SYNOPSIS

Nutrient induced pollution is one of the major environmental concerns in India. It needs to be addressed on priority basis. Rapid urbanization and increased need of adequate sewerage facilities have made the task of municipal authorities difficult to handle this problem. In the absence of adequate sewerage facilities, the use of septic tank is inevitable. But it works inconsistently and generates septage which contains high contents of nutrients and other offensive contaminants. In India there are no strict regulatory norms imposed for septic tank installation, operation and effluent disposal practices. The unsafe effluent disposal practices pose risk to the public health and environment. The high concentration of nutrients in surface water causes eutrophication and degrades the habitat for fish and other aquatic organisms. Chronic consumption of high level nitrate causes blue baby syndrome and has carcinogenic and teratogenic effects. Phosphorus does not have direct relation with health problems but is obnoxious for its contribution to eutrophication and its interference with water treatment processes. There are reports suggesting increased levels of nitrates in ground water from various parts of India. However, there is still no amendment in tolerance limits for disposal of sewage for Indian conditions as far as Nitrogen (N) and Phosphorus (P) concentrations are concerned. The conventional treatment system does not remove nutrients. An advanced treatment option which can be implemented at household level to hinder nutrient induced pollution is not practical and may no be affordable. The treatment systems for nutrient removal should be cost effective and easy to operate and maintain. Root Zone Treatment Systems (RZTS) is an emergent treatment option to control nutrient induced pollution. But it is not adopted and assessed extensively for Indian conditions.

The RZTS, also known as subsurface constructed wetland treatment system, is typical engineered system, designed and operated on natural principles involving wetland vegetation, supporting bed medium and their associated microbial assemblage for the treatment of variety of wastewater. The worldwide usage of RZTS has shown ample 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 is limited to feasibility studies and seems to be not

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.

This study investigated the effectiveness of the RZTS for nutrient removal. It was focused to have engineering insight of the mechanisms responsible for nitrogen and phosphorus removal in RZTS in comparison with non planted reference reactor. Other objective of this study was to work out kinetics of nutrient removal from domestic wastewater in RZTS. The study consisted mainly four parts.

The first part of the study deals with identification of appropriate combination of plant and media for better nutrient removal in RZTS. In this study, performance evaluation of four native macrophytes viz. *Typha Latifolia, Canna Indica, Phragmitēs Australis* and *Colcacia Antiquorum* in combination with the bed media viz. stone grit, sand and plastic granules was carried out for nutrient removal. The typical experimental set up used for this study consisted of wastewater feeder tank, RZ reactor bed and effluent collection tank. The studies were conducted in up-flow mode of operation. In all twelve reactors were developed for various combinations of media and plants. All the reactors were planted with pre-developed root sections of same weight and same number of corns. In order to assess the performance of RZ reactor in absence of the wetland plants, three different reference reactors were also established for each medium. Both, RZTS reactor and reference reactor, were established in duplicate so as to know performance variation under similar working conditions. In order to assure proper bacterial growth, the reactors were fed with 100 ml of settled sewage initially. Thereafter, all the reactors were assessed for their performance using synthetic wastewater. The quality of the synthetic wastewater was maintained to be uniform for the entire study period of 90 days. Hydraulic retention time of 24 hours was maintained in all reactors. The height of plants during different periods of the study was recorded to determine growth rate parameters. All the bed media used in reference reactors had 43% to 55% efficiency for nutrient removal. Also, the use of these media in planted reactors found to support growth of all the macrophytes used in the study. The use of the plastic granules in reference reactor showed that its potential for nutrient removal is higher than that of stone grit and sand. However, in planted reactors it does not support growth of all kinds of macrophytes. Also, its individual removal potential was suppressed in combination with *Colcacia Antiquorum* and *Phragmites Australis*. The mineral content in

sand and stone grit media seems to be non extractable and did not have much contribution for nutrient removal by chemical precipitation. For all the media, physical parameters were dominant factors affecting nutrient removal. All the macrophytes viz. *Typha Latifolia, Colcacia Antiquorum, Canna Indica,* and *Phragmites Australis* had different growth and nitrogen removal rates in stone grit, sand and plastic granules under same environmental conditions. With the exception of plastic medium, the nutrient removal performance of all the RZTS combinations was found to be higher than that of reference reactors. Almost all combinations took 45 to 60 days to give steady performance of nutrient removal. *Colcacia Antiquorum* had highest growth rate of 0.016 d^{-1} in plastic granules. But the nitrogen removal rate by this plant was higher (1.3 d^{-1}) in sand medium. *Colcacia* with sand can be a potential combination. But the plant does not have dense lateral spread and may provide lesser surface area for bacterial attachment. *Canna Indica* has comparatively better growth rate (0.03 d^{-1}) in sand and stone grit medium. But the nitrogen removal rate by this plant was higher (1.6 d^{-1}) in sand medium. *Canna Indica,* which is an ornamental plant with soft tissues, was observed to be easily susceptible to diseases and insect attack. Hence this plant is not suitable for the usage in RZTS. The growth parameter of *Phragmites Australis* was found to be highest (0.029 d^{-1}) in stone grit medium. It performs better with sand bed medium and has N removal reaction rate parameter of 1.22 d^{-1}. Phragmites with stone grit can be a potential combination. This plant is reported to be very invasive. *Typha Latifolia* was better grown in stone grit medium having highest growth parameter of 0.034 d^{-1}. It has N removal reaction rate parameter of 1.27 d^{-1} and 1.39 d^{-1} in stone grit and plastic at 75 days after plantation respectively. Typha with stone grit and plastic can be a potential combination. But, the growth rate of this plant is small (0.02 d^{-1}) in plastic medium. The P removal performance of macrophyte and bed media combinations did not vary to very great extent in relation with macrophyte and media characteristics. For all the combinations P removal was found to be ranging in 42% to 48%. The RZTS created with random selection of aquatic plants or naturally colonizing plants with arbitrarily chosen media may not give desired performance. The selection of macrophyte and media combination characterized by higher nutrient removal in lab scale study would provide greater efficiency in actual condition. The growth rate and nutrient removal capabilities of the macrophytes are not related to each other. The combination of stone grit and *Typha* was chosen to be an appropriate combination based on high growth rate, adequate nutrient removal potential,

cost effectiveness, convenient operation and maintenance, local availability, easier plantation, non invasive nature and resistance to insects attack.

The second part deals with study of combination specific performance of *Typha Latifolia* in stone grit medium for nutrient removal. The dominant nutrient removal mechanisms within RZTS and nutrient uptake pattern of the plant at its different life phases were also studied. The experimental set up was designed in such a way that, the contributions of plant and medium in nutrient removal could be differentiated. To facilitate this, pilot experimental set up was constructed in a single unit having two identical compartments separated by feeding inlet chamber between them. One of the compartments was planted with known mass of *Typha* root sections in stone grit medium to act as RZ bed reactor. Other one was reference reactor having only stone grit medium with no vegetation. Both the reactors were fed with 100 ml of settled sewage initially. Thereafter, both the reactors were operated in batch mode using synthetic wastewater of uniform quality. The batch of synthetic wastewater of volume 50 liter was used in both the reactors. Before placing the next batch the synthetic wastewater present within the reactors was drained totally and filled with fresh batch. The period between plantation and fully grown vegetation with consistent performance of nutrient removal in the RZTS is designated as initial period. The period during which RZTS has fully grown vegetation and performing consistently for nutrient removal is designated as established period. The sampling was started for analyses with 7 days HRT in the beginning in order to know treatment potential of RZ bed during the initial period to its established period. After two months the RZ bed reactor had fully grown vegetation. After this, several batches each of 7.5 days duration were run for a total period of 60 days. The nutrient levels within the reactor beds were determined for HRT values in multiple of 1.5 days each. An average of the nutrient values obtained from the batch runs, were taken for assessing the performance of reactors at various HRT. The results obtained from this study indicated that, RZ bed created with combination of *Typha* and stone grit requires at least 45 days for reasonable performance. The initial period was characterized by inconsistent behavior, increased concentrations of TKN and P, small reduction in NH_4- N, small nutrient uptake by plants and dominance of denitrification over nitrification. However, this combination creates favorable condition for removal of nitrogen as the RZ bed becomes established. The evapotranspiration loss of the RZ bed was observed to be 3 cm/day (10% of inflow). In the established phase, the RZ bed

supports both nitrification as well as denitrification. The RZ bed gives more than 95% removal of TKN at HRT of 7.5 days. The NH_4 -N adsorbed around the particles of bed material was found to be 0 mg/gm, 0 .015 mg/gm, and 0.016 mg/gm of stone grit media at 0^{th}, 60^{th}, and 120^{th} days respectively. Though some removal was observed due to adsorption in initial 60 days, there is very small change in adsorption level over next 60 days. Thus, the negligible change in adsorbed NH_4 -N levels around particles indicates that adsorption phenomenon is not a dominant mechanism for NH_4 - N removal. The total nitrogen uptake of *Typha* plants was found to be 1176.11 kg/ha.year based on analysis of dry biomass of plant components. The nitrogen storage of *Typha* plant in roots is slightly higher (38%) as compared to leaf (31%) and stem (31%). Based on the mass balance studies, the contribution of plant uptake of *Typha* plants, denitrification and adsorption for nitrogen removal was worked out to be 74%, 23% and 3% respectively. Thus, plant uptake was found to be dominant in total removal. The contribution of volatilization (pH<7.5) and cation exchange adsorption for N removal was found to be negligible in the matured RZ bed. The P sorption capacity of stone grit media is 0.02 mg/gm of the media and was used up within initial four months. The phosphorus uptake of *Typha* plant was worked out to be 147.89 kg/ha.year based on the analysis of dry biomass of plant components. Further component wise analysis showed that, the root, stem and leaves contribute 40%, 36% and 24% for P- storage respectively. From this it is deduced that, only *Typha* uptake causes about 24% of P-removal. As compared to N-storage values, these P values are less indicating lesser P-demand of *Typha* for its growth.

In the third part of this study, the performance of *Typha Latifolia* in combination of stone grit medium, was assessed in field conditions for the treatment of septic tank effluent. The experimental set up was designed so as to know the contributions of plant and medium in nutrient removal. The set-up consists of two compartments having size of 6.0 x 0.6 x 0.90 m with 30cm free board. The compartments were constructed side by side so as to establish total flow path of length 6m.The initial end was provided with inlet chamber of size 0.45 x 0.60 x 0.90 m with inlet structure at bottom end so as to assure uniform distribution of the flow across the section. A 15 cm diameter outlet pipe was established at the other end so that wastewater level will be maintained below the top surface of reactor bed. The structure was of burnt brick masonry and plastered to effect waterproof. The bottom of the bed was provided with 1% slope. This served as RZ bed whereas reference

reactor was mirror image on the other side. One feeder tank 250 liter PVC drum was connected with both RZ and reference reactor through 2.5 cm diameter GI pipes of same lengths and equipped with control valves. The RZ bed was allowed to be established with full grown plants by feeding the settled septic tank effluent once in a day for one hour over the period of three months. The reference reactor was also subjected to similar loading condition as that of RZ reactor. Both the reactors were run as batch type reactors thereafter. The several batches of duration ranging from 1.5 day to 7.5 days in multiple of 1.5 days were run. Both the reactors were subjected to varied nutrient loadings. The average of results obtained from these batches for various parameters were considered for further analysis. The study showed that, the growth of *Typha* plants with the feed of septic tank effluent is more proliferating as compared to that with feed of synthetic wastewater. But performance for nitrogen removal by the field scale RZ bed was lower as compared to lab scale RZ bed. However, the mechanisms for nutrient removal in field scale RZ bed were similar to lab scale RZ bed. In addition to adsorption, nitrification, denitrification and plant uptake, removal of organic N is possible due to filtration and subsequent sedimentation of solids entering in the RZ bed. The N removal decreases with increase in N loading rate. The maximum N loading rate was found to be 20 kg/ha.d to achieve 40% to 55% N removal. The study also showed that there was not significant increase in N removal beyond a HRT of 4.5 days. The nitrification was found to be significant beyond 3 days of HRT. But it improves with time and was higher during HRT of 4.5 to 6 days. In field conditions though simultaneous nitrification and denitrification is possible, the rate of denitrification is low in the RZ bed. The rate of denitrification is assumed to be retarded due to complex form of carbon in the RZ bed. The P removal in field scale RZ bed was found to be higher than that in lab-scale RZ bed. This is attributed to, proliferate growth of *Typha* in the field scale RZ bed as compared that in lab scale bed, presence of particulate P in the septic tank effluent and its subsequent filtration and sedimentation. The removal of P goes on decreasing with increase in its loading. It was inferred that the RZ bed can be loaded up to 15 kg/ha.d to achieve 20% to 55% of P removal. Also there was not significant change in P removal beyond HRT of 6 days.

The design criteria developed for RZTS in earlier studies is based on thumb rules, first order models and Monod type kinetics. These models are system/environment specific. Thus it would be important to test other reaction kinetic models to assess their usefulness

and applicability. The modeling of RZTS is carried out in the present study by incorporating the reaction kinetics expressions describing the phenomenon occurring within the system. The models developed are based on lumped parameter and distributed parameter approaches using the data obtained from laboratory scale study. The processes considered in the distributed parameter model for nitrogen transformations are ammonification, nitrification, plant uptake and denitrification. The reaction rate parameters involved in the adopted models were estimated using non linear least square analysis. The lumped parameter approach showed that the nutrient concentrations are better predicted by plug flow and complete mix conditions in the planted and reference reactors respectively. The reaction rates for the removal of nitrogen forms are higher by 2 to 2.5 times in planted reactor than the reference reactor. The distributed model results indicated that the plant uptake rate for nitrate removal was found to be higher than the denitrification. The nitrification and plant uptake are equally dominant for the removal of ammonia nitrogen. The denitrification rates are found to be more than the nitrification rates in the reference reactor. The simulated values of ammonia nitrogen, TKN and total nitrogen for field scale experiments by lumped parameter and distributed parameter models differ by a smaller extent. But the relative contributions by the various processes for nitrogen removal can be established using the distributed parameter model. The organic and nitrate nitrogen simulations by distributed model are relatively better. However, there is a variation between the simulated and field observed values for both the reactors and it is attributed to the characteristics of wastewater. The reaction rates are higher in laboratory scale studies than the field scale study. The developed simulation model can be used as a RZTS planning and design tool for the effective control and treatment of nutrient induced pollution.