# Development and Demonstration of Vertical Flow Constructed Wetlands as Decentralized Wastewater Treatment System in Tropical Climate

**THESIS**

Submitted in partial fulfillment
of the requirements for the degree of

**DOCTOR OF PHILOSOPHY**

By

**Mr. Anant Yadav**

Under the Supervision of

**Prof. Srikanth Mutnuri**

and Co-Supervision of

**Prof. Florent Chazarenc**

**BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI**

**2019**

**Table of Contents**

# 1. Abstract

Wastewater treatment is one of the most severe issues in the country. Wastewater is generated from various sources that enter the sewage system, such as households, schools, hospitals, companies, restaurants, etc. It ends up in rivers without appropriate treatment from the sewage treatment system, causing issues such as waterborne diseases, eutrophication of water bodies, i.e. reducing the quantity of oxygen in water and disturbing the ecology of the water system. The number of treatment facilities in the country is very low compared to the amount of wastewater produced every day. Different sewage sources produce different quality of wastewater and treatment systems should be designed based on the quality of the sewage generated. Most wastewater treatment plants (STPs) in India are based on conventional designs with the same treatment method for all kinds of wastewater generated from distinct sources.

All states in India currently generate 61948 MLD of wastewater and the wastewater treatment facility installed is only 23277 MLD, showing a huge gap of 38671 MLD. There are only 522 operating plants in the country out of a total of 816 treatment plants, suggesting a treatment plant for only 18883.2 MLD. Most of the plants operating in the county are under construction or not maintained due to the low supply of resources, the lack of skilled staff at the site, which further degrades the quality of wastewater dumped in the open setting. Decentralized wastewater treatment scheme such as Constructed wetlands could be a useful wastewater treatment alternative. Constructed wetland system requires very low maintenance and operating costs and can also be operated without any skilled worker. The primary goal of the thesis was to develop a system that could operate with all the different wastewater.

The second chapter of the thesis aims at identifying suitable plants for the wetland. Plants play a very significant role in the wetlands, they need to be selected very carefully. Four plants were selected for the study: *Ageratum conyzoides, Typha latifolia, Canna indica* and *Hybrid Napier spp*. They were selected and compared on the basis of their bio-methane potential. The volume of biogas produced and the percentage of methane in the biogas generated were estimated by water displacement method and gas chromatography respectively. The cumulative volume of biogas generated in 100 ml batch rectors by *Hybrid Napier spp., Ageratum conyzoides, Canna indica* and *Typha latifolia* was 187 ml (54.59 percent methane) at 4gVS / l, 166.5 ml (62.24 percent methane) at 4gVS / l, 166.5 ml (63.53 percent methane) at 3gVS / l and 157 ml (62.22 percent methane) at 4gVS / l, respectively. Despite *Canna indica's* low biochemical methane potential (BMP), it has been shown to be appropriate for both wastewater treatment and anaerobic digestion, considering factors such as effectiveness in wastewater treatment, simple

establishment, high growth rate, ease of harvesting. In 200 liters of drums, a vertical flow constructed wetland was set up at the campus to comprehend the working and select an appropriate plant for single-household reactor. *Typha angustata* and *Canna indica's* nutrient removal efficiency and Biochemical Methane Potential (BMP) were studied by 200L drum experiments for the constructed wetlands. *Typha angustata* was chosen for planting in the single household two-stage vertical flow wetland system (VFCW) as it is common in Goa's natural wetlands, as well as having high BMP efficiency than *Canna indica*. The system was operated for a period of two years at two different hydraulic loading rates. The nutrient removal efficiency of the VFCW pilot scale was monitored at two Hydraulic Loading Rate (HLR) i.e. 0.150 m / day and 0.225 m / day. Since the treatment capacity of the systems was satisfactory at a higher load rate, the overall footprint of the system was reduced from 1.5 m2 per person to 0.79 m2 per person.

The 4$^{th}$ chapter of the thesis deals with the removal of phosphorus; the aim of the study was to select a suitable reactive material that can be used for scrubbing phosphorus from treated waste water. The removal of phosphorus primarily occurs in vertical wetlands through substratum adsorption, to a lesser extent plant uptake and incorporation into organic matter can remove a fraction of Phosphorus, but this is not sustainable. Seven different materials have been analyzed for their ability to remove phosphorus from synthetic waste water. Steel slag (SSGS), kiln ash (KAS), bauxite ore (BOX), bentonite clay (BNC) and fire (Red) brick (RB) were obtained from India. Bovec Nervac (BON) and Binvec Pivel (BOP) are obtained from drinking water treatment facilities in France. It was discovered that BON and BOP are very efficient substrate for phosphorus removal, having a phosphorus removal capacity of 7.6 mgP/g and 10 mgP/g respectively.

A two-stage vertical flow built wetland was set up at Dr K B Hedgewar School, Cujira, Bamboli, Panjim to comprehend the further functioning of wetland in different types of wastewater. School wastewater quality is very different from the campus raw sewage. The idea was to alter the hydraulic loading method and design of 2$^{nd}$ stage to increase system efficiency. The wetland's 1$^{st}$ phase was properly aerated and the aeration tubes were removed in the 2$^{nd}$ phase to create anaerobic conditions for denitrification. The system tested two different condition. The removal efficiency of COD, TKN, nitrate, nitrites, $NH_4$-N, and Phosphorus was around 89 %, 57 %, 38 %, 64 %, 62 % and 62 % respectively in the 1$^{st}$ set of experiments and in the 2$^{nd}$ set of experiment the removal efficiency of COD, TKN, Nitrate, Nitrites, $NH_4$-N, and Phosphorus was around 84 %, 64 %, 4 %, 46 %, 69 % and 63 % respectively. Both statistics indicate that the nitrification and denitrification rate of the system also decreased as the COD/N ratio decreased. This could be due to the increase in the effectiveness of ammonia nitrogen treatment. The effectiveness of phosphorus removal in both the test set was the same. It was found that the system's overall pollutant removal effectiveness was better in the first approach. Based on the outcomes acquired from the BITS pilot scale system and school wetland, a 500 $m^2$ wetland was constructed for the treatment of the water from Sal river at Margaon whole sale fish market. This developed as per the HLR of BITS campus VFCW and 2$^{nd}$ stage of the system was made anaerobic as per the school wetland. As the C/N ratio of the inlet wastewater (3.5) was very low for denitrification to happen. This could be increased by adding the wastewater from fish market which have COD (980 mg/L) and Nitrogen (TKN =117 m/L). This could be the future of the work.

## 2. Gaps in Existing research

CWs are popular systems which effectively treat different kinds of polluted water and are therefore sustainable environmentally friendly solutions. However, there is a need to understand the mechanisms (Organics, Nitrogen and Phosphorus Removal mechanism) occurring in wastewater treatment wetlands. Several CWs are in operational in India. Up to now, the design of wastewater treatment wetlands is very empirical. The objective of this work is to design vertical VFCW systems to answer a need by adapting this well-known technology to Indian requirements (effluent quality, climate, etc.). Although CWs are recognized as an excellent alternative for conventional wastewater treatment systems, their application in India has remained limited. Most of the CW systems designed in India were built at experimental scale, treating different kinds of wastewater (Juwarkar et al., 1995, Billore et al., 1999, Billore et al., 2001, Billore et al., 2002).

One of the major constraints to field-scale CW systems is the requirement of a relatively large footprint not always available but lower than what is expected for WSP (waste stabilization pond) ($10m^2$/Pe for a WSP, about 2-3 $m^2$ per PE for a VFCW). However, unlike traditional biological treatment systems, no specific guidelines exist for designing a CW system. Several key aspects including the selection of plant species, the hydraulic retention time, organic and hydraulic loading rates are not documented at all for India

## 3. Aims and objectives of the research work

The aim of this study was to develop a small-scale wastewater treatment solution in the Indian context and then to undertake the technology transfer of these processes to Indian companies for their commercialization. It was clear that according to the context, the treatment requirements might vary. Indeed, the needs and the financial means for wastewater treatment of a hotel in Goa, for example, might be very from those of a small village or a slum.

VFCW technology is considered as "Extensive" since it requires low energy input and no chemical addition for treatment. It also has the advantage of being one of the most cost-effective wastewater technologies in the market, which is easy to operate and reliable. VFCWs require a larger area than conventional extensive wastewater system but it can be more adaptable to small and medium-size villages.

One of the innovative aspects of this work is to optimize VFCWs to Indian specific sewage and climatic conditions and to develop a system which can treat wastewater from all the type of sources and effectively consider all the type of pollutants.

The four objective proposed the study:

- Experiments at laboratory scale and construction of the demonstration plant.
    - Initially lab experiments had been conducted to characterize the wastewater at different locations. The aim of this experimental work was to go deeper into specific problems, which still need further investigations before the implementation of pilot scale processes. One of the main parameter to study was the organic loading rate (OLR) to apply. The choice of the OLR was a very important parameter as it is used to calculate the volume of the tank. In this context, it was important to run experiments with different organic loading rates in order to study the influence of the OLR on different parameters, such as pollution removal efficiency, settleability of the sludge, excess sludge production etc.

- Demonstration plants construction (condominium/ small village / slum) follow up protocol implementation.
    - In parallel to the experimental work being done, pilot-scale platforms have been implemented. The platform was demonstrated inside the campus of BITS Pilani K.K.

Birla Goa campus so that they are field ready for a slum. The results of the laboratory experiments carried out were integrated before the final implementation of the pilots.

- Scientific investigations, treatment performances, and follow-up to validate systems under process conditions at the demonstration plants.
  - The pilot plants were operated for 1 year at field-scale to validate their design and operation. The reactors were fed with domestic wastewater pumped from the receiving tank of the existing treatment plant. The reactors were operated according to the optimal OLR found during the first experiments carried out.

- System up-scaling to add the systems as a new competitive commercial offer.
  - At the end of the experimental phase, all the partners were work together on the up-scaling of the processes in order to propose a new competitive commercial offer on the Indian market for **decentralized treatment of small sources of pollution of domestic origin** in different ranges: wastewater generated at house level (4-8 people) or by small settlements, condominium or hotels (100-400 people) or by small villages (400-1,000 people).

## 4. Summary of Results and conclusion

India being a developing country is facing many environmental issues, including the treatment and management of wastewater in extremely alarming conditions. Most of the large towns in India were developed on the banks of rivers. Water is procured upstream of the rivers for domestic uses and other industrial purposes. After use, wastewater is discharged downstream of the river or to other water bodies like ponds, lakes etc. with minimal treatment or with no treatment in most of the cases, polluting these water bodies. The disposal of wastewater into these water bodies increases the nutrient content of the ecological system and leads to eutrophication, which is the main cause of the consumption of dissolved oxygen in water bodies, resulting in the death of fish and other undesirable impacts. The problem arises due to a considerable gap in the production of sewage and treatment facilities available. Although, the number of treatment systems in India have increased, the country's wastewater treatment capacity has not been fully developed to fulfil the growing rate of sewage generation. Most of the treatment facilities currently available in India are centralized systems that are underutilized or not functioning due to absence of proper sewage pipeline, adequate funding and skilled labour. The rural areas of India mostly do not have sewage treatment plants, the wastewater from these small villages and towns is discharged into the rivers directly. There is a need to develop an extensive decentralized technology that requires very low energy input, can be effortlessly managed and treat wastewater at the point of generation, offering an excellent alternative for treating wastewater in rural areas of India.

Constructed wetlands (CW), because of their benefits of high effectiveness, a suitable ecological environment, low price and aesthetic value, have been commonly used in many nations and regions in the past few decades. CW is a complete ecosystem which provides an environment for the growth of diverse flora and fauna. In CWs many physical, chemical and biological processes are simultaneously active and mutually influence each other to make the system entirely natural for the treatment wastewater.

In this study we have successfully carried out treatment of wastewater from various sources.

In CW, plant plays a very important role, hence selection of plant is a crucial factor for its working. In this study, the selection of plant was done on the basis of their Biochemical methane potential (BMP). BMP of wetland macrophytes i.e. *Ageratum conyzoides*, *Typha latifolia*, *Canna indica*, and Hybrid *Napier* spp. was estimated by seeding different loading rates of biomass i.e., 0.5, 1, 2, 3, 4 gVS/L in 130 ml glass serum vials at room temperature. The volume of biogas produced by *Ageratum conyzoides*, Hybrid *Napier* spp., and *Typha latifolia* with 0.5gVS/L were 85.5 ml, 98.5 ml, and 79 ml, respectively. For an OLR of 4 gVS/L, the BMP for *Ageratum conyzoides,* Hybrid *Napier* spp., and *Typha latifolia* were found to be 166.5 ml, 187 ml, and 157 ml, respectively. For *Canna indica*, at OLR 3g VS/L and 4g VS/L, produced biogas volume of 166.5 and 130 ml, respectively. Hybrid *Napier* spp. produced a high volume of biogas i.e., 187 ml (4gVS/L loading rate) compared to other macrophyte biomass. The percentage of methane present in the biogas produced from *Ageratum Conyzoides* biomass were 62.24% and 65.73 % for OLR of amount 0.5 gVS/L and 4 gVS/L, respectively. The percentage of methane present in biogas produced by Hybrid *Napier* spp.*, Canna indica,* and *Typha latifolia* for OLR of 0.5gVS/L were 65%, 73.19%, and 69.49%, respectively and the amount of methane produced was 64.03, 61.11 and 54.90 ml, respectively. In spite of the low BMP of *Canna indica* it has been proved to be suitable for both wastewater treatment and anaerobic digestion, considering the factors like wastewater treatment efficiency, easy establishment, high growth rate, and ease of harvesting.

A Drum experiment was first conducted to select the most suitable plant species adapted to the tropical climate of Goa, India. *Typha angustata* and *Canna indica* were selected because of their natural availability in Goa, India. The removal efficiency of both the plant species was found to be very similar but the overall methane production of green *Typha angustata* (230.0mL) at the highest loading rate (i.e.; 4gVS/L) was much higher than green *Canna indica* 94.5mL. So, *Typha angustata* was selected as a plant species for the pilot scale plant at BITS goa campus. Based on the drum experiment, a demonstration-scale Two Stage Pilot VFCW experiment was implemented and regularly monitored at two different HLR i.e. 0.150 m/day and 0.225 m/day for 40 weeks. At higher loading rate the removal of COD, BOD, TDS, TVS, TKN and $NH_4$-N at 1$^{st}$ stage was 61%, 62%, 33%, 40 %, 35 % and 58%; and for the 2$^{nd}$ stage 90%, 84%, 61%, 64%, 47% and 82% respectively. At higher organic loading rate, the system footprint got reduced from 1.47 $m^2$ to 0.79 $m^2$ per person. The main problem faced in maintaining the system was that *Typha* was difficult to handle in vertical flow wetland constructed as it needs stagnant water to grow in the wetland. So, for further studies in chapter 5 and chapter 6 *Canna Indica* was planted in the system as it does not require stagnant water and are suitable for vertical flow constructed wetlands.

CWs systems provides efficient treatment for BOD, suspended solids (SS) and Kjeldahl nitrogen but are limited in their phosphorus removal abilities. Phosphorus removal in French VFCW depends on many biotic and abiotic factors which are present in the media of the wetland. The primary Phosphorus removal mechanism in VFCW is phosphorus adsorption in the media of the wetland. The phosphorus sorption capacity of the media mainly depends on the iron, aluminium and calcium content of the media which is not sustainable. Eight different reactive materials such as Steel slag (SSGS), kiln ash (KAS), Bauxite ore (BOX), Bentonite clay (BNC), red brick (RB) BOP (Binvec Pivel) and BON (Bovec Nervac) were collected from different places in India and France and were analysed for their phosphorus removal capacity (PRC). The research demonstrates that BOP and BON from the drinking water plant could be an effective solution for removing P from wastewater treated in constructed wetlands. The P removal capacity of the samples BOP and BON (10 mg P/g and 7.6 mg P/g respectively) was found to be highest. It was observed that the samples provide $Ca^{2+}$ and $OH^-$ for the formation of HAP complex. The molar ratios $PO_4$-P/Ca of BOP and BON was 1.7 and 1.9, which supports the formation of more stable HAP complex. Also the BOP and BON solutions have higher pH which supports the formation of stable calcium phosphate complex. The study suggest that the P removal capacity of the samples depend on the release of $Ca^{2+}$ and $OH^-$into the water samples.

To understand the further working of CW with low C/N wastewater a two-stage vertical flow wetland was designed and implemented in Dr. K B Hedgewar School, Cujira, Bamboli, Panjim, Goa, India. The 1$^{st}$ stage of the wetland was passively aerated by natural percolation with unsaturated flow whereas in the 2$^{nd}$ stage, the aeration pipes were removed to make anoxic conditions and by implementing saturated flow for denitrification. In this case two feeding strategies were applied. In the first feeding strategy the wastewater (10 $m^3$/day) was pumped for 15 weeks from the first chamber of a septic tank (before settling) to the 1$^{st}$ stage, from there it flows to 2$^{nd}$ stage which is kept anoxic. In the second feeding strategy 50% of the waste water was pumped for 8 weeks to the 1$^{st}$ stage and the rest was pumped to 2$^{nd}$ stage directly. This was done to increase the COD content in the 2$^{nd}$ stage for denitrification. It was observed that the COD in the septic tank was around 302 mg/l and the total nitrogen was 102 mg/l. Therefore the COD/N ratio was 2.95 in the 1$^{st}$ stage and 1.85 in the 2$^{nd}$ stage. Theoretically, the COD/N requirement for nitrification and denitrification is 2.86 considering the electron transmission balance between organics and nitrates, but in practice the values will always be larger than 2.86. After 4 months of working during the 2$^{nd}$ feeding strategy, the COD in the intel wastewater was decreased. This was primarily due to the operation of wetland which was not allowing the solids to accumulate in the septic tank. Due to this, COD/N ratio was also reduced to 2.0 in the 1$^{st}$ stage (OLR for the 1$^{st}$ stage = 0.69 kg/$m^2$/day). As per the 2$^{nd}$ set of experiments, the COD/N ratio for the 2$^{nd}$ stage was just 1.68 (OLR for the 2$^{nd}$ stage = 0.26 kg/$m^2$/day). A decrease in the treatment efficiency of Nitrate and Nitrites was observed after $2^{nd}$ stage, which indicate that, as the COD/N ratio got decreased in both the stages, the nitrification and denitrification rate also got reduced. The efficiency of the system can be increased by providing some source of carbon in the inlet water.

On the basis of result obtained from BITS Goa campus pilot scale system and the VFCW at school. A $500m^2$ two stage vertical constructed wetland was designed and implemented at Margaon wholesale fish for treatment of 40 $m^3$/day of water from river Sal and fish market wastewater (if needed). This river is about 35 kms long and is contaminated by domestic wastewater and industrial waste having an average content of 73mgCOD/L, 55 mgN-NO3/L and 31 mg $NH_4$-N/L which make it closer to a primary settled domestic wastewater rather than a surface water. The recent report by the Goa state pollution control board (GSPCB) had categorised River Sal as the most polluted river in the state. The $1^{st}$ stage has total surface area of 150 $m^2$ and the $2^{nd}$ stage has of 350 $m^2$. The VFCW at fish market was designed based upon VFCW already operational in BITS campus (Chapter 3). The BITS campus system was operated with an OLR varying from 71.6 g/L/day (HLR = 0.15 m/day) to 275.96 g/L/day (HLR = 0.225 m/day). Following the same HLR and OLR, the VFCW at fish market was specifically designed for 0.266 m / day HLR and 80.74 g/L/day OLR consider high COD of fish market water i.e. 980 mg/L. The $2^{nd}$ stage of the system was made anaerobic, based on the school wetland design (Chapter 5) to increase the denitrification rate. The Nitrate removal efficiency of the system was low. The nitrogen in the River water was high and the COD was very low. The C/N ratio of the inlet River water was just 3.5. High C/N ratio was needed for denitrification to happen in the $2^{nd}$ stage. To increase the COD, the wastewater from the fish market, which is about 10 $m^3$ with COD of 980 mg / L needed to be transfer to the septic tank and mixed with the river water to provide more carbon for denitrification.

## 5. Future Scope of Work

- There is need to understand the bacterial diversity of the wetland to understand how fauna of the system is getting effected by different quality of wastewater.
- Need to understand the ecology (interaction of abiotic and biotic factors) to find out how the abiotic factors effects biotic factors of CW.
- The wetlands should be run continuously for much more years and the samples should be analysed at regular intervals, to understand how it behaves in tropical climate after several years to understand life of wetland.
- More work is needed to understand, how the C/N ratio in the wastewater effect the nitrifications and denitrification in the system.
- Different types of media need to be investigated which can have better treatment efficacy for the removal of different types of nutrient from the CW. There also a need to find more suitable substrate for phosphorus removal.

## 6. List of publication

- **Yadav, A**., Choudhary, P., Atri, N., Teir, S. and Mutnuri, S., 2016. Pilot project at Hazira, India, for capture of carbon dioxide and its biofixation using microalgae. *Environmental Science and Pollution Research*, *23*(22), pp.22284-22291.

- **Yadav, A**., Chazarenc, F. and Mutnuri, S., 2018. Development of the “French system” vertical flow constructed wetland to treat raw domestic wastewater in India. *Ecological Engineering*, *113*, pp.88-93.

- Talekar, G.V., Sharma, P., **Yadav, A**., Clauwaert, P., Rabaey, K. and Mutnuri, S., 2018. Sanitation of blackwater via sequential wetland and electrochemical treatment. *npj Clean Water*, *1*(1), p.14.

## 7. List of conferences, workshops and Courses

- Participated in “Conference on Terra Preta sanitation and decentralized wastewater system” on 19-21 November 2015, at BITS Pilani Goa Campus, Goa.
- Attended a workshop on “BIRAC Workshop on Bio-entrepreneurship Grant writing and Intellectual Property Management” on 18-19 February 2016 at BITS Pilani Goa campus, Goa.
- Presented in a workshop on “Novel Sanitation Approaches and Emerging Trend in Wastewater Treatment technologies” on 19-21 December 2017 at BITS Pilani Goa campus, Goa.
- Participated in the “4$^{th}$ Asia Pacific- International Society of Microbial Electrochemistry and Technology (AP- ISMET) Meeting with a special focus on Bio-electrochemical and Electrochemical Approaches for Decentralised Sanitation” on 13-17 November 2018 at BITS Pilani Goa campus, Goa.
- Participated in “Fulbright Specialist Program on Engineering-Economics-Entrepreneurship” on 18 may – 6 July 2018 at BITS Pilani Goa campus, Goa.

  Completed a 3-credit unit course in “Water Sanitation and Solid waste management – BIOF216” a Joint programme of Ewag-Sandec and BITS Pilani Goa campus, Goa

## 8. Brief Biography of the Candidate

Personal details

| | |
|---|---|
| Name | Mr. Anant Yadav |
| Education | B.Tech – M. Tech Biotechnology(Dual degree) Jaypee University of Information Technology, India |
| E-mail | anantyadav27@gmail.com |

**Research Experience**

- Research Project (1st August 2017- till date)

Currently working on the project funded by DBT titles "Demonstration of River Sal Cleaning by Vertical Wetlands and Riverbed filtration" as a Junior, research fellow.

- Research Project (2nd February 2017-31st July 2017)

Visiting Research Scholar IMT Atlantique, 4 Rue Alfred Kastler, 44300 Nantes, France.

Project title: Use of reactive material for P removal in small treatment plants, the potential of industrial by-products in India. Funded by CEFIPRA (Raman Charpak Fellowship)

- Research Project (Ph.D. Work) (25th October 2014- 31st January 2017)

Junior research fellow in BITS Pilani K.K. Birla Goa campus on a research project entitled "Development and Demonstration of two decentralized wastewater treatment plants," funded by CORE WWE Birla Group.

- Research project (5th June 2014-24 October 2014)

Completed Oil and Natural Gas Corporation(ONGC) sponsored research project entitled "Setting up of a pilot project at Hazira for fixation of carbon dioxide and greenhouse gas abatement with microalgae" as a junior research fellow at ONGC Hazira, Surat, Gujarat.

## 9. Brief Biography of the Supervisor

Dr. Srikanth Mutnuri is a recipient of DAAD-UGC Scholarship to complete his Doctoral Research at UFZ – Centre for Environmental Research, Germany and obtained his degree from Anna University Chennai in the year 2004. He joined BITS Pilani K.K Birla Goa Campus as a full-time faculty by 2005. He worked as convener for three International Conferences in Environmental Biotechnology held in the year 2009, 2011 and 2014 at BITS Pilani K.K Birla Goa Campus. Dr. Srikanth Mutnuri conducted International Workshop on Bioremediation in association with Dr. Max Haggblom, Rutgers University USA for two weeks from January 4 – 16, 2010. He was the principal investigator for four research projects funded by DST, DBT, UGC, and GEDA and currently, he has research projects funded by CSIR, GIZ and DBT BIRAC & Bill and Mellinda Gates foundation. He has published 21 research papers in International Journals and written two Book Chapters. He received Helmholtz association's Junior Scientist Award and FEMS Young Scientist Award to participate in International Conference on Environmental Biotechnology, Leipzig, Germany, 2006 and 14th International Biodeterioration and Biodegradation symposium Sicily, Italy, 2008 respectively. He had attended National and International Conferences to present his research work as Oral and Poster presentations. He has Research Collaborations with Scientists from IISc Bangalore, INRA France, UFZ Germany, GTZ-BMU Germany, Ecole de mines Nantes – France, Caltech – USA, International Water Management Institute Colombo – Srilanka, Cranfield University – UK and Rutgers University USA. He is a Recipient of American Society for Microbiology & Indo US Science and Technology Forum (ASM IUSSTF) Indo US Research Professorship for October 2010. There are two start-ups from his lab one is Sustainable Biosolutions LLP started by two of our former M.E Biotech students and other started by him is Bactreat Environmental solutions LLP, his company has bagged 25 lacs from DBT BIRAC for its project on Resource Recovery from Septage project.

## 10. Brief Biography of the Co–Supervisor

Dr. Florent Chazarenc is a Ph.D and Engineer in environmental engineering. He is working as a senior Researcher (Director of Research) and group leader at Irstea in the research unit REVERSAAL (Lyon-France). He had done his PhD in Environmental Engineering at the University of Savoie, France. He carried out his post-graduate research jointly at Polytechnique Montréal and at Institut de recherche en biologie végétale in Montréal, before returning to France in 2007 where he took his accreditation to Lead Research in 2013. Having organized the 5$^{th}$ WETPOL conference (International Symposium on Wetland Pollutant Dynamics and Control) in 2013 in Nantes, he is also strongly involved in specialist groups of the IWA (International Water Association) on the subject of reed bed filters and water pollution control. He also successfully organised the 14th Specialized Conference on Small Water and Wastewater Systems in 2017 (S2SMALL2017). He was principal investigator for many research projects funded by national and international agencies. He had attended National and International Conferences to present his research work as Oral and Poster presentations. He has published 46 research papers in International Journals and written two Book.