Chapter 2

LITERATURE SURVEY

2.1 Introduction

Nutrient induced pollution is less attended but a serious problem in most of the cities in India. There are 423 class I cities and 498 class II towns harboring population of 22.2 crores and generating about 26254 mld of wastewater of which only 7044 mld is treated. A large part of the domestic sewage is not even collected (CPCB, 2004). The untreated or partially treated wastewater joins water resources and cause nutrient induced pollution. Conventional mechanized waste water treatment plants require a large capital investment and demand high operation and maintenance (O/M) cost. Such treatment options may not suit developing country like India and is not a feasible option for a small waste producer. Conventional onsite treatment methods can be adopted but may not provide total solution for abatement of nutrient induced pollution. Therefore appropriate wastewater technologies are required so that the technology will be adopted, owned and operated at micro level. The Root Zone Treatment Systems (RZTS) may prove to be a viable alternative for treatment of domestic wastewater at household level for small wastewater producers.

In Germany, during the 1960s and 1970s water quality monitoring at some discharge sites promoted an awareness of the water purification potential of wetlands, which led in turn to deliberate efforts to exploit wetlands for water pollution treatment. The effectiveness of artificial ponds with wetland vegetation was studied as a method for treating municipal wastewater. The success of these investigations led to development of full-scale treatment wetlands, and research on Constructed Wetland Treatment Systems

(CWTS) for various types of wastewater (EPA, 2000). In early literature subsurface constructed wetland treatment systems (SSF CWTS) are reported as RZTS. They are also referred as Reed Bed Treatment Systems (RBTS) due to their characteristic use of Common Reed (*Phragmites Australis*) in horizontal subsurface treatment beds. However the RZTS can be brought under CWTS, the term which encompasses various methods based on use of aquatic plants with different flow configurations. CWTS have proved to be well suited for treating municipal wastewater, agricultural wastewater and runoff, industrial wastewater, storm water runoff from urban, suburban and rural areas. As a result the technology is widely accepted for domestic as well as industrial wastewater treatment in European countries. However the benefit of their experience is not taken in tropical country like India. As a result awareness of RZTS as a viable low cost treatment system for domestic wastewater is relatively poor in India.

In this context, the work done on RZTS in India and other countries is reviewed. In this review the term RZTS and CWTS is interchangeably used. Based on the literature review, scope and objective of the present work is defined. The kinetics related review is separately taken in Chapter- 4.

2.2 Review of Root Zone Treatment Systems (RZTS) in India

In India, so far there have only been a few isolated laboratory and pilot scale experiments to study the performance RZTS. However state and central pollution control boards in India have taken good deal of interest in research and application of RZTS recently and have established pilot scale RZTS at Rajasthan (1995), Tamil Nadu (1998), Chennai (1999), Mother Dairy, Delhi (2000), Punjab (2002) and Haridwar (2004) under various development programs in collaboration with European countries. The objective of such projects is to assess the efficiency of RZTS for treatment of domestic wastewater and polishing of treated wastewater under Indian condition and to optimize the system parameters. In addition to this a few scientists are involved in research for better understanding of the technology. A few of the cases are recited as follows.

Juwarkar et al., (1995) are the pioneer group who studied potential applicability of constructed wetlands to treat domestic wastewater in India. The preliminary studies dealt with constructed wetland of 0.1256 sq.m. area consisting of emergent macrophytes *Typha*

Latifolia and *Phragmites Carca* grown in mixture of 30% soil and 70% sand as filter bed material. The hydraulic loadings were maintained to be 5cm/day. This unit reported removal efficiencies of 78-91%, 65-73% and 20-25% for BOD, TN and TP respectively. Based on preliminary studies India's first CWTS, a horizontal flow pilot scale subsurface system of 90m x 30m size, has been constructed at Sainik school, Bhubaneshwar, Orissa to treat part of the generated wastewater from the school in 1994. The RZTS treats 180-200 cu.m. wastewater to remove 67-90% BOD and 58-63% nitrogen. According to the authors CWTS is efficient and economically viable treatment option.

Billore et al., (1999) have installed a pilot scale RZ system to study the performance in treating the wastewater from small community in Ujjain, Madhya Pradesh in 1997. This plant has been reported to achieve removal efficiencies of 65%, 78%, and 60% for BOD, TSS and TN respectively. The system is not essentially aimed at nutrient removal studies.

Baetens, (2000) has taken overview of various pilot RZTS constructed during 1995-1998 at Auroville (India) under European Union funded project on Decentralized Wastewater Systems, (DEWATS). For a certain plant constructed for Samasti community with 20 people a RZTS has been designed to treat septic tank effluent. The plant species are *Arundo Donax* grown in filter media of granite pebbles. He observed 91% COD removal and 24% TKN removal for design capacity of 4 cu.m./day. For another CWTS with design capacity of 10 cu.m./day and pretreatment using imhoff tanks they could obtain 64% TKN removal. In other plant with baffle reactors pretreatment, with *Canna Indica* grown in pebbles covered with sand there was no removal of TKN but addition. P - removal performance was not studied under the scope of his work. The project is not essentially aimed at nutrients removal but organic and bacterial reduction.

Schindler et al., (2003) designed and commissioned two pilot RZTS under the German technical cooperation program for the treatment of domestic wastewater at Anna University, Chennai in 2000. They developed preliminary design criteria based on their earlier experience with RZTS operated in Europe. They predicted that with the tropical conditions of India 10% faster reaction rates can be achieved.

CPCB, (2004) has taken up another technology assessment program at Sewage Treatment Plant (STP), Jagjitpur, Haridwar. The wastewater is treated by SSF RZTS. Further, the treated wastewater is polished in a similar RZTS. In both these systems, sand from the river Ganga is used as bed material and planted with *Phragmites Karaka.* The performance of the bed has been tested at various hydraulic and organic loading with different hydraulic retention time. The RZTS removed 10%- 59% TKN, 8%-98% BOD and 11%-29% TP during the studies.

The potential of CWTS for nutrient removal is encouraging but its overall adaptability in India is minimal. The RZTS technology has entered in India but still is in much of its infancy stage. Most of the studies conducted in India are related with pilot scale plants. Though there are few plants working as full fledged STP e.g. Bhopal, Madhya Pradesh, and few as polishing unit e.g. Chennai, Tamil Nadu, the results are not well documented and even nutrient removal aspect not seems to be covered to the great extent. However potential of this technique for nutrients removal is better exploited in other countries as reviewed in following citations.

2.3 Review of Root Zone Treatment Systems (RZTS) in other Countries

In contrast to the apathetic scenario of usage of this technique in India, western countries seem to have made many advances in this technology so to make it viable option for domestic and industrial wastewater treatment.

Winter and Kickuth, (1985) emphasized proper dimensioning of RZ system and selection of soil components to achieve reliable performance. They claimed 80 - 90% N - removal and 98% of P – removal in their soil and plant based RZTS. The N - removal rate was increasing with purification distance of their plant set up. They have not revealed specific configuration they adopted for this removal to occur but have suggested dominance of denitrification and less contribution of plants and sedimentation reactions in N - removal. The elimination of phosphates can be achieved by employing correct combination of soil composition such as iron, aluminium, calcium, magnesium and clay minerals.

Cooper, (1990) has suggested the use of *phragmites* species grown in gravel or soil bed media for RZTS, but not to use these systems for P removal. In his guide lines it is

15065

mentioned that N fixation on clay particles does not occur to noticeable extent. The harvesting of plant biomass will contribute less than 5 % N removal. According to the authors special system design is essential for nitrification and denitrification to occur. However in subsequent studies Cooper and Green, (1995) developed various configurations which could be accepted for nitrification with pot-grown *phragmites australis* in gravel-based RZ systems to avoid overland flow instead of soil-based horizontal-flow systems.

Rogers et al., (1990) report plant uptake to be main mechanism in nutrient removal and represents a long term irreversible mechanism in batch loaded bucket systems.

Haberl and Perfler, (1991) used pilot scale horizontal flow formats and their findings indicated that plant uptake was not a significant pathway in nutrient removal.

Vymazal, (1995) reported experience of RZTS employing *phragmites australis, canary grass, American mannagrass, carpet bent grass, meadow fox tail* grown in filtration bed media of a wide range of sand, gravel and their mixtures to treat domestic and municipal sewage. The designed flow ranges from 0.6 m^3/day to 248 m^3/day. He suggested that the removal of nutrients is lower and further investigation is needed to increase nitrogen removal.

Hiley, (1995) conducted a study to develop design criteria for sewage treatment using RZTS. He suggests ammonia removal by plant uptake or by direct loss to atmosphere but with rare chance of oxidization of ammonia to nitrate in the RZTS designed for BOD removal. According to him ammonia removal in RZTS is possible if large land area is provided and BOD falls below 20 mg/L. Nitrate removal depends upon absence of oxygen and good degree of contact between wastewater and soil. P - accumulation is possible in plants and sediments till both are saturated. Saturated sediments would have to be replaced to restore P removal. He further suggests specialized P treatment stage before or after the RZTS to minimize expense of maintenance.

Li and Jiang, (1995) reported 29% – 83% N removal and 55% - 86% P removal based on their studies conducted with *Phragmites Australis* and hydraulic loading of 2-20 cm/day in China. They have not discussed probable mechanism but claim that wetland systems constructed on saline alkali soil can effectively improve under ground water quality. Hong and Weiran (1995) could obtain 60% to 90% TN, 62%-92% NH_4-N removal rates during winter operations even at temperature range of -2^0 to -4^0 C in their study in north China consistently for two years at yearly hydraulic loading rate of 14-20m.

Mahelum, (1995) had used RZTS in combination with aerated lagoon to treat landfill leachate. The study shows that 60 to 95% removal of N and P in combined treatment system even at extreme cold temperatures. The filter size adopted was 13m x 25m x 0.9m and consists of light expanded clay aggregate, LECA, 10-20mm size covered with 10cm washed gravel. The wetlands units were planted with *Phragmites Australis, Typha sp.* and *Scirpus Lacustris*. The wetland units were designed to treat loading rate of 50 m^3/day with retention time of five days. The study was carried out in Esval treatment park, Oslo, with mean air temperature of minus 7^0 C and annual rain fall of 800mm. He has also suggested that, full treatment performance can not be had until vegetation is established which may take couple of years.

Breen and Chick, (1995) points out that the main water body avoids the dense root zone in RZTS and passes through the deeper gravel zone untreated and the plant uptake is considered as a minor process in nutrient removal.

Zurayk et al., (1997) studied three pilot scale systems planted with *Phragmites Australis, Cattail*, and *water hyacinth* to know the role of the soil matrix in phosphorus (P) removal over a period of five months. They found that phosphorus removal was superior in the soil-based systems with a mean P reduction from the influent concentration (24 mg/L) of 80% compared with 54% in the soil less bed. Recycling the effluent into the system in order to increase the detention time did not contribute to improving removal, except in the soil less bed. According to them P removal in the soil-based systems is rapid, and an equilibrium value may be reached beyond which no further removal is possible. The effect of a lime amendment on the improvement of P removal was also studied in batch tests. The results suggest that P removal from wastewater can be greatly enhanced by the addition of small amounts of lime to the soil substrate.

Maschinski, (1999) carried out his studies on three RZTS cells in series using 16 previously untested native Arizona plants. The TKN removal found to be 73%. He observed that a combined nitrification/denitrification process is active in the system. After 9 months of operation, he found nitrification rates exceeding denitrification rates and that the wetland cells are aerobic.

Cottingham et al., (1999) assessed the hypothesis that increasing available oxygen by aeration of the wastewater in the treatment beds increases nitrification and nitrogen removal rates. They used two pilot scale constructed wetlands (30m x 5m), one planted with *Phragmites Australis* and the other serving as an unplanted control to treat primary domestic sewage. Prior to aeration. the influent nitrogen load in the wastewater passing through the beds was reduced by approximately 45% and 10% in the planted and control beds respectively. The aeration of the wastewater results in nitrogen removal of 51% and 20% for the planted and control beds respectively. High rates of nitrification were recorded for the planted bed with aeration, but removal of nitrogen by denitrification was limited, because of the absence of a suitable carbon source. High nitrification rates were not recorded in the unplanted control bed.

Del Bubba et al., (2000) investigated nitrogen removal in a pilot-scale RZTS, planted with *Phragmites Australis* and receiving domestic wastewaters for two years. They found that nitrification and denitrification simultaneously occurred in this system, showing the presence of both aerobic and anaerobic sites.

Drizo et al., (2000) investigated ammonium distributions in a pilot-scale RZTS with *Phragmites Australis* and shale as bed medium. The system was set up in a greenhouse, and comprised of four tanks with and four tanks without *Phragmites Australis.* In the planted systems, NH_4^+-N concentrations were low at all depths throughout their length. Generally, NH_4^+-N concentrations decreased exponentially along transect of tank inlet to the outlet. NH_4^+-N in the unplanted systems was relatively high throughout the period of investigation. In both planted and unplanted tanks, NO_3^- N concentrations were very low at the inlets and increased only slightly towards the outlets. Although the presence of *Phragmites Australis* had a significant effect on N concentrations at all depths and along the length of the tanks, the nutrient distribution followed the same trend as in unplanted tanks.

Arias et al., (2001) evaluated the P-removal capacities of different sands for use as media in RZTS. The P – removal capacities were evaluated in short term isotherm batch experiments as well as percolation experiments in absence of plant, mimicking the P-loading conditions in RZTS. The P- removal capacity of the sands of different geographical origin varied considerably and the suitability of sands for use as media in RZTS differs. The P removal capacity of some sands will be used up after only a few months whereas that of others will persist for a much longer time. It was suggested that a quick method for screening of potential media for P - removal is to perform isotherm batch experiments.

Brix et al., (2001) conducted various experiments for media selection for sustainable P removal in RZTS. The P- binding capacities of Light Expanded Clay Aggregate (LECA), crushed marble, diatomaceous earth, vermiculite and calcite media were tested. Particularly calcite and crushed marble were found to have high P-binding capacities. It is suggested that mixing one of these materials into the sand or gravel medium can significantly enhance the P-sorption capacity of the bed medium in RZTS.

Davison, et al., (2001) summarize the results of studies on four RZTS. The RZTS with gravel media were planted with *Phragmites Australis* and were subjected to a variety of effluent types. N removal efficiency observed to be 38% to 66% and that of P was 42% to 70%. Treatment performance (particularly for TIN) was found to be negatively correlated with rainfall during their study. They also claim that the system saturates after eight years operation and further P removal is not possible. Occasionally P concentration may exceed their inlet concentration after this period.

Wallace, (2002) reports that, most of the standard wetland systems do not supply enough oxygen to allow nitrification to occur. The systems are well suited for denitrification to occur because of predominance of reducing environment. He suggested use of cyclic fill and drain systems, advanced wetlands to enhance oxygen transfer, vertical flow wetlands, and paired vertical/subsurface flow systems for effective N removal.

Arias et al., (2003) found RZTS unsuitable for P-removal. According to them the only sustainable process for P removal is binding to the bed medium as plant uptake can be neglected in long term. Even if a medium of high binding capacity is selected its binding capacity will be used up after a few years.

Bayley et al., (2003) studied influence of depth, HRT and pre nitrification on nitrogen removal from domestic effluent using RZTS planted with *Phragmites Australis* in 10mm diameter gravel. They achieved 58% total nitrogen (TN) removal under the HLR of 22mm/day and HRT of 10.5 days. They could also notice varied rates of nitrification and denitrification along the depth of the reactor bed. The TN concentration found to decline steadily in all layers up to HRT of 8.7 days.

Browning and Greenway, (2003) investigated suitability of *Baumea, Carex, Philydrum* and *Schoenoplectus*, native species in combination of 5 to 20 mm gravel for subsurface constructed wetlands in Brisbane, Australia. They used pilot scale system receiving secondary treated effluent at HLR of 12 cm/day. The field trial has shown that *Carex* in combination with 5mm new gravel is the most suitable species of the four trialed accounting 11% of N removal and 3% of P removal, for use in RZTS.

Picard et al., (2005) investigated the seasonal efficiency of wetland macrophytes to reduce soil leachate concentrations of TN and TP in experimental RZTS (microcosm). Each microcosm contained one of six vegetation treatments: unplanted, planted with one of four species (*Carex lacustris, Scirpus validus, Phalaris arundinacea* and *Typha latifolia*) in monoculture or planted with an equal abundance of all four species. Microcosms exhibited a typical pattern of seasonal nutrient removal with higher removal rates in the growing season and lower rates in the winter months. In general, planted microcosms outperformed unplanted microcosms. Among the plant treatments, *Carex lacustris* was the least efficient. The four remaining plant treatments removed an equivalent amount of nutrients.

Zhang et al., (2006) conducted glasshouse experiment to test the feasibility of using ornamental wetland species in constructed wetlands to remove nutrients (N and P) from secondary treated municipal wastewater and the potential of different species in mixculture. Ten emergent wetland plants, including six ornamental species: *Canna indica, Lythrum sp., Alocasia macrorrhiza, Zantedeschia aethiopicia, Iris louisiana, Zantedeschia sp.*, and four native rush species: *Carex tereticaulis, Baumea juncea, Baumea articulata* and

Schoenoplectus validus were planted in microcosm and fed a synthetic wastewater solution in concentrations similar to the secondary treated municipal wastewater. Significant differences among species in accumulations of N and P were detected in both above- and below-ground tissues, with highest being in *Alocasia macrorrhiza*. In addition, significant differences of pH and dissolved oxygen (DO) were found in the effluents. The highest pH was recorded in the effluent from microcosm containing *Schoenoplectus validus* and the lowest in the effluent from microcosm with *Canna indica*. The highest DO was also found in the effluent from microcosm containing *Canna indica*. Nonetheless, it was suggested that *Schoenoplectus validus* and *Canna indica* might be two suitable candidate species to test in mixed culture in the constructed wetland for more efficient use and removal of both N and P from the wastewater.

2.4 Discussion

It can be seen from this literature review that as far as the usage of RZTS in Indian conditions is concerned, India lags behind by 25 years when compared to western countries. The technology was introduced during 1993-94 and not yet fully established. However on account of experience of other countries RZTS seems to be an attractive option for nutrient removal from domestic wastewater. In this context many researchers, both in India and abroad, have been working on this technology to understand the process and amend such systems for its wide acceptance. But there is considerable variation among the conclusions drawn. The nutrients removal performance ranges from negative to greater than 90% depending on locality, season and designed configuration. The sizes of RZTS as well as plant and media configuration employed by the researchers seem to affect the conclusion either way. e.g. Winter and Kickuth (1985) reported 98% P removal in their plant and soil system, whereas Cooper, et al. (1990); Arias, et al. (2003) found RZTS to be unsuitable for P removal. According to Winter and Kickuth (1985) and Arias, et al. (2003) plant uptake is negligible but Rogers et al., (1990) reports plant uptake to be main removal process. Armstrong, et al. (1990) found oxygenated zone in 6-8 weeks at rhizosphere of *Phragmites Australis* whereas according to Hiley, (1995) and Wallace, (2002), plants do not provide oxygen in rhizosphere. Maehlum, (1995) reported 60-90% removal at 800mm rainfall whereas Davison et al., (2001), found wetland performance negatively correlated with rainfall. Though such reports are site specific and based on individual's experience, in the absence of comprehensive widely accepted data, the available information leads to misinterpretation and may hamper overall acceptance of this technology.

The performance standards developed in other countries may not be applicable to India for the development of RZTS as climatic conditions, wastewater composition, treatment process and effluent standards are different. The technology should not be taken as "Black Box" approach as the nutrient removal reactions are dependent upon temperature, pH and oxygen availability. The RZTS performance may also differ according to filter media characteristics (Arias et al., 2001), plant uptake (Rogers, et al. 1990), plant growth and their ability to develop microbial colonies on root surface and in rhizosphere (Ottova et al., 1997; Brix, 1996; Abbasi, 2001). In this context, much attention should be paid to individual component of RZTS such as its individual plant specie, potential of media, and their combined mechanism for nutrient removal.

The RZTS are characterized by presence of wetland vegetation. The type of plant used in RZTS can be a key to the success of wastewater treatment. The literature review shows that *Phragmites Australis* is the most preferred one. In India also very recent experimental RZTS at Haridwar employs similar one (CPCB, 2004). However, each of the species may have different potential for nutrient removal depending upon their uptake, growth pattern, size of supporting bed material (Browning, 2003), oxygenation ability, nature of wastewater and season (Picard et al., 2004). Even individual specie can alter pH and dissolved oxygen level of the wastewater being treated (Zhang et al., 2006) which may considerably affect nutrient removal mechanism. In this context there is a necessity to identify wetland plants which would be compatible with selected bed material and be efficient for nutrient removal.

Variety of bed materials has been subsequently assessed as clogging problems were experienced with traditional soil bed media (Cooper, et al., 1990), giving consideration to short circuiting of flow patterns in between inlet and outlet structures, pond formations at intermediate levels, clogging of root zone etc. Many of the studies (Winter and Kickuth, 1985; Wathugala et al., 1987; Brix et al., 2001; Arias et al., 2001; Arias et al., 2003) also concentrated on selection of bed media based on their P sorption capacity. However compatibility of such materials with the growth of specific plant species has not been studied to a greater extent. Also the combined effect of media size and specific wetland specie on nutrient removal has not been studied extensively. Thus comparative data among different plant and media combinations under similar conditions is still sparse. It is obvious that size and surface nature of the media will offer different sites for adsorption and biofilm development. The growing roots will occupy different volume depending on porosity of the media. The dense root system may also interfere with designed flow path (Breen and Chick, 1995). The surface available for development of bacterial colonies by the roots will depend on their extent and may vary from plant to plant. The porosity of the media and occupancy of the roots will ultimately affect HRT. Thus every plant and media combination may have different treatment potential. In order to extract maximum treatment potential from RZTS plant and media combination is critical. Thus combination specific study is required to know treatment potential of RZTS better.

Further there is need to have an engineering insight in to the mechanism of pollutant removal in RZTS. In consideration to the nutrient removal mechanisms in RZTS, basic understanding of the role of each of its components in the removal is not much clear and there is no phenomenal consensus. The mechanism should obviously be different for nitrogen and phosphorus, and may also depend on site-specific variables such as RZTS configuration, wetland plant, bed media and hydraulics. In addition to these factors, climatic factors may also have substantial impacts on nutrient removals within constructed wetlands. If these factors are not taken into account, RZTS may prove to be unreliable or unpredictable system for nutrients removal. Thus it is necessary to evolve sound methodologies which will help for clear understanding of involved mechanism.

The design criteria and other parameters that affect system performance should be based on both laboratory and field studies with due consideration to economy and environmental impact assessment. Identification of nutrient inducing sources, establishment of full-fledged treatment plants, understanding the real performance in field conditions, deciding maintenance strategies and optimization of design configuration based on actual experience are few of the issues which will attract subsequent consideration to foster the technology.

RZTS have been used for domestic wastewater treatment in almost all regions of the world. But the constructed wetlands, technology as such is still in developing phase. In India though it may prove to be viable option for decentralized treatment its use is limited to only pilot scale studies. The nutrient removal aspects with this treatment option have not been studied to a greater extent. RZTS seems to be an attractive option for the abatement of nutrient induced pollution in India. On the background use of RZTS in other countries the acceptance and development of this technology is relatively poor in India. The relevant gap can be bridged if the ongoing technical research is directed to identification of wetland plants, supportive bed materials, their combination specific comparative performance under similar conditions and their associated mechanism for nutrients removal. The development strategy should give due consideration to the contributions of other countries so as to avoid unnecessary repetition of work which will in turn save undue expenses of time, money and efforts and help for the real acceptance of RZTS for Indian conditions.

2.5 Scope and Objectives of the Proposed Study

The present study is undertaken to have an engineering insight into the removal mechanisms responsible for nutrients in RZTS. The kinetics of nutrient removal in RZTS for domestic wastewater is another objective. This will be achieved through strategic investigations in various phases exploring the nutrient removal processes occurring within the Lab-scale and Field- scale models of RZTS. The study is essentially aimed at providing cheaper solution against reduction of pollution caused due to unsafe disposal of septic effluent by small waste producers. The usage of RZTS has shown wide variation in its performance. There have been contrasting conclusions drawn based on number of pilot scale and field scale studies on nutrient removal. Further, the relative dominance of mechanisms governing the nutrient removal has not been ascertained with certainty. The works carried out on nutrient removal are predominantly site specific in nature. The application of RZTS in India has not been widely practiced due to lack of established performance and design criteria under tropical conditions. Thus there is a scope to study potential of RZTS for nutrient removal in Indian conditions. It would also be useful to determine relative contribution of components for nutrient removal in RZTS. The plant and medium combination also plays an important role. If properly designed and applied, RZTS would be convenient, efficient and cost effective technique to mitigate nutrient induced pollution. In this context the study is organized with following objectives.

2.5.1 Identification of Desirable Combination of Macrophyte and Medium

1. To identify locally available wetland plants (Macrophytes) and assess their potential for nutrient removal in different media.
2. To develop RZ set up in various plant and media combinations and reference (in absence of plant) experimental set ups.
3. To study the growth rates of vegetation used.
4. To study nutrient removal efficiency for each of the combinations and to work out desirable combination giving better nutrient removal performance.

2.5.2 Laboratory Scale Study of *Typha Latifolia* and Stone Grit Combination

1. To develop laboratory scale RZTS and reference set up for the treatment of synthetic wastewater
2. To study combination specific performance of *Typha* plants in stone grit medium for nutrient removal in comparison with reference set up at different HRT
3. To study the dominant nutrient removal mechanisms within RZTS
4. To study nutrient uptake pattern of the plant at its different life phases and to define contribution of plant uptake in nutrient removal
5. To study contribution of stone grit media in nutrient removal

2.5.3 Field Scale Study of *Typha Latifolia* and Stone Grit Combination

1. To develop field scale RZTS and reference set up for the treatment of septic tank effluent.

2. To assess nutrient removal performance of the combination in practical situation in comparison with the reference set up.

3. To study influence of variable nutrient loadings on the performance of RZTS and occurrence of any other mechanism.

4. To have comparison of performance and mechanism observed in laboratory and field scale studies.

2.5.4 Kinetics of RZTS

1. To work out kinetics of nutrient removal based on lab scale study and to develop predictive model for assessing nutrient removal.

2. To assess validity of the model with field scale data.

2.5.5 Practical Application of Project Outcome

1. To design a typical treatment plant for a residential complex based on kinetic parameters worked out in the present study and to provide typical RZTS configuration details.

2.6 Organization of the Proposed Study

The proposed study outlined above is organized into five sections

1. Introduction
2. Literature Review
3. Results and Discussion
4. Reaction Kinetics
5. Conclusion

The introduction section discusses problem background related to nutrient induced pollution and current scenario of nutrient pollution control in urban and suburban environments of India. Emerging treatment methodologies for nutrient removal and theoretical concepts of Root Zone Treatment System (RZTS) are also discussed in this section. The use of RZTS technology for nutrient removal in India and other countries is separately reviewed in literature review section. The cited literature findings are discussed and the scope of present study is defined in the section. The third section deals with various methodologies adopted for experimental phases outlined in the scope of study. The results are also discussed in this section. The reaction kinetics for nutrient removal based on experimental work is defined in the 4th section. The applicability of potential models and estimation of reaction parameters for lumped and distributed model is also discussed in this section. The final section of the report outlines the conclusions drawn from the study and future scope of the work.

At the end bibliography of various references cited in this report is included.

The report contains two annexure.

- Annexure I contains a brief information of the macrophytes used in this study
- Annexure II contains typical constructional details of RZTS for nutrient removal from domestic wastewater