small divisions using floating bamboo type materials to avoid waves and flow caused due to wind), ponds in series or raceway ponds maintaining plug flow regime. However, the cost of construction, operation and maintenance and yield varies according to the complexity of the design. The duckweed system needs impermeable strata which can be constructed by lining of soil or artificial material. Although duckweed system infers high carbon and nutrient uptake, it is highly recommended to have grease separation unit, grit chamber and settling tank as pre-treatment to it in order to increase its efficiency and longevity. The duckweed pond functions excellently when BOD is lower than 80 mg/L and generates water of tertiary treatment level (Chen et al., 2018). The land requirement for duckweed ponds is reported in Table 10 below.

Table 10: Land requirement for duckweed pond systems, adopted from (Arceivala and Asolekar, 2017)

Pond detention time (days) for pond depth of 2 m	Approximate pond water surface area required (m^2/ person)	Overall land requirement (m^2/ person)
7	0.5	2-2.5
13	1	-
20	1.5	6

As the system functions efficiently at limited carbon and nutrient concentration with low pathogen removal, it is predominantly used along with UASB, aerated lagoons, waste stabilization ponds (WSP) or fishponds. Therefore, the overall land requirement includes preliminary treatment, pre-treatment (UASB/ aerated lagoon/ WSP), actual duckweed ponds, fish ponds and other miscellaneous items. For variable operating depths (1.25-2 m) (ex: during periodic draining of basin), the outlet should be designed so that it can remove the effluent from various depths.

2.2.3. Floating wetlands/ Aquatic macrophytes

2.2.3.1. Basic description

Floating wetlands are a form of in-situ treatment option for the revival of water bodies that are frequent recipients of wastewater. They comprise of a freely floating mat which supports the growth of plants on them. The composition of such a mat consists of mineral sediments, dead organic matter as well as live biomass, which are all held together by roots, rhizomes and stems. Lentic environments i.e. stagnant fresh water bodies are suitable habitats for floating wetlands mainly due to the presence of high nutrients and relative stability of water levels. Apart from improving the quality of surface water bodies, floating wetlands also restore the ecological habitat of the aquatic ecosystems and provide an opportunity for revenue generation by harvesting fish or certain crops. Many plants of economic importance are found in the rich speciation of plants found in a floating wetland. As in the case of Kashmir lakes, these floating wetlands can also be utilized to cultivate vegetables or food crops (John et al., 2009).

The aquatic macrophytes significantly contribute to the productivity of water bodies. They mobilize the minerals from sediments, and provide shelter to aquatic organisms like fish and other macro invertebrates. They are known to respond to the changes in water quality and are hence useful as 'bio-indicators' of pollution. Due to their ability to directly assimilate nutrients, aquatic macrophytes have been used to tackle the eutrophication problem in water bodies (Ramachandra et al., 2017).

2.2.3.2. Aquatic macrophyte species

Water hyacinth is among the commonly used macrophytes for aquatic treatment systems such as floating wetlands. However, Vetiver grass (*Chrysopogon zizanioides*) and water lettuce (*Pistia stratiotes*) are some of the known species used specifically in floating wetlands in India. Additionally, canna, vetivers, cattalis, cintronella, hisbiscus, bulrush, fountail grass, certain flowering herbs like tulsi and ashvagandha are also the known species. Growth of plants in floating wetlands takes place in both vertical as well as horizontal directions with different doubling time of 5-15 days for different species. The growth of water hyacinth is described either as the percentage pond surface covered over a given time period or the plant density (number of wet plants per unit surface). The water hyacinth systems are observed to have more consistent values of effluent with respect to monthly variations. This greater stability of systems is associated with structural and physiological diversity provided by the roots. However, due to short roots, it is suitable only for water bodies with low depth. Water hyacinth has proven its ability to survive in severe nutrient concentrations and assist in nutrient removal. Apart from nutrients, this hydrophyte is reported to effectively remove phenols, fecal coliforms, suspended particles and heavy metals (Patil et al., 2016).

Water lettuce is devoid of stem, has 14 cm long leaves and needs temperature of at least 15 ℃. It is observed to withstand high salinity but does not grow in wastewater with high COD levels. Vetiver grass is a tall and erect flowering plant with large biomass and has very dense system of roots that extends up to 3 m deep. With highest survival at hydroponic condition, the plant is known to sustain -15 ℃ to 60 ℃ temperature that is completely suitable for Indian conditions.

The aquatic macrophytes are broadly classified as:

1. Submerged macrophytes that are largely or completely submerged in the water bodies and may or may not have roots
2. Floating macrophytes in which the entire plant is seen to be floating on the water bodies
3. Emergent macrophytes that are not submerged in water
    a. Erect leaved emergent plants
    b. Floating leaved emergent plants

The species under each category are listed in Table 11 below.

Table 11: Listing of species under categories of aquatic macrophyes (Ramachandra et al., 2017)

Sr.	Free floating	Emergent	Submerged	Floating attached
1	*Eichhornia*	*Ipomea aquatica*	*Hydrilla verticillata*	*Potamogeton*
2	*Crassipes*	*Ludwigia*	*Ceratophyllum*	*Nymphaea*
3	*Azolla pinnata*	*Polygonal glabrum*	*Vallisneria*	*Nelumbo nucifera*
4	*Pistia stratiotes*	*Colocasia esculenta*	*Ottelia alismoides*	*Nymphoides*
5	*Salvinia*	*Sagittaria*	*Najas*	*Marsilea*
6	*Lemna minor*	*sagittifolia*		
7	*Spirodella*	*Typha angustata*		
8	*Wolffia*	*Cyperus rotundus*		
9		*Bacopa monnieri*		
10		*Eleocharis*		
11		*Urochloa panicoides*		
		Alternenthera - philoxeroides		

The nutrient content and nutrient removal capacity for species is mentioned in Table 12 below.

Table 12: Characteristics of commonly used aquatic macrophytes (Ramachandra et al., 2017)

Sr	Scientific name	Common name	Species type	Nutrient content (% dry weight)		Nutrient removal capacity (kg/ha-day)	
				N	P	N	P
1	*Eichhornia crassipes*	Water hyacinth	free floating	1 to 4	0.1-1.2	12.78	2.43
2	*Azolla pinnata*	feathered mosquito fern/ water velvet	free floating	2.5 - 4.5	0.1 - 0.39	1.08	0.33
3	*Pistia stratiotes*	water cabbage/ water lettuce	free floating	1.2-4	0.2-1.2	9.85	2.18
4	*Salvinia*	giant salvinia, kariba weed, water moss, water fern	free floating	2-4.8	0.2-0.9	-	-
5	*Ludwigia*	water primrose,	Emergent	2.5-4.5	0.4-0.6	8.26	1.2

		water dragon, marshy jasmine					
6	*Alternenthera philoxeroides*	alligator weed	Emergent	1.5-3.5	0.2-0.9	4.88	0.55
7	*Colocasia esculenta*	elephant ears, potato of the tropics	Emergent	0.6-1.9	0.1-1.3	-	-
8	*Typha angustata*	cattail	Emergent	1.2-2	0.1-0.35	7.2	1.1
9	*Cyperus rotundus*	Nut grass	Emergent	0.71-1.75	0.02-1	7.4	1.3
10	*Ceratophyllum*	coontail, common hornwort	Submerged	3.5-4.2	1-1.4	-	-
11	*Potamogeton*	pond weed	Floating attached	2.7-4	0.5-1	-	-
12	*Nymphoides*	water snowflake	Floating attached	1.5-3.5	0.5-1.2	-	-
13	*Marsilea*	water fern, water clover, four leaf clover	Floating attached	2.3-3.6	0.5-0.7	-	-

2.2.3.3. Removal principles

The floating islands are designed to maximize the formation of biofilm. A combination of aerobic, anaerobic and anoxic conditions is prevalent beneath the plants. The plant roots aid in achieving increased values of dissolved oxygen whereas the plants and biofilm contribute to the uptake of nutrients and heavy metals, which also results in BOD and COD reduction. For the restoration of freshwater lakes, it is sufficient to construct floating wetlands in 5-10% of the total area.

For the floating wetlands, the BOD and TSS removal efficiency is higher than that of nutrients and metals. The portion of suspended solids not settled by gravity is removed by filtration through water hyacinth roots. The transport of wastewater to the root system of water hyacinth should be ensured. With time, the solids continue to accumulate on the root surfaces, which subsequently senesce and drop to the pond bottom. Phosphorus removal in these systems is not efficient so there is a necessity of pretreatment or post treatment, especially in the scenario of limits to phosphorus removal.

In some cases, specific types of insects are observed on the basic structure that survives on the aerobic bacteria. This helps to attract various birds and gives helping hand to form a complete ecosystem.

2.2.3.4. Design of floating wetlands

Basic parameters considered for the design of floating wetlands include the type and composition of wastewater, depth of water body and selection of plant species. A general structure of floating wetland comprises of four parts namely i) the basic structural framework made up of floating material such as bamboo or PVC pipes ii) a filler material to basic framework where cubical or rectangular Styrofoam with multiple holes is used iii) a covering of complete framework with gunny bags and iv) gravels on the upper most layer. This structure can be modified according to the budget and the availability of local materials. As floating wetlands have a tendency to flow in the direction of wind, all the individual wetlands may gather together and reside at the bank of the water body. In order to control this phenomenon, anchoring of wetlands is done. Attachment of anchor (usually made up of stainless steel in helical shape) can be done either at the bottom of the water body or at the rigid supports at its bank depending upon its size and depth. These steps are followed by the most essential step of plant species selection, which is dependent upon the physiochemical properties of wastewater, climatic conditions and depth of waterbody. Usually a polyculture is used that can smartly tackle the climatic conditions, increase the range of toxin removal and provide versatile root support for microorganisms throughout the depth of water body. After the installation of floating wetlands, it is important continuously monitor them up to three weeks in terms of wear and tear of basic framework, growth of plants, changes in the shade of leaves, flowering, and removal of debris inside the water body as well as on the wetland. In some cases, external aeration is provided to the pond system that facilitates circulation of wastewater and enables to adopt organic loading rates 4 times as high as that adopted in designing non-aerated systems. In case of aerated systems, it is important to use devices producing fine bubbles, which facilitate higher oxygen transfer efficiency. On the contrary, coarse air bubbles tend to uplift the root of plants by exerting a greater buoyant force. (Case Study, 2004)

2.2.3.5. Studies conducted on floating wetlands

A combination of *Typha* species with water hyacinth and water lettuce reported the nutrient uptake rate of water lettuce as almost 1.5 times that of hyacinth. Sulphate removal efficiency for hyacinth and *Typha* is higher than that of lettuce. The maximum growth of water hyacinth was observed at nutrient concentrations 28 mg/L and 7.7 mg/L of total-N and total-P respectively (Datta et al., 2016). An artificial island of $200m^2$ area (100 units of $2m^2$ area each) was constructed in-situ on river Kshipra and tested for domestic wastewater. The treatment performance was evaluated on the basis of monthly sampling, on the basis of 2 sampling points 40 m apart, before and after the artificial floating island. Satisfactory removal of solids, BOD, TKN (Total Kjehldalh Nitrogen) and other nitrogen species was observed, which was also established by mesocosm studies (Billore et al., 2009).

Recently, there has been a shift towards bio-eco-engineering technologies in the sector of wastewater treatment. Floating islands can be considered as a variant of the traditional constructed wetlands, as they have the potential for restoration of the water bodies which are either stagnant or flowing at a slow pace. However, this technology lacks adequate scientific base including design criteria, installation, monitoring, and maintenance procedures.

2.3. Systems using bioremediation

2.3.1. Waste stabilization ponds

2.3.1.1. Basic description

The waste stabilization ponds (WSP's) are primarily divided in three categories namely anaerobic, facultative and maturation (or aerobic) ponds. The removal of BOD forms the basis for design of anaerobic and facultative ponds, whereas maturation ponds are designed for the removal of fecal bacteria. An individual pond functions like a completely mix series reactor. A series of ponds, function as a series of completely mix reactors, thereby achieving the benefits of a plug flow reactor. Since the plug flow regime gives the best results, a series of ponds is always the preferred choice for wastewater treatment. Natural treatment systems such as WSP's have the advantage of better pathogen removal than mechanized systems. Waste stabilization ponds are capable of achieving 4-log removal of pathogens as against the 2-log removal for activated sludge process. This is the reason why National River Conservation Directorate in the Ministry of Environment, Forests and Climate Change, had recommended only WSP's. Additionally, WSP's are resilient to organic and hydraulic shock loadings due to the long retention time. Waste stabilization ponds was identified as one of the four sustainable methods in the context of developing countries, the other three being CW, UASB and Soil aquifer treatment (Das and Bokshi, 2017).

However, there are certain perceived disadvantages with the pond systems which are responsible for it to be an unpopular choice for wastewater treatment. The mechanisms for WSP's are too simple and the lack of sophisticated technology as used in Activated Sludge Process (ASP) raises doubt about its efficiency. It is difficult to mimic WSP designs as per the different climatic conditions observed through the globe. Also, the fear of odor and mosquitoes contributes to its unpopularity. However, it should be realized that the odor arises only in the case of incorrect design of ponds or overloading of ponds.

The algal-bacterial symbiosis is the key mechanism for BOD removal. Hence, the presence of algae in ponds as well as in the effluent is obvious. It results in a high BOD and regulatory authorities are bound to take action. However, the filtered BOD i.e. non-algal BOD should be tested and compared with the limits. European standards take the algal BOD in account and specify limits as

Filtered BOD < 25 mg/L and

Algal suspended solids < 150 mg/L

The presence of algae in the effluent of waste stabilization ponds contributes to its potential for reuse in irrigation. Algae act as slow release fertilizers which improve the organic content as well as water holding capacity of the soil with time.

2.3.1.2. Classification

Waste stabilization ponds or algal ponds are primarily classified as aerobic, anaerobic and facultative ponds depending on the conditions in which microbial decomposition takes place in the ponds. The classification of waste stabilization ponds is illustrated in Figure 4 below.

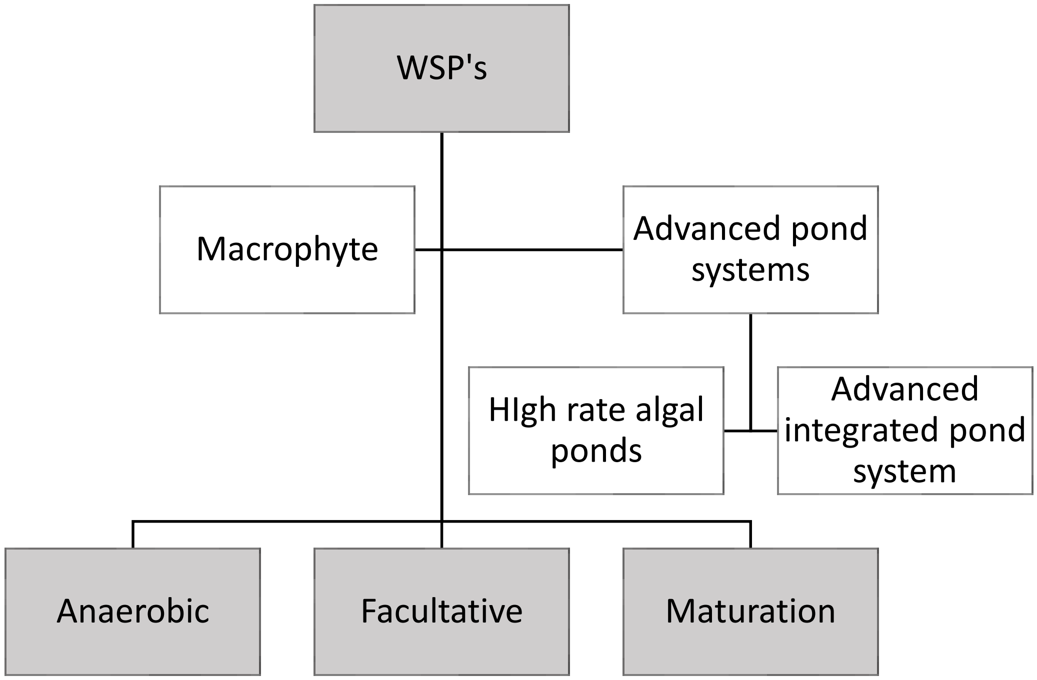


Figure 4: Classification of waste stabilization ponds

Anaerobic ponds:

Anaerobic ponds constitute the first pond in the series of waste stabilization ponds. They are responsible for the primary treatment of wastewater and also reduce the area requirement of further ponds. Also, the presence of certain harmful compounds in industrial wastewaters is toxic to algae and might affect the efficiency of facultative ponds. In such cases, the use of anaerobic ponds before treatment in facultative ponds reduces this risk.

The rate of accumulation of sludge is very gradual in these ponds and desludging is typically required to be carried out once in 1 to 3 years. In the absence of sludge layer, the volume in anaerobic pond available for digestion is completely utilized; hence the rate of sludge accumulation is higher in the beginning. With time, as sludge starts depositing at the bottom, the volume available for digestion reduces and this results in a decreased rate of sludge accumulation.

Facultative ponds:

The facultative ponds can be classified on the basis of their position in treatment chain. Primary facultative ponds receive raw wastewater whereas secondary facultative ponds receive wastewater after sedimentation. The micro-algae constituting the wastewater impart a green color to the ponds. Occasionally, due to overloading, the pond may appear to look pink or red, owing to the presence of purple colored anaerobic sulphide oxidizing photosynthetic bacteria.

Sulphide and ammonia toxicity:

The sulphates are reduced to sulphides by bacteria. With a decrease in pH, the amount of sulphide present in pond as dissolved hydrogen sulphide (H_2S) gas increases. H_2S is capable of penetrating the algal cell membrane thereby inhibiting algal growth. Experiments conducted have found the growth to be inhibited by almost 50% due to low levels of H_2S. As a solution to this problem, it is suggested to introduce the effluent from anaerobic ponds in the lower part of pond, at least 0.8 m below the water surface. In a similar way, unionized ammonia is also toxic to algae. However, ammonia toxicity increases with an increase in pH.

Maturation ponds:

Maturation ponds are secondary waste stabilization ponds receiving pre-treated wastewater either from a facultative pond or any other conventional treatment plant. The typical detention time in these ponds is around 5 to 7 days and the purpose of these ponds is to refine the quality of final effluent. Apart from natural bacterial die-off occurring in the ponds, the presence of predators (like fish or crustaceans) make these systems function as hybrid systems. Among the series of ponds constituting WSP's, the maturation ponds are vital in coliform removal due to high DO, large surface area and an increase in the hydrogen ion concentration facilitating a low survival rate of coliform (Kapilesh and Indrani, 2018).

Maturation ponds are aerobic throughout the depth and show less stratification in comparison to facultative ponds. The greater light penetration facilitates greater removal of bacteria and virus. Unlined ponds with depths < 1m have a tendency for the growth of emergent macrophytes which become habitats for mosquitoes. To avoid the nuisance of mosquitoes, it is recommended to provide a depth > 1 m for unlined canals or adopt lining of canals for pond depth < 1m.

2.3.1.3. Removal principles

A rich diversity in organisms plays a significant role in self-purification capacity of the pond (Shanthala et al., 2009). The prominent bacteria removal mechanisms in stabilization ponds are adsorption, sedimentation and solar radiations apart from which physicochemical conditions, excretion of toxins by certain algae and antagonism predation are the factors affecting coliform removal. The ability of algae to fix carbon dioxide photosynthetically using solar energy and convert them to carbohydrates makes them a key species in the functioning of any aquatic system. Although this photoautotrophic life form is dependent on a number of physicochemical and biological interactions taking place, the temperature and nutrient concentrations play an important role in case of high altitude ponds (Rai and Muniyandi, 1981).

Mechanisms involved in facultative pond:

The wind, heat and pond inlet design are the three factors majorly affecting the degree of mixing of wastewater within the pond. Proper mixing of wastewater minimizes the risk of hydraulic short circuiting in the pond and avoids the formation of stagnant regions. The photic zone, where the action of photosynthesis is effective, comprises of top 300 mm of the pond. The thermocline, which is the dense layer of abrupt temperature change, lies below the photic zone and acts a light barrier. The thermal stratification in the pond induces algal banding. The algal bands on attenuating light induce physicochemical stratification resulting in pH high enough (from 9 to 10) to cause die-off of fecal bacteria. In case of ponds with depth exceeding 1.8 m, the oxy-pause (depth at which DO becomes zero), is created near the surface and anaerobic conditions are caused in the pond below. There is substantial algal movement within the pond during the daytime, so there is variation in the effluent quality which is drawn off from a fixed depth of pond.

In facultative ponds, sewage is partly converted to algal biomass as a result of algal-bacterial activities thus sewage COD undergoes a transition to algal COD. The algal activity was observed only in the top 40-50 cm of pond depth (Mahapatra et al., 2013).

2.3.1.4. Design guidelines

Pond geometry (L, B); dispersion number d and HRT are the basic characteristics of WSP's. The properties and design guidelines for ponds are mentioned in Table 13 and Table 14 below respectively.

Table 13: Characteristic features of algal ponds (Arceivala and Asolekar, 2017)

Point of difference	**Aerobic**	**Anaerobic**	**Facultative**
Conditions	Aerobic conditions throughout pond depth	Absence of DO for microbial activity	Partly aerobic and partly anaerobic
Depth	0.3 m or less	3-4 m	1-2 m
Application	Ultimate harvesting of algae is desired	Effluent not fit for discharge without further treatment	-
Characteristics	-	Organic loadings > 100 $g/m^2/day$	Volumetric BOD loading around 15-40

		acceptable	$g/m^2/day$

Table 14: Design guidelines for anaerobic and facultative ponds (Mara, 1997)

Sr	Design Parameter	Unit	Anaerobic	Facultative pond
1	Depth of pond	m	2-5	1-1.8
2	Organic loading	kg-BOD/ha-day	3000	100-400
3	Retention time	days	1	4-5
4	Sulphate loading	mg/L	<500	-
5	Rate of sludge accumulation	m3/person/year	0.04	-
6	Area for drying bed	m2/ person	0.025	-
7	Algal biomass	mg chlorophyll a/ litre	-	500-2000

The studies based on waste stabilization and algal ponds across various states in India are discussed in the section below.

2.3.1.5. Studies conducted on waste stabilization ponds

1. The algal dynamics of a high altitude pond in Shillong were analyzed after one year of phycological study. The high species diversity all-round the year and the spring association of the algae supports the hypothesis of obliotrophic nature of high altitude ponds (Rai and Muniyandi, 1981).
2. Water quality studies were conducted for one year in Bhopal on a single cell as well as on a series of stabilization ponds. The climate of Bhopal is observed to be favorable for the sewage treatment in stabilization ponds. Improved DO in pond effluent was observed, reduction of coliforms was highest in the series of ponds. 4 pm observed highest values of pH, DO, algal cells and lowest values of alkalinity (Rao, 1983).
3. The diversity of algal species in terms of diversity indices (defined as the mathematical functions explaining the number of species in a biological community (Shanthala et al., 2009)) was analyzed. The common species observed in stabilization ponds were *Chlorella, Euglena*, and *Scenedesmus* out of which *chlorella* was the dominant one. *Euglenoids* exhibited greater adaptability to varying BOD and nutrient levels whereas *Cyanophyceae* was found to be highly tolerant to pollution (Shanthala et al., 2009).
4. The algal dynamics in wastewater treatment were analyzed from multiple dimensions based on field investigations carried out at Vidyanarayanpura STP located in Mysore (Mahapatra et al., 2013).

5. A treatment plant of 45 MLD based on waste stabilization ponds was constructed in Jodhpur. Seasonal variation showed greater removal efficiencies in summer for all parameters as compared to winter. The high temperature, long photoperiod (exposure time) and high light intensity were considered as the factors contributing to better removal efficiencies. The fecal coliform values exceeded the permissible limits for reuse in agriculture, which was attributed to the lack of maturation ponds (Goyal and Mohan, 2013).
6. The removal efficiency of total coliform and thermo-tolerant coliform has been estimated for integrated WSP system in central India using dispersed flow regime. The shallow ponds with relatively higher detention time were seemed to perform better than deep ponds having lower detention time (Kapilesh and Indrani, 2018).

The guidelines for wastewater reuse in agriculture depend on the prevailing climate as well as type of food crop. In order for effluent from WSP to be reused in agriculture, construction of maturation pond is a necessity. Other options can be mechanical filtration, slow sand or rock bed filtration followed by disinfection by chlorine (Goyal and Mohan, 2013).

2.4. Systems using zoo-remediation

Zoo-remediation involves the treatment of wastewater or conversion of organic waste by animals such as earthworms. It is of utmost importance to maintain the temperature and humidity suitable for survival of the organisms in these systems.

2.4.1. Vermifiltration

Earthworms were termed as 'unheralded soldiers of mankind' by Darwin as they assist in the formation of fertilizer from waste organic materials. The fertilizer formed is termed as 'vermicompost'. Involvement of earthworms in solid waste management is widely known however, their habit of consuming waste and generating a worthy fertilizer was also used to treat wastewater. Earthworm assisted wastewater treatment is known as vermifiltration.

2.4.1.1. Basic description

Vermifiltration is known to have many advantages such as completely aerobic process, odor-free, no sludge formation, no landfill disposal requirement and no use of chemicals. Vermifiltration is also known to degrade complex chemical entities such as dieldrin and Poly-

Chlorinated Biphenyls. The process generates value added products through wastewater treatment namely compost and biomass of worms. Vermifiltration is known to be efficient for treatment of concentrated as well as diluted wastewater.

Anatomically cylindrical, boneless, long, narrow, cylindrical, bilaterally symmetrical and segmented body of earthworm acts as a ‘bio-filter’ to the waste consumed by them. The average weight of 2000 adult earthworms was observed to be around 1kg. They have 3-7 years average life span and 60-70 days doubling time with wide range of microflora especially nitrogen fixing and decomposing bacteria in their gut. This microflora is termed as ‘vermicast’. There are many species of earthworm of which only few are used widely for waste management process. The acute specifications of earthworms regarding size, weight microflora, color, life span, doubling time and composition vary according to their species and ecological situations. The major part (70-80%) of their bodyweight is made up of lysine rich protein followed by 14% carbohydrates and fats.

2.4.1.2. Species used

Earthworms are broadly classified as epigeic, anecic and endogeic worms of which epigeic earthworms have high metabolic and reproductive rate with comparatively short lifespan. They are mainly observed in agricultural farms and reside not too deep in the soil. They involve many species like *Dendrobaena veneta*, *Eisenia andrei*, *Dendrobaena, hortensis*, *Dendrodrilus rubidus*, *Dendrobaena, octaedra*, *Eiseniafetida*, *Eiseniella tetraedra* and *Allolobophoridella eiseni.* Among them *Eisenia Andrei*, *Eisenia fetida*, and *Lumbricus rubellus* are commonly used for vermicomposting. *Eisenia fetida* is the most widely used earthworm for vermifiltration. It is also known as tiger worm or red worm. The species is known to utilize fresh human faces with high moisture conditions and remove hazardous pathogens efficiently. It has high salt tolerance than other species which is about half of the seawater. It can also withstand with high organic pollutant load with 1.5% crude oil. Additionally, it is known to survive at high heavy metal content and adsorb them.

2.4.1.3. Removal principles

Mechanism of vermifiltration is complex and has many dimensions. The overall mechanism of vermifiltration can be mentioned as simultaneous microbial and vermiprocessing of waste involving multiple unit operations such as aeration, adsorption, absorption, bioaccumulation, bio-magnification, grinding, crushing, degradation and bioconversion.

Cylindrical tubular shaped earthworm infers 60% voids and therefore provides high specific surface area for waste processing. Thus, more entrapment of suspended and dissolved particles is taken care of that eventually gets adsorbed, absorbed or channelized through filter bed and undergo bioprocessing. Earthworms granulate the clay particles and grinds slit and sand particles. This phenomenon helps in increasing hydraulic conductivity and available surface area of the filter bed.

The worm's breath through their skin eventually increases oxygen concentration in adjacent area. This phenomenon boosts the aerobic condition in vermifilter and promotes growth of aerobic decomposer bacteria in soil and wastewater. Additionally, millions of bacteria and actinomycetes assessing biodegradation of organic matter are hosted by earthworms in their gut. The overproduced gut bacteria are excreted out in the soil along with nitrogen and phosphorus rich nutrients. This excreted mixture in termed as 'vermicast'. The bacterial species observed in vermicast are *Azoarcus, Pseudomonas, Paenibacil- lus, Burkholderia, Mucor, Acidobacterium, Spiroplasm* and *Acaligenes*.

Earthworms also secretes certain enzymes that mainly consist of lipase, amylase, cellulose and protease that helps in degrading almost all type of major biomolecules like oils, fats, cellulose, carbohydrates, complex sugars, protein, antigen, antibodies, hormones *etc*. Worms thus utilizes biomass equivalent to half of their bodyweight. All these simultaneously occurring processes along with moment of earthworms and voidage created by them efficiently prevent clogging of continuously operated vermifilter and maintain its efficacy throughout.

2.4.1.4. Design guidelines

Earthworms are very sensitive to touch, pH, ventilation, light, moisture content, organic load and dryness. This sensitivity affects the efficacy of vermifiltration. Reduction in temperature have shown very slow rate of bioconversion by earthworms. On the other hand, increase in temperature tends to kill the earthworms instantly. Therefore, proper maintenance of external parameters within permissible limit is mandatory for maximum and consistent output. Additional parameters affecting efficiency of vermifiltration are HRT, Hydraulic Loading Rate (HLR) and earthworm density. The quantitative range of operating conditions needed for vermifiltration is mentioned in Table 15 below.

Table 15: Operating conditions for vermifiltration

Parameter	Unit	Minimum	Maximum	Optimum range
Temperature	°C	4	40	15–25
Moisture content	%	40	75	50–65
Earthworm Density	worms/sqm	6000	10000	8,000

2.4.1.5. Studies conducted on vermifiltration

Pathogen removal efficiency of vermifiltration is well explained by every research article related to it. However, Arora et al., (2016) have performed detail study of pathogen removal by vermifiltration. Their research clearly mentions quantitative data of total coliform, fecal coliform, *E.coli*, *Salmonella*, total bacteria, total fungi and *actinomycetes* reduction using vermifiltration.

Integration of vermifilters with constructed wetland and microphytes were also studied by the researchers. Additionally, comparative study of use of *E. eugeniae* and *E. fetida* for vermifiltration was executed by Taylor et al., (2015). Their observation clearly mentioned *E. fetida* as more suitable strain for vermifiltration.

The overall efficiency of pollutant removal by duckweed ponds from literature is documented in Table 16 below.

Table 16: Efficiency of parameter removal by vermifiltration

Sr.	**Parameter**	**Efficiency**	**Reference**
1	BOD TSS TDS	96 90 82	(Kumar et al., 2015)
2	TC FC FS E.Coli Salmonella	98.78 98.2 98.6 99.88 96.21	(Arora et al., 2016)
3	BOD COD TDS TSS	98 80-90 90-92 90-95	(Singa et al., 2006)

2.4.1.6. Commercial/ patented technologies based on vermifiltration

Tiger Filters/ Tiger Toilets:

Certain areas in rural part of country have unplanned random houses that lack proper collection system for wastewater. In this situation, there is a need of providing onsite localized solution for wastewater and fecal waste treatment. Tiger treatment claims to be one such efficient on-site solution that can treat fresh fecal matter. Some existing systems such as soak-pits have disadvantages such as cost, space requirements, difficulty in emptying which may lead to the reintroduction of pathogens into the local environment, and lack of immediate treatment of fecal matter. Tiger filters claim to resolve most of these problems. The nomenclature of the filter is based on the species of earthworm called 'Tiger worm' commonly used in vermifiltration. Transchem Agritech limited, Gujarat is one firm providing technological assistance in installation of tiger filters.

2.4.2. Aquaculture

2.4.2.1. Basic description

Aquaculture is the process of raising aquatic animals such as fish, daphnia, and brine shrimps in wastewater treatment lagoons. Daphnia and brine shrimps are crustaceans which are known to efficiently remove algae and suspended solids from wastewater. The fish yields from sewage fed ponds are observed to be lower than those obtained from duckweed fed ponds. There have been successful demonstrations of culturing animals; however, the improvement in water quality is not satisfactory. Hence, this treatment should be adopted only when the objective is to cultivate fish. However, despite biological studies reporting no contamination in fish, the regulatory authorities are doubtful about human consumption of fish produced from wastewater. As a result, this fish produce can be effectively used as pet supplement food, fertilizer or bait fish.

The use of human and animal wastes in aquaculture is not a new phenomenon in Asia, and at least 2/3rd of the global yield comes from such fertilized ponds. Since ancient times, carp and tilapia have notably been used for fish culture and annual yields of tilapia fish of 2600 kg/ha-year are reported. Moreover, aquatic crops such as water lotus, water chestnut, water spinach and water caltrop are common (Ghangrekar et al., 2007). It is important to note that sewage fed aquaculture is suitable for rural areas where the wastewater is dominated by organic wastes, resulting in products being safe and contaminant free for consumption (Ansal et al., 2010).

2.4.2.2. Flow Diagram

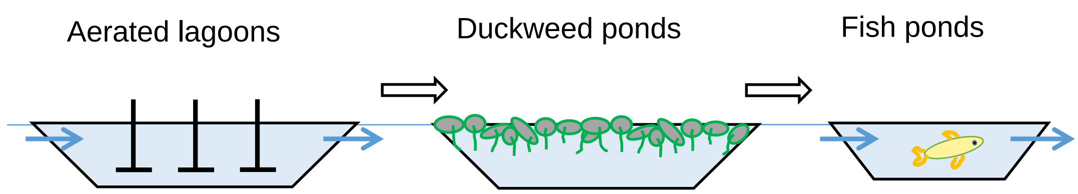


Figure 5: Flow diagram for sewage-fed aquaculture

2.4.2.3. Removal principles

An ecosystem approach is required or successful pisciculture. Compatibility between different elements such as fish, food, pond conditions needs to be maintained. The fish needs to be introduced in the last compartment of series of ponds and be fed with sewage or duckweed from time to time.

<u>Species used:</u>

Preferred species for Indian farmers:

Indian carps: catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*)

Exotic fish: silver carp (*Hypophthalmichthys molitrix*), common carp (*Cyprinus carpio*)

A one year study at a sewage-fed Jannapura tank has assessed the microbial parameters along with some physicochemical parameters and analyzed the fishery activities. Apart from commonly found species, other fish observed in Jannapura tank, Karnataka are *Osteobrama cotio cunma, Salmostoma untrahi, Cirrhinus fulungee, Rasbora daniconius, Garra kempi, Puntius chola, Mystus cavasius, Amblypharyngodon melettinus, Labeo calbasu, Clarias batrachus, Aplocheilus panchax, Mastacembalus armatus Channa striatus, Ambassis kopsii, C. marulius, C. punctatus,* and *Gambusia affinis* (Kiran, 2014).

2.4.2.4. Design guidelines

Fish survive in the pH range of 6.5 to 9. They require dissolved oxygen level > 2 mg/L and ammonia concentrations < 1 mg/L. Also, phosphate concentration < 4 mg/L needs to be maintained in the fish pond to prevent large algal growth depleting the DO level.

2.5. Natural hybrid systems

Almost all of the existing natural treatment systems work on the symbiotic association of two or more organisms. However, several new technologies have been evolved from the domain of natural wastewater treatment systems especially constructed wetlands claiming to have involved additional biological functional factors. Some have combined plants and worms, or plants and bacteria and are known to have developed their own technologies with signature nomenclature. Some of the popular technologies are described below.

2.5.1. Phyto + Bio

1] Green Bridge Technology

The combined the mechanisms of phytoremediation and bioremediation i.e. plants and microbes both contribute to the removal of pollutants from wastewater. The Green Bridge Technology is an approach developed by SERI (Shristi Eco Research Institute, Pune) particularly for in-situ treatment on rivers. Microbes and plants are the drivers for this technology which function based on filtration, biosorption and biodegradation. The green bridge is an active consortium of microbes, biomats, sand, gravel and plants. The sand and boulders acting as filtering materials prevent the entry of solids through the bridge whereas the flora grown on the banks contribute to wastewater treatment. The design parameters for the green bridge largely depend on the actual river/ stream site where treatment is desired.

The first pilot project on green bridge technology was implemented at river Ahar flowing through Udaipur to treat 100 MLD of wastewater flowing in the river. The project was funded by the people and no government authority was involved in the construction. A metamorphic change was observed within two months of the green bridge construction. Bio-indicators such as birds, insects and fish had returned to the river, indicating the improved river water quality. However, the treatment facility is not in a working condition currently due to road construction.

2.5.2. Bio + Zoo

1] Soil Biotechnology

The combination of bioremediation and zoo-remediation is another hybrid natural treatment system. A technology recognized by the name of ‘constructed soil filters’ (CSF) or soil biotechnology (SBT) developed at IIT Bombay, works on similar phenomenon. The media or filters used comprise of local weathered rock having desired mineral constituents and a culture of the mix of bio-indicator plants, native microflora and specific earthworms. The primary mechanisms contributing to pathogen removal are the ability of media to retain pathogens during filtration, physicochemical environment and the effect of predator population which regenerates the filter bed. Constructed soil filters are able to handle high rates of hydraulic loading due to their low HRT. This technology eliminates the requirement of mechanical aeration that may result in very low energy demand (approximately, 0.04 kWh/m^3) in the form of pumps or sprinklers. Additionally, there is no sludge production and a green ambience is achieved at the wastewater treatment sight (Kadam et al., 2007).

2] Nualgi Technology

This technology provides micro-nutrients through nano particles which trigger the growth of diatoms i.e. algae in water, simultaneously preventing the growth of blue green algae and water hyacinth. The major constituent of the nano particles is silica, whereas iron, magnesium and manganese constitute the nano particles as well. The growth of algae increases the dissolved oxygen content in the water bodies. This further encourages the growth of zooplanktons and aquatic fishes, thus restoring the food chain in the aquatic bodies. As part of treatment, the powder is simply spread over the water surface and this technique is particularly useful for the restoration of water bodies.1 kg of Nualgi is reported to treat 4 MLD of water.

2.6. Primary treatment for NTS

The natural treatment systems have been considered for tertiary treatment earlier. However, they are now being thought as potential technologies for secondary treatment of wastewater or domestic sewage, especially in peri-urban and rural areas. It is important to note that natural technologies, like any other mechanized treatments, are less likely to function independently from the point of view of achieving National Green Tribunal (NGT) norms. If used as secondary treatment, the primary treatment needs to perform efficiently so as to ensure design load being obtained by the natural treatment system. Improper or ineffective performance of primary treatment or any of the units prior to the natural treatment system will lead to failure of the system. This may be seen in the form of clogging of wetland beds, odor issues in case of waste stabilization ponds, inefficient removal of pollutants due to overloading of the system *etc*. The use of septic tank in case of households or decentralized treatment, use of settling tank and anaerobic digester for a community scale or aeration followed by sedimentation in centralized treatment where NTS is used as tertiary treatment are some of the suitable pretreatments.

2.6.1. Preliminary treatment units

Preliminary treatment commonly referred to as pre-treatment, involves removal of various solids in wastewater (leaves, fibres, trash) or sludge constituents such as oil and grease. These units are built before the conveyance or treatment units to avoid the blockages of subsequent units. They contribute to reduced abrasion of mechanical equipment, thereby increasing the life of wastewater infrastructure. Pre-treatment technologies involve physical operations such as screening, floatation and settling.

2.6.1.1. Screens

The wastewater carries solid waste during its conveyance, which has the potential to choke the further treatment units. It is beneficial to remove the solid contaminants as early as possible within the treatment chain. Screens are the devices used to obstruct the coarse particles such as leaves, rags, plastic bottles *etc*. from flowing to the treatment units. The spacing between screens ranges from 15 mm to 40 mm. They are classified as fine or coarse screens, depending on the bar spacing adopted in design. Regular cleaning of screens is vital; otherwise it results in reduced flow to the treatment plant. The screens can be cleaned manually or mechanically. Manual cleaning is slow and is feasible only for higher cleaning frequencies. The schematic diagram of a screen is illustrated in Figure 6 below.

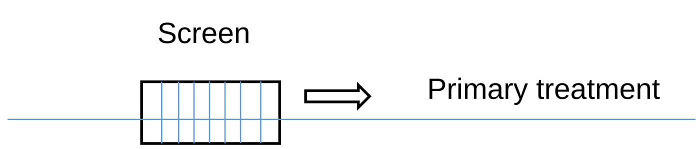


Figure 6: Schematic diagram of screen

2.6.1.2. Oil and grease traps

Oil and grease form an important constituent of the wastewater coming from kitchen, garages or restaurants. If it is not removed, it results in hampering the primary settling process. It is suggested to remove oil and grease through separately designed traps. The oil and grease traps can be constructed using bricks, plastic or concrete. The baffles at the entry and exit of trap reduce the turbulence, and facilitate the removal of oil and grease. The floating oil and grease particles can thus be removed from the trap, and needs to be disposed carefully. It can be also used for energy production (biodiesel) or recycled. The schematic diagram of an oil and grease trap is illustrated in Figure 7 below.

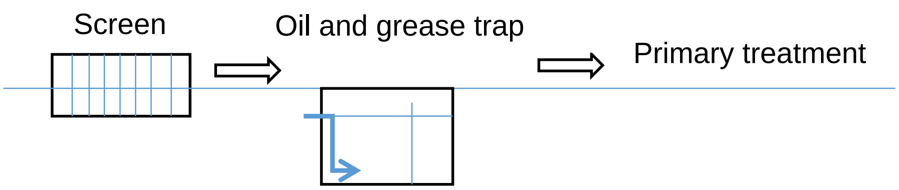


Figure 7: Schematic diagram of oil and grease trap

2.6.1.3. Grit chamber

Grit chambers allow for the removal of the heavy inorganic particles of wastewater (like sand or grit) by settling. The three main types of grit chamber are horizontal flow, aerated or vortex chambers. In all designs, only the heavy inorganic fraction is removed, whereas the lighter particles remain in suspension and are removed by subsequent processes. The schematic diagram of a grit chamber is illustrated in Figure 8 below.

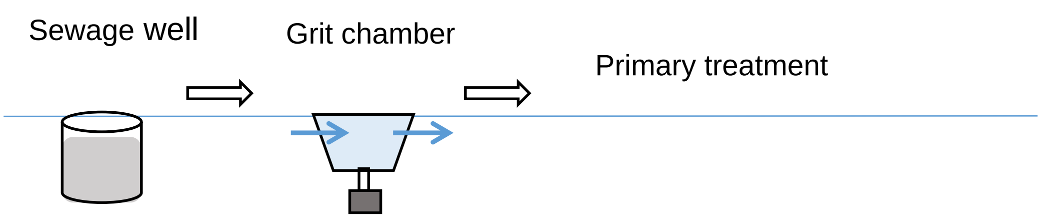


Figure 8: Schematic diagram of a grit chamber

2.6.2. Primary treatment units

The primary treatment units which are commonly adopted before natural treatment technologies are described in the section below.

2.6.2.1. Settler

Settlers are primary treatment devices designed to remove the solids through sedimentation mechanism. They are used in variety of forms, and at various stages in a wastewater treatment chain. They are known as sedimentation or settling tanks or clarifiers. The design of inlet and outlet is crucial so as to maintain quiescent conditions in the tank to facilitate settling. Use of baffles or T-shaped pipes is adopted for the same. Around 50 – 70 % of solids removal along with 30 – 40 % of BOD removal is achieved by this step. Settlers may be designed as rectangular or circular tanks, for a retention time of 1.5 to 2.5 hours. In settlers which are not designed for anaerobic digestion, removal of sludge at regular intervals should be practiced. This avoids the development of septic conditions within the tank, which might lead to re-suspension of settled particles caused by release of harmful gases. There is a tendency of short circuiting of currents which might be prevented in a well-designed sedimentation tank. The schematic diagram of a settler is illustrated in Figure 9 below.

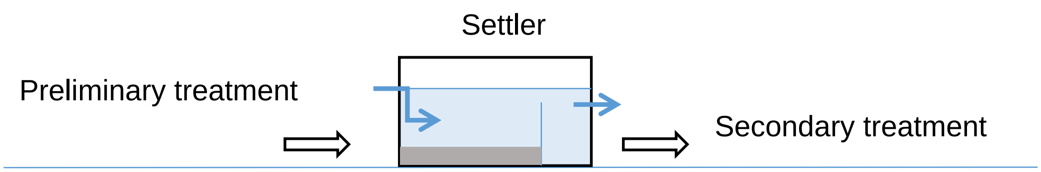


Figure 9: Schematic diagram of a settler

2.6.2.2. Imhoff tank

The imhoff tank is primarily designed to achieve separation of solids and liquids followed by digestion of the settled sludge. It is a V-shaped chamber with gas vents. It is a robust device in which 50-70% solids removal occurs along with COD reduction of 25-50%. It is usually built underground but can also be constructed above ground to facilitate sludge removal by gravity. The hydraulic retention time is kept between 2-4 hours. The digestion chamber is designed for a period of 4-12 months. Due to lower digestion rate in colder climates, the size requirement of chamber increases. To ensure efficient functioning of the imhoff tank, pre-treatment by bar screen and grit chamber is recommended. They are capable of treating high organic loads and can even withstand shock loads. The pathogen removal is not achieved in this treatment unit, so workers involved in removal of sludge, effluent and scum must take adequate safety precautions. The schematic diagram of an imhoff tank is illustrated in Figure 10 below.

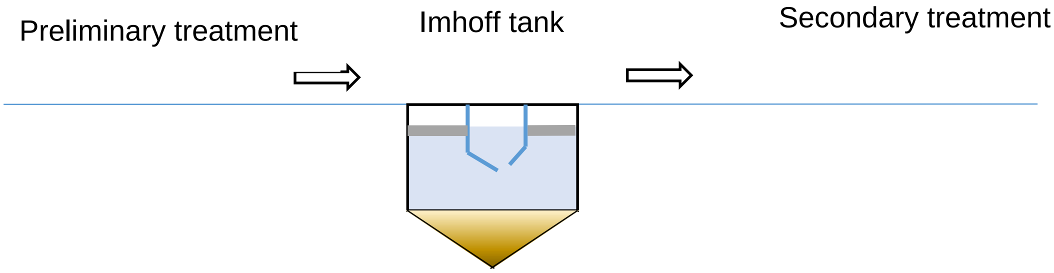


Figure 10: Schematic diagram of an imhoff tank

2.6.2.3. Septic tank

The septic tank is a watertight chamber constructed of concrete or plastic. It is useful at household level or in places where there are no connections to the sewer line. There are at least two chambers within a septic tank. Settling and anaerobic digestion of organic matter are the prominent mechanisms taking place in a septic tank. The hanging baffle prevents the settled solids as well as the floating scum to go to the next chamber from where the effluent goes out. The septic tank is designed as per number of capita it caters to, water consumption, temperature and the desludging frequency. Vents should be provided in the tank for the release of harmful gases. The retention time adopted for septic tank is generally 2 days. Typically a desludging of septic tank needs to be practiced after an interval of 2 to 5 years. Care should be taken while desludging since the effluent contains pathogens and there is a possibility of obnoxious odors. The location of tank should be such that all chambers are accessible for operation and maintenance. The practice of constructing septic tanks below houses especially below bathrooms is totally wrong since it blocks the access to the chambers. Septic tanks are known to remove 50% of solids and 30-40% BOD, thereby achieving a moderate treatment. The effluent needs to be conveyed to a treatment plant. The septic tanks should not be located in areas having ground water table very high, since it has risk of contamination due to leakages in the tank. The water tightness of tank should thus be monitored from time to time. They can be constructed in all types of climate; however the treatment achieved is faster in summer. The schematic diagram of a septic tank is illustrated in Figure 11 below.

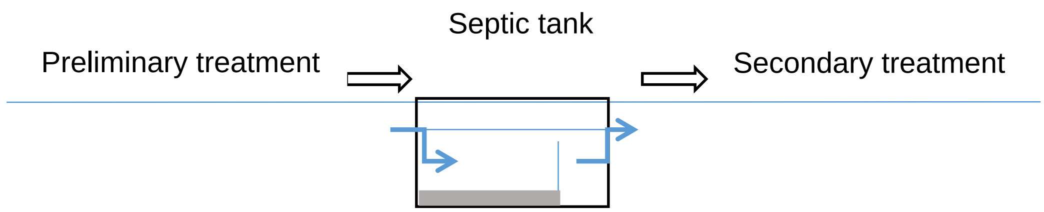


Figure 11: Schematic diagram of a septic tank

2.6.2.4. Anaerobic baffled reactors

Anaerobic baffled reactors (ABR) are an improved version of the traditional septic tank and can be used for a community level. The baffles create multiple compartments in the reactor, which increases the contact time of wastewater, resulting in enhanced treatment efficiency. The solids get settled at the bottom of the compartments. The up-flow of wastewater within the compartments increases the organic removal efficiency. Up to 90% BOD removal is achieved in ABRs which make their performance superior to that of septic tanks. It is important to note that despite improved BOD removal, the nutrients and pathogens are not removed so further treatment of the effluent is desirable. The reactor takes significant amount of time to get started and achieve the full treatment capacity. This is due to the slow growth rate of anaerobic biomass responsible for digestion. In these circumstances, cow dung or the sludge from an existing septic tank can be used to hasten the process. The construction and operational problems of ABRs are similar to those of septic tank. The schematic diagram of anaerobic baffled reactor is illustrated in Figure 12 below.

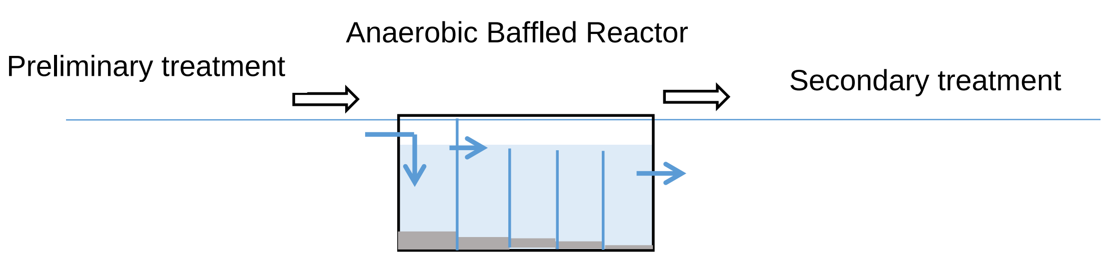


Figure 12: Schematic diagram of anaerobic baffled reactor

2.6.2.5. Anaerobic filters

Anaerobic filters are similar to anaerobic baffled reactors with the addition of fixed film biomass in the compartments, in which wastewater treatment occurs through filtration mechanism. Anaerobic filters can thus be treated as fixed film biological reactors with multiple filtration chambers in series. The operation of anaerobic filters in an up-flow mode reduces the risk of washing away the fixed biomass. The water level above filter media should be maintained at least 0.3 m. The HRT adopted ranges from 1 to 3 days (Tilley et al., 2008). Adequate preliminary and primary treatment is suggested before the use of anaerobic filters so as to avoid the clogging of filters. In the integrated design, the first chamber acts as a sedimentation zone, followed by filter beds in subsequent compartments. If anaerobic filters are used in semi-centralized treatment plants, separate sedimentation unit is constructed prior to the filters, which eliminates the need of settling zone. Adequately large surface area for the growth of bacteria is preferable. Also, the pores should be large enough to prevent clogging. Typical size of filter material ranges from 12 to 55 mm diameter, whereas it 90 to 300 m^2 area/ m^3 wastewater is desirable (Tilley et al., 2008). Crushed sand, gravel, plastic media, bricks *etc*. can be used as media depending on the local availability. The precautions to be taken while constructing and operating an anaerobic filter are the same as that of septic tank. The schematic diagram of anaerobic filter is illustrated in Figure 13 below.

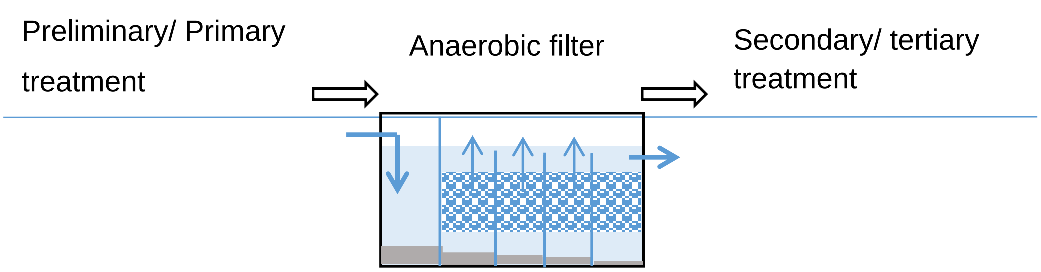


Figure 13: Schematic diagram of anaerobic filter

2.7. Other aspects of NTSs

2.7.1. Precautions to be taken while adopting NTS

The NTS adopting natural functions are slow processes thereby resulting in a larger land area requirement. It should be noted that NTS like CWs will function to desired efficiency only along with adequate pre-treatment and post-treatment. Constructed wetland or duckweed ponds are not independent treatment units which can cater to the incoming sewage directly. These can be used for secondary or tertiary treatment as per requirement of treatment effluent for reuse or disposal purpose. In case of disposal of effluents in water bodies, NTS can be used as secondary or in-situ treatment options. Similarly, when the treated effluent is to be reused in industry, agriculture or any other beneficiary purpose, tertiary treatment becomes mandatory. Instead of going for uneconomical options mechanized treatment (for heavy metal or nutrient removal), it is desired to adopt NTS for tertiary treatment. It is important to control the algae concentration and DO reduction during night in ponds otherwise it is beneficial to practice aquaculture separately in ponds apart from oxidation pond (Ghangrekar et al., 2007).

2.7.2. Potential for revenue generation

The number of natural wastewater treatment system installations in India is increasing over the years. The growing interest of researchers in the decentralized solutions especially for the peri-urban and rural areas has resulted in an increasing number of case studies. Also, along with reduced energy requirement and operation costs, the NTS have added advantages of potential for revenue generation. Global studies have reported that the revenue generated from NTS exceeds the operation and maintenance costs of treatment plants, making them sustainable solutions. A significant number of by-products can be recovered from NTS, as seen in Figure 14 below.

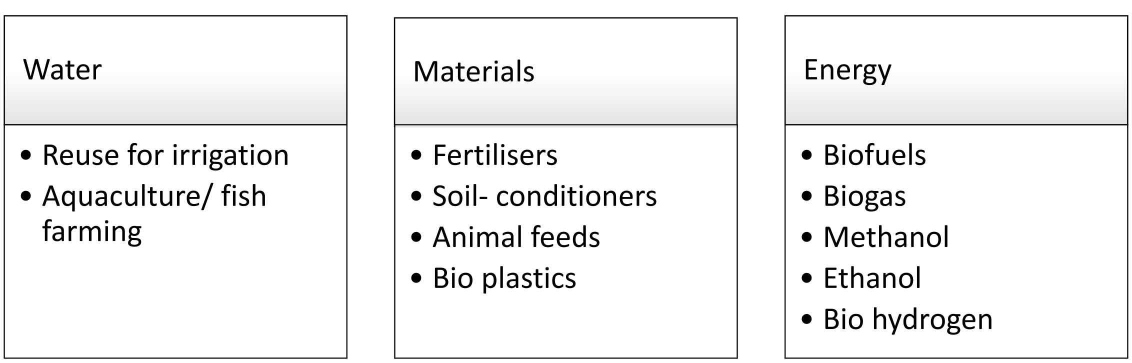


Figure 14: Possible by-products recovered from NTS

3. Inventory of Natural Treatment Systems in India

The section below describes the manner in which inventory was compiled, gives geographical details of NTS installations across India and gives details of NTS installations by experts working in the field.

3.1. Methodology adopted for inventorization

The aim of this report is to compile an inventory of the natural treatment system installations in India. For this purpose, a template for getting the information regarding various plants was devised. This template included the following details related to wastewater treatment plants:

i. Geographical details
ii. Construction details
iii. Design details
iv. Performance parameters
v. Operation and maintenance details
vi. Recovery details
vii. Financial details
viii. Contact details

Next, various organizations, researchers, experts and private companies engaged in this sector were listed. The template for NTS inventory was mailed to 23 organizations and 30 researchers/ academicians *in September,* who have worked on pilot or field scale projects based on NTS. A reminder mail was sent to everyone *in November*.

Four persons, mainly researchers, reverted back saying they no longer work in this field. The publications in NTS domain were just a part of their thesis work. Dr. Suresh Kumar Rohilla, Dr. Manoj Chaturvedi, Mr. Sampath Kumar, Mr. Dhawal Patil, and Dr. Geetanjali Kaushik gave further contacts of associated persons in NTS sector. Mr. Aviraj Dutta, ICRISAT; Mr. Tejas Kotak, Hunnarshala Foundation; Mr. Tushar Murade, SERI and Mr. Anil Mehta, Jheel Sanrakshan Samiti responded that they will revert back on the same in few days. An interaction of IIT Bombay team was scheduled with Mr. Dhawal Patil, Mr. Chandrashekhar Shankar and Mr. Anil Mehta regarding natural treatment systems, the schedule of which is mentioned in Table 17 below. The Centre for Science and Engineering, Delhi has prepared an inventory which is available online on the platform MOUNT, CSE. Substantial information of NTS installations was available from this platform. Only three persons (Mr. Ankit Shrivastav, Delhi Jal Board; Mr. Dhawal Patil, Ecosan Services Foundation, and Mr. Rahul Babar, Energy Tech Solutions Pvt. Ltd) positively responded by actually filling the details of the installations in the inventory template. Mr. Chandrashekhar Shankar, Mr. Ankit Shrivastav, Dr. Dinesh Kumar and Prof. A.B. Gupta assisted in coordinating NTS site visits for IIT Bombay team, the details of which are mentioned in Table 18 below. The inventory covers 75 installations, details of which have been obtained from sources mentioned in Table 19 below.

Table 17: Schedule of interactions

Sr	Date	Contact person	Organization
1	9th Sep, 2019	Mr. Dhawal Patil	Ecosan Services Foundation, Pune
2	12th Nov 2019	Mr. Chandrashekhar Shankar	Vision Earth Care, Mumbai
3	13th Feb 2020	Mr. Manoj Kumar	Sulabh International, Delhi
4	22nd Feb 2020	Mr. Anil Mehta	Jheel Sanrakshan Samiti, Udaipur

Table 18: Schedule of site visits

Sr	Date	Contact person	Location
1	9th Aug 2019	Mr. Omkar Singh	Roorkee, Uttarakhand
2	9th Dec 2019	Mrs. Kokate, MCGM	Worli, Mumbai
3	11th Dec 2019	Mr. Chandrashekhar Shankar	Virar, Mumbai
4	14th Feb 2020	Mr. Ankit Shrivastav	Rajokri, Delhi
5	14th Feb 2020	Mr. Ankit Shrivastav	Bawana Ghogha, Delhi
6	16th Feb 2020	Dr. Dinesh Kumar	Jwalamukhi, Himachal Pradesh
7	16th Feb 2020	Dr. Dinesh Kumar	Nagrotaba, Himachal Pradesh
8	17th Feb 2020	Dr. Dinesh Kumar	Dharamshala, Himachal Pradesh
9	19th Feb 2020	Prof. A. B. Gupta	Jaipur, Rajasthan
10	19th Feb 2020	Prof. A. B. Gupta	Jaipur, Rajasthan

Table 19: Details of NTS inventory

No. of installations	Source
17 (1 – 17)	Mr. Rahul Babar, Energy Tech Solutions Pvt. Ltd., Pune
5 (18 – 22)	Mr. Dhawal Patil, Ecosan Services Foundation, Pune
2 (23 - 24)	Mr. Ankit Shrivastav, Delhi
19 (25 – 43)	Mr. Bhitush Luthra, MOUNT CSE
16 (44 – 59)	Literature review
9 (60 – 68)	DBT report on CW Manual
5 (69 – 73)	Dr. Dinesh Kumar, Rebound Enviro Tech Pvt. Ltd.
2 (74 – 75)	IC-EcoWS Inception Meet at Roorkee

3.2. Some of the organizations implementing NTSs

In the wastewater sector, amidst the popular firms working on and providing consulting services for mechanized treatments, however, there are certain firms exploring the potential of natural systems for wastewater treatment. Here, we provide information about some of the organizations to which with IIT Bombay team could able to contact and had interaction. It must be noted that there are many other organizations working in implementation of NTSs which are not mentioned here.

3.2.1. Ecosan Services Foundation, Pune

Ecosan Services Foundation (ESF) was established in 2006 in association with the Innovative Ecological Sanitation Network of India (IESNI) and with the support of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Their vision is to promote ecological sanitation and sustainable sanitation practices along with efficient water and wastewater management practices in India. Ecosan Services Foundation is empaneled as a Key Resource Centre (KRC) under the Ministry of Drinking Water and Sanitation and it conducts training sessions, capacity building workshops, orientation of different stakeholders, facilitates knowledge sharing and learning, documents best practices, *etc*. under the Swachh Bharat Mission (Gramin) across the country. The details of constructed wetlands installed by ESF are summarized below.

- Sub-surface horizontal flow wetlands have been constructed at four sites in Maharashtra with the exception of vertical surface flow design adopted at Shivaji Nagar hostel site.
- Apart from Canna indica, banana mango trees have been planted at the Kamalini Kuteer resort site.
- For systems A, B, C at one site, the area requirement varies from 1.4, 2.85 to 5 m^2/KLD respectively. For other sites the area varies from 2.5 - 9 m^2/KLD.
- The pre-treatment adopted before constructed wetlands is screening- anaerobic settler- anaerobic baffled reactor- anaerobic filter. The post treatment is dual media filtration followed by UV disinfection. However, polishing ponds have been provided in the institute at Badlapur.
- Bed height for gravel is about 1.2 m and gravel size adopted in 1 to 100 mm.

- Retention time adopted ranges from 1 to 2.5 days.
- 2 to 3 wetlands are working in parallel
- Desludging is practiced once in a year or in 2 years whereas pruning is performed 2 to 4 times annually. Periodic cleaning of screens is also practiced.
- The treated wastewater is mainly used for gardening whereas in COEP hostel, it is also used for flushing.
- Non-monetary benefits as they are saving fresh water intake and electricity from borewell.
- The operation and maintenance cost occurred is around INR 20k to 30k annually.

3.2.2. Energy Tech, Pune

M/S. Energy Tech Solutions Pvt. Ltd. is an environmental engineering firm based in Pune since 1996 offering expertise in setting up Solid Immobilized Bio-Filter (SIBF) system - a non-conventional, eco-friendly and natural wastewater treatment system. Mr. Navin Singh is the Chairman of the organization whereas Mr. Rahul Babar and Mr. KVS Gopikrishna are the directors. The details of constructed wetlands installed by Energy Tech, Pune are summarized below.

- The construction and maintenance is done by the client in all construction cases.
- 12 years maximum life of CW by SIBF team; plants reported to be functional to current date.
- Area under NTS varies from 57 to 80% with 70% average value.
- Area requirement for CW varies from 3.75 to 12 m^2/kLD with around 5.3 m^2/kLD average value
- Majority of sites in Maharashtra with a couple of constructions in Gujarat and Karnataka as well.
- Most of the wetlands are operating for domestic wastewater. However, wastewater from slaughter houses, food processing and pharmaceutical industrial wastes have also been treated and are reported to function properly.
- Surface flow vertical type of wetland is constructed at all locations (SFV adopted for design in SIBF system)

- Oil trap and septic tank is the most common pre-treatment form adopted for domestic wastewater treatment. Fat trap, equalization tank and sedimentation units are added for slaughter houses, food processing and pharmaceutical industrial wastes
- Disinfection is adopted as post treatment measure for all locations.
- The systems have been designed for hydraulic retention time of 1 to 1.5 hours.
- The treated wastewater is mostly used for gardening and farming. Only at Kimmins High school and Chaitanya Homes the water is used for toilet flushing apart from gardening. Kanakpura, Bangalore plant also utilizes the water in construction activities.
- Frequency of septic tank desludging varies from once in 6 months to once in 2 to 3 years
- No effect of seasonal variations observed on the plant
- Revenue generation (in terms of savings) is assumed considering 10 KL tanker price of INR 1000/-

3.2.3. Rebound Enviro Tech Pvt. Ltd., Meerut, UP

Mr. Dinesh Kumar Poswal is the founder of the environmental firm Rebound Enviro Tech Pvt. Ltd. As per the recent NGT order, the disposal standards have been made stringent. However, considering the energy and technological advancement required to achieve these lower standards, it is not observed to be economically viable to achieve the desired effluent water quality. In this context, the use of NTS can be adopted, as done by Rebound Enviro Pvt. Ltd. In Himachal Pradesh, where the existing sewage treatment plants of Himachal Pradesh Municipal Corporation have been upgraded to achieve tertiary treatment using the cheap option of constructed wetland. The characteristic features of constructed wetlands developed by Rebound Enviro Tech Pvt. Ltd. are as follows:

- The wetlands have been designed as sub-surface vertical flow wetlands treating domestic wastewater. Deeper wetlands have been designed, which sustain the cold climate of Himachal Pradesh.
- The ornamental plant species *Canna indica* is used in wetlands due to its high oxygen diffusion through roots and ability to grow easily in soil free media.

- The pretreatment units adopted at various sites include screens, grit chamber, multi-baffled anaerobic digester. In case of Municipal STP's, aeration followed by sedimentation is the secondary treatment received.
- The post treatment comprises of multimedia filtration and chlorine contact tank.
- As part of operation and maintenance, desludging is practiced twice a year. Selective cutting of plants is done at regular intervals. Also, back-flushing of multi-media filters is performed twice in a year.

3.2.4. NEERI Phytorid technology

Phytorid is a patented technology by NEERI (National Environmental Engineering Research Institute, Nagpur) which is an application of constructed wetlands to treat wastewater. Phytorid is basically a low cost, no energy wetland with that can be operated with least manpower, operation and maintenance with sub-surface or free surface or hybrid flow wetland. This technology emphasis use of flow dividers in the wetland in term of baffles that ensures horizontal flow with improved mixing and root contact. The technology claimed use of many plant species especially *Elephant grass* along with *cattails, Canna lilies, reeds,* and *yellow flag iris*. The technology can be applied to wastewater generated from residential, industrial and public zones, nallah treatment. The application of technology for improving the quality of water bodies was also claimed where the treated water was used for irrigation. The porous media in the inlet area comprises of bricks, sand, gravel and stones, through which the wastewater passes and travels to the next compartment of plants. For more details following patent can be referred:

Patent details:

Title: System and Method for the treatment of wastewater using plants

Patent No: WO 2004/087584 A1

Applicant: Council of Scientific and Industrial Research

Inventors: Rakesh Kumar, Sandeep Tayade, R.N. Singh

3.2.5. BlueDrop Enviro Pvt. Ltd., Hyderabad- Integrated Constructed Wetlands

The "Integrated Constructed Wetlands" is marked by BlueDrop Enviro Pvt. Ltd., Hyderabad, Andhra Pradesh. This company provides environmental friendly solutions for sewage treatment to save on the operation and maintenance expenses incurred daily by mechanized treatment systems. They offer expertise in STP's, ETP's, nalla/ lake treatment and performance improvement of defunct STP's. Some of the prominent installations include constructed wetlands for railway station at Bhuj, nalla treatment at Mahabubnagar, University of Hyderabad, and Kanha township, Hyderabad. For more details following patent can be referred

Patent No: 3307/CHE/2014

3.2.6. Vision Earthcare - Soil Bio Technology

Vision Earthcare is initially incubated company at IIT Bombay and provides wastewater treatment solutions using Soil Bio Technology (SBT) developed at IIT Bombay. SBT falls in hybrid NTSs ad has been applied at various locations across India. More than 100 SBT plants have been implemented across India with a cumulative installed capacity of 45 MLD. For more details following patent can be referred:

Patent No: US 6,890,438 B2.

Applicant: IIT Bombay

Inventors: Hariharan S. Shankar; Biplab R. Pattanaik, Uday S. Bhawalkar, Pune (IN)

3.2.7. Delhi Jal Board, Uttar Pradesh

There are 1100 water bodies in Delhi spread in an area of 1492 km^2, out of which around 600 can be rejuvenated while the others are encroached. Out of these, 250 water bodies are taken up by Delhi Jal Board (DJB) currently. First task done by DJB was to redefine the term 'water body rejuvenation' as 'bringing life to water'. Otherwise, the earlier practices of water body rejuvenation only considered aesthetic parameters such as landscaping, making boundary, *etc*. Water bodies rejuvenated earlier would get clogged within 12-15 days of rainfall. The design style adopted at the two wetlands and on the basis of which further water body rejuvenation is planned is briefly described below. Both the wetlands have been constructed by the Irrigation and Flood Control Department, Delhi Government.

- Pre-treatment given is anaerobic baffled reactors (ABR) and its desludging is done once in 6 months. Cutting of flowers at regular interval is done to favor proper root growth. Timely cleaning of bio-digestor is recommended to avoid the entry of solids in the gravel bed.
- Sub-surface horizontal flow wetlands have been designed. Recommended range of aspect ratio for the wetland bed is 1:5 - 1:8, if exceeded beyond range might result in flooding.
- Poly-culture of *Canna indica*, *Typha latifilia* and *Cypersus* is used at the site.
- The post-treatment comprises of activated carbon filter, pressure sand filter and disinfection using hypochlorite. Floating wetlands are being used for tertiary level treatment.
- The wetlands are observed to be resilient to the extreme seasonal variations. Rajokri, being a slum area receives very low flow during summer. On the other hand, the open Ghogha drain receives high flows during monsoon.
- Currently, the treated wastewater is disposed in a pond and a lake. However, there is a plan to sell the treated water at the cost of INR 7/ KL in future.

3.3. Google earth mapping of NTS distribution across India

The 75 installations compiled in the inventory are spread in the varied geographical and climatic regions across India. Natural treatment systems have been observed and reported to be working successfully in rural and urban, hot and cold, humid and dry regions throughout India, indicating the potential of natural treatment systems for wastewater treatment in India. The geographical locations of all NTS installations which are a part of the inventory are represented in Figure 15 below.

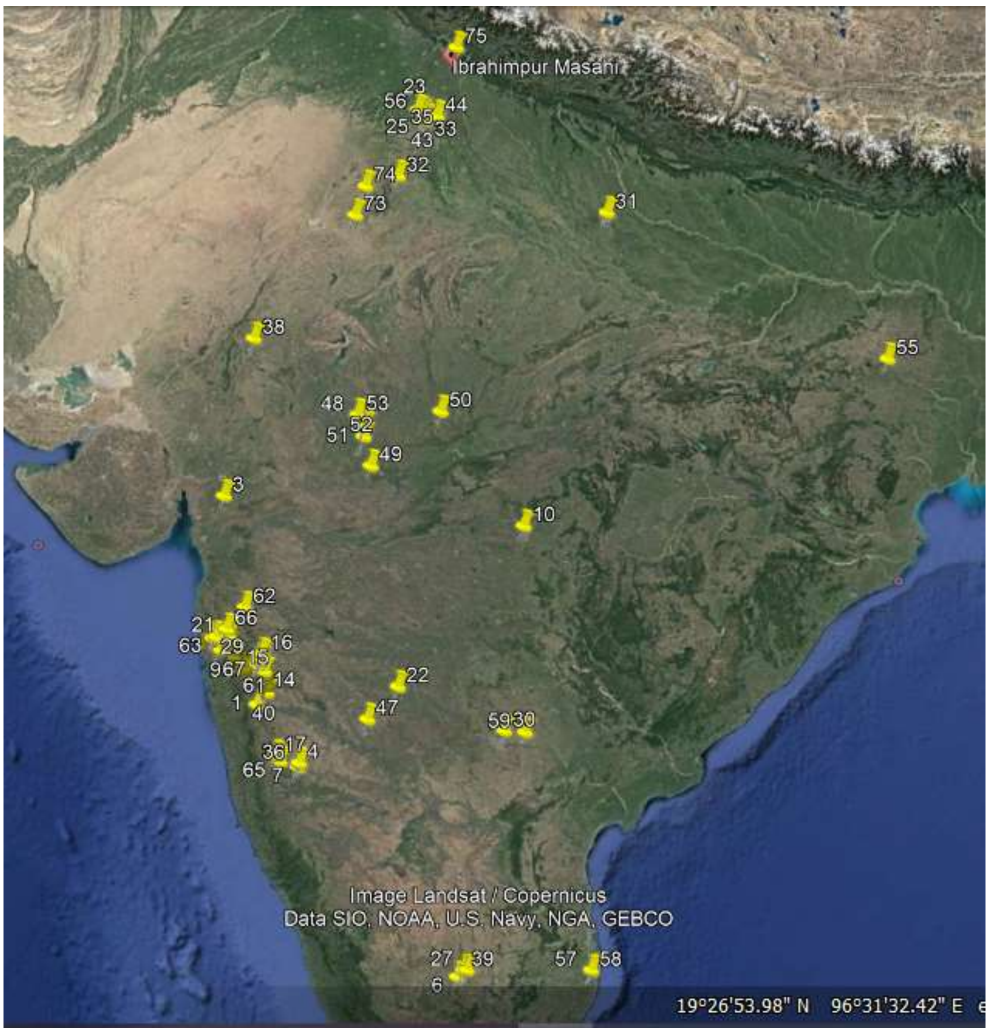


Figure 15: NTS installations for wastewater treatment throughout India

3.4. Inventory of natural treatment systems installations

The details of all natural treatment systems are documented in an excel sheet. It is a compilation of data from field scale installations as well as studies from literature based on natural treatment systems. A brief summary of the natural wastewater treatment installations including the location of plant, their capacity and organizations involved in the design and construction has been outlined in the Table 20 below. The details of construction, operation and maintenance and revenue generation is included in the excel sheet.

Table 20: Summary of natural treatment system installations

Type of NTS	Organization	Location of plant and capacity
Constructed wetland	NIH Roorkee	Ibrahimpur Masahi, Roorkee (40 KLD)
Constructed wetland	Indian Agricultural Research Institute	Pusa, Delhi (2.2 MLD)
Constructed wetland	IIT Bombay	Powai, Mumbai (25 KLD)
Constructed wetland (Soil Immobilized Bio-filters)	Energy Tech Pvt. Ltd., Pune	Panchgani, Satara (40 KLD) Khopoli, Raigad (250 KLD) Jhagadia, Bharuch (30 KLD) Sangli (400 KLD) Kolwan, Pune (150 KLD) Kanakpura, Bangalore (450 KLD) Jaisingpur, Kolhapur (50 KLD) Wadgaon, Pune (200 KLD) Jambulpada, Raigad (10 KLD) Hingana, Maharashtra (40 KLD) Narhe Ambegaon, Pune (50 KLD) Mulshi, Pune (300 KLD) Ranje, Pune (50 KLD) Mundhwa, Pune (15 KLD) Chakan, Pune (25 KLD) Rajgurunagar, Pune (40 KLD) Shirala, Sangli (70 KLD)
Constructed wetland	Ecosan Services Foundation, Pune	Lavale, Pune (75 KLD) Shivaji Nagar Pune (180 KLD) Purandar, Pune (5 KLD) Badlapur, Mumbai (8 KLD) Ausa, Latur (30 KLD)
Constructed Wetland Based on SWAB Technology	Delhi Jal Board	Bawana, Delhi (1 MLD) Rajokri, Delhi (600 KLD)

Constructed wetland	Petrichor (Private Company); NEERI	Rainbow Drive Society, Bangalore (250 KLD)
Soil Biotechnology	Mumbai Municipal Corporation	Lovegrove Pumping Station, Worli (3 MLD)
Soil Biotechnology	Naval administration	Kanjurmarg, Mumbai (50 KLD)
Soil Biotechnology	Life Links Eco Technology Pvt Ltd	Vazir Sultan Tobacco, Hyderabad (100 KLD)
Soil Biotechnology	Airport Authority of India	Lucknow Airport, Uttar Pradesh (150 KLD)
Soil Biotechnology	CSE, New Delhi and Vision Earthcare	Anil Agarwal Environmental Training Institute, Alwar, Rajasthan
Soil Biotechnology	New Delhi Municipal Corporation	Lodhi Gardens, New Delhi (500 KLD)
Soil Biotechnology	Vision Earthcare & EPC Ecosystem	Nehru Park, New Delhi (500 KLD)
Soil Biotechnology	Vision Earthcare & Ecoshripad	Gole Market, New Delhi (200 KLD)
Fixed film bio-filter technology	Resident, Mr. Shripad Khire	Dhamli road, Sangli (1 KLD)
Bio-sanitizer	Bhawalkar Ecological Research Institute, Pune	Residence at Salunke Vihar, Pune (1 KLD)
Green Bridge Technology	Jheel Sanrakshan Samiti, Udaipur and Shristi Eco Research Institute, Pune	Ahar River, Udaipur (Drain flow - 100 MLD)
Nualgi Technology	Nualgi Nano Biotech, Bangalore	Madivala lake, Bangalore (10 KLD)
Soil scape filter technology	Shrishti Eco Research Institute , Pune	Nichrome India Ltd, Shirwal (10 KLD) Pune (1 KLD)
Anoxic bioremediation	JM Enviro technologies Pvt. Ltd and Delhi Development Authority	Hauz Khas Lake, New Delhi Kushak Drain, New Delhi (3 MLD)
Constructed wetland		Vikram University campus, Ujjain (18 KLD) Ravindra Nagar, Ujjain (40 KLD) Barwaha Distillery, Madhya Pradesh Ekant Park, Bhopal (70 KLD) MR 11 Mahakal commercial area, Ujjain (221 KLD) River Kshipra, Madhya Pradesh
Constructed wetland (Phytorid technology)	National Environmental Engineering Research Institute, Nagpur	Kalina University campus, Mumbai (50 KLD) Premier Auto Ltd, Pimpri Chinchwad, Maharashtra (150 KLD) Mahindra & Mahindra Ltd, Nashik (60 KLD)

		Siemens Factory (500 KLD) Ajay Metachem Pvt Ltd, Pune (2 KLD) Warana Industries Ltd, Kolhapur (10 KLD) Kolimb Agricultural college, Thane (5 KLD) Bharat Forge Ltd, Baramati (100 KLD) Matheran hill station, Maharashtra (20 KLD)
Constructed wetland	Rebound Enviro Tech Pvt. Ltd.	Jwalamukhi, Himachal Pradesh (3 MLD) Nagrotaba, Himachal Pradesh (1.4 MLD) Dharamshala, Himachal Pradesh (200 KLD) Orient Residency, Jaipur (100 KLD) Rajnish hospital, Jaipur (60 KLD)
Constructed Wetland	BlueDrop Enviro Pvt. Ltd.	Cherlapalli, Hyderabad (70 KLD)

3.5. Learnings from NTSs installations in India

3.5.1. Geographical details

The inventory covers installations from ten states which include Andhra Pradesh, Gujarat, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Uttarakhand, and Uttar Pradesh. The locations include a variety of climatic conditions ranging from hot and dry parts of Rajasthan, humid climate of Mumbai, cold climate in mountainous regions of Himachal Pradesh, water scarce areas of Gujarat and Rajasthan, and tropical, semi-arid areas of Maharashtra and Tamil Nadu. Satisfactory performance of natural treatment plants has been reported in all varied climatic conditions across India. Apart from sewage treatment, natural treatment systems have been implemented to restore water bodies including rivers, lakes and drains as well.

3.5.2. Application and Construction details

The use of NTSs has been adopted by various academic institutions, hospitals, schools and hostels, airports, residential societies, and even Municipal Corporations. Either research institutes or certain private environmental firms have been associated with the construction of NTSs in these locations. In most of the cases, the plants constructed are handovered to the clients themselves for operation and maintenance. However, in case of Rebound Enviro Tech Pvt. Ltd. the operation and maintenance of constructed wetlands is done by the company itself.

The capacity of NTS installed varies from 1 KLD (individual household level plants) to up to 1 MLD, the higher capacity being of water bodies or drains. Decentralized treatment plants for factories or private companies have been designed and are mostly found to have capacity up to 100 KLD. Generally, wastewater treatment plants up to 500 KLD capacity designed for institutions are commonly found. In Delhi, wastewater coming from drains is treated with constructed wetlands designed for a capacity of 1 MLD. In Himachal Pradesh, constructed wetlands have been used for upgrading the existing centralized sewage treatment plants to tertiary level treatment, and have been designed for a maximum capacity of 3 MLD.

3.5.3. Design details

The dominant natural treatment system adopted throughout the country is constructed wetlands. Almost all the variants of constructed wetlands can be found in the inventory. Surface flow (vertical) form a characteristic feature of Soil Immobilized Bio-Filter system. Sub-surface flow wetland is the most popular flow pattern among all CW installations. A combination of the same has been used in some cases. Among the wetland species, *Canna indica* is the most popular choice of species. The other species adopted in Indian CWs are *Typha Latiflia, Cypersus, Phragmites karka, Phragmites Australia, Typha Augustifolia, E. Crassipes, C. Esculenta* and local plants such as banana and mango plants, elephant grass, lemon grass *etc*. The common source of wastewater as received by the natural treatment systems includes domestic wastewater. However, wastewater generated from cafeteria and hostel wastewater, laundry services and industries including food processing, pharmaceutical, dairy, tobacco processing plant, pulp and paper industry, distillery, tannery *etc*. has also been successfully treated through NTS.

Almost all of the natural treatment systems have been installed along with necessary pretreatment. Screens, oil traps, fat traps, equalization tanks, sewage wells and grit chambers are common preliminary treatment units. The dominant forms of primary treatment include septic tanks, sedimentation, anaerobic baffled reactor, anaerobic filter, tube settlers, and multi-baffled anaerobic reactors. Disinfection is the mandatory post treatment adopted at all plants, either by using hypochlorite or adopting UV radiation. Apart from that, activated carbon filters, pressure filters, dual media and multi-media filters, and chlorine contact tanks are commonly adopted as post treatment units. The use of polishing ponds is reported only in a couple of installations.

3.5.4. Operation and maintenance details

One of the important advantages of the use of NTS is relatively easier operation and maintenance of the systems. In comparison to mechanized systems, NTS do not require daily and frequent maintenance. Septic tanks are used in almost every form of NTS. The desludging of septic tanks is generally carried out once in two to three years. In case of constructed wetlands, the pruning of wetland species (trimming of plants) is carried out once in two to six months. For better growth of plants, selective cutting of only the flowering stems of plants is suggested. The frequency of back-flushing of multi-media filters is twice in a year. The gravel used for media in constructed wetlands need to be replaced or thoroughly cleaned after few years. It should be ensured that during maintenance, the gravels are re-laid as per design and not laid randomly. However, the NTS inventory shows in most cases NTSs are not functioning well due to poor O&M and lack of good primary treatment.

3.5.5. Recovery details

The most common reuse of treated wastewater is gardening/ farming/ horticulture or landscaping and toilet flushing. Disposal of wastewater treated (meeting discharge standards) in adjoining water bodies such as rivers, lakes, ponds or even drains is reported. One installation reported providing the recycled wastewater to a race course and sports club and for cooling purpose within its own premise. In case of reuse for gardening, only a part of the treated wastewater is used whereas the remaining treated sewage finds its way in the sewer lines.

The recovery of algae, duckweeds and aquatic plants is reported to have a variety of uses in literature. Most of the recovery is adequate enough to run the treatment plants and cover the operation and maintenance cost, even generating excess amounts. However, hardly any of the NTSs installations have reported harvesting algae or plant species and using the same for generating revenue. One major reason is lack of adequate field studies reported in inventory that are based on waste stabilization ponds or duckweed pond system, which prominently have potential for recovery in terms of algae or duckweed harvesting. None of the duckweed based sewage treatment systems in the knowledge of the authors was found to be functional in the current scenario. Some installations have mentioned about their plans of generating revenue from NTS in the coming years. In case of constructed wetlands, it can be said that water is the resource recovered, the reuse for secondary purposes thereby reducing the demand for freshwater. Hence, the revenue generation as output of using NTS is mainly reported as savings on freshwater demand. Non-monetary benefits such as savings on fresh water intake and electricity from bore-well usage have been reported by Ecosan Services Foundation, Pune. Revenue generation (in terms of savings) has been reported by Energy Tech Pvt. Ltd. on the assumption of 10 KL tanker price costing INR 1000/-.

3.5.6. Financial details

Operation and maintenance cost of about INR 6/ m^3 has been reported by Energy Tech Pvt. Ltd. for surface flow vertical constructed wetlands. The capital cost as reported by Ecosan Services Foundation ranges from INR 30 to INR 66 per KLD of wastewater, whereas annual operation and maintenance cost ranges from INR 20,000 to INR 30,000. The rejuvenation of water bodies and drain carried out by Delhi Jal Board (adopting constructed wetlands) costs around 1.28 to 1.38 crore/ MLD which includes operation and maintenance cost for a period of 5 years. Soil Biotechnology plants in Delhi report capital cost ranging from 10k to 18k/ KLD wastewater. The operation and maintenance cost inclusive of electricity is reported to vary significantly from 20k to 80k monthly. The CW constructed by Indian Agricultural Research Institute reports capital cost of INR 0.54 crore/ MLD and annual maintenance cost of INR 607/MLD, which are relatively on a lower side.

4. Site Visits to NTSs Installations in India

IIT Bombay team visited ten wastewater treatment plants based on natural treatment systems. The visits were scheduled in five states namely Uttarakhand, Maharashtra, Delhi, Himachal Pradesh and Rajasthan. They are briefly described in the section below.

4.1. Site visit in Roorkee

Site visit number	1	**Date of visit**	9th Aug 2019
Location of site	Ibrahimpur Masahi	**Plant capacity**	40 KLD
NTS type	Constructed wetland		
Process train	Screen – Grit chamber – Constructed wetland – Pond		
Description of photos	1] Screen 2] *Canna indica* species in constructed wetland 3] Village pond in which the effluent of wetland enters		

	4] Installation board of constructed wetland

4.2. Site visits in Mumbai

Site visit number	2	**Date of visit**	9th Dec 2019
Location of site	Worli	**Plant capacity**	3 MLD
NTS type	Natural hybrid system (Commercial name: Soil Bio-technology)		
Process train	Bar screens - Settling tanks - SBT reactors - Pond		

Note: Permission for taking photographs was not granted

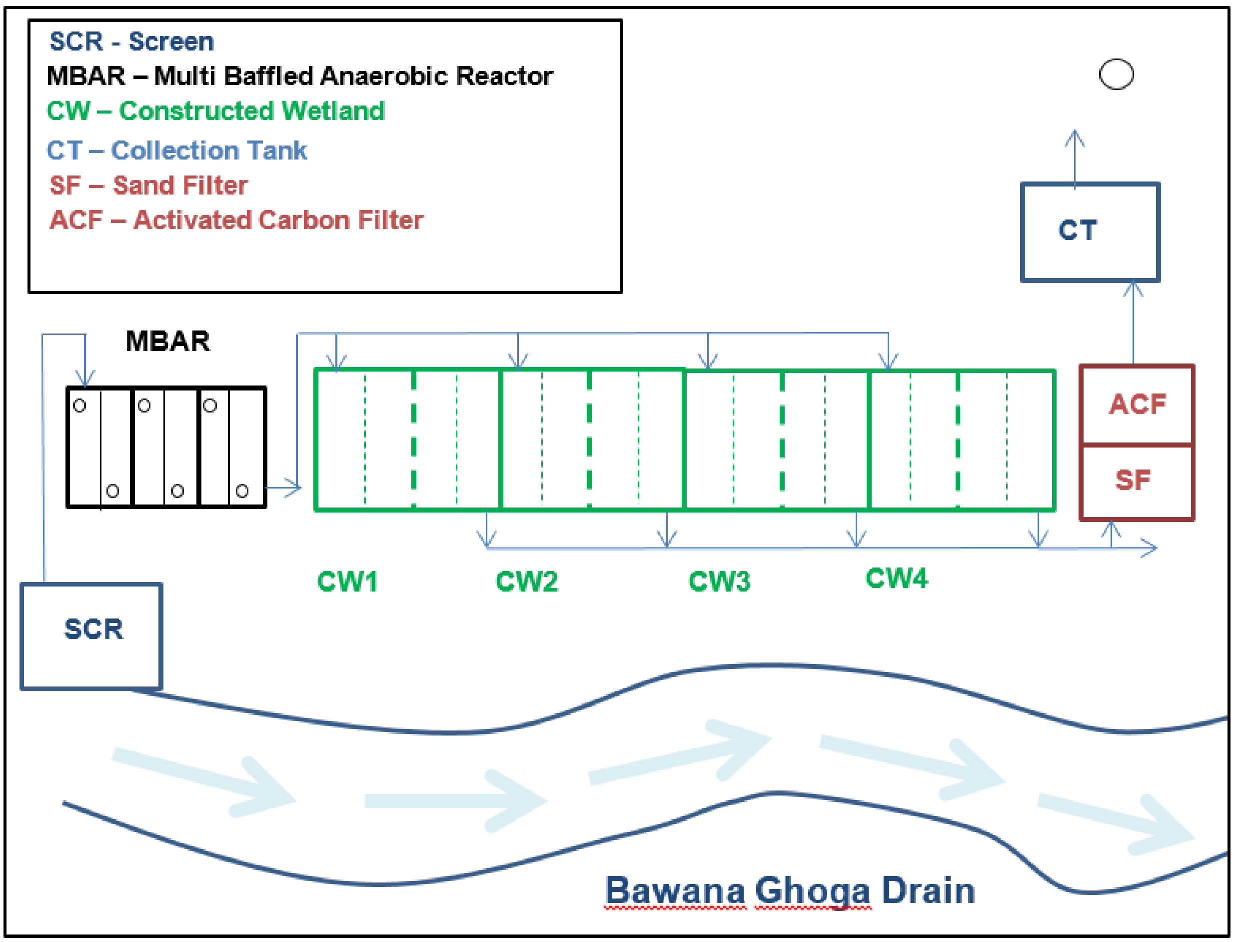
Site visit number	3	**Date of visit**	11th Dec 2019
Location of site	Virar	**Plant capacity**	660 kLD
NTS type	Natural hybrid system (Commercial name: Soil Bio-technology)		
Process train	Wet wells – Primary settling (horizontally baffled) – Bioreactor 1 – Collection tank 1 – Bioreactor 2 – Collection Tank 2 – Flushing		
Description of photos	1] Bioreactors installed in a residential society 2] Soil bio-filters and media 3] Top view of wastewater treatment facility		

4.3. Site visits in Delhi

Site visit number	4	**Date of visit**	14th Feb 2020
Location of site	Rajokri	**Plant capacity**	0.6 MLD
NTS type	Sub-surface flow constructed wetland (Commercial name: Scientific Wetland with Activated Bio-digestion)		
Process train	Multiple baffled anaerobic reactor – Collection tank – Constructed wetland (sub-surface flow) – Floating wetlands in pond		
Description of photos	1] Location of Rajokri pond 2] Effluent wastewater after anaerobic reactor entering wetland 3] Horizontal sub-surface flow wetland 4] Rajokri pond with floating wetlands, receiving effluent of CW		




Site visit number	5	**Date of visit**	14th Feb 2020
Location of site	Bawana Ghogha	**Plant capacity**	1 MLD
NTS type	Sub-surface flow constructed wetland (Commercial name: Scientific Wetland with Activated Bio-digestion)		
Process train	Screen - Multiple baffled anaerobic reactor – Sub-surface vertical flow wetland (4 in parallel) – Free-surface wetland – Collection tank – Sand filter – Activated carbon filter		
Description of photos	1] Screen installed in Ghogha drain 2] Constructed wetland beds 3] One chamber of wetland bed 4] Lake in which disposal of treated effluent is proposed		

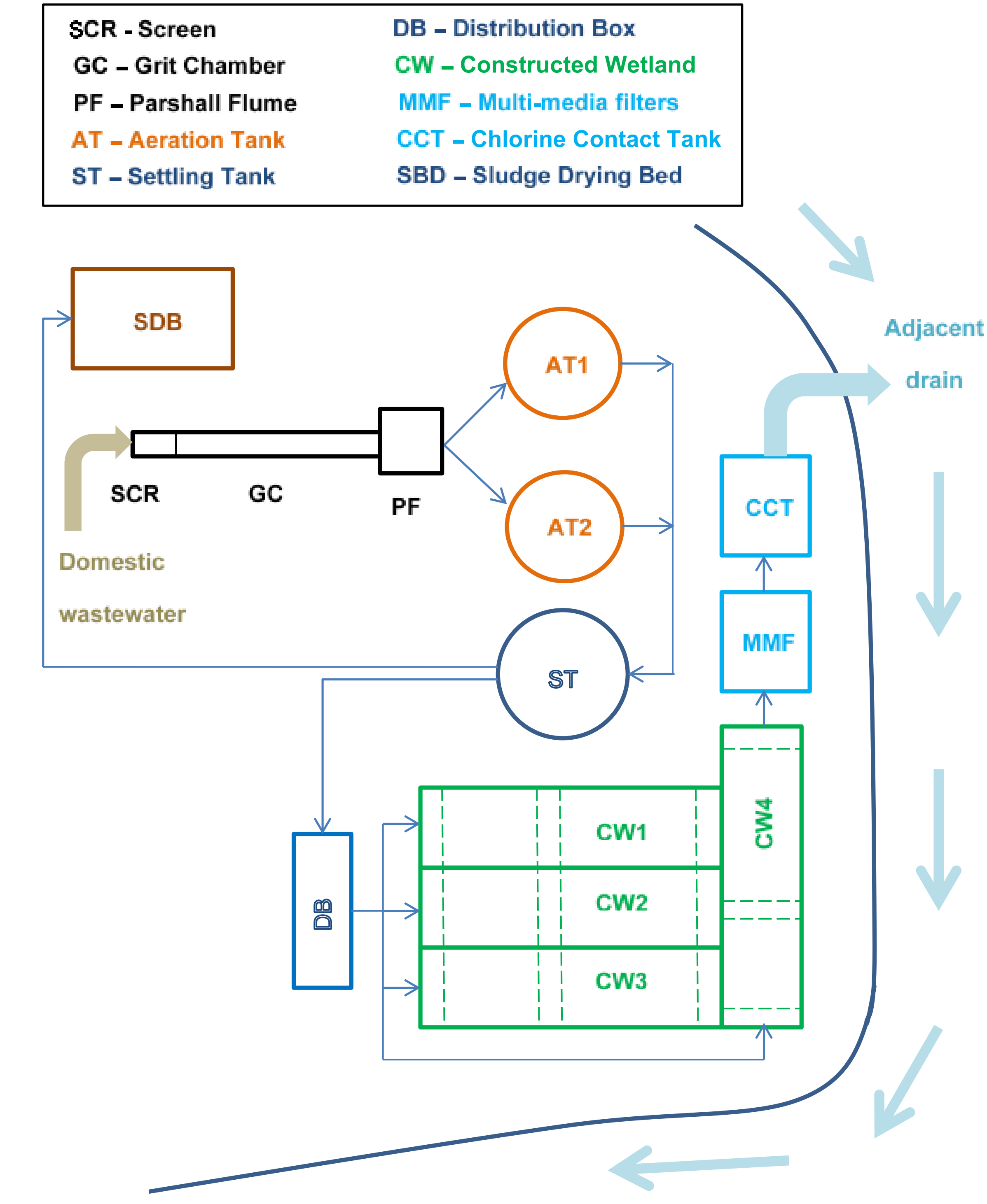



Treatment flow at Bawana Ghogha, Delhi

4.4. Site visits in Himachal Pradesh

Site visit number	6	**Date of visit**	16th Feb 2020
Location of site	Jwalamukhi	**Plant capacity**	3 MLD
NTS type	Sub-surface Constructed wetlands		
Process train	Screen – Grit chamber – Aeration tanks (2 in parallel) – Settling tank – Distribution box – Constructed wetlands (4 in parallel) – Multi-media filter – Chlorine contact tank – disposal in adjoining drain		
Description of photos	1] Aerators used for primary treatment 2] *Canna indica* used as wetland species 3] Constructed wetland beds 4] Sludge drying beds		



Treatment flow at Jwalamukhi, Himachal Pradesh

Site visit number	7	**Date of visit**	16th Feb 2020
Location of site	Nagrotaba	**Plant capacity**	1.4 MLD
NTS type	Sub-surface flow constructed wetland (Under commissioning)		
Process train	Screen – Moving bed bioreactor (2 in parallel) – Tube settler – Constructed wetland (2 in parallel) - Multi- media filter – Chlorine contact tank – Reuse for irrigation (proposed)		
Description of photos	1] Bridge constructed for sewer line 2] Primary treatment – Moving bed bioreactors 3] Constructed wetland bed under commissioning 4] Stretch of constructed wetland beds		

Site visit number	8	**Date of visit**	17th Feb 2020
Location of site	Dharamshala	**Plant capacity**	0.2 MLD
NTS type	Sub-surface flow constructed wetland		
Process train	Screen - Multiple baffled anaerobic reactor – Sub-surface vertical flow wetland (4 in parallel) – Multi- media filter – Chlorine contact tank		
Description of photos	1] Installation board of Dharamshala sewage treatment plant 2] Constructed wetland beds 3] Multi-media filters		

	4] Chlorine contact tank

4.5. Site visits in Jaipur

Site visit number	9	**Date of visit**	19th Feb 2020
Location of site	Orient Residency	**Plant capacity**	100 kLD
NTS type	Sub-surface flow constructed wetland		
Process train	Screen – Septic tank (baffled proposed in modification) – Sub-surface flow constructed wetland		
Description of photos	1] Constructed wetland beds along compound wall of residential building 2] *Canna indica* used as wetland species		

Site visit number	10	**Date of visit**	19th Feb 2020

Location of site	Rajnish Hospital	**Plant capacity**	60 kLD
NTS type	Sub-surface flow constructed wetland		
Process train	Screen – Septic tank - Sub-surface flow constructed wetland (3 in series) – Reuse for irrigating lawns		
Description of photos	1] Constructed wetland beds along compound wall of hospital 2] Series of constructed wetland beds		

5. Summary and Conclusions

Natural treatment systems have tremendous potential in wastewater treatment, food production as well as relieving the pressure on the underground resources. However, the NTSs need to be carefully planned in order to leverage on the all benefits of the NTSs. The advantage of NTS is that skilled personnel is not required for operating the plants. For effective operation and maintenance, unskilled labor can be trained for few days on various aspects of O&M and they can handle the treatment plants. The adoption of NTS can thus provide a helping hand to tackle the unemployment problem in India to an extent along with wastewater treatment.

5.1. Necessity of establishing field-scale projects

As it can be seen from the inventory list from this report most of the NTSs in India are pilot scale. However, considering the enough available experience there is need to initiate large field scale NTSs implementation. The design of natural treatment systems depend on the geographic conditions and climate of a particular region. India is a large country with varied climatic and geographic conditions throughout its extent. Although natural treatment systems are working successfully in these diverse regions, there is a need to establish such large scale projects and disseminate the NTSs. This will aid in developing specific guidelines for Indian conditions.

5.2. Need to develop business models

Along with field-scale projects, there is also a need to establish business models for the self-sustenance of NTS which will attract the investors and businessmen. Several benefits of adopting natural treatment units have been proven globally through field as well as lab studies. However, there is a need for the knowledge to be disseminated to various stakeholders. From the inventory collected, hardly any installation has reported data pertaining to revenue generation, which implies that the revenue generation potential of NTS is not fully utilized. Young entrepreneurs should be made aware of the potential of natural treatment systems and incentives should be given for investments of business models in the wastewater sector.

The NTS inventory reported in this work reveals that there is huge potential for NTS in India. Different scales of implementation for various applications are found across India. However, to further adopt the use of NTSs there is need for "technology packages" meaning the surrounding support system to sustain the NTSs. The further research in this project will aim at developing such "technology packages".

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Disclaimer

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Appendix

Table 21: List of organizations contacted for inventory

Sr	Name	Organization	Place
1	Pravinjith KP	Ecoparadigm	Bangalore, Karnataka, India
2	Deep Rathi	IWA environment solution Pvt. Ltd	Tamil Nadu, India
3	Aviraj Datta	Scientist, IDC, ICRISAT Patancheru	
4	Mr. Ganesh Mule	Shrishti Eco-Research Institute (SERI)	Sinhagad Road, Pune, Maharashtra
5	T. Sampath	Nualgi Nanobiotech	Jayanagar, Bangalore 560041
6	Mr. S. Vishwanath	Biome Environmental Solutions	Bangalore
7	Dr Chandrashekhar Shankar	Director, Vision Earth Care (VEC)	IIT Mumbai
8	Mr. P.K. Jain	UIT Alwar	Alwar, Rajasthan
9	Dr. Suresh Kumar Rohilla	Program director, CSE	CSE Delhi
10	Consortium of DEWATS Dissemination (CDD)Society	Consortium of DEWATS Dissemination (CDD)Society	Bangalore, Nagpur
11	Delhi Jal Board	Delhi Jal Board	Karol Bagh, New Delhi
12	Tejas Kotak	Hunnarshala Foundation	Bhuj, Gujarat
13	MMR-Environment Improvement Society	MMR-Environment Improvement Society	Bandra Kurla Complex, Bandra (East)
14	Dr Uday S Bhawalkar	Bhawalkar Ecological Research Institute	Padma Park, Behind Padmavati Temple Pune
15	Anil Mehta	Jheel Sanrakshan Samiti, Udaipur	Udaipur – 313001, Rajasthan
16	Ganges Reddy	Bluedrop Enviro	Hyderabad
17	Dr. Dinesh Kumar	Rebound Enviro Tech Pvt. Ltd.	Himachal Pradesh
18	Dhawal Patil	Ecosan Services Foundation	Pune
19	Prof. Nadeem Khalil	Aligarh Muslim University	Uttar Pradesh
20	Prof. Ligy Phillip	IIT Chennai	Chennai
21	V. K. Mishra	IGNTU (Indira Gandhi National Tribunal University)	MP
22	Rita Shingare	Env. Biotechnology and Genomics Div, India	
23	Rahul Babar	Energy Tech Solutions	Pune

Table 22: List of academic institutions contacted for inventory

Sr	Name	Academic Institute	Place
1	Dr. Renu Khosla	Centre for Urban and Regional Excellence	New Delhi
2	Prof. Kantha Deivi Arunachalam	SRM, University	Chennai, India
3	Harini Nagendra	Azim Premji University	Bangalore, Karnataka, India
4	Ms. Mamtha AS	Environment Engineer	Devnahalli Town Municipal Council
5	Dr. Debraj Bhattacharyya	Indian Institute of Technology, Hyderabad	Hyderabad
6	Sonia Rani	TERI	Delhi, India
7	Mr. Ganesh Mule	Shrishti Eco-Research Institute (SERI)	Sinhagad Road, Pune, Maharashtra
8	Dr. Riteish Vijay	NEERI	Nagpur
9	Prof. H.S. Shankar	IIT Bombay (SBT)	Bombay
10	Prof. Shyam Asolekar	IIT Bombay	Bombay
11	Prof. Nadeem Khalil	Aligarh Muslim University	Uttar Pradesh
12	Prof. Ligy Phillip	IIT Chennai	Chennai
13	V. K. Mishra	IGNTU (Indira Gandhi National Tribunal University)	MP
14	Sahebrao Sonkamble		Hyderabad study
15	Shrihari		Site in Tamil Nadu
16	Rita Shingare	Env. Biotechnology and Genomics Div, India	
17	J. S. Sudarsan	SRM University	Tamil Nadu
18	A. K. Haritash	Dept Env. Engg, Delhi Technical University	
19	Subodh Kumar Maiti	DepEnv. Sci and Engg (Indian School of Mines)	
20	Prashant sir	Centre for Env Sciences, University of Bihar	Bihar
21	Geetanjali Kaushik	Civil Engg, Jawaharlal Nehru Engg College	Aurangabad
22	R. Biswas	Water Technology Division, CSIR NEERI	Nagpur
23	Neetu Rani	Dept of Applied Sciences, Gyan Bharti Institute of Technology	Meerut, MP
24	Jadhav Kapilesh Jadhav Indrani	Jaipur National University	Jaipur
25	Sutapa Das	Architecture and Regional Planning, Indian Institute of Technology Kharagpur, Kharagpur, India	Kharagpur

26	Bhawana Goyal	Jai Narain Vyas University	Jodhpur
27	D.M. Mahapatra	Energy and Wetlands Research Group, Centre for Ecological Sciences	Indian Institute of Science, Bangalore
28	R.Walia; P.Kumar	Rajarshi Shahu College of Engineering; IIT Roorkee	Pune; Roorkee
29	Shanthala M	Center for Applied Genetics, Bangalore University	Karnataka
30	Dr. M.K. Chaturvedi	Centre for Env Sciences, University of Bihar	Bihar

Table 23: Photos of species commonly used in constructed wetlands, India

Sr.	**Species**	**Photo 1**	**Photo 2**
1	Typha Angustifolia		
2	Phragmites australia		

3	Typha capensis		
4	Brachiria mutica		
5	Typha Latifolia		
6	Colocasia Esculenta		

7	Phragmites karka		
8	Canna indica		
9	Eichhornia Crassipes (water hyacinth)