

# Developing an Artificial Wetland System for Wastewater Treatment: A Designing Perspective

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**Abstract** - Out of the available water resources 97% of water is present in oceans, 2% polar ice caps and fresh water lakes constitute 1% of the water. India is likely to be water scarce by 2050. It is therefore important to increase the efficiency of water use, explore options to augment water supply in critical areas, and ensure more effective management of water resources. Among the Eight missions stated in the National Action Plan for Climatic Changes (NAPCC, INDIA), National Water Mission (NWM) lays stress on sustainable use and reuse of water and wastewaters.

The aim of this research paper lays stress on using phytoremediation for wastewater treatment and designing a pilot wetland system. The aquatic plant species which are disease and drought resistant, heat, cold, salt, chemical, insect and stress tolerant should be identified. Other selection criteria are growth rate/biomass production and reproduction rate. Some common aquatic plant species used in wastewater treatment are *Eichhornia crassipes*, *Azolla* spp. *Ceratophyllum demersum*, *Chara* spp, *Hygrophila polysperma*, *Ipomoea aquatica*, *Pistia stratiotes*, *Typha latifolia*, *Brassica juncea*, *Helianthus annuus* and *Medicago sativa*. They are basically responsible for removal of nutrients such as COD, heavy metals like Cd, Cr, Cu, Fe, Ni, Pb, Zn, nitrate, phosphorus as well as hydrocarbons and suspended solids.

The methodology adopted will help in the identification of pollutants in domestic and industrial wastewater which will undergo the process of phytoremediation. For this purpose wastewater sampling of domestic and industrial water such as hospital, steel, coal mining etc. will be collected depending upon the availability. The comparative analysis of species will be performed so that construction of a Pilot wetland system for treatment of wastewater can be designed. Constructed wetlands can mitigate ecological risks to aquatic receiving systems by decreasing concentrations and toxicity of contaminants. Water quality assessment before and after the treatment will indicate the removal efficiency of nutrients by the species as well as design approach of constructed wetland in treating wastewaters to meet the regulatory discharge limits. Based on the results the feasibility of the pilot study can be recommended for study at large scale.

The scope of the work if completed successfully would help in attaining National Water Mission of India. Wastewater can be reused which are being generated by different human based activities (approximately 80% of water being used is returned as wastewater). It can also be implemented in town planning and residential complexes.

## Keywords

Phytoremediation; phytoremediator; domestic and industrial wastewater; wastewater treatment; contaminants of concern (COC); metallophytes, decentralized, removal efficiency, mesocosm, constructed wetland (CW); Removal Efficiency

## I. INTRODUCTION

Out of the available water resources 97% of water is present in oceans, 2% polar ice caps and fresh water lakes constitute 1% of the water. India is likely to be water scarce by 2050. It is therefore important to increase the efficiency of water use, explore options to augment water supply in critical areas and ensure more effective management of water resources. The **National Water Mission (NWM)** lays stress on sustainable use and reuse of water and wastewaters.

Wastewater is the mixture of water and waste products which arises from domestic and industrial sources. Treatment of wastewater is required because it causes foul smell, bad odours, demand for dissolved oxygen in the water bodies, adds nutrients (nitrate and phosphate) and increases suspended solids or sediments in streams. The untreated water also contains pathogenic bacteria [1].

Wastewater treatment is a problem that has plagued man ever since he discovered that discharging his wastes into surface waters can lead to many additional environmental problems. The Clean Water Act (1972) and its more recent amendments has led to the construction of many new wastewater treatment facilities across the country which helps to control water pollution.

Multifarious treatment technologies are available today to restore and maintain the chemical, physical and biological integrity of the nation's waters. The potential use of a variety of natural biological systems like ponds, land treatment and wetlands systems helps to purify water in a controlled manner. These systems show their efficiency due to their design, performance, operation and maintenance [2]. These systems must be upgraded from time to time to ensure the removal efficiency of the contaminants.

Constructed wetlands are decentralized, low-energy, low-cost systems to improve water quality. They rely on natural wetland function which includes plants and microorganisms which uptake and breakdown the wastewater nutrients either aerobically or anaerobically. These systems are responsible for providing multiple benefits like improvement in water quality, water security & reuse, CO<sub>2</sub> reduction, provides habitat for many plants and animals. It also acts as a source for recreation, education, aesthetic/amenity value [3]. Plants (free-floating, emergent or submergent vegetation) are the part of constructed ecosystem to remediate contaminants from municipal, industrial wastewater, metals, acid mine drainage [4].

The microorganism (which lives on the exposed surfaces of the aquatic plants and soils) remove the dissolved and particulate organic matter to carbon dioxide and water. The process of active decomposition in the artificial wetland produces the effluent which has lower pH and BOD.

The green technology that uses plants for remediation of contaminants and restoration is known as phytoremediation. The process is a natural method, cost effective and multiple contaminants can be removed by a single species. It also reduces the potential for transport of contaminants by wind and it reduces soil erosion. Some plant species like *Eichhornia crassipes*, *Chara* spp, *Ipomoea aquatica*, *Pistia stratiotes*, *Typha latifolia*, *Brassica juncea* and *Helianthus annuus* can be used for eliminating the COC. They are responsible for removal of nutrients such as heavy metals like cadmium, chromium, copper, iron, nickel, lead, zinc, nitrate, phosphorus as well as hydrocarbons, suspended solids and COD. Plant selection depends upon plant characteristics such as tolerance to pH and salinity of wastewater, translocation and uptake capabilities, transpiration rate or water use, depth of root zone, native and non-native species and also commercial availability. They should be disease, drought resistant, insect and stress tolerant. Growth rate/biomass production and reproduction rate are also an important selection criteria that affects the phytoremediation process as well as the designing of the pilot scale study.

## II. LITERATURE REVIEW

A pilot study documents phytoremediation under real site conditions and if successful can be implemented for full-scale application. Pilot testing may consist of planting the appropriate plant species and developing a monitoring plan for chemical fate over time in the soil, water and plant material. The main goal and objective of the pilot test is to assess if the plants will survive and the roots will reach the contamination for remediation, removal and recovery.

The basic mesocosm design parameters include wetted area, lower loading rate (amount of water going in), retention time, plant type and species, warmer temperatures and wetland components. All the parameters have their own significance. Plants offers resistance to the flow of wastewater, increases retention time, facilitates settling of suspended particles. It also improves the conductance of water through the media as root grows. Further they are responsible for transportation of oxygen to the deeper layers of the media and hence assist in oxidation and precipitation of heavy metals on root surface.

Sand is the substrate on which plant species grows. It acts as a filtering media but due to clogging the efficiency may be reduced. Clogging takes place due to accumulation of solids in the void spaces. The main use of gravel is that it provides adsorption site for the removal of phosphorus apart from acting as a filtering media which is porous in nature. The containers can be rectangular or cylindrical depending upon the availability. A slope of 30° at the base of the container increases the effluent from the outlet.

The conceptual design of the mesocosm was prepared by the information which was synthesised from published literature and to provide modification, if necessary to incorporate into the final design. The Monitoring parameters which is taken into consideration are total solids, total volatile solids, suspended solids, total chemical oxygen demand, dissolved chemical oxygen demand, total Kjeldahl nitrogen, ammonia, nitrate, faecal coliforms and heavy metals. Analytical methods for these parameters will be according to Standard Methods for the Examination of Water and Wastewater [5].

Constructed wetlands are classified according to water flow regime (surface and sub-surface) and the

type of macrophytic growth [6]. The types of wastewater that can be treated by any CW are municipal, industrial, leachate, acid mine drainage, surface runoff, sludge dewatering, prevention of eutrophication and agroindustrial [7] The removal of metals in wetlands occurs through a number of processes which includes sedimentation/ coagulation, filtration, plant uptake/removal efficiency, adsorption (binding to sand particles and root), formation of solid compounds, cation exchange and microbial-mediated reaction, especially oxidation [8]

The different types of constructed wetlands for wastewater treatment can be categorized as either Free Water Surface (FWS) or Subsurface Flow (SSF) systems. In FWS systems, the flow of water is above the ground and plants are rooted in the sediment layer at the base of water column. In SSF systems, water flows through a porous media such as gravels or aggregates, in which the plants are rooted. There are two types of SSF systems: horizontal flow SSF (HSSF) and vertical flow SSF (VSSF). The vertical flow CW is particularly efficient in removal of suspended solids, carbon and nitrification process. Denitrification is poor because of aerobic condition. VSFCWs are characterized by an intermittent (discontinuous) feeding where the wastewater vertically percolates through a substrate layer which consists of mainly consists of sand, gravel or a mix of all these components [9]

Green technology is a technology which uses plants to clean up the contaminants from a specified area [10]. The process is relatively known as phytoremediation. It mainly works on five mechanism – phytoextraction, phytovolatilization, rhizosphere degradation, phytodegradation and hydraulic control [11] the removal of contaminants. Currently, phytoremediation is used for treating many classes of contaminants such as heavy metals, pesticides, petroleum hydrocarbons, explosives, radionuclides, CVOCs etc. [12]. The term heavy metals refers to metals and metalloids having densities greater than  $5 \text{ g cm}^3$  and is usually associated with pollution and toxicity although some of these elements (essential metals) are required by organisms at low concentrations [13]. Unlike organic compounds, metals cannot be degraded, and their cleanup requires their immobilization and toxicity reduction or removal [14]. For the construction of

artificial wetland/ pilot scale study the basic components used are containers, plant species, sand and gravel media in certain ratio. Microbes and other invertebrates develop naturally [5]. There are three life forms of macrophytes which are basically used for construction of constructed wetland. They are floating macrophyte (i.e. *Lemna spp* or *Eichornia crassipes*), submerged macrophyte (i.e. *Elodea canadensis*) and rooted emergent macrophyte (i.e. *Phragmites australis*, *Typha spp*,...)[15].

The phytoremediator plant species should have high growth rate, high biomass, adapt ecologically to diverse habitats, ability to accumulate the target metal in the above-ground parts. They should also be able to tolerate high metal concentration and have an adaptive tolerance may be essential for several metals simultaneously [16] The inhibition of growth of one plant species by the other plant species due to the chemicals produced by the other is known as allelopathy. For mixed culture this property must be considered to ensure that none of the species are harmed. Mixed stands (mixed culture) of plants are more stress resistant/ tolerant than monocultures and they establish a higher diversity of rhizobacteria. It is because the combination of plants are able to degrade specific COC and therefore the removal efficiency is increased [4]. The concentration of contaminants to be removed should be from low to medium because excess concentration may inhibit plant growth [17]. The vegetation must be harvested each growth season so as to maximize the removal of pollutants by the plant species. Harvesting before senescence may permanently remove nutrients from the systems. The removal of phosphorus and metals depends on harvesting. It is less for nitrogen. The roots are also harvested because the belowground biomass constitutes a significant reservoir (possibly half) of the nutrients and metals [18]. Many hyperaccumulators have been identified which are capable to clean metal polluted soils. There are nearly 400 known hyperaccumulators but most are not appropriate for phytoextraction because of their slow growth and small size. Study by Cobbett [19] shows that currently there are about 420 species belonging to about 45 plant families recorded as hyperaccumulators of heavy metals The process of metal hyperaccumulation (i.e., the ability to accumulate at least 0.1% of the leaf dry weight in a

heavy metal), is only exhibited by < 0.2% of angiosperms [20], which makes the selection of native species for phytoremediation a bit difficult task. Five different explanations was given by **Boyd and Martens [21]** and **Boyd [22]** for why hyperaccumulators may have evolved have been proposed. The hypotheses put forward are (i) plants may hyperaccumulate trace elements because storing large quantities of metals may be a means of metal tolerance and disposal, (ii) hyperaccumulating plants may use metals as elemental allelopathy against nearby competitors, (iii) metals may serve as osmotic resistance to drought, (iv) accumulated metals may defend the plant against herbivores or pathogens, and (v) metal accumulation may be accidental.

The plant species that have the ability to survive and reproduce on metal rich soils without any toxicity are known as metallophytes [23]. Some metallophytes have a specialization to concentrate elements at levels that would be toxic to nonaccumulators.

This innate ability to hyperaccumulate trace elements in plant leaves has been observed in species that grow naturally on metal-rich substrates [24], [25], [26] but the trace element accumulation potential in hyperaccumulators may not be solely a matter of their habitat.

For the construction of mesocosm generally materials which are found on site are used. It should be taken into consideration that contaminated soils should not be used if the water quality is to be improved. The topsoil in which the species are to be planted should be imported from the planted area or in some conditions organic matter can be added to provide a suitable growing environment for the macrophytes [27]. The gravel that are used can be augmented with any other supplemental media which is specific to any pollutant. For example activated carbon is used both for complex organic like pesticides, dissolved metals and petroleum hydrocarbons. Blast furnace slag, iron-ore, iron wool, limestone, aluminum oxide, dolomite, iron-infused resins are used for removal of dissolved phosphorus [18]. The gravel media is porous, acts as a filtering media and provides adsorption sites for removal of phosphorus [28]. It acts as a substrate for growth of bacteria, facilitates the removal of nitrogen and degradation of petroleum and other organic compounds [18]. Sand is used for the growth of the species. It acts as a filtering media

but the efficiency is reduced due to clogging which reduces the voids between the sand particles [9].

**Baveye et al. [29]** summarised the methods for clogging study, and considered that the clogging of porous media was intrinsically a physical phenomenon, formed by three classes: physical, chemical, and biological (microbial). **Blazjewski & Murat Blazjewski [30]** also concluded that the main causes for clogging were the accumulation of wastewater solids, the growth of the biofilm and the deposition of chemical precipitates. Moreover, researchers found that inorganic particulates, organic matter and biofilm growth were mainly accumulated on the upper layer, and described clogging as primarily a surface phenomenon [31].

The management of “municipal solid wastes”, treatment of “municipal & industrial wastewater”, remediation of “PAHs contaminated soils” by use of vermicompost at Griffith University, Australia showed that wastes were degraded by over 75% faster than conventional systems and compost produced are disinfected, detoxified, richer in nutrients & beneficial soil microbes; BOD loads & TSS of wastewater is reduced by over 95%; PAHs from contaminated soils are removed by over 80% in just 12 weeks; and crops growths are promoted by 30-40% higher as compared to chemical fertilizers. Earthworms are both “protective” & “productive” for environment and society [32]. Earthworms act as aerators, grinders, crushers, chemical degraders and biological stimulators [33]. These decompose organics, mineralize nutrients, ingest the heavy metals and devour the pathogens (bacteria, fungus, nematodes and protozoa). Properly designed and operated water hyacinth systems remove 60- 95% of the BOD from wastewater. A significant portion of the oxygen necessary to support the aerobic processes in wetland hydrosols can be supplied by aquatic macrophytes via translocation of oxygen from the atmosphere to the rhizosphere [34].

Water hyacinth systems may also be more economical than conventional wastewater treatment plants. One study reported that a hyacinth system would cost only half as much to construct and only two-thirds as much to operate as an activated sludge plant [35]. In small systems, the savings may be even greater.

Hyacinth systems can be made even more profitable. K products such as compost, methane gas, cattle feed, paper, or protein extract can be developed and marketed.

The important characteristics of water hyacinths is that they possess attractive biological support media for bacteria which grow in their extensive root system and their rapid growth rate. The growth rate is limited by their temperature sensitivity and they get killed by winter frost conditions [36].

### III. METHODOLOGY

For the present experimentation the methodology used is the identification of contaminants of concern (COC) both in influent and effluent water samples. With the help of literature review as well as wastewater sampling, testing will be performed based on APHA, AWWA 1998. For this purpose sampling of domestic and industrial water such as hospital, steel, coal mining etc. will be collected depending upon the availability. The study will be performed either in pre-monsoon or post-monsoon seasons and also for two successive years. Both pre and post season will help to know the climatic variability, seasonal variability as well as species variability. Rain causes two opposing effects, dilution of waters which reduces the material concentrations and increased water velocity which is responsible for increasing the water retention time within a wetland. A pilot wetland system will be constructed for treatment of wastewater (mesocosm). This mesocosm will have components such as sand, gravel and plant species depending upon the type of wastewater other supplemental media such as charcoal, limestone, aluminium oxide or activated carbon can be used to remove target pollutants like dissolved metals, hydrocarbons, dissolved phosphorus etc. [37]. Other component like microorganisms and invertebrates will develop naturally. It is important that the plant species that are identified should have high tolerance level towards the contaminants present in wastewater. So the identification and selection of suitable Phytoremediation species for WWT should be considered. For the experimentation *Eichhornia crassipes* and *Typha sp.* will be used after species suitability assessment according to literature review. Finally the species and wastewater was applied in the

The emergent macrophyte i.e *T. latifolia* actively aerates its root zone, enhancing microbial activity responsible for BOD degradation and is therefore used for wastewater treatment. Growth rate of *T. latifolia* is relatively rapid and decay of detritus is relatively slow ( $t_{1/2} \gg 6$  mo.), thus having minimal influence on BOD due to decomposition [31]. *Typha* is able to oxygenate the sediments thus they enhance the development of microorganisms and increase oxygen process rate.

pilot wetland setup for water quality analysis. Three important points that were considered for the experimentation are species variation, climatic variation and effluent variation. Water quality results would be analysed to know the removal efficiency (Removal efficiency (%) = [(inlet pollutants-outlet pollutants)/ inlet pollutants] x 100) of the species as well as the construction of mesocosm [7]. Based on the results obtained recommendations could be made whether the design and construction as well as the plant species can be utilized for large scale purpose for the removal of contaminants of concern. Water quality assessment before and after the treatment will indicate the removal efficiency of nutrients by the species as well as design approach of constructed wetland in treating wastewaters to meet the regulatory discharge limits. The feasibility of pilot wetland setup at large scale will also be assessed. Based on the result recommendations would be made in this regard.

Study of two successive years will help to find out the relationship between the influent and the effluent for certain time period.

Objective 1: Identification of pollutants in domestic & industrial wastewater

Objective 2: Construction of a Pilot wetland system for treatment of wastewater.

Objective 3: Identification of suitable Phytoremediation species for WWT.

Objective 4: Comparative analysis of species for WWT.

Objective 5: Assessing the feasibility of pilot study at large scales.

#### A. Designing of Mesocosm

The design criteria's for the construction of microcosm or the sand filtration pot will consists of gravel (10cm) at the bottom, then sand (10cm) above it. Finally 10 cm of wastewater above the sand layer. A space of another 10 cm below the pot lip should be kept for aeration purpose and space be left for efficient plant growth. The height of the microcosm should be approximately 45-50 cm and the diameter be 36 cm. A gradient level of approximately 30° slope is kept to facilitate flowing of wastewater [7]. Wetland component, the sand is used as a substrate for the growth of the species. It acts as a filtering media but due to clogging the efficiency is reduced [9]. The sand used should be passed through 2mm sieve for the specific size, best effluent flow rate and retention time [7]. The initial weight of the sand will be taken and oven dried at 110° C for 3 hrs. For the sand to be resistant it will be placed in 40% HCL for 24 hours and that sand particles will be used which does not loose 5% of its weight [38]. Gravel acts as a filtering media as well as provides adsorption sites for removal of phosphorus. The plant species offers resistance to the flow of wastewater and increases the retention time. It also facilitates the settling of suspended solids and improves the conductance of water through the soil media as root grows. Further it transports oxygen to the deeper layers of the media and assists in oxidation and precipitation of heavy metals in the root surface. Approximately 30-45 days

would be needed for the plants to adapt to the new environment [7]. Four types of wastewater will be taken i.e hospital WW, domestic WW, mining WW and industrial WW. Each of the sample will be tested by monoculture, mixed culture and mixed culture with earthworms. A control will be kept for each four samples. The potential of phytoremediation will be tested taking into consideration the monoculture and comparing it with the mixed culture of species. The microcosm with high removal efficiency will then be compared with the microcosm containing mixed culture with the earthworms The use of earthworms would reduce the production of sludge on the surface thereby reducing clogging [7]. This will indicate the benefit of using earthworms into the CW. The parameters that will be considered are heavy metals like Fe, Mn, Zn, Cu etc. [7], dissolved oxygen (DO), total nitrogen (TN), biochemical oxygen demand (BOD) [39], nitrogen (NH<sub>4</sub> - N), nitrate, chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS) and total solids (TS). The samples of both influent and effluent will be analysed according to Standard Methods for the Examination of Water and Wastewater [8] and the removal efficiency will be calculated. The species as well as design approach of constructed wetland in treating wastewaters to meet the regulatory discharge limits. Based on the results the feasibility of the pilot study can be recommended for study at large scale.

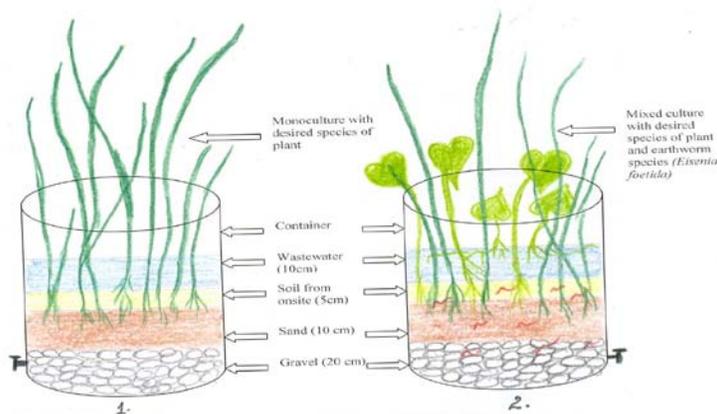


Fig 1: DESIGNING OF MESOCOSM 1. Monoculture setup 2. Mixed culture with Earthworm species



Fig 2: EXPERIMENTAL MESOCOSM SETUP



Fig 3 : *Typha sp.* SELECTED FOR THE EXPERIMENTATION

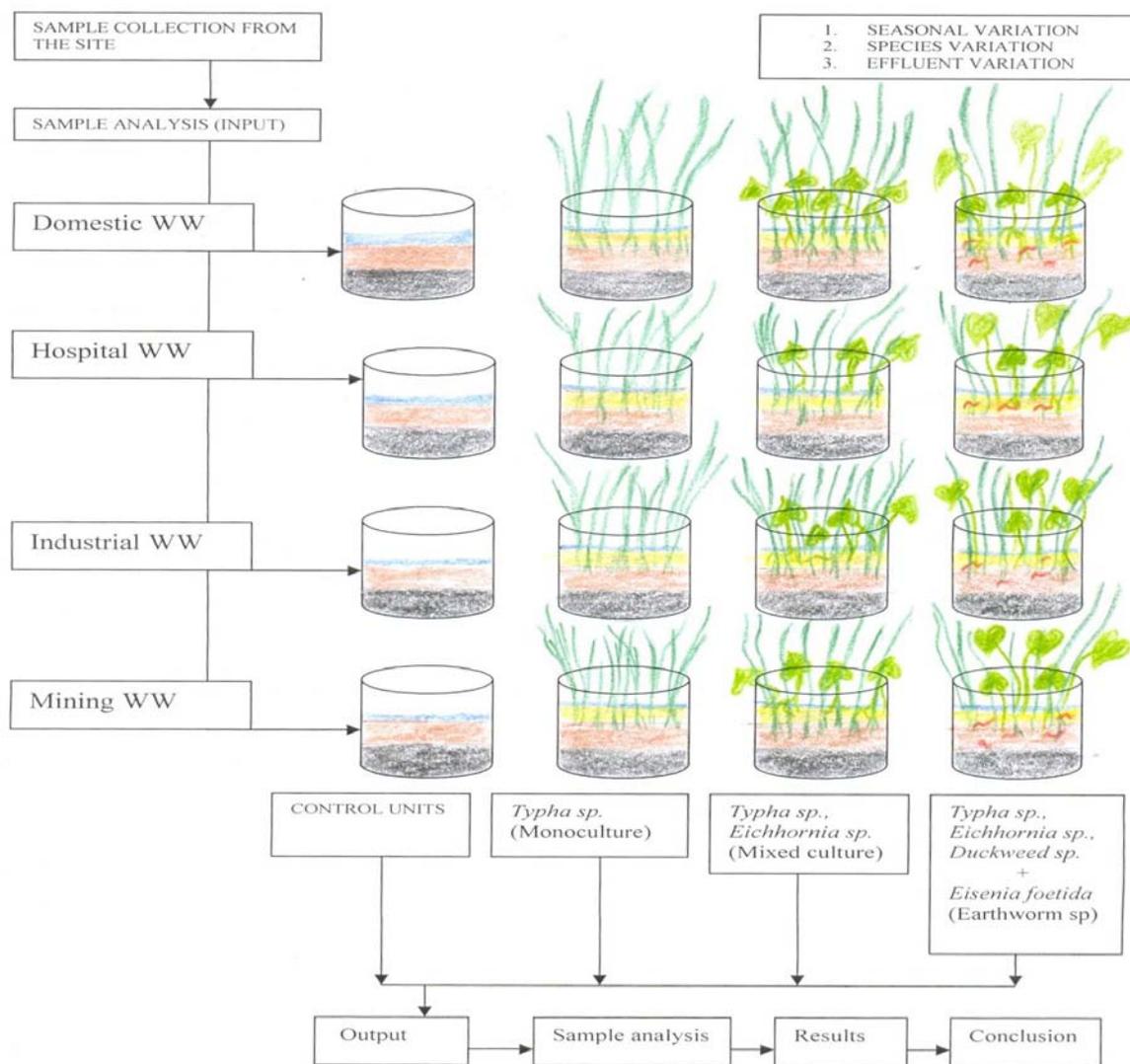


Fig 4: METHODOLOGY FOR THE ONGOING EXPERIMENT

IV. CONCLUSION

When compared to traditional sewage treatment methods, 'green technologies' are more appropriate for water clean up because they are responsible for decomposing organic pollutants to non-toxic low molecular substances which can easily be degraded

by microorganisms. This technology does not introduce any additional chemical substances into the environment (solvents, alkali, PEG). They are

relatively easy to manage and they can be easily adopted to the local needs. The best application is that they are able to remove several pollutants which are in combination.

The constructed wetlands (CWs) are considered as low cost alternatives for treating municipal, industrial and agricultural wastewater. The naturalized (decentralized) treatment system has a great potential for wastewater treatment and resource recovery. Therefore they are used for nutrient removal from water bodies and eutrophic lakes.

A number of problems can be solved by constructed wetland like denitrification, adsorption of ammonia,

metal ions, heavy metals, pesticides, phosphorus compounds, removal of pathogens, uptake of toxic substances as well as decomposition of biodegradable organic matter and toxic organic compounds. The plant species which are native can be used for recycling of water in the water bodies. The concentration of contaminants should not be in excess to ensure that they do not affect the growth rate of the plant species as excess may cause toxicity. The basic advantage is that it uses a natural process, simple in construction, improves water quality as well as recycling of water. Apart from that it uses local materials and plant species and no electricity is required. Thus it also contributes to conservation of energy. The only disadvantage is that it requires regular maintenance, certain life span and its construction cost. They must be effectively managed if they are to continue to improve water quality. The present work will help in attaining National Water Mission of India, reuse of wastewater being generated. It will also identify the suitability of

locally available Aquatic species in WWT and can be implemented in Town Planning and Residential complexes

Hence, such systems will operate with reasonable input of resources, as they represent microcosms that stabilize themselves. Plant harvest, maintenance, and de-clogging are low input activities that require no specifically educated personnel. Public acceptance of green technologies is generally higher than that of industrial processes. The expected, excellent water quality will lead to additional consumer satisfaction, sustainability for future generations, contribute to recreation and ecoesthetics.

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