Identifying best available technologies for decentralized wastewater treatment and resource recovery for India

Overview of project achievements

Dr. Markus Starkl, BOKU
Prof. M.M Ghangrekar, IITKGP

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Overview Saraswati 2.0

Problem: Saraswati 1 has shown that smaller scale decentralized STPs often not functioning in India – need of new/better technologies

Overall objective: Identify best available as well as affordable technologies for decentralized wastewater treatment:

1. Piloting candidates for best available technologies for India (WP2)
   - Decentralized WWT
   - Black-water
   - Sludge
   - Post-treatment
2. Monitoring, experimental work, and performance assessment (WP3)
3. Developing suitable automation and control strategies (WP4)
4. Assessing overall sustainability and identifying BATs (WP5)
5. Dissemination (WP6)

Expected Impact

1. Contribution to improved and efficient wastewater treatment systems and resource recovery

2. Contribution to improved smart and comprehensive solutions for both quality and quantity monitoring and management of water resources.

3. Contribution to strengthening the Sustainable Development Goals' (SDGs) agenda on water

4. Contribution for boosting initiatives like the Ganga Rejuvenation Initiative, fostering the emergence of quick–win business, affordable, innovative solutions based on integrated Indian and EU best practices

5. Contribution to creating a level playing field for European and Indian industries and SMEs working in this area, paving the way for a potential joint venture for manufacturing of water treatment technologies and systems.

Overview Saraswati 2.0 – Project consortium

No.	Participant organisation name	Short name	Country
1	University of Natural Resources and Life Sciences Vienna (CO EU, WPL 5)	BOKU	Austria
2	Delft University of Technology (WPL 4)	TU Delft	Netherlands
3	Fundacion Centro de las Nuevas Tecnologias del Agua, Sevilla (WPL 2)	CENTA	Spain
4	University of Tartu (WPL 3)	UT	Estonia
5	University of Antwerp	UA	Belgium
6	Sociedade Portuguesa de Inovação, Porto (WPL 6)	SPI	Portugal
7	Centre for Environmental Management and Decision Support, Vienna	CEMDS	Austria
8	Biokube, Tappernoje	BIOK	Denmark
9	Cambi Group AS, Asker	Cambi	Norway
10	Ben Gurion University, Beersheba	BGU	Israel

No.	Participant organisation name	Short Name	State
11	Indian Institute of Technology Kharagpur* (CO India, WPL 2)	IITKGP	West Bengal
12	Indian Institute of Technology Roorkee (WPL 3)	IITR	Uttarakhand
13	Indian Institute of Technology Madras* (WPL 4)	IITM	Tamil Nadu
14	Indian Institute of Technology Bhubaneswar	IITBBS	Odisha
15	National Institute for Industrial Engineering, Mumbai (WPL 5)	NITIE	Maharasthra
16	Malaviya National Institute of Technology Jaipur* (WPL 6)	MNIT	Rajasthan
17	TERI School of Advanced Studies (formerly TERI University), New Delhi	TU	Delhi

*Note: Partners IITKGP, IITM and MNIT have additional partners

Transfer/exchange of knowledge and technology

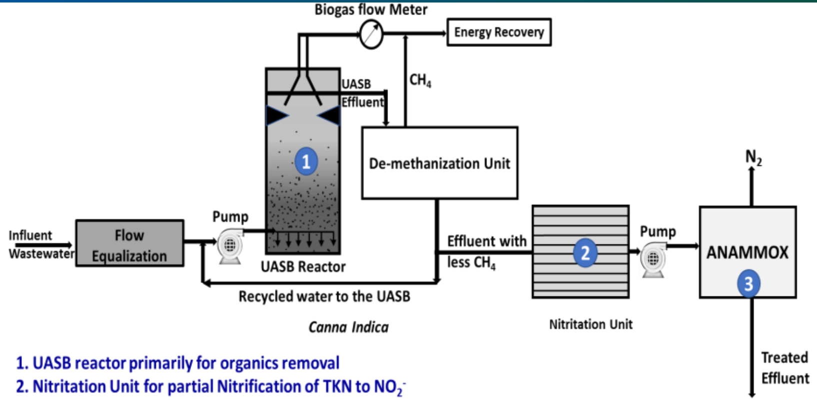
Pilot	Description / Pilot co-leaders/TRL	Transfer/exchange of knowledge and technology; Scope for adoption and scale up
1	UASB-deammonification plant (UT/IITBBS) TRL: 7	• Technology has been transferred from university of Tartu, Estonia. • No IPR protection foreseen, all publications co-authored and knowledge will be made available to public.
2	Small scale SBR (IITR) TRL: 7	• Technology developed by IITR – only indirect transfer involved, as inspired by CTech (which is based on an Austrian patent). • Further testing needed (higher BOD and flow variations) to reach TRL 8 • Large potential for scale up in smaller towns & villages, but depending on governmental funding. IITR to give licence to selected companies for this technology.
3	Biokube Package treatment (Biokube/MNIT) TRL: 8-9	• Biokube has given licence to Indian company for Indian market, and technology is manufactured in India (Rajasthan) for Indian market. • Large potential for India (e.g. plant requires no local operator), but institutional barriers, in particular tendering procedure in India (L1 principle).
4	RBC and disinfection (CENTA/NITIE)TRL:	• RBC developed by IIMM, disinfection technologies advocated by CENTA, Spain. Pilot still in monitoring phase.
5	Anaerobic Digestor-Photobioreacor (TU Delft/IITKGP) TRL: 6	• Technology provided by the TU Delft and UA, Belgium. Can be used at decentralised STPs for recovering valuable products (VFA, Protein). • Establishing optimal operating conditions need to be established to enhance TRL to 7-8, so as to avoid contamination of biomass.

Transfer/exchange of knowledge and technology

Pilot	Description / Pilot co-leaders/TRL	Transfer/exchange of knowledge and technology; Scope for adoption and scale up
6	Anaerobic Digestor-Electrically Conductive Biofilter (CENTA/IITKGP) TRL: 7	• Technology advocated by CENTA, Spain (which is patented by METfilter S.L., Spain). • Large potential for market adoption in the Indian context for municipal sewage. • Further investment needed to reach TRL 8-9 (See Day 2)
7	Thermal Hydrolysis Plant (Cambi/IITR) TRL: 7 (India)	• Technology provided by CAMBI, Norway. • Scope for large and small cities/towns, industries; • Further investment needed to reach TRL 9, institutional barriers (See Day 2)
8	Ultrasonic Sludge Disintegration and Disinfection (TU Delft/IITKGP) TRL: 7	• Modular sized ultrasound reactor developed by Managing Innovation, India and adopted by IIT Kharagpur. • It has promising application for decentralized sewage treatment plants for treatment of sludge generated from biological processes.
10	Ion Exchange membrane Bioreactor for Nitrogen Removal (BGU/IITM) TRL: 6	• Technology based on patent of 2001 and proposed by BGU. System used in pilot includes modifications which have been co-develop by BGU and IITM, which can be protected (IPR). Piloted system has successfully demonstrated post treatment application for the existing aerobic technologies in Indian environment.

WP2 & WP3

Pilot 1 UASB – Deammonification pilot



1. UASB reactor primarily for organics removal
2. Nitritation Unit for partial Nitrification of TKN to NO_2^-
3. ANAMMOX unit for conversion of ammonia and nitrite to N_2 gas

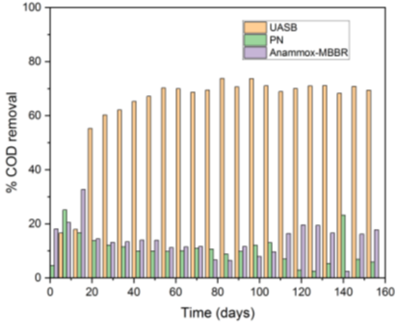
Summary

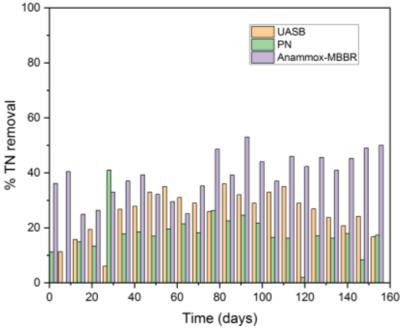
- COD Removal 85- 92%
- BOD removal 90-95%
- TSS removal 87- 93%
- TP removal 75-80 %
- TN removal 86- 91 %

- Anammox processes are much more economical treatment paths due to no requirement of organic carbon, less sludge production and 50% less aeration energy needed for the treatment.
- Methane gas production : 8.5 m^3/d
- Digested sludge is utilized as manure in horticulture
- Treated water can reused for non-potable purposes

- **Purpose of technology:** Reducing organic matter, producing biogas, and efficiently eliminating nitrogen to minimize the environmental impact of wastewater discharge with low cost treatment technology.
- **Research question**: Implementing affordable technology for wastewater treatment with higher treatment efficiency. The plant's commendable performance in effectively reducing various pollutants from the wastewater, depicting a promising outcome for water treatment processes.
- **Results:**

Parameters	Concentration (mg/L)	
	Untreated	Treated
BOD_5	180-280	10 - 20
COD	270-430	20-30
TSS	210-240	20-40
pH	7.5-8.1	6.6-6.9
NH_4^+-N	30-70	2 - 7
NO_2^--N	1 - 5	0.1-0.5
NO_3^--N	10 - 18	1 - 3
TN	52-105	7 - 15
TP	10 - 20	1 - 2





- **Purpose of technology:** Selector-based sequencing batch reactor (SBR) system is well established for larger scale (>1MLD), however, no experience of very small plants which are difficult to operate and maintained
- **Research question:** Large capacity selector-attached SBRs are working well in India, but very limited small-scale systems are available. Small-scale SBRs are very difficult to operate & maintained due to unavailability of skilled manpower and variable flow and BOD load. Operational characteristic need to be optimized to achieve new NGT Standards and reuse guidelines
- **Results:**

Parameters	SRT=10days DO=0.5-2.5 mg/L Cycle time= 2h		NGT Effluent Standards
	Inlet	Outlet	
pH	7.1 ± 0.1	7.3 ± 0.1	
COD (mg/L)	205 ± 62	21 ± 8	50
BOD (mg/L)	109 ± 27	7 ± 1	10
TSS (mg/L)	137 ± 42	10 ± 2	20
TN (mg/L)	37.5 ± 1.3	4.4 ± 0.8	10
TP (mg/L)	2.9 ± 0.3	0.7 ± 0.4	1

Summary

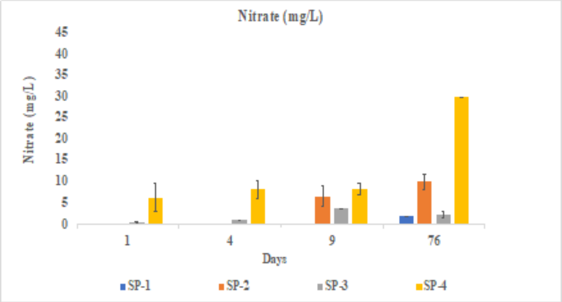
- 100 KLD SBR pilot plant satisfies NGT effluent standards of INDIA.
- DO values of 0.5-2.5 mg/L and 10 days SRT, 2-3 h cycle time is the optimal operational condition to achieve better effluent quality
- High Settling/Total time Ratio (0.33) and lower recirculation rates (to selector) (6.4%) can be able to achieve > 90 % simultaneous nitrification-denitrification (SND) and > 60% enhanced biological phosphorus removal. Without selector operation (internal recirculation) reduces the treatment efficiency.

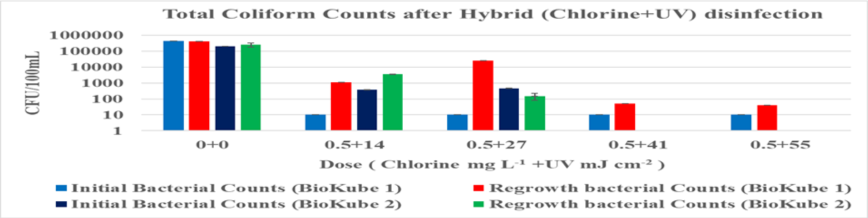
Pilot 3: Biokube Packaged Decentralized wastewater treatment plant

(1)

(2)

- **Purpose of technology:** To offer solution for decentralized treatment of sewage to produce treated water safe for reuse.
- **Research question:** focus will be on analysing reuse potential of the treated wastewater with extended research into pathogen detection (variety of bacteria) and removal (hybrid disinfection)
- **Results:**





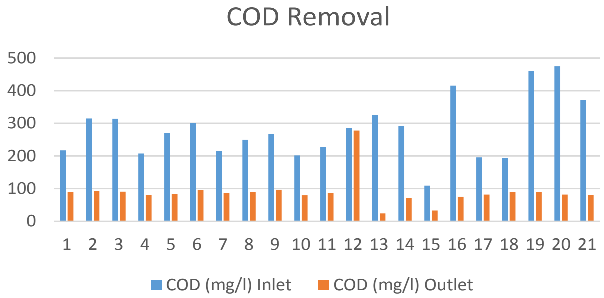
Summary:

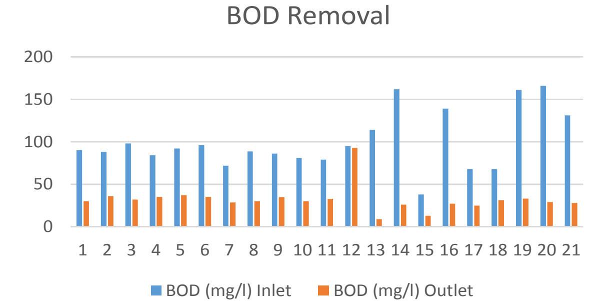
- For adaptation to clinical wastewater (Biokube 1), it will require more detailed studies with respect to organics, nutrients and AMR removal to support our results. A cost comparison with existing systems is needed to prove its competitiveness with other systems for which our results on hybrid- disinfection can be highly useful.
- For domestic wastewater (Biokube 2), it conforms to the discharge standards for organics, but modifications will be needed for extending the process for nutrient removal.
- However, cost-effectiveness of this technology need to be further evaluated to compare with existing decentralized systems.

Pilot 4&9 RBC coupled with three stage disinfection

- **Purpose of technology:** Optimizing performance of RBC with modifications in design and operation for reuse at small scale.
- **Research question:** To Implement affordable technology for sewage treatment with higher treatment efficiency and facilitate reuse of treated water.

Results:





TSS Removal	82-95%
BOD Removal	59-83%
COD Removal	58-93%
Turbidity Removal	74-95%
TDS Removal	16-38%
Oil and Grease Removal	86-100%
Phosphorous Removal	49-70%
Ammonical N Removal	41-77%
Total Nitrogen Removal	14-77%
Fecal Coliform Removal	42-88%

Summary:

Parameters	Average Concentration (mg/L)	
	Untreated	Treated
pH	7.13	7.19
BOD	90.45	32.14
COD	194.61	89.28
TSS	110.09	24.42
Ammoniacal N	12.21	4.67
Total Nitrogen	248.59	9.50
Fecal coliform	15.71	10.02

Pilot 5: Anaerobic digestion coupled with photoheterotrophic bacteria

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- **Purpose of technology:** To provide cost-effective wastewater treatment and resource recovery in the form of biomass (purple nonsulfur bacteria)
- **Research question:** Raceway ponds present an alternative method to conventional photobioreactors, offering a potential reduction in costs and the opportunity to valorize nutrients from wastewater through the cultivation of microbial biomass (purple non-sulphur bacteria)

Summary:

- The PNSB consortia demonstrated the ability to effectively remove organic matter and recover nutrients from wastewater in the form of biomass.
- The study demonstrated successful scale-up of raceway reactor from 500 L to 750 L to 1000 L for photoheterotrophic growth of PNSB for protein production and thus lays foundation for future outdoor cultivation of mixed consortia.
- Steady state has been reached after 30 days of operation of raceway pond

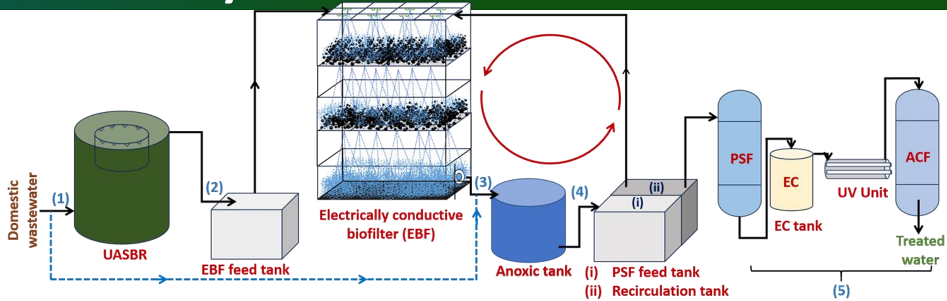
Results:

	Batch mode (5 days)						Continuous mode
	Fermented sewage with synthetic media			Fermented sewage without synthetic media			
Raceway reactor volume (L)	500 L	750 L	1000 L	500 L	750 L	1000 L	500 L
Biomass (g VSS/L)	0.9	0.85	0.81	36 h: 0.11 72 h: 0.03	0.1 0.03	0.09 0.03	2.8
μ (h^{-1})	0.0831	0.0742	0.0621	0.0282	0.0271	0.0265	NA
COD removal (%)	89	86.2	83.2	72.7	71.1	69.3	**69. 6**
NH_4^+- N removal (%)	92.5	91.3	87.6	72.9	65	60.6	**63.7**
PO_4^{3-} - P removal (%)	80.7	74.3	69.3	72	70.5	67.9	**54.3**
Protein content (% w/w)	43.9	42.1	40.3	18.9	17.4	15.6	**19.3**

- HRT = 24 h
- F/M ratio =0.2 – 0.3
- SRT = 4 days
- MLVSS = 2500 - 2800 mg/L

Pilot 6 Anaerobic digestion coupled with electrically conductive biofilter

Saraswati 2.0

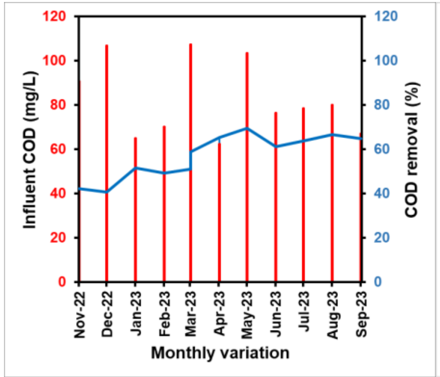


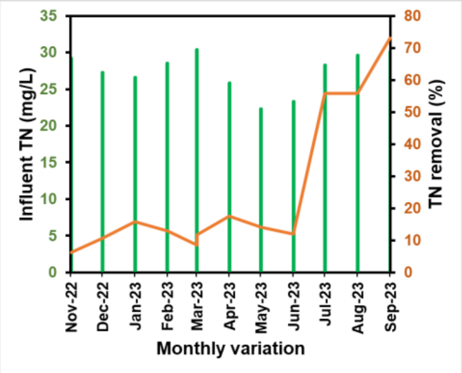
- **Purpose of technology:** To produce treated water safe for reuse while upgrading existing sewage treatment plant
- **Research question:** To check the technical, economical and environmental assessment of the adopted integrated technology

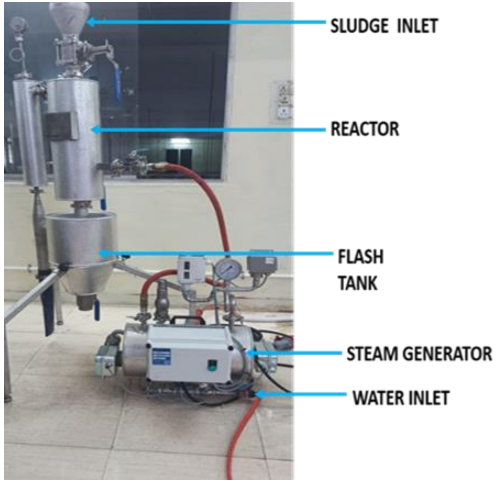
- **Summary:**
  - The successful implementation of the technology results in treated wastewater with reusable quality (BOD < 3 mg/L) and negate the water demand for non-potable usage.

Parameters	Biofilter effluent	NGT Standards Effluent parameters
pH	7.8± 1.15	5-9
COD (mg/L)	25.23 ± 1.15	50
TSS (mg/L)	5 ± 1.1	20
TN (mg/L)	7 ± 1.5	10
TP (mg/L)	1.0 ± 0.3	1
MPN (unit/100 mL)	<3	<100

- **Results:**



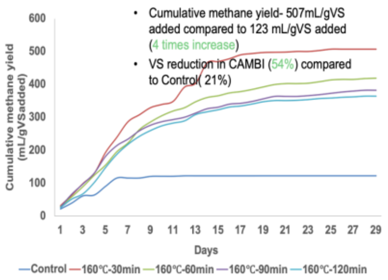


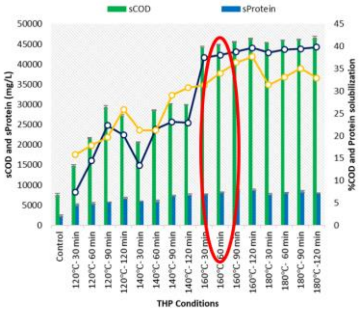


- **Purpose of technology:** Thermal hydrolysis process (THP) tested and applied at full scale in developed nations. Quality of Indian sludge (VS/TS ratio 0.4-0.6) is quite different than developed nations (VS/TS ratio >0.7).

- **Research question:** THP-AD process shows 2.4 to 3.8 times higher methane generation over conventional anaerobic digestion.

- **Results:**





CambiTHP was operated at 14-16% DS, 160 ºC, 6 bar, 30 min

Summary:

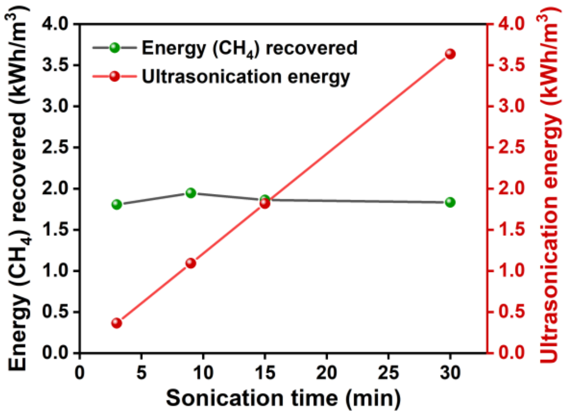
- SBR sludge: CAMBI-AD yielded 3.8 times more methane than mesophilic anaerobic digestion
- CAS: CAMBI-AD yielded 2.4 times more methane than mesophilic anaerobic digestion

Pilot 8: Ultrasonic treatment of sludge for sludge disintegration and disinfection

- **Purpose of technology:** to provide pretreatment to the aerobic sewage sludge prior to anaerobic digestion
- **Research question:** Emphasizing on upscaling towards direct hygienization of sewage sludge and low operator effort
- **Results:**

- Reactor volume: 20 L
- Aerobic MBBR sludge
- Flow rate: 15 L/min @ 12 g/L TS
- Sonication time: 10 min
- 14% increment in CH_4 for MBBR sludge
- 20% increment in CH_4 for ASP

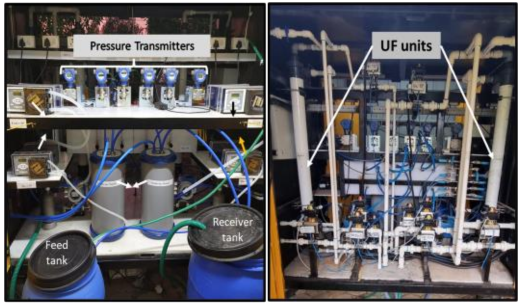
	Sludge type	
	MBBR	CAS
Volatile solids reduction (%)	29.6	34.3
methane production (mL/gVS removed)	343	389
methane content (%)	65	72



Summary:

- The maximum methane production evident from lower energy inputs was due to sono-dispergation (disintegration) rather than sonolysis (cell lysis).
- The sludge volume index (SVI), COD solubilization, ammonia solubilization has maintained linearity with increase in specific energy.
- Partial disinfection was also observed with 1.43 log reduction from 620000000 MPN / 100 mL to 23000000 MPN/100 mL after 10 min of sonication and subsequent UV treatment.

Pilot 10: Nitrate removal using Ion Exchange Membrane Bioreactor (IEMB)



Trolley 1- front   Trolley 1- back

Location 1 - IIT Madras
(installed in Feb. 2022)

Location 2 - Municipal STP
(Installed in Sep. 2022)

- **Purpose of technology:** Nutrient pollution is a significant issue in India. The described system can serve as add-on units to complement any existing wastewater treatment plant with elevated nitrate and nitrite levels.
- **Research question:** IEMB has been successfully implemented at lab-scale level but there are no studies at field-scale level. Goal is to check the technological, economical, and environmental feasibility of the technology in removing/recovering nutrients from secondary effluent at a pilot-scale level.

Summary:

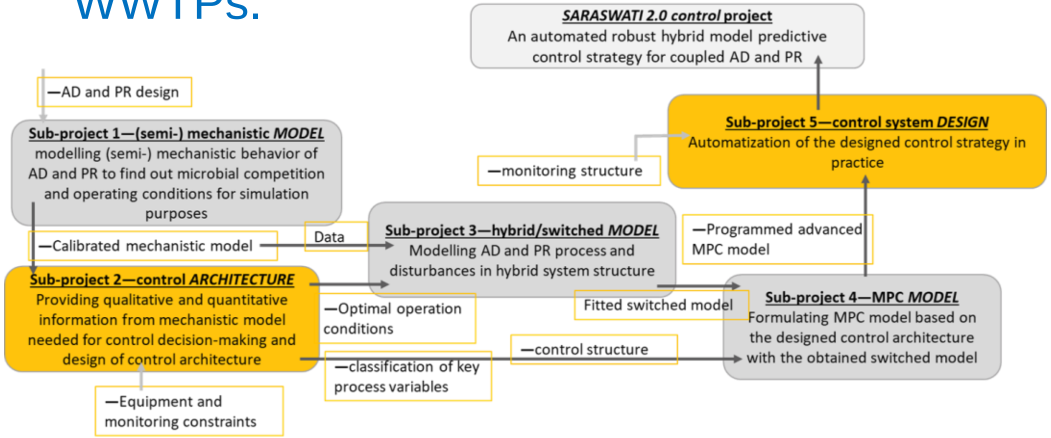
- Nitrate removal of more than **90 %** was achieved from secondary effluent in **Donnan dialysis** at a driving ion concentration of 50 – 55 mM NaCl.
- Denitrification in FBBR was **> 95 %** at **C/N: 1.8 – 2** by glycerol with an HRT of **2 h** resulting **effluent nitrate < 1 mg N/L**.
- Polishing unit (aerobic system) with an HRT of 0.5 h resulted an effluent **COD < 5 mg/L.**
- The presence of sulphate had minimal effect on Denitrification.
- Automation based on **PLC** (Programmable Logic Controller) at IITM and **Microcontroller** at Nesepakkam was successfully installed.
- The operational cost of the treatment is **Rs. 17/m^3.**

- **Results:**

Parameter	Inlet	Outlet
Nitrate (mg/L)	20.4 ± 7.75	2.01 ± 0.65
Sulphate (mg/L)	77.52 ± 12.96	24.77 ± 6.13
Phosphate (mg /L)	2.18 ± 0.7	0.86 ± 0.39
Chloride (mg/L)	247.07 ± 50.44	374.19 ± 60.05

WP4 – Automation and control

- WP4 has provided recommendation on basic control strategies applied in several of the Saraswati pilots and evaluated them.
- A case study of advanced control strategy based on MPC system in Pilot 5 and partly 10 has been investigated through modeling and simulation studies, which shows improvement in terms of treatment efficiency particularly in the absence of skilled labors as a major concern for the process supervision.
- Based on the experiences, WP4 will elaborate recommendations on how advanced control strategies can help to improve operation and automation of decentralized WWTPs.



- This WP covers LCA, LCC
  - **LCA** will cover GWP, EUP, ADP, ACP, POP, FAE and TE.
  - **LCC** will cover CAPEX, OPEX and resource recovery.
- Other sustainability aspects to be added as required for each pilot study
- Valuation of health benefits of wastewater treatment using cost of illness method
- Barriers & drivers, BATs

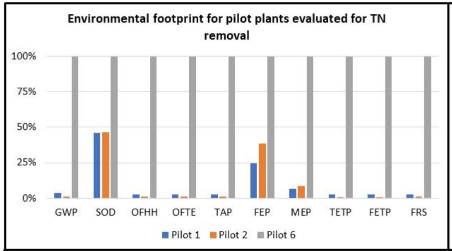
water

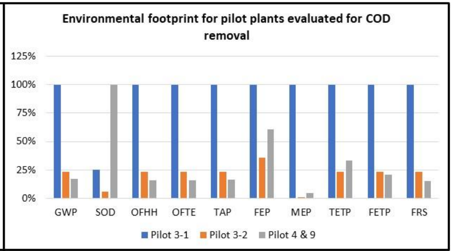
MDPI

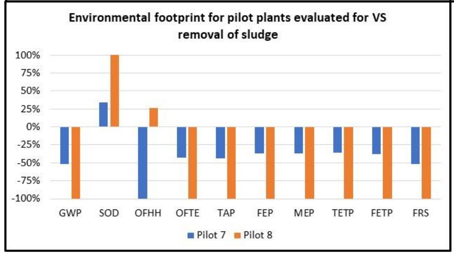
Article

Decentralized Wastewater Management in India: Stakeholder Views on Best Available Technologies and Resource Recovery

Norbert Brunner [1,*], Sukanya Das [2], Anju Singh [3] and Markus Starkl [4]







Impact category	Impact category
GWP	Global warming
SOD	Stratospheric ozone depletion
OF_{HH}	Ozone formation, Human health
OF_{TE}	Ozone formation, Terrestrial ecosystems
TAP	Terrestrial acidification
FEP	Freshwater eutrophication
MEP	Marine eutrophication
TETP	Terrestrial ecotoxicity
FETP	Freshwater ecotoxicity
FRS	Fossil resource scarcity

Pilots after project completion

Pilot	Description	Activities after project completion
1	UASB-deammonification plant (IITBBS)	STP will continue to be operated by IITBBS, no challenges expected
2	Small scale SBR (IITR)	Temporary installation, will not be used after project completion
3	Biokube Package treatment (MNIT)	Expected to be permanent installation for B.Lal. and CURAJ
4	RBC and disinfection (NITIE)	STP will continue to be operated by BMC.
5	AD-Photobioreacor (IITKGP)	STP will continue to be operated by IITKGP, no challenges expected
6	AD-ECB (IITKGP)	System will continue to be operated by IITKGP, no challenges expected
7	Thermal Hydrolysis Plant (IITR)	THP will continue to be operated by IITR, no challenges expected
8	Ultrasonic Sludge… (IITKGP)	System will continue to be operated by IITKGP at existing sewage treatment plant, no challenges expected
9	Combined with Pilot 4	Combined with Pilot 4
10	IEMBR for Nitrogen Removal (BGU/IITM)	Mobile unit, currently installed at Nesapakkam STP in Chennai

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