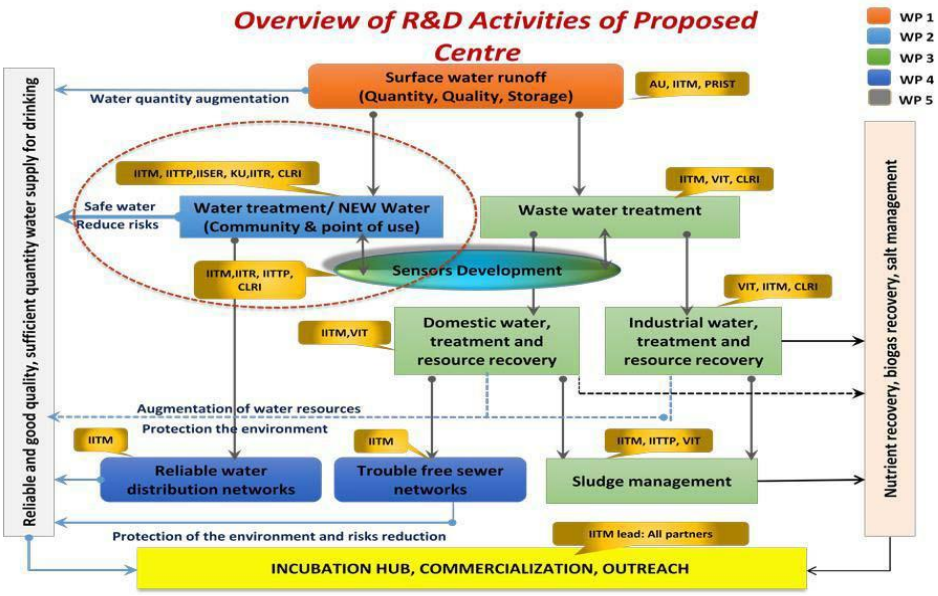
Water Technology Research and Innovation Centre

Centre for Sustainable Treatment, Reuse and Management for Efficient, Affordable and Synergistic solutions for Water

(WATER-IC of SUTRAM for EASY WATER)



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By

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Annual Progress Report

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<u>ANNUAL PROGRESS REPORT</u>

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1. DST File No : **DST/TM/WTI/WIC/2K17/82(G)**
2. Project Title :**WATER-IC of SUTRAM for EASY WATER**
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5. Date of fund received: **23/10/2018, 4/9/2020, 26/10/2021and 12/1/2023**

6. Progress Report Serial No: **4**
7. Reporting Period: **April 2022 to March 2023**
8. **Accomplishments in Terms of Activities for the Review Period (WP-1 to WP-5):**

Work Package	Activity	Progress	Responsible Organization
WP1	Emerging contaminants analysis	Received emerging contaminants results for one quarry water sample.	Anna University and IITM
	Concentrate samples for identification of rare elements	Eleven quarry water samples were concentrated and yet to be analyzed to identify some rare trace elements	Anna University and IITM
	Development of LID modules in FORTRAN for incorporation with SWAT model.	Completed	IIT Madras
	Development of SWAT model for Chennai basin.	Completed	IIT Madras
	Comparison of LID module formulation with implicit LID modelling in HYDRUS 1D for various native soil conditions	Completed	IIT Madras
	Trend Analysis of Precipitation and Groundwater levels in Chennai Basin	Completed	IIT Madras
	Model simulation with varying hydrologic sceneries	Completed	PRIST
	Evaluation of predominant and worst situations	Completed	PRIST
	Assessment of Model Applicability to areas other than study areas	Ongoing	PRIST
WP2	Fabrication of a portable colorimetric sensor based on Basic Fuchsine for the detection of nutrition in the	Completed	IIT Madras

	aqueous system		
	Assessment of competitive adsorption of pharmaceuticals and personal care product on carbonized absorbent derived from waste: Single and Multicomponent study	Completed	IIT Madras
	Colorimetric Sensors for the detection of phosphate	Completed	IIT Madras
	Adsorptive removal of plasticizers using composite biochar	Completed	IIT Madras
	MOF and LDH structure for the capture of phosphate	Completed	IIT Madras
	Installation of pilot-scale pulse power plasma reactor	Completed	IIT Madras
	Single pollutants study for three pharmaceuticals compounds	Completed	IIT Madras
	Effect of flow rate on the degradation of organic pollutants	Completed	IIT Madras
	Binary and tertiary pollutants mixed system study	On going	IIT Madras
	Degradation pathways determination of pollutants	On going	IIT Madras
	Demonstration of the ionic porous organic polymer (iPOP-Cl) for permanganate and dichromate ion removal, elucidation of the ion- exchange mechanism through various spectroscopic techniques	Following tasks are completed: (i) Scaling up of iPOP-Cl and its characterisation of through XPS and FESEM for the understanding the ion-exchange process (ii) Recyclability study and column-based separationof oxoanions employing iPOP-Cl	IISER Bhopal
	Iodine sequestration employing pyridine-rich crystalline covalent organic	Fabrication, characterization, and iodine sequestration from vapour	IISER Bhopal

	framework (COF)-based adsorbents	phase, water and organic solvents using pyridine-rich COF and its recyclability	
	Removal of carbamazepine, caffeine, and diclofenac removal by SKTPS through adsorption and ultrasonication techniques.	Carbamazepine, caffeine, and diclofenac removal by sulfonated solvent knitted triptycene-based hypercrosslinked polymer (SKTP) through adsorption and ultrasonication techniques	IISER Bhopal
	Manuscript and book chapterwriting	(i) One manuscript is revised and accepted: “iminecage-derived covalent organic framework film for nanofiltration application” (ii) One manuscript submitted: “The development of ionic porous organic polymer for oxoanion removal” (iii) One manuscript on COF-based adsorbent for iodine capture is under preparation	IISER Bhopal
	Fluoride-free drinking water	Field trials, testing and validation are over	IIT Madras
	Sensors and Kits for Water Quality Monitoring	Testing and validation are completed	IIT Madras
	Low-cost microfluidic platform for multi-analyte assessment of water quality	Process validation to detect multi contaminants has been completed	IIT Madras
	Atmospheric Water Capture	Completion of Field trials & Deployment	IIT Madras
	CDI Prototype	Integration with electronic and photovoltaic systems	IIT Madras
	Synthesis and characterization of	Completed	IIT Tirupati

	affordable composite materials for the removal of heavy metals and microbes		
	Performance evaluation of the materials	Completed	IIT Tirupati
	Reuse/ Recycle of spent materials	Completed	IIT Tirupati
	Prototype: design, development, and evaluation	Completed	IIT Tirupati
	Field trials - household unit	On going	IIT Tirupati
	Development of single probe multi-analyte sensor for different metal ions with specific focus on Cr (III & VI), As (III & V), and Hg (II)	Following works are completed (i) Evaluation of the handheld electrochemical device of the sensor was carried out to various concentration of Hg (II) and Cr (VI) (ii) Optimization parameter of L- Cysteine functionalized graphene oxide (iii) Protein-based metal bio-cleaner for detoxification of wastewater (iv) Development of novel, low cost colorimetric and fluorescent probes	CSIR-CLRI
	Synthesis of graphene based Fe_3O_4 nanocomposites with solid waste derived graphene oxide	Completed	Kumaun University
	Lead removal study	On going	IIT Madras
	Synthesis and characterization of few layered graphene nanosheets from fruit waste: kinnow peel waste	Completed	Kumaun University

	Synthesis of reduced graphene sheets using coconut husk	Completed	Kumaun University
	Development of graphene based materials for water purification membrane	Completed	Kumaun University
	Testing of graphene based materials for water purification membrane	On going	Kumaun University
	Removal of toxic organic, inorganic and pathogenic water pollutants using GO-modified PU granular composite	Completed	Kumaun University
	Dye removal study using rGO synthesized from tamarind seeds	Completed	Kumaun University
WP3	Fate of carbamazepine and its effect on physiological characteristics of wetland plant species in the hydroponic system	Completed	IIT Madras
	Installation and modification work for pilot scale reactor with 250 nm ceramic filter membrane and priming the membrane filter with clean water.	Completed	IIT Madras
	Filtration experiments with 250 nm pilot scale ceramic filter membrane by fixing feed flow rate from 2-3 m^3/h with secondary treated wastewater as feed.	Completed	IIT Madras
	Monitoring the Flux along with Transmembrane pressure and volume of water treated in a filtration process adapted with a pneumatic pressurized backwash process	Completed	IIT Madras
	Quality analysis for the parameters like pH, COD,	Completed	IIT Madras

	Fecal coliform, and Turbidity for the Ceramic filter was compared with the existing UF system.		
	Optimization of Chemical Enhanced Backwash (CEB) and water + air backwash with different backwash water flow rates (9, 15 & 30 m^3/h).	Completed	IIT Madras
	Optimization of feed water flow rate and cycle duration with different feed water flow rates (3, 6 & 9 m^3/h) and cycle time duration of 20 and 10 min.	Completed	IIT Madras
	Running filtration process with proper SOP under complete automation with PLC control	Ongoing	IIT Madras
	Finding optimum parameters for the growth of microalgae, bacteria, and microalgae-bacteria consortia	Ongoing	IIT Madras
	Removal of target pollutants using microalgae, bacteria, and microalgae-bacteria consortia	Ongoing	IIT Madras
	Microalgae-bacteria consortia formation	Ongoing	IIT Madras
	Effect of pH, salinity, dye and biomass concentration on decolorization of azo dye methyl orange in denitrifying conditions	Completed	VIT Chennai
	A review on sustainability of Aerobic granular system	Completed	VIT Chennai

	Feasibility studies of decolorization of selected mixed azo dyes in denitrifying conditions	On going	VIT Chennai
	Pilot plant set-up for SBR operation	Initiated	VIT Chennai
	Effect of sulfur loading rates in real tannery wastewater with SBR	Two different microalgae species (*Chlorella vulgaris* & *Chlorococcum sp.*,) were studied for the removal of sulfur from SBR treated tannery wastewater	CSIR-CLRI
	Metagenomic sequencing studies of the developed microbial consortia	Semi - continuous studies were carried out under different sulphur loading rates by *Chlorella vulgaris* in a photobioreactor	CSIR-CLRI
	Detailed parameter Sensitivity for the lab-scale model	Ongoing	PRIST
WP4	scheduling for water distribution networks	(i) Pure data driven methods are demonstrated on laboratory network (ii) Heuristics for reducing computational effort for model-based formulation are developed (iii) Python based web application has been developed and is currently being tested	IIT Madras
	Network discovery	Algorithms for network discovery developed. Software under development	IIT Madras
	Sewer Network Retrofit Model	Coding has been completed; Code has been tested; Validated for a realistic network	IIT Madras
	Pipe Material Selection	Decision Aiding Tool is developed	IIT Madras

WP5	Incubation Hub	Continuation and completion of incubation	IIT Madras
	Green energy harvesting using advanced materials	Completed	IIT Madras
	Analysis of water quality in stone quarries	Analysis of such water is being done	IITM-Anna university

9. Accomplishment in Terms of Milestone for the Review Period: April 2022 to March 2023

Work Package	Milestones	Target month	Progress
WP1	Assessment of quarry water, surface water and groundwater quality	Periodical collection	Sample collection and analysis have been completed until September 2022 and the samples collected in February 2023 is yet to be analyzed
	Identification and assessment of various interventions	May 2022	Controlled reservoir operation has been planned and assessed using the HEC-HMS software package and procured feasible results. Some hydrological interventions that facilitate flood mitigation and groundwater augmentation like additional check dams, and interlinking waterbodies are under assessment using MIKE11 NAM and MIKESHE packages. The groundwater zonation maps were prepared to identify the recharge zones. The effect of rooftop rainwater harvesting in reducing runoff generation was estimated and found feasible.
	Modelling to assess the impact of identified measures	June, 2023	Conceptual Rainfall-runoff (R-R) modelling had been set up for the upstream part of Chembarambakkam reservoir,

			calibrated and validated with good correlation. The simulation continued with the projected rainfall scenarios. Water balancing based on multi reservoir approach was performed to reduce flood inundation, evaporation loss and better water supply. Integrated flow modelling of Adyar and Kovalam watershed have to be calibrated and validated.
	Formulation of Optimization problem based on Genetic Algorithm for regional planning of LIDs	March 2023	Ongoing
	Comparison of the LID modules developed with HYDRUS 1D and SWMM model	October 2022	Completed
	Collaborations with ARU for a combined paper based on LID modelling Practices in India, UK and Brazil	March 2023	Ongoing
	Development of SWAT model for Chennai Basin	March 2023	Completed
	Calibration of SWAT Model	March 2023	Ongoing
	Trend Analysis of Precipitation and Groundwater level	December 2022	Completed
	Assessment of performance of LID using coupled surface and vadose water flow model (coupled SWMM-HYDRUS1D)	December 2022	Completed
	Simulated Generalized Model with varying scenarios predictability (incl. non- study area as well)	43-48 Month	1.Calibration of HEC-HMS model and prediction for various scenarios 2.Reassessment of variation of cyclicity, seasonality and trend of time series of precipitation

			data of study area and time and frequency domain-based modeling 3.Recalibration of ARIMA-based time series model developed for previous years for rainfall prediction at the study area for current year.
	Further study on Biogas upgrading in AD-MEC	43-48 Month	1. Column/recirculation studies (with optimized parameters) of lab-scale up flow anaerobic digesters (comprising of MEC-AD combined system), using rice-mill wastewater. 2. Estimation of optimum volumetric discharge rate and breakthrough characteristics with varying electrode materials (viz. Aluminium mesh, waste-plastic derived graphene-impregnated cloth) 3. Assessment of CO_2 profile of pre- and post-acclimatized culture and their time series characteristics with regard to the varying voltages (in the MEC-AD system)
WP2	Lab scale continuous phosphate recovery setup	April 2023	Ongoing
	Installation of pilot scale pulse power plasma reactor of capacity 1 m^3/day	November 2022	Completed
	Performance evaluation of the pilot reactor for three pharmaceutical compounds in a single, binary, and ternary mixed system	February 2023	Completed
	Degradation pathways, mechanism of the process identification	March 2023	Ongoing
	Manuscript writing and submission	April 2023	Ongoing

	Critical analysis of the purified water (% of pollutants, salts), long term stability and reusability of thematerials.	(41st to 54th month)	▪ Ionic POP was demonstrated as a suitable material for selective removal of oxoanions ▪ The recyclability study was carried out and the material was used as a test-bed for water column filtration ▪ Iodine sequestration study employing crystalline pyridine-rich COF adsorbents ▪ Preparation and submission of manuscripts and book chapter ▪ Publication of the work on cage-derived COF film for the separation of organic micropollutants
	Field trials, testing and validation	March 2023	Completed
	Testing and validation	March 2023	Nearly complete
	Process validation to detect multi contaminants	March 2023	Nearly complete
	Completion of Field trials & Deployment	Oct 2023	Complete
	Integration with electronic and photovoltaic system	March 2023	Nearly complete
	Continuation and completion of incubation	Oct 2023	Complete
	Cytotoxic study on the AgNC treated water against human cell lines.	40-45 Month	Completed
	The effect of bicarbonate on AgNPs based disinfections system.	45-48 Month	Completed. (The enhanced ability of AgNPs to disinfect water in presence of bicarbonate was studied. A mechanism for enhanced disinfection is

			proposed)
	Development of a household water disinfection system	40-48 Month	Completed. (A 3-cartridge water purification system was developed. The first two cartridges were filled with AgNC-coated sand, and the third cartridge was packed with activated carbon to take care of the excess silver released as well as other impurities)
	Performance evaluation of 3 cartridge household water disinfection system.	40-50 Month	Completed (The performance is evaluated by spiking groundwater with 10^3 CFU/mL of *E.coli.)*
	A protocol for AgNC functionalized sand.	48-50 Month	In Progress.
	Development of disposal strategy for U(VI) loaded self-combustion graphene-oxide (SCGO) adsorbent	40-50 Month	Completed. The U(VI) loaded adsorbent is added to cement mortar and checked for compressive strength of mortar cube and leachability of U(VI) from cement mortar by TCLP.
	Phosphate functionalized granular iron chitosan phosphate for the adsorption of uranium from ground water.	45-50 Month	In Progress. (The primary adsorption experiments are completed and an adsorption capacity of 71 mg/g at pH 4, 30^0C is obtained. Development of regeneration protocol is in progress.)
	A chitosan-AlOOH granular adsorbent for the removal of aqueous selenium	45-50 Month	In Progress. (The primary adsorption experiments are completed and an adsorption capacity for Se(IV) 205 mg/g, and Se(VI) 220 mg/g at pH 7, 30^0C is obtained. The regeneration and lifecycle assessment studies are in progress.)
	Project initiation, identifying the structural	6^{th} Month	Structural motifs are identified and are synthesized.

	motif's		
	Synthesis of intermediate compounds	12^{th} Month	Signaling units and receptor units were identified. Three derivatives were synthesized and characterized and their preliminary studies are in progress.
	Preliminary investigation of sensing the metal ions	24^{th} Month	Few receptors were developed to sense the Hg^{2+} at the picomolar level using optical methods
	Fabrication of electrochemical device and multiplex sensors for different ions	36^{th} Month	Multiplex sensor for chromium and Hg has been developed. The work on the addition of functional groups for arsenic is also in progress. In addition, the molecular probes to improve the sensitivity and selectivity is also in progress
	Optimization of electrochemical devices and new materials for electrochemical, colorimetric and fluorescent sensors	48^{th} Month	The device is optimized for electrochemical sensors. New colorimetric and fluorescent probes were developed. Novel protein-based sensors were also being developed.
	Development of nanocomposite for the removal of all kind hazardous impurities (biological/non- biological).	42-54 Month	Under progress
	Synthesis and characterization of carbon nanocomposites	42-54 Month	Under progress
	Research Papers	42-54 Month	4-Published 1-Communicated
	Patent	42-54 Month	1-Granted
	Book Chapters	42-54 Month	5

WP-3	Selection of plant species and determination of their characteristics	Oct 2021	Completed
	Batch hydroponics experiments in the exposure phase and recuperation phase	Oct 2021-Jan 2022	Completed
	Extraction of target pollutants from plant tissues and analysis; Analysis of plant characteristics; Prediction of degradation pathways; Pearson correlation analysis; multi-criteria decision-making analysis	Nov 2021-May 2022	Completed
	Manuscript preparation and submission to a journal	May – July 2022	Completed
	Installation and modification work for pilot scale reactor with 250 nm ceramic filter membrane and priming the membrane filter with clean water.	Apr-May 2022	Completed
	Filtration experiments with 250 nm pilot scale ceramic filter membrane by fixing feed flow rate from 2-3 m^3/h with secondary treated wastewater as feed.	May-June 2022	Completed
	Monitoring the Flux along with Transmembrane pressure and volume of water treated in a filtration process adapted with a pneumatic pressurized backwash process	June-Aug 2022	Completed
	Quality analysis for the parameters like pH, COD, Fecal coliform, and Turbidity for the Ceramic filter was compared with the existing UF system.	May-Sep 2022	Completed

	Optimization of Chemical Enhanced Backwash and water+air backwash with different backwash water flow rates (9, 15 & 30 m^3/h).	June-Nov 2022	Completed
	Optimization of feed water flow rate and cycle duration with different feed water flow rates (3, 6 & 9 m^3/h) and cycle time duration of 20 and 10 min.	Nov-Feb 2022	Completed
	Running the filtration process under PLC control fully automatically with proper SOP	Feb-March 2023	Ongoing
	Removal of target contaminants (antibiotics and nutrients) using microalgae, bacteria, and microalgae-bacteria consortia	May 2023	Ongoing
	Microalgae-bacteria consortia formation	April 2023	Ongoing
	A book chapter publication on Nutrient removal	40th Month	Completed
	Publication of Effect of pH, salinity, dye and biomass concentration on decolorization of azo dye methyl orange in denitrifying conditions	46th Month	Completed
	Publication of a review on sustainability of Aerobic granular system	50th Month	Completed
	CNS removal in SBR under different nitrogen loading rates	7th Half yearly period (End of March 2022)	CNS removal of tannery wastewater has been carried at nitrogen loading of 0.145 $kg/m^3/d$ with SBR.

	CNS removal in PBR under different sulphur loading rates	8th Half yearly period (End of September 2022)	Batch studies in SBRTWW using *C.vulgaris* and *Chlorococcum sp.* was performed Semi - Continuous studies on sulfur removal in Photo bioreactor was carried out using *Chlorella vulgaris* with 0.2, 0.4 & 0.6 g/L/d sulphate (SO_4-S) loading rate and 6, 3 & 1.5 days HRT respectively
	Metagenomic sequencing studies of the developed microbial consortia	9th Half yearly period (End of September 2022)	Meta genomic studies, validation and comparison of SBR biomass with CETP and STP sludge is under progress
WP-4	Software for network mapping	Month 40	Network mapping methodology developed . web application being developed
	Generation of test cases,	Month 48	. Ongoing
	Sewer Network Design: Computationally efficient models	Month 48	Completed
	User Manual	Month 54	In progress
WP5	Continuation and completion of incubation	Oct 2023	Completed

10. Completed/ongoing activities during the review period: April 2022- March 2023 (WP 1 - WP 5)

S. No	Review Period	Completed Activities	Ongoing / Pending Activities
WP1	**April 2022- March 2023**	• Identification of pits, quarries and lakes for water storage and recharge • Spatial and temporal	Integrated flow model of the entire Adyar and Kovalam basins is under refinement using

		rainfall analysis for past 39 years • Box model for controlled reservoir operation of Chembarambakkam reservoir • Rainfall-runoff modelling using MIKE11 NAM for the upstream side of Chembarambakkam reservoir. • Water balancing using multi reservoir approach to mitigate floods, reduce water loss due to evaporation and to improve water supply • Downscaling and bias correction of projected rainfall till 2100 under RCP 4.5 and RCP 8.5 • Water quality analysis of surface, ground and quarry water samples (periodic analysis – till May 2022) • Potential recharge zone maps for different Land use and Land cover changes using LULC projection	calibration and validation Prediction of changes in future runoff due to climate change
	September 2022-February 2023	• Comparison of LID module performance with HYDRUS 1D based implicit modelling technique for several soil samples across the soil textural triangle using automation in MATLAB and HYDRUS • Analysis on the sensitivity of the developed LID modules to capture the variations in the hydraulic parameters of the native soil • Comparison of LID modules for bio-retention cell, rain gardens, infiltration trench, permeable pavements, green roofs and swales with SWMM and HYDRUS 1D. • Conversion of LID module	• Integration of LID modules with SWAT • Determination of optimal combination of LIDs suitable for sub-basins in Chennai basin using Genetic Algorithm.

		codes into FORTRAN for incorporating them in SWAT	

	September 2022 – February 2023	• Development of SWAT model for the Chennai Basin
		  ○ Adyar Basin
		  ○ Cooum Basin
		  ○ Kovalam Basin
		  ○ Araniyar Basin
		• Trend Analysis of Precipitation and Groundwater levels in the Chennai Basin
			• Development of SWAT Model for Kosasthalaiyar Basin
			• Calibration of SWAT Model
			• Site Suitability Analysis for LID elements

	September 2022 – February 2023	Incorporation of runoff routing module to coupled SWMM-HYDRUS1D model	
	43-48 Months	Model simulation with varying hydrologic sceneries	Sensitivity study of HEC-HMS model using synthetic dataset generated by Monte-Carlo simulation
	43-48 Months	Evaluation of predominant and worst situations	Assessment of optimum landuse pattern catering to varying scenarios predicted by HEC-HMS model
	43-48 Months	Assessment of Model Applicability to areas other than study areas	Statistical assessment of significance among the model outputs corresponding to varying scenarios
WP2	July- Dec 2019	Fabrication of a portable colorimetric sensor based on Basic Fuchsine for the detection of nitrite ion in an aqueous system	Completed
	July – Jan 2020	Assessment of competitive adsorption of pharmaceuticals and personal care product on carbonized absorbent derived from waste: Single and Multicomponent study	Completed
	July -March 2020	Colorimetric Sensors for the detection of phosphate and nitrate	Completed
	July-Sept2020	Risk Dynamics of Emerging Contaminants and Heavy Metals in the River Ecosystems	Completed

	Jan Dec 2021	Selective removal of Phosphate via MOF	Completed
	Jan-Dec 2022	LDH derived structure for the capture of phosphate	Ongoing
	Jan- May 2023	Fabrication and operation of continuous phosphate recovery set up	Ongoing
	1st-40th month	Connecting the Dots: Knitting *C*-Phenylresorcin[4]arenes	NA
		Submission of Indian patent and writing of manuscript on triaminoguanidinium- based ionic porous organic frameworks (POFs) for heterogeneous catalysis and broad-spectrum antimicrobialapplication.	*Patent (ongoing)* Application No. 201921010663 A
		Multifunctional ionic porous frameworks for CO2 conversion and combating microbes, *Chem. Sci.* **2020**, *11*, 7910-7920.	NA
		Nanostructured hypercrosslinked porousorganic polymers: morphological evolution and rapid separation of polarorganic micropollutants, *ACS Appl. Mater. Interfaces* **2022**, *14,* 7369-7381.	NA
	41st to 52nd month	Transformation of imine cage to covalent organic framework film at the liquid- liquid interface *Angew. Chem. Int. Ed.* 2023, *e202219083(Just accepted)*	NA
		Pyridinium-functionalized ionic porous organic polymer for rapid scavenging ofoxoanions from water	*Manuscript submitted (Manuscript ID: marc.202300138)*
		Technological solutions for water sustainability; Book Chapter 6: Function-led design of porous organic materials forwater treatment	*Book chapter submitted(IWA Publishing)*
	1-48 Months	Identification of structural motifs, their synthesis and characterization and evaluation of sensing activities. Fabrication of functionalized	Evaluation of the low-cost sensing device developed by SUTRAM for EAST Water and optimization

		electrodes, development of the handheld device developed by CSIR-CLRI for Cr(VI) sensing	process. Development of new sensor molecules
WP3	Mar 2022 -Feb 2023	Fate of carbamazepine and its effect on physiological characteristics of wetland plant species in the hydroponic system	NA
	April 2022 – March 2022	Installation and modification work for pilot scale reactor with 250 nm ceramic filter membrane and priming the membrane filter with clean water.	
		Filtration experiments with 250 nm pilot scale ceramic filter membrane by fixing feed flow rate from 2-3 m^3/h with secondary treated wastewater as feed.	
		Monitoring the Flux along with Transmembrane pressure and volume of water treated in a filtration process adapted with a pneumatic pressurized backwash process	
		Quality analysis for the parameters like pH, COD, Fecal coliform, and Turbidity for the Ceramic filter and it was compared with the existing UF system.	
		Optimization of Chemical Enhanced Backwash and water+air backwash with different backwash water flow rates (9, 15 & 30 m^3/h).	
		Optimization of feed water flow rate and cycle duration with different feed water flow rates (3, 6 & 9 m^3/h) and cycle time duration of 20 and 10 min.	
		Running the filtration process under PLC control fully automatically with proper SOP	
	Jan-June, 2022	Finding optimum light-dark period for microalgal growth	Completed
	Mar-Aug, 2022	Nutrient removal using microalgae and bacteria	Completed
	Oct 2022-April 2023	Microalgae-bacteria consortia formation	In progress
	Sept 2022-May 2023	Comparison of antibiotics and nutrients removal using	In progress

		microalgae, bacteria, and microalgae-bacteria consortia (Without acclimatization)	
	April 2022 – March 2023	Effect of pH, salinity, dye and biomass concentration on decolorization of azo dye methyl orange in denitrifying conditions	Feasibility studies of decolorization of selected mixed azo dyes in denitrifying conditions
	April 2022 – March 2023	A book chapter publishing on Nutrients removal	
	April 2022 – March 2023	A review on sustainability of Aerobic granular system	Pilot plant start-up
	April 2022 – March 2023	Batch studies on removal of Sulphur, residual organics and nitrogen from SBR treated tannery effluent were studied using *Chlorella vulgaris* and *Chlorococcum sp.*, Semi - Continuous studies on sulfur removal in Photo bioreactor using *Chlorella vulgaris* with loading rate of 0.2, 0.4 and 0.6 g/L/d	Meta genomic studies of microbial consortia from SBR Amino acid sequencing for microalgae
	42-54	Synthesis of graphene based Fe_3O_4 nanocomposites with solid waste derived graphene oxide and their dye removal study	Completed
	42-54	Synthesis and characterization of few layered graphene nanosheets from fruit waste: Kinnow peel waste	Completed
	42-54	Synthesis and characterization of reduced graphene sheets using coconut husk	Completed
	42-54	Development of graphene based material for water purification membrane	Testing of material for water purification membrane is going on.
	42-54	Removal of toxic organic, inorganic and pathogenic water pollutants using GO-modified PU granular composite	Lead removal study in acidic, basic and neutral medium is going on.
	43-48 Months	Detailed parameter Sensitivity for the lab-scale model	Effect of shock loading on performance parameters of MEC-AD system
WP-4	April 2022 – March 2023	Developed method for reconstructing networks from road layout and explainable AI	Web based application has been developed and is under testing
		Robust optimization formulations developed to address Data	Web based application under testing

		uncertainty	
		Problem for network calibration has been formulated and demonstrated on small sized networks	Demonstration and extension to large scale networks is in progress
		Derived general results for continuous and discrete operation	-
		Pipe material selection: Decision Aiding Tool	Coding is over; user manual- in preparation
		Testing of retro-fit models for sewer networks: Demonstration of application to a real life case is in progress	Completed
		Manual for model usage	In progress
WP-5	April 2022 – March 2023	Continuation and completion of incubation	Completed

11. A Brief Description of Technical/Scientific Achievement for the period (April 2022 – March 2023):

WP-1

- The Topographic map (from SRTM), digital elevation model (from SRTM), geology & geomorphology map (from GSI), drainage map (from toposheet, DEM), Stream order map, land use land cover map (from LISS-III, 2017), Thiessen polygon map (from rain gauge stations) were prepared and used as layers in integrated flow modelling.
- Demarcation of various quarries, old channels in Chennai region were carried out with Satellite imagery and toposheets and possible interventions were noted based on the base maps prepared in ArcGIS 10.4 software package.
- Volume of the quarries, water availability in quarries and water bodies, surface and groundwater level in different locations and elevations were assessed, thus possible links and diversions were conceptualized.
- Rainfall occurrence and variation studies for the Adyar sub-basin for the past 39 years were analyzed using the homogeneous and autocorrelated rainfall records procured from IMD and PWD.
- a box-model approach for reservoir operation (Chembarambakkam reservoir) under extreme conditions has been developed and the performance was ascertained using the correlation coefficient and Nash–Sutcliffe efficiency with an average error

estimation of 15% and 25% in water level, 21% and 18% in outflow simulation, respectively.

- The R-R model for the Chembarambakkam sub-catchment was set up using MIKE11 NAM package and the performance of this model was ascertained using the Coefficient of determination and water balance error with 0.72 and -10% respectively.
- The Chembarambakkam reservoir (3.65 TMC) and the three abandoned quarries (1 TMC approx.) at the downstream part of the modeled Chembarambakkam sub-catchment were used for distributing and storing the simulated discharge to achieve improved water storage, reduced inundation and better water supply.
- Water balancing using multi reservoir approach was performed and better management scenarios were predicted.
- Importance of rooftop rainwater harvesting in terms of runoff reduction was assessed by selecting highly populated and vulnerable places of Chennai and the results were so promising in terms of flood mitigation.
- The flow model of the Adyar and Kovalam watershed using the MIKE SHE package has been set up. Calibration and validation are in progress.
- The daily rainfall data, projected under RCP 4.5 and 8.5 from RegCM 4.4 prepared by IITM, Pune was acquired for the Chennai region and was downscaled and bias-corrected by linear scaling method using IMD daily rainfall data. The projected rainfall data until 2100 will be used for further simulations of the model.
- The water samples from abandoned quarries, lakes, ponds and groundwater were collected and analyzed periodically once in three months

- Comparison of the LID model performance for bio-retention cell and rain garden, for various soil samples spread over soil textural classes with HYDRUS 1D based implicitly modelled LIDs.
- Analysis on the sensitivity of the developed LID modules (generic modules for three layered and two layered LID) in capturing the variations in the hydraulic conductivity of the native soil.
- Classification of the sub-basins based on: area, elevation, precipitation, land use, soil types, slope and aspect, into hydrologically similar groups using principal component analysis and K-means cluster analysis- performed in QGIS and MATLAB.
- Conversion of the MATLAB based LID module codes into FORTRAN for incorporating them into SWAT
- Formulation of objectives, constraints and algorithm for optimizing LIDs for classified sub-basins based on Genetic Algorithm.
- Journal paper titled ‘Development of Multi-layer Green-Ampt infiltration-based modelling framework for Low Impact Development Techniques’ – submitted to the Journal “Water Research”.
- Journal paper titled ‘Assessment of Low Impact Development techniques performance using coupled SWMM-HYDRUS1D model’ – under preparation.
- Collaboration with ARU on a combined paper regarding LID modelling Practices in India, UK and Brazil.

- Going to coordinate and participate in the Brazil-India-UK Summer School on Sustainable Drainage Systems in Sao Paulo, Brazil in June 2023.

- Completed the Trend Analysis of IMD Gridded Rainfall data and the observed groundwater levels for the Chennai basin.
- Calibration of HEC-HMS model with varying scenarios and uncertainties
- Calibration and assessment of time-series characteristics of rainfall data of current year (with regard to its components: trend/cyclicity/seasonality) and integration with prior model and re-computation of ARIMA.
- Study on effect of varying scenario on the model outputs, their sensitivity and corresponding projected landuse pattern
- Performance assessment of lab scale AD-MEC unit (at static and quasi-static environment) with optimized process parameters using varying electrode materials
- Process monitoring study of AD-MEC based on CO2 profile using online CO2 emission sensor with regard to variation in process parameters

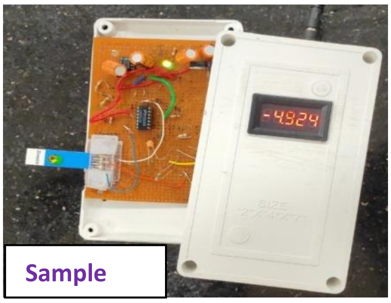
WP-2

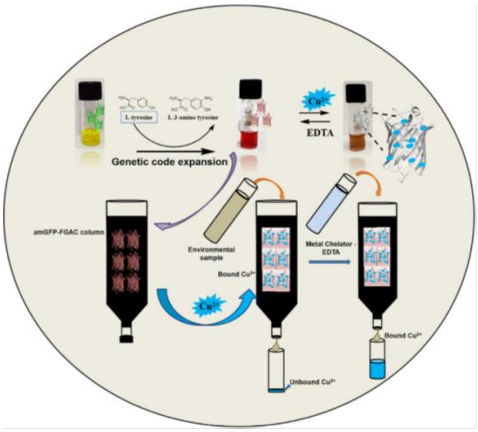
- Developed portable and low-cost techniques for detecting and removing trace pollutants. For this, a traditional method such as a paper strip sensor and carbon-based adsorbents from waste have been tested. At the same time, two low-cost green adsorbents were made from agriculture and sewage sludge to remove emerging contaminants. A risk assessment model was developed to characterize the hazard efficiency of micropollutants in the Cauvery river basin. Additionally, the application of MOF and LDH for sorptive and electrosorption removal of phosphate was tested.
- The pilot scale pulse power plasma reactor setup of capacity 1 m^3/day was fabricated on basis of the continuous flow plasma reactor at lab scale study. To evaluate the performance of the pilot plant the setup was established at the IIT Madras wastewater treatment plant where the SBR-treated water was used as feed to the reactors and studied as a tertiary treatment option. The SBR treated water was spiked with various pharmaceutical compounds and fed to the reactors and the quality of treated samples was analyzed. Moreover the degradation mechanism of pollutants and their pathways were determined to check the daughter compounds role effects in treated water quality.
- Apart from higher removal, lesser accumulation, and lower oxidation stress, multi-criteria decision analysis showed that C. indica is a potential plant species for the removal of CBZ.
- Manifestation of ionic pyridinium-based porous organic polymer for selective and rapid uptake of permanganate and dichromate and its use in column-based water purification
- Development of pyridine-rich crystalline covalent organic framework (COF)-based adsorbents for the sequestration of iodine from vapour, water and organic solvents
- Submission of manuscripts and book chapter
- Work on cage-derived COF film for the separation of organic micropollutants has been published in a highly coveted scientific platform, Angew. Chem. Int. Ed.

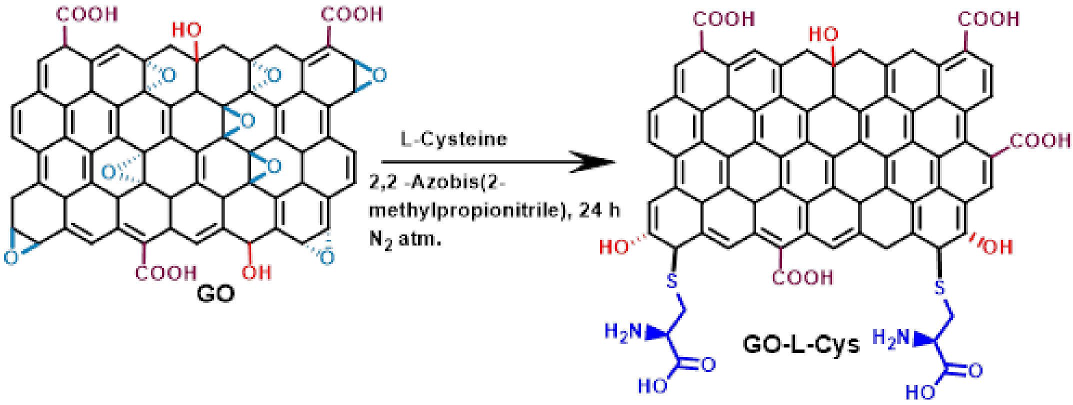
- Best poster presentation award in the international conference, ‘Water for Life’ organized by IIT Madras
- Nanocellulose reinforced organo-inorganic nanocomposite for synergistic and affordable defluoridation of water and an evaluation of its sustainability metrics
- We developed new defluorination material; published one paper; Patent applied for “Hearing to the Controller”
- Sensors and Kits for Water Quality Monitoring: Testing of the nanomaterial-dye sensing system for colorimetric detection of analyte (F^-) using visual and spectroscopic techniques.
- Scalable drop-to-film condensation on a nanostructured hierarchical surface for enhanced humidity harvesting; one paper has been published. This work involves understanding the condensation phenomena for water harvesting.
- CDI (Capacitive Deionization) Prototype: The properties of the electrochemical cell (adopted with three-electrode configuration) was measured by Electrochemical impedance spectroscopy (EIS) and cyclic voltammogram (CV). This work is in progress now; Synthesis of positively and negatively charged electro-adsorbent ion-exchange resins (EAIERs) is completed.
- A Covalently Integrated Reduced Graphene Oxide–Ion-Exchange Resin Electrode for Efficient Capacitive Deionization”. One Paper published.
- This work involves the development of ion exchange resin-incorporated graphene electrode.
- Industrial Utilization of Capacitive Deionization Technology for the Removal of Fluoride and Toxic Metal Ions ($As^{3+/5+}$ and Pb^{2+}): Paper published; We tested the developed electrodes for CDI applications.
- Low-cost microfluidic platform for multi-analyte assessment of water quality: Preconcentration of As (III) samples in microchannels and their detection by Ion Concentration Polarization and subsequent voltametric measurements.
- Green energy harvesting using advanced materials: Paper published “Ion-exchanging graphenic nanochannels for macroscopic osmotic energy harvesting”
- Preparation of ion-exchange membranes with covalent functionalization to achieve chemical and operational robustness
- Test the prepared membranes under different salinity gradients using a two-compartment electrochemical cell

- The cytotoxic studies against human cell lines (HaCaT) revealed that 60-90% of the cells are viable, and the AgNC-treated water is safe for human consumption
- AgNC coated sand-packed 3-cartridge system treated 2400 L of groundwater, sufficient for a family of 4 members to meet the daily water demand of 20 L for 120 days with intermittent regeneration.
- The performance of the 3-cartridge system is under investigation to extend the service life by varying operating parameters and regeneration.

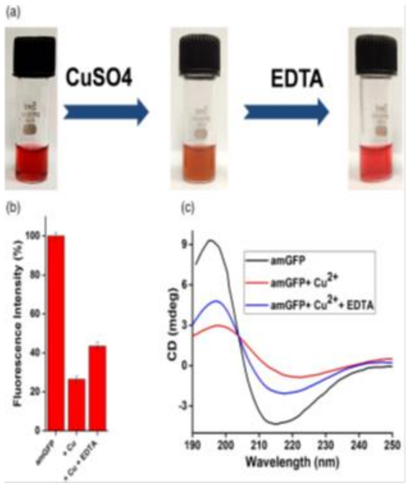
- Citric acid solution is found to be better than hot water washing for the regeneration of exhausted AgNC-coated sand. Hence a regeneration protocol was developed using citric acid for enhanced silver leaching and disinfection by AgNC coated sand.
- The evaluation of citric acid solution as a regenerant was performed in a column scale. The initial observations revealed that the service life of the AgNC-coated sand could be doubled.
- A disposal protocol has been developed for recycling AgNC into a microcrack sealant.
- A protocol has been developed to recycle graphene-based adsorbent incorporating the spent adsorbing in concrete.
- A handheld electrochemical device has been devised for on-site detection of chromium (VI) in an environmental water sample. The present approach, of targeting the different metal ions with selective functionalization of more than one functional group in a graphene platform, offers a potential methodology in developing the integrated sensor array without cross-reactivity. Further, wider linear limits for both metal ions are also an essential parameter for on-field applications.

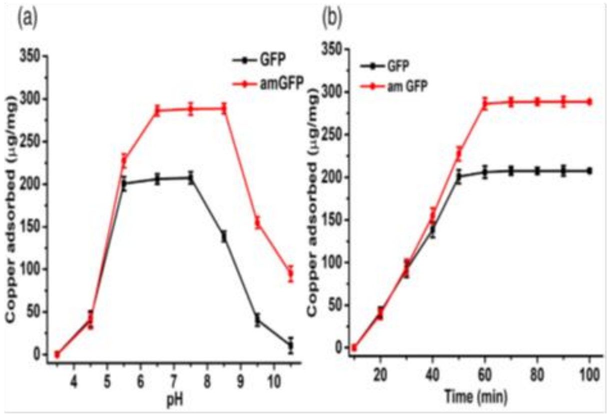




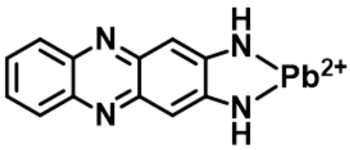


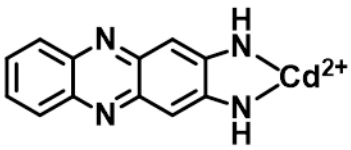
- Further, optimization of the electrochemical performance of the multiplex sensor was carried out to understand the influence of crucial parameters including incubation time, deposition potential, deposition time, and solution pH and the details are given in Figure (data not shown). The electrodes were subjected to the different deposition potential ranging from -0.1 to -1.0 V as the concentration of analytes at the electrode surface are crucial and has been found that -0.3 V is ideal to provide the better response. Further, the 60 seconds deposition time and incubation time were found be an optimized condition. The electrode's performance under different pH conditions reveals the moderate influence on the detection at lower pH, but above pH 4.5, the response seems to be identical within the experimental limit, thus offers the workability under different solution conditions.
- The copper is an essential redox-active transition metal accessible in the very least amount in healthy living cells. Exposure to heavy metals through contaminated soil, the food chain and drinking of contaminated groundwater affects cellular metabolism in the human body. Hence, developing innovative next-generation approaches with a dual function such as efficient detection and removal of heavy metals (Cu2+) in the environment is of paramount importance. Our study deals with an engineered biologically compatible green fluorescent protein (GFP) with metal-binding amino acid (3-aminotyrosine) for effective sensing and removal.
- The fluorescent-based sensing of congener protein (amGFP) with heavy metal Cu2+ was extensively explored through fluorescence, circular dichroism spectroscopic and computational simulation approaches. The amGFP exhibits a low dissociation constant value of 5.25 µmol L−1. In addition, the engineered congener protein was used as a bio-cleaner to remove Cu2+ from environmental samples. The copper binding capacity of engineered protein (amGFP, 346.46 µg mL−1) showed a 1.6-fold increase compared with native protein (GFP, 214 µg mL−1). GFP and amGFP immobilized on ethylenediamine-functionalized granular activated carbon (FGAC) were applied to environmental samples; FGAC-immobilized amGFP exhibited Cu2+ removal of about 85%, which was twofold higher than that of FGAC-immobilized GFP.

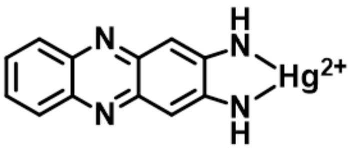




- For colorimetric sensing, the following molecules were synthesized, characterized and the sensing studies are being evaluated.







- We have published one research article entitled "Environmental application of amine functionalised magnetite nanoparticles grafted graphene oxide chelants" in the journal of Environmental Science and Pollution Research, 29, 86485–86498, 2022.
- We have communicated other research article entitled "Development of waste plastic derived reduced graphene oxide and its composites with Fe_3O_4 for applications drugs removal and energy storage" in the journal of Environmental Science and Pollution Research, 2023.
- We have also published the manuscript entitled "A novel, efficient and economical alternative for the removal of toxic organic, inorganic and pathogenic water pollutants using GO-modified PU granular composite" in the journal of Environmental Pollution, 2023.
- One patent has been granted on Graphene based nanomaterials derived from *Drepanostachyum falcatum* for water Purification, Australian patent Application No. 2021104582, Grant No. 202111031289.
- We also prepared the few-layer graphene nanosheets from fruit waste: kinnow peel waste (KPW) for the first time, via two-step pyrolysis. And also the confirmation was done with the help of RAMAN, XRD, FT-IR, SEM, and TEM.

- We synthesized the reduced graphene sheets using coconut husk as a natural and green precursor, and characterize this material with RAMAN, XRD, FT-IR, SEM, and TEM.
- We have successfully developed nanocomposites using agricultural waste and waste plastic derived graphene. The synthesized materials have been characterized by Raman, XRD, FTIR, UV, and TGA. Some characterization and lead removal studies are in progress.
- Also in this frame of time, we developed the material for graphene-based water filters. The synthesis of the material has been completed and the testing of the water filter made from our sample is in progress.
- We have successfully developed nanocomposites using agricultural waste and waste plastic derived graphene. The synthesized materials have been characterized by Raman, XRD, FTIR, UV, and TGA. Some characterization and lead removal studies are in progress.

WP-3

- In this work, batch hydroponics studies were carried out to assess the removal, fate, and antioxidative response of carbamazepine (CBZ) in four wetland plant species (*Canna indica, Colocasia esculenta, Phragmites australis, and Chrysopogon zizanioides*).
- The specific uptake potential of CBZ (in terms of plant dry biomass) was found to be in the order: *C. indica* (14.48 mg/g) > *P. australis* (11.71 mg/g) > *C. esculenta* (8.67 mg/g) > *C. zizanioides* (6.04 mg/g).
- The results showed that exposure to CBZ (0-30 days) caused an accumulation of reactive oxygen species (ROS) in the plant tissues, causing a decline in chlorophyll content, root activity, and increased oxidative stress. However, the selected plants could recover from the oxidative damages to a certain extent in the recuperation phase (31-60 days).
- *C. indica* exhibited relatively lesser ROS accumulation and oxidative damage during the experimental phase than other selected plants.
- The study also showed that plant biomass, transpiration rate, chlorophyll content, root exudates, and root activity influenced the removal of CBZ by various plants (r – 0.76 to 0.98, $P < 0.05$).
- Performance of a pilot-scale ceramic membrane filter with a pore size of 250 nm was tested for treating secondary treated wastewater under different operating conditions.
- Studies showed that the filter was able to achieve better-treated wastewater quality with respect to pH, Turbidity, COD, and Fecal coliforms.
- Removal efficiency of different pollutants such as turbidity, COD, and Fecal coliform ranged between 95-99%, 45-60%, and 80-90% respectively for a 250 nm pilot scale ceramic filter.
- Filtration process was carried out to check the efficiency of the filter by fixing the flow rate between 2 to 9 m^3/h till the pressure reaches 1.5 bar.
- For every cycle (cycle running time by 20 and 10 minutes), the flux value has been calculated by using the volume of water treated obtained from a digital rotameter and the Transmembrane pressure evolves during each cycle.

- Air + water Backwash was initiated at the end of each cycle. The provision of air + water backwash was able to recover the original flux during each cycle of operation.
- Air + water Backwash was initiated for the Pneumatic pressurization backwash process (3-sec pressurization and 5-sec backwash) at the end of each cycle and the volume along with the percentage of water used for backwash was also estimated for every cycle.
- Chemical-enhanced backwash was found to be effective in flux recovery. Chemical washing was initiated to clear the blockage due to fouling when the transmembrane pressure was not reduced as much after the air and water backwash.
- Chemical-enhanced backwash was initiated in an efficient way by combining Caustic and hypochlorite and was found to be effective. The chemical backwash was optimized with different flushing and soaking time.
- The treated wastewater quality from the ceramic filter (CF) denoted the better filtration performance of the 250 nm ceramic filter (CF) than the existing ultrafiltration (UF) outlet in IITM STP.
- For this study, microalgae were collected from the sewage treatment plant, IIT Madras, and Activated sludge from the same STP is being used as a bacteria source.
- If we compare the growth and nutrient removal of microalgae or bacteria alone, bacteria grow faster and remove nutrients in lesser time than microalgae.
- For microalgae-bacteria consortia formation, different inoculum ratios of microalgae: activated sludge 10:1 and 5: 1 are being used. This work is under process
- Simultaneous decolorization and mineralization of high concentrations of methyl orange (500 mg/L) in an anoxic up-flow reactor in denitrifying conditions was developed and reported very recently (Swathi et al., 2021, https://doi.org/10.1016/j.jwpe.2020.101813). To supplement this work, various batch reactor studies were carried out to study the effect of (i) pH (4 to 9), (ii) salinity (1 g/L NaCl to 10 g/L NaCl), (iii) dye concentration (100 mg/L to 1000 mg/L), (iv) biomass concentration (0.3 g/L to 0.21 g/L); on the process, and (iv) kinetics of decolorization in denitrifying condition. These batch studies were done using the adapted biomass drawn from a simple sequencing batch reactor (SBR), which gave an effective decolorization (99%) and denitrification (98%) at 2 d cycle time. The results of batch studies showed that the adapted mixed microbial consortium was capable to simultaneously remove color, COD, and NO_3^--N under denitrifying conditions even at high methyl orange (MO) concentrations of 1000 mg/L at 84 h, while effective color removal was achieved at 12 h with an initial dye concentration of 100 mg/L. Though the decolorization is possible in wide ranges of pH, better performance was obtained in alkaline pH. The decolorization performance increases when biomass concentration increases and not affected up to salinity of 10 g/L NaCl. Batch kinetic studies have shown that the MO decolorization followed first-order kinetics with a rate constant of 0.279 h^{-1}. Results of these studies may help in the future application of textile effluent treatment using a high biomass retention reactor in denitrifying conditions with minimum sludge disposal cost

- **Mixed Azo dye degradation:**

- Structurally different three azo dyes (Tartrazine, orange G, Amaranth) have used for degradation studies in batch reactor using varied COD/NO3-N ratios (5,15,30,45,60).
- Initial studies were done using individual dyes having concentration 100 mg/L in synthetic wastewater, which is having an initial COD of 1800 ± 200 mg/L and ADMI 6000±500.
- Incubation time for the batch reactors were 72 h. pH, ORP, COD, ADMI were analyzed during the studies.
- Activated sludge from STP of VIT Chennai campus was used as seed sludge in the batch reactors.
- The average COD reduction for Orange G was 80%, 70%, 50%, 42%, 40% for COD/NO_3-N ratios 5,15,30,45 and 60 respectively. The corresponding color removal (ADMI) was 33%, 62 %, 51%, 66%, 68%
- The average COD reduction for Tartrazine was 77%, 67%, 54%, 46%, 35% for COD/NO_3-N ratios 5,15,30,45 and 60 respectively. The corresponding color removal (ADMI) was 36%, 66%, 50%, 70%, 64%
- Then two dyes mixture Orange G and Tartrazine were mixed in 1:1 ratio. The dye mixture concentration was kept 100 mg/L. Initial ADMI value of the mixture was 3155±300
- The average COD reduction for above 2 dye mixture were 78 %, 73% 57%, 46%, 35% for COD/NO_3-N ratios 5,15,30,45 and 60 respectively.
- After that, three dyes mixture Orange G, Tartrazine an Amaranth dyes were used in 1:1:1 ratio and the total concentration of the mixture were kept at 100 mg/L.
- The average COD reduction for three dye mixture were 82%, 82%,73%, 74%,72% for COD/NO_3-N ratios 5,15,30,45 and 60 respectively. The corresponding color removal (ADMI reduction) were 70%,79%,76%,79%, 69%
- The pH of the influent dye wastewater was 7.54±0.45 and outlet pH was 6.07±0.33
- The measured ORP of the outlet of batch reactors were lies between -198 to -287 mV.

The above feasibility study showed effective degradation and color removal of mixed dyes at low concentrations.

- **Brief description of the review paper titled "A Review on the Stability, Sustainability, Storage, and Rejuvenation of Aerobic Granular Sludge for Wastewater Treatment"**

  - Aerobic granular sludge (AGS) is a recent innovative technology and is considered a forthcoming biological process for sustainable wastewater treatment.
  - This review focuses on the granulation process and characteristics of AGS, granulation time and the stability of AGS under different conditions, the comparison of different storage methods of granules, their recovery and rejuvenation, as well as the sustainability aspects of AGS.

- Physical size and structure of granules are determined by the composition and operational circumstances of the feed wastewater in order for AGS systems to perform well. In fact, it is important to note that substrate type, method of influent addition, hydraulic shear forces, organic loading rate, operational hydraulic and sludge retention times, and settling time have an impact on AGS stability.
- A major focus of contemporary research in this area is to develop operational strategies for maintaining long-term stability based on a better understanding of the microstructural characteristics that ensure AG's integrity.
- However, the current research developments are insufficient to meet the needs of large-scale industries and inadequate for the cost-effective and efficient usage of AGS.
- Further investigation is required to determine granule stability and disintegration processes caused by unknown factors to support the large-scale cost-effective usage of AGS.
- The storage of AGS could provide a potential remedy to the prolonged initial time frame needed to grow granular sludge and for maintaining the stability of granules.
- There are different storage methods for AGS out of which dehydration and drying methods are quite efficient.
- Due to intra-granular protein hydrolysis during storage in a wet media, the granule lost structural integrity. Granule storage at sub-freezing temperatures, however, was impractical. In comparison with wet granules, dried granules were easier to store and handle.
- In recent studies, most of the researchers stored granules by drying it. Dehydration and drying are preferred over other storage methods because of their effectiveness in rejuvenating and removing contaminants.
- The storage of granules and recovering them for later use eliminates sludge disposal and its consequences. All of these factors contribute to the AGS being a more sustainable method of treatment.
- From this review, it is evident that additional research is required to assess the effectiveness of regenerated AGS after prolonged storage to promote AGS technology for commercial applications.

- **<u>Tannery Wastewater</u>**
    - Batch studies in SBR treated tannery wastewater (SBRTWW) using C.vulgaris for a period of 10 days showed COD removal efficiency 67.2 % with a final COD concentration of 95.76 (± 32.3) mg/L, 95.5 %TKN removal efficiency and 96.3 % NH4-N removal efficiency with the final concentration of 2.3 mg/L and <1 mg/L respectively. Nitrate removal efficiency of 86.9 % with the final nitrate concentration of 23.6 (± 2.8) mg/L was obtained.
    - C.Vulgaris shows 48.7 % Sulfate assimilation with the final Sulphate concentration in the effluent of 535.2 (± 5.71) mg/L.

- Batch studies in SBR treated tannery wastewater (SBRTWW) using Chlorococcum sp., for a period of 10 days showed COD removal efficiency 60.3% with a final COD concentration of 115.9 (± 40.6) mg/L, 95.5 %TKN removal efficiency, 96.3 % NH4-N removal efficiency with the final concentration of 2.3 mg/L and <1 mg/L. Nitrate removal efficiency of 89.3% was obtained with the final nitrate concentration of 19.3 (± 1.5) mg/L.
- Chlorococcum sp., shows 34.1 % Sulfate assimilation with the final Sulphate concentration in the effluent of 687.6 (± 9.52) mg/L.
- Semi - continuous studies on sulfur removal in Photo bioreactor was carried out using Chlorella vulgaris with 0.2, 0.4 & 0.6 g/L/d sulphate loading rate and 6, 3 & 1.5 days HRT respectively with the initial concentration of sulphates in SBRTWW was 1211.4 (± 22.8) mg/L
- The removal efficiencies of sulphates at 0.2, 0.4 & 0.6 g/L/d sulphate loading rate were found to be 55.2 %, 39.8 % and 35.2 % with the final effluent sulphates concentrations of 542.8 (± 42.4), 729 (± 76.3) and 784.7 (± 44) mg/L.
- The uptake of sulfur by C.vulgaris and deposition in the cells was further confirmed by SEM-EDAX characterization of C.vulgaris biomass. The amount of Sulfur deposited in the individual cells ranges from 30-32 %.
- Amino acid sequence for the C.vulgaris is under progress in order to find the sulfur containing amino acid in the biomass.
- Meta genomic studies, validation and comparison of SBR biomass with CETP and STP sludge are under progress

WP-4

- The existing water network facility was upgraded with new continuous control valves for controlling overall flow with funding from IIT M. In addition, 9 solenoid valves were replaced with continuous control valves, level sensors were replaced.
- We have derived analytical results for quantifying difference in performance between continuous and discrete actuation for control of water networks. The results are general and give insight into the theoretical performance of networks and have been extended to general network operation.
- Model based operation of water networks requires a well calibrated model. Using available data (flow, pressure, heights of water in tanks), a nonlinear least squares problem is formulated to estimate the network parameters. Network parameters are guessed in an outer loop while the hydraulic simulation is carried out in the inner loop. The converged hydraulic simulation is used to develop a reduced Hessian in the outer loop. This decomposition allows multiple loadings to be treated efficiently.
- Model based scheduling of water distribution networks results in a nonlinear mixed integer optimization problem. In the past, we have reformulated the same as an integer linear program improving the tractability of the problem. We have developed heuristics to improve the solution times considerably. A web based application is under active testing.
- We have also developed pure data driven techniques for scheduling which use only flow data and require no network or hydraulic model. This has been validated on a 9 tank

system in the IIT Madras laboratory network using discrete valves and 4 tank system using continuous control valves.

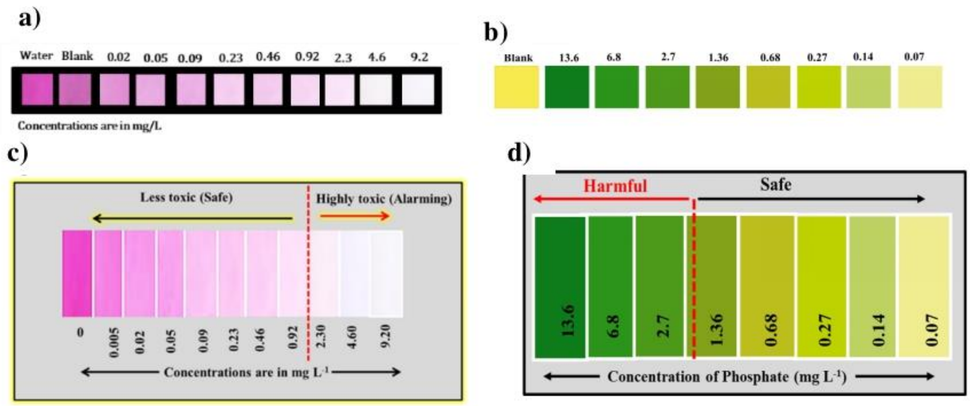
- We have formulated and demonstrated a methodology for reconstructing a putative water network from street network. Openstreetmap data of Chennai city from openstreetmaps was used to extract the network and connectivity structure of the road/street along with additional useful and relevant information (eg., type of structure- residential/commercial etc.) Appropriate graph algorithms (eg., shortest path tree/minimum spanning tree) were used to generate candidate network structures for the WDN. A web based software for the same has been developed and is under testing.
- A computer code is developed for optimal implementation of recycling and reuse of treated wastewater by retrofitting existing sewer networks. It has been verified. Application for realistic systems is demonstrated. An optimization model is also developed for the design of new sewerage systems, with recycling and reuse component. This is also verified and validated. Preparation of user manual is in progress.
- A decision aid tool is prepared for selection of pipe material. It is currently being tested.

12. Provide details of any Technologies/ Prototype/ Process/ Materials developed:

IIT Madras

1. Fabrication of Portable Colorimetric Sensor for the Detection of Eutrophying Ions in an Aqueous System

The low-cost and straightforward colorimetric paper strip-based method was developed for detecting nitrite (NO_2^-), nitrate (NO_3^-), and phosphate (PO_4^{3-}) in aqueous systems. The colorimetric probes were developed using stable dyes like Basic Fuchsine (BF) (for NO_2^- and NO_3^-) and Brilliant Green (BG) (for phosphate). To make the sensors portable, the selected dyes were loaded on Whatmann paper using surfactant like Tween-80. The naked eye detection limit obtained for nitrite and phosphate were 0.05 mg/L and 0.17 mg/L respectively. Moreover, the developed strips were stable for more 90 days when stored in amber bottle. In the presence of interfering ions, high selectivity was maintained. This was due to the target ion specific interactions. For example, for nitrite diazotization reaction was primary meachanism, while for phosphate, formation of phophomolybednum complex goverened the detection. The cost analysis confirmed that the synthesizeda low-cost (Rs. 1-1.5/ 10 strip). Overall, cost-effective and portable toll for on-site measurement of eutophying ion was developed..



(a)Sensing of nitrite using portable colorimetric strips at various concentration ranges (b) color pallet for selective nitrite sensing, (c) detection of phosphate using developed strip, (d) standard colorimetric chart for phosphate measurement.

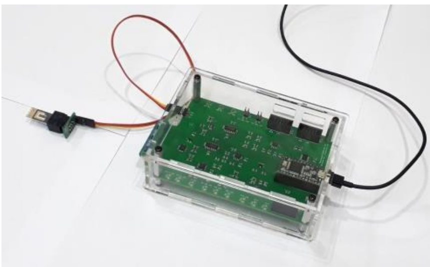
2. Vertical Flow constructed wetland Treating Greywater and Septic Tank Effluent from the Rural Community in India

Rural sanitation is gaining greater attention for achieving the environmental and economic development of the country. Due to lower maintenance and less labor-intensive, constructed wetlands (CWs) may be suitable for wastewater treatment in rural areas. A widespread occurrence of pharmaceuticals and personal care products (PPCPs) is reported in all the environmental matrices. Thus, the present study investigated the prevalence of these emerging contaminants in the wastewater from the rural community of Vichoor village, Tamil Nadu, India and its fate in the decentralized treatment system. Greywater and the septic tank effluent from each household were transported to a treatment site through a small-bore system. The pre-treatment of wastewater was done with a three-chambered septic tank and a three-staged settling tank. The effluent from the settling tank was fed into the vertical flow constructed wetland (VFCW). Among the 14 investigated PPCPs, caffeine, triclosan, bisphenol A (BPA), and diethyl phthalate (DEP) were the most frequently detected compounds in the concentration range of 5 ng/L to 250.14 μg/L. The overall removal efficiencies of organics, ammonia, phosphate, and pathogens were found to be more than 90.25 ± 1.71%, 85.25 ± 1.51, 79.81 ± 1.15%, and 99.9 ± 0.81%, respectively. Also, VFCW exhibited substantial removal of the selected pollutants in the range of 81 to 97.7%. Microbial degradation (74.9 to 93.8%) and sorption over the substrate materials (0.54 to 12.56%)seem to be the predominant mechanism for pollutants degradation. The ecological and human health risk assessment witnessed that PPCPs concentration in the treated effluent contributed lower risk to human and aquatic organisms. The quality of reclaimed water from the system (with little disinfection) could comply with the discharge standard suggested by the central pollution control board (CPCB) of India.

3. Pilot Scale Pulse Power Plasma Reactor for Pharmaceutical Degradation

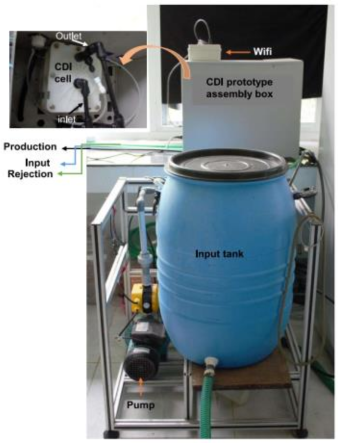
The study was carried out at operational conditions of input voltage of 23 kV, frequency of 1.5 kHz, a flow rate of 20 lit/hour,HRT of 3.75 hours, and pollutant load of 1 mg/l. The synthetic wastewater was prepared with IIT Madras wastewater treatment plant treated effluent.The results showed, 67.33% and 89.52% degradation of DCF and CBZ respectively. The TOC reduction was 49.18% and 65.87% in the case of DCF and CBZ spiked wastewater. Moreover, other water quality parameters such as pH were increased slightly from 8.76 to ~ 8.83, electrical conductivity increased from 2.59 mS/cm to 2.64 mS/cm, and NO_3 concentration was also found to increase due to the atmospheric nitrogen reaction with plasma in the reactor.

4. Prototyping of smartphone-based fluoride sensor is in progress.



A hand-held electrochemical sensor system developed in the lab, output goes to a mobile phone

5. Prototype of CDI



Prototype of CDI experimental setup, developed in the lab

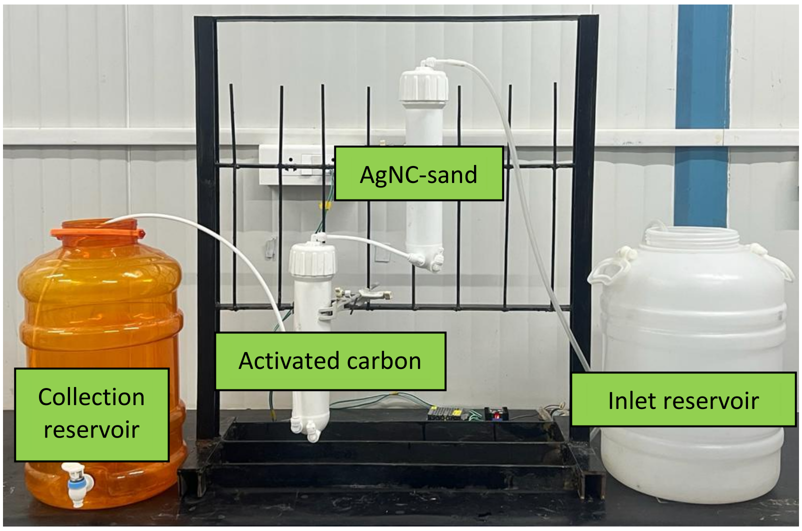
6. Sensor for Fluoride

An integrated sensor assembly for fluoride sensing.

IIT Tirupati

A household point-of-use water disinfection system:

The two-cartridge filter consists of AgCN-coated sand and activated carbon, as shown below. The disinfection ability of the treatment unit is demonstrated. The developed prototype can be served as a portable and low-cost water purifier for rural areas. The post-treatment with an activated carbon cartridge could remove residual silver in water.



A household point-of-use water disinfection system was developed

Kumaun University

- **Graphene based nanomaterials derived from Drepanostachyum falcatum for water Purification**

13. Shortfalls in Achievements of Activities for the Period:

Activity	Shortfall (*if any*) in Specific Terms	Responsible Organization
Microbial community structure and diversity in SBR system	Meta genomic studies of microbial consortia from SBR has to be evaluated	Central Leather Research Institute (CSIR-CLRI)
Manpower recruitment	Funds allocated are too small for the purpose	Need to release more funds in this head (IIT Madras)
	CoVID induced disruptions, closure of laboratory facilities, non-availability of spares affected the progress of the work during the earlier quarters. However, we have made full attempts to make up for shortfall by optimizing resources and time.	IIT Madras

14. Journal publication during the period:

Title of the paper	Journal, Issue, etc.	Authors
2021 Chennai Floods - An Overview (Published)	Journal of Geological Society of India / 2022	Kartheeshwari, M. R., Elango, L.
Spatio-temporal analysis of rainfall, meteorological drought and response from a water supply reservoir in the megacity of Chennai, India (Published)	Journal of Earth System Science / 2021	Anandharuban P, Elango L
A box model approach for reservoir operation during extreme rainfall events: A case study (Published)	Journal of Earth System Science / 2019	Anandharuban P, Michele La Rocca, Elango L
Organic micropollutants in groundwater of India – A Review (Published)	Water Environment Federation / 2019	Merin Sackaria, Elango L
Analysis of Challenges and Opportunities for Low-Impact Development Techniques in Urbanizing Catchments of the Coastal City of Chennai, India: Case Study	Journal of Hydrologic Engineering, Volume 25 Issue 10, 2020	Bakkiyalakshmi Palanisamy, Shubham Shaurabh, and Balaji Narasimhan
Development and performance assessment of a Castor-based vertical flow Constructed Wetland system for utilization of Landfill Leachate	Desalination and Water Treatment, 2022, 270, pp. 313–319	P. Parthiban, S. Malathi, B. Manjubarkavi, S. Sivaranjani, Ashutosh Das
Evaluation of dephenolation capacity by column adsorption studies	Desalination and Water Treatment, 2022, 269, pp.	Srihari V., Subramanyam B.,

	132–140	and Das, A
Enhanced degradation of complex organic compounds in wastewater using different novel continuous flow non – Thermal pulsed corona plasma discharge reactors	Environmental Research, Volume 203 Article number 111807, DOI: 10.1016/j.envres.2021.111807	Nippatla N, Kamaraj Ramakrishnan and Ligy Philip (2022)
Fate of carbamazepine and its effect on physiological characteristics of wetland plant species in the hydroponics system	Science of the Total Environment, 846, 157337. https://doi.org/10.1016/j.scitotenv.2022.157337 (Impact Factor – 10.753).	Ravichandran, M.K., Philip, L.(2022)
Assessment of the contribution of various constructed wetland components for the removal of pharmaceutically active compounds	Journal of Environmental Chemical Engineering, Volume 10, Issue – 3, Article Number: 107835, DOI: 10.1016/j.jece.2022.107835	Ravichandran M.K, and Ligy Philip (2022)
Fabrication of portable colorimetric sensor based on basic fuchsin for selective sensing of nitrite ions	Journal of Environmental Chemical Engineering, 7(5), 103374.	Vellingiri, K., Choudhary, V., & Philip, L.(2021)
Potential nanomaterials-based sensors and treatment methods for detecting and removal of aqueous chloroform	Environmental Nanotechnology, Monitoring & Management, 100487.	Choudhary, V., Vellingiri, K., & Philip, L. (2021).
Stable paper-based colorimetric sensor for selective detection of phosphate ion in aqueous phase	Microchemical Journal, 171, 106809.	Choudhary, V., & Philip, L. (2021)
Sustainability assessment of acid-modified biochar as adsorbent for the removal of pharmaceuticals and personal care products from secondary treated wastewater	Journal of Environmental Chemical Engineering, 10(3), 107592.	Choudhary, V., & Philip, L. (2022)
Role of Inner-Sphere Complex Interaction for Phosphate Removal on Metal-Organic Frameworks: Experimental and Theoretical Investigation	Environmental Science: Water Research & Technology. https://doi.org/10.1039/d2ew00636g	Choudhary, V., Boukhvalov, D. W. & Philip, L.(2022)
Effect of Water Quality on the Yield and Quality of the Products from Hydrothermal Liquefaction and Carbonization of Rice Straw	Bioresource Technology, 351, 127031. https://doi.org/10.1016/j.biortech.2022.127031	Harisankar, S., Mohan, R. V., Choudhary, V., & Vinu, R.(2022)
Green and Cost-Effective Synthesis of 2D and 3D Graphene-Based Nanomaterials from Drepanostachyum Falcatum for Bio-Imaging and Water Purification Applications	Chemical Engineering Journal Advances 10(January): 100265. https://doi.org/10.1016/j.ceja.2022.100265	Chetna Tewari, Gaurav Tatrari, Sumit Kumar, Sandeep Pandey, Anita Rana, Mintu Pal, Nanda Gopal Sahoo (2022)
"Analysis of a Direct Microcontroller Interface for Capacitively-Coupled	IEEE Transactions on Instrumentation and	Areekath L., George B. and Reverter F

Resistive Sensors	Measurement, vol. 70, Art. no. 1501010, pp. 1-10, 2021. DOI: 10.1109/TIM.2020.3034969	(2021)
A Cantilever-based Flow Sensor for Domestic and Agricultural Water Supply System	IEEE Sensors Journal, vol. 21, no. 23, pp. 27147-27156, Dec. 2021.	Harija H., George B. and Tangirala A (2021)
Assay of Inductive-Capacitive Probe for the Measurement of the Conductivity of Liquids	IEEE Transactions on Industrial Electronics (IEEE Trans. Ind. Elec., IM 8.7), vol. 68, no. 9, pp. 8911-8918, Sept. 2021	Tejaswini K. K., George B. and Kumar V. J (2021)
Feasibility of a Planar Coil-Based Inductive-Capacitive Water Level Sensor with a Quality-Detection Feature: An Experimental Study	Sensors 22, no. 15: 5508, July 2022. https://doi.org/10.3390/s22155508	Lakshmi Areekath, Gaurav Lodha, Subham Kumar Sahana, George B., Ligy Philip, and Subhas Chandra Mukhopadhyay (2022)
Transformation of imine cage to covalent organic framework film at the liquid-liquid interface	*Angew. Chem. Int. Ed.* 2023, *e202219083 (Just accepted)*	Arkaprabha Giri, G. Shreeraj, TapasKumar Dutta, Abhijit Patra*
Pyridinium-functionalized ionic porous organic polymer for rapid scavenging of oxoanions from water	*Manuscript communicated (Manuscript ID: marc.202300138)*	Mr. Shibashis Nayak, Mr. Aniket Sahoo,Ms. G Swarna Naidu, Mr. Arkaprabha Giri*, and Dr. Abhijit Patra*
Nanocellulose reinforced organo-inorganic nanocomposite for synergistic and affordable defluoridation of water and an evaluation of its sustainability metrics	ACS Sustainable Chem. Eng. 2020, 8, 1, 139-147 (DOI: 10.1021/acssuschemeng.9b04822	Sritama Mukherjee, Haritha Ramireddy, Avijit Baidya, A. K. Amala, Chennu Sudhakar, Biswajit Mondal, Ligy Philip, and Thalappil Pradeep
Scalable drop- to-film condensation on a nanostructured hierarchical surface for enhanced humidity harvesting	ACS Appl. Nano Mater., 2021 (DOI: 10.1021/acsanm.0c03032	Ankit Nagar, Ramesh Kumar, Pillalamarri Srikrishnarka, Tiju Thomas and Thalappil Pradeep
A covalently integrated reduced graphene oxide-ion exchange resin	Adv. Mater. Interfaces, 2020 (DOI:	Md Rabiul Islam, Soujit Sen Gupta,

electrode for efficient capacitive deionization	10.1002/admi.202001998)	Sourav Kanti Jana, Pillalamarri Srikrishnarka, Biswajit Mondal, Sudhakar Chennu, Tripti Ahuja, Amrita Chakraborty and Thalappil Pradeep
A smartphone-based fluoride-specific sensor for rapid and affordable colorimetric detection and precise quantification at sub-ppm levels for field applications	ACS Omega, 5 (2020) 25253–25263 (DOI: 10.1021/acsomega.0c03465)	Sritama Mukherjee, Manav Shah, Kamalesh Chaudhari, Arijit Jana, Chennu Sudhakar, Pillalamarri Srikrishnarka, Md Rabiul Islam, Ligy Philip and Thalappil Pradeep
Aminoclay-graphene oxide composite for thin-film composite reverse osmosis membranes with unprecedented water flux and fouling resistance	Adv. Mater. Interfaces, 2021, 2100533. (DOI:10.1002/admi.202100 533)	Md Rabiul Islam, Pratishtha Khurana, Pillalamarri Srikrishnarka, Ankit Nagar, Madhuri Jash, Shantha Kumar Jenifer, Mohd Azhardin Ganayee, Mathava Kumar and Thalappil Pradeep
Industrial utilization of CDI technology for removal of fluoride and toxic species ($As^{3+}/^{5+}$ and Pb^{2+})	Global Challenges, 2022, 2100129. (DOI: 10.1002/gch2.202100129)	Md Rabiul Islam, Soujit Sen Gupta, Sourav Kanti Jana and Thalappil Pradeep
Ion-exchanging graphemic nanochannels for macroscopic osmotic energy harvesting	ACS Sustain. Chem. Eng., 2022. (DOI: 10.1021/acssuscheme ng.2c04138	Ankit Nagar, Md Rabiul Islam, Kartheek Joshua, Tanvi Gupte, Sourav Jana, Sujan Manna, Tiju Thomas, and Thalappil Pradeep
A resource-efficient and portable nanotechnology-enabled disinfection system: Performance studies and a novel strategy to recycle spent material	*Process Safety and Environmental Protection*, 171, 2023, 532-540	Uthradevi Kannan, and Shihabudheen M. Maliyekkal
Feasibility of surface dielectric barrier discharge in wastewater treatment: Spectroscopic modeling, diagnostic, and dye mineralization,	*Separation and Purification Technology*, 296, 2022, 121344.	S. M. Allabakshi, P.S. N. S. R. Srikar, R. K. Gangwar, S. M. Maliyekkal

Protein-based metal bio-cleaner for detoxification of wastewater	Journal of chemical technology and biotechnology 2022 v.97 no.9 pp. 2581-2591	Valappil Sisila, Asuma Janeena, Suresh Prem, Pachaiyappan Mohandass, Jayaraman Narayanan, Shanmugam Easwaramoorthi, Shanmugam Ganesh, Numbi Ramudu Kamini, Niraikulam Ayyadurai
Green and cost-effective synthesis of 2D and 3D Graphene-based nanomaterials from *Drepanostachyum falcatum* for Bio-imaging and Water purification applications	Chemical engineering journal advances https://doi.org/10.1016/j.ceja.2022.100265	Chetna Tewari, Gaurav Tatrari, Sumit Kumar, Sandeep Pandey, Anita Rana, Mintu Pal, Nanda Gopal Sahoo
Mechanistic insights into carbo-catalyzed per-sulfate treatment for simultaneous degradation of cationic and anionic dye in multicomponent mixture using plastic waste derived carbon	Journal of Hazardous Materials https://doi.org/10.1016/j.jhazmat.2022.128956	Sumit Kumar, Chetna Tewari, Nanda Gopal Sahoo, Ligy Philip*,
Environmental application of amine functionalised magnetite nanoparticles grafted graphene oxide chelants	Environmental Science and Pollution Research https://doi.org/10.1007/s11356-022-21407-3	Prateekshya Suman Sahu, Ravi Prakash Verma, Chetna Tewari, Nanda Gopal Sahoo, Biswajit Saha
A novel, efficient and economical alternative for the removal of toxic organic, inorganic and pathogenic water pollutants using GO-modified PU granular composite.	Environmental Pollution https://doi.org/10.1016/j.envpol.2023.121201	Prateekshya Suman Sahu, Ravi Prakash Verma, Ajinkya Hariram Dhabade, Chetna Tewari, Nanda Gopal Sahoo, and Biswajit Saha.
Effect of pH, Salinity, Dye, and Biomass Concentration on Decolourization of Azo Dye Methyl Orange in Denitrifying Conditions	Water 2022, 14 (22), 3747. https://doi.org/10.3390/w14223747	Aditi Trivedi, Desireddy Swathi, Sabumon Pothanamkandathil Chacko (2022)
Development and long term operation of aerobic granular system for simultaneous removal of COD, nitrogen, and phosphorous in a conical SBR	Environmental Engineering research, 28(3): 220015. DOI:10.4491/eer.2022.015.	Desireddy Swathi, Sneha Madhavan, Sabumon P.C (2023)
A Review on the Stability, Sustainability, Storage and	Water 2023, 15, 950.	K.S. Shameem and P.C. Sabumon

Rejuvenation of Aerobic Granular Sludge for Wastewater Treatment	https://doi.org/10.3390/w15050950	(2023).
Emerging Biotechnological Processes in Controlling Nitrogen Pollution to Minimize Eutrophication of Surface Waters in Asia	Environmental Degradation: Challenges and Strategies for Mitigation. pp 125–147, Water Science and Technology Library, vol 104. Springer, Cham, 2022.	Sabumon Pothanamkandathil Chacko (2022)
Continuous and discrete operation of water distribution networks.	*Optim Eng* (2023). https://doi.org/10.1007/s11081-022-09787-4	Velmurugan, S., Kurian, V. & Narasimhan, S

Communicated and under review

Title of the paper	**Journal, Issue, etc.**	**Authors**
Assessment of the impact of sea level rise on groundwater resources using groundwater flow modelling for Chennai city (under preparation)		Anna University
Modelling the dynamics of land use land cover and its impact on groundwater recharge in and around Chennai metropolitan city with policy recommendations (Submitted)		Anna University
A multi-reservoir optimization approach for mitigating floods and managing water resources in a fast-growing metropolis in India (under Preparation)		Anna University
Evaluation of infiltration based LIDs for urbanizing coastal catchments of Chennai City, India - A case study	Under review	Bagya Lakshmi, Rutwik Borkar, and Narasimhan,B.
Development of Multi-layer Green-Ampt Infiltration Based Modelling Framework for Low Impact Development Techniques Measures	Under review by "*Water Research*"	Sreethu, S., Narasimhan, B., and S. Murty Bhallamudi
Process optimization of Microbial Fuel Cell (MFC) with Conventional Proton Exchange Membranes (PEM's) through Factorial Design Approach	Sustainable energy technologies and assessments (Communicated)	Sathiskumar P., N. Baskar., Bharathirajan S., Nilavu B., Parthiban P., and Das, A
Parametric Optimization and performance assessment of graphene impregnated polyaniline	Research Journal of Chemistry and Environment (Under	Ponmani P., Nilavu B., Parthiban P., Mahesh R., Sivanantham M., Tewari C., Sahoo N.G and Das, A

coated electrode based Microbial Fuel Cell using mixed culture obtained from Canteen wastewater	Review)	
Technological solutions for water sustainability: challenges & prospects; Chapter 6: Function-leddesign of porous organic materialsfor water treatment	*IWA Publishing (Submitted)*	Arkaprabha Giri, G. Shreeraj, AniketSahoo, Abhijit Patra*
Influence of water quality parameters on point-of-use silver-based disinfection system: An unrivalled effect of bicarbonates (In Peer review)	RSC Environmental Science: Water research & Technology (under review)	Uthradevi Kannan, Gayathri Pullangott, Nikita Shraogi, P. Amesh, Satyakam Patnaik, and S.M. Maliyekkal
Combustion-based graphene oxide is a bulk production technique for the practical removal of U(VI) from groundwater (to be communicated soon)	Chemical Engineering Journal (Under review)	T. Pushparaj Gandhi, S Gomosta, P. Amesh, Naga Jyothi M.S.V, and Shihabudheen M. Maliyekkal
Electrochemical sensor based on one-step covalently L-Cysteine–Graphene oxide on Glassy carbon electrode detection of arsenic (III)	Manuscript under preparation	Narayanan Jayaraman, Raghava Rao Jonnalagadda and Easwaramoorthi Shanmugam
Development of Mesoporous Carbon Composites with Waste Plastics Derived Graphene and Mno2 for Supercapacitor Applications	Environmental Science and Pollution Research (Communicated)	Chetna Tewari, Gaurav Tatrari, Sumit Kumar, Mayank Pathak, Sunil Dhali, Biswajit Saha, Yong Chae Jung, Prithu Mukhopadhyay, Nanda Gopal Sahoo
Classification and management of waste via upcycling into value added nanomaterials for water remediation	Waste management strategies, challenges and future directions (Published by Nova Science Publishers, Inc. New York,	Chetna Tewari, Sandeep Pandey, Sumit Bhardwaj, Nanda Gopal Sahoo
Emerging carbon-based nanocomposites for the removal of hazardous materials	Submitted	Chetna Tewari, Sumit Kumar, Biswajit Saha, Yong Chae Jung and Nanda Gopal Sahoo
Carbon-based filters for water and wastewater treatment	Submitted	Vajitha, Chetna Tewari, Madan Kisan Pradhan, Shihab Nanda Gopal Sahoo
Water Pollution Abatement using waste-derived materials: A sustainable approach	Submitted	Vaishali Choudhary, Sumit Kumar, Chetna Tewari, Nandagopal Sahoo, and Ligy Philip

Managing waste plastic by conversion of carbon-based nanomaterials for water treatment and supercapacitor applications	Submitted	Chetna Tewari, Gaurav Tatrari, Nanda Gopal Sahoo, Prithu Mukhopadhyay*
Effect of initial inoculum in symbiotic bacterial – microalgal system and its optimization for the treatment of tannery wastewater	Under review (Journal of Environmental management – Elsevier)	V. Nagabalaji, P. Maharaja, R. Nishanthi, G. Sathish R. Suthanthararajan, S. V. Srinivasan*
Effect of Cycle time on the acclimatization of bacterial consortia for removal of organics, nitrogen and degradation of protein associated to tannery wastewater using Aerobic sequential batch reactor (ASBR)	Communicated – (Environmental Science & Technology – ACS publications)	Nagabalaji, Karthik Shankar, Sneka S, Maharaja P, S V Srinivasan*,
Removal of Sulphur and residual nitrogenous compounds from SBR treated tannery wastewater	Will be communicated shortly	-

15. Presentations in Symposia/ Conferences during the period

Title of the paper presented	**Symposium/ Conference**	**Dates of the Symp/Conf.**	**Authors**
Stepwise calibration against sub-flows and validation of extreme flow events using Mike 11 NAM	International Conference on Water and Environmental Management WEM-2022 - CWRDM - Kerala	22 - 24 June 2022	Rinisha Kartheeshwari M and Elango L
Assessing the significance of Water resource management in improving the socio-economic and environmental status of a fast-growing urban community: A case study from Southern India.	IAHS 2022 XI scientific assembly, Montpellier	29 May - 3 June 2022	Rinisha Kartheeshwari M and Elango L
Delineating groundwater recharge potential zones for Chennai city	One-Day National Seminar on Advances in Water Resources Planning and Management, IITM, Chennai	22 May 2022	Razi Sadath, P V and Elango L
Rainfall-Runoff modelling for Chembarambakkam Sub-catchment of Adyar basin concerning climate	First International Conference on Circular Economy for Sustainable Water	23-25 March 2022	Rinisha Kartheeshwari M Razi Sadath P V and Elango L

change using MIKE11 NAM	Management by Prospective Center of Excellence (pCoE) on Water & Sustainability Indian IIT Madras, India in virtual mode		
Flow modelling of Chennai's Adyar sub-basin to predict and manage the extreme weather events using MIKE SHE	38th and 39th AHI Annual National Seminar on Hydrology, Focal theme Changing Climate and Extreme Hydrological Events in virtual mode	24 - 26 February 2022	Rinisha Kartheeshwari M and Elango L
Land use land cover change detection and future prediction for Chennai city	38th & 39th AHI seminar on 'Hydrology' with focal theme on "Changing Climate and Extreme Hydrological Events", Andhra University, Visakhapatnam,	24 - 26 February 2022	Razi Sadath P V and Elango L
Challenges and opportunities for storage and infiltration based LIDs in coastal catchments of Chennai, India.	12th Urban Drainage Modelling Conference, California	January 2022	B.Palanisamy, R.Borkar, K. Modi, S.Sreethu, S. Shaurabh and B.Narasimhan.
Analysis of the long-term performance of sustainable practices using SWMM and HYDRUS-1D coupled model	First International Conference on Circular Economy for Sustainable Water Management	March 2022	K. Modi and B.Narasimhan
Site Suitability Analysis with GIS and Multi-Criteria approach for Sustainable urban Drainage System (SuDS) components.	First International Conference on Circular Economy for Sustainable Water Management	March 2022	Arun RS and Narasimhan.B
Development of LID process modules for SWAT to enable planning and assessment of basin scale sustainable practices.	First International Conference on Circular Economy for Sustainable Water Management	March 2022	Sreethu, S., Narasimhan, B., and S. Murty Bhallamudi
Simplified Process Model Representation of Low Impact Development Techniques for Watershed Scale Analysis.	23rd Congress of The International Association for HydroEnvironmental Engineering and Research – Asia Pacific Division	December 2022	Sreethu, S., Narasimhan, B., and S. Murty Bhallamudi
Attenuation and Fate of Pharmaceutically Active Compounds in the Baffled Constructed Wetland	1st International Conference on Circular Economy for Sustainable Water Management 2022	23rd – 25th March 2022, IIT Madras (Online)	Manthiram Karthik Ravichandran and Ligy Philip

Treating Greywater"			
Ultrasound-assisted sorptive removal of textile dyes using low-cost bamboo-derived biochar	1st International Conference on Circular Economy for Sustainable Water Management 2022	23rd – 25th March 2022, IIT Madras (Online)	Sumit Kumar and Ligy Philip*
Enhanced removal of pharmaceutically active compounds using biochar derived from various agricultural waste	1st International Conference on Circular Economy for Sustainable Water Management 2022	23rd – 25th March 2022, IIT Madras (Online)	R. Nishanthi[1], Sumit kumar[2], G. Sathish[1], Nagabalaji[1], Ligy Philip[2], S.V. Srinivasan[1*]
Removal of Emerging Contaminants Using Engineered Natural Treatment Systems	First International Conference on "Water for Life 2022"	IIT Madras, India, 15th – 17th December 2022	Ligy Philip and Manthiram Karthik Ravichandran
Effect of various physical activation on plastic-derived char to boost activation of peroxymonosulfate	CESE-2022 The 15th CESE Conference	27 Nov. – 1 Dec. 2022	Sumit Kumar & Ligy Philip
Wastewater Recycling for Indirect Potable Reuse: Technologies and Approaches for Risk Reduction	13th IWA International Conference on Water Reclamation and Reuse	Chennai, INDIA, 15th – 19th January 2023	Ligy Philip and M.R. Jaishankar
Risk Management Associated with Loading of Emerging Contaminants in Waterways	13th IWA International Conference on Water Reclamation and Reuse	Chennai, INDIA, 15th – 19th January 2023.	V. Choudhary and Ligy Philip
Performance of Pilot Scale Hybrid Constructed Wetland for Greywater Treatment	13th IWA International Conference on Water Reclamation and Reuse	Chennai, INDIA, 15th – 19th January 2023.	M. K. Ravichandran and Ligy Philip
Preporous Molecules to PorousOrganic Polymers: SelectiveScavenging of Organic MicropollutantsThrough Sorption and Nanofiltration	The international conference, 'Water for Life' organized by IIT Madras. (Best Poster Award)	Poster presenta tion:15-18th December, 2022	ArkaprabhaGiri, AbhijitPatra
Nanomaterials for water treatment	Water for life	Dec 15-17, 2022	Prof. T. Pradeep
Removal of Se(IV) and Se(VI) from water by a Chitosan-AlOOH granular adsorbent	International Congress on Separation and Purification Technology	10-14 December, 2022	M.S.V. Naga Jyothi, P. Amesh, B.J. Ramaiah, and S.M. Maliyekkal
Fe-Mn binary oxides granules for mercury removal from water	First International Conference on Circular Economy for Sustainable Water Management	23-25th March 2022, IIT Madras	M.S.V. Naga Jyothi, and S.M. Maliyekkal

	(SuWaM- 2022)		
A scalable and affordable method for production of graphene oxide: Application in the removal of aqueous uranium.	Roorkee Water Conclave	March 02-04, 2022, IIT Roorkee	T. Pushparaj Gandhi, S Gomosta, S Sengupta, S. M. Maliyekkal.
Multiplex Electrochemical Sensor for Metal Ions using Covalent Dual Functionalization of Graphene Oxides	Water for Life An International conference- 2022	Dec 15-17 2022	Narayanan J., Raghava R. J., and Easwaramoorthi S.
Development of waste plastic derived reduced graphene oxide and its composites with Fe_3O_4 for removal of drugs from water samples	An International Conference on Water for Life, IIT Madras, Chennai, India	15-17th December, 2022	Chetna Tewari, Tanuja Arya, Nanda Gopal Sahoo*
Development of hybrid biological treatment system for composite tannery effluent	Water for life, an international conference - 2022 held at IIT madras	December 15-17, 2022	V.Nagabalaji, P.Maharaja, R. Nishanthi, G. Sathish, U.Sathya, S.V. Srinivasan*
Data driven approach for equitable water supply	CCWI –WSDA 2022	July 2022	R Adhityan, V. Kurian, Sridharakumar Narasimhan
Data Driven Model for Optimal Scheduling and Parameter Estimation of Water Distribution Networks	ICC 2022	Dec 14-16, 2022	Akshaya Venkataramanan, Sridharakumar Narasimhan
Comparison of continuous and discrete operation	SIAM OPT 23		Varghese Kurian and Sridharakumar Narsaimhan

16. Patents Filed during the period: (Copyright filed)

Sl.no	Title	Inventors	Filed on	Granted
1	Solar and wind augmented Composter	Ashutosh Das, TTM. Kannan, P. Parthiban	341584-001	Granted
2	Paper sensor for detection of phosphate in water and wastewater	Philip, L. Choudhary, V., & Vellingiri, K	406442.(2022)	Granted
3	Layered double hydroxide-based electrochemical system	Philip, L. Choudhary, V,	2242	Provisional filing

	for phosphate recovery from wastewater.			
4	A Non- Intrusive Flow Measurement Method Using Inductive Proximity Sensing Technology for Pipelines and Open Channels	Harija H., Boby George, and Arun T	202241041886, 21/07/2022).	Granted
5	Simple direct microcontroller interface for capacitively-coupled resistive sensors	Lakshmi A., Boby George, and Ferran R.,	(202041021691, 22/05/2020).	Granted
6	A Planar Coil-Based Water Level and Quality Monitoring System	Gaurav L., Subham K. S., and Boby George, Subhas C. Mukhopadhyay and Ligy Philip	201941021491, 24-July-2019	Granted
7	A smartphone integrated fluoride-specific sensor for rapid and affordable colorimetric detection,	T. Pradeep, S.Mukherjee, K.Chaudhari, M.Shah	202041026054 June 20, 2020.	
8	An Integrated CDI Electrode	T. Pradeep, Md R. Islam, S. S. Gupta, P. Srikrishnarka, S. K. Jana	US Patent no.: US20200331778A1 October 22, 2020.	Granted
9	An Integrated CDI Electrode	T. Pradeep, Md R. Islam, S. S. Gupta, P. Srikrishnarka, S. K. Jana	PCT patent no.: WO2019130355A1 July 4, 2019.	Granted
10	A point-of-care (POC) ampherometric device for selective arsenic sensing	T. Pradeep, S. K. Jana, K. Chaudhari, and Md R. Islam	202041023576 June 5, 2020	
11	A compact, modular and scalable continuous-flow greywater sink for potable and non-potable uses	T. Pradeep, A. Nagar, Md R. Islam	202141054715 November 26, 2021	
12	Material and method for sustainable and affordable atmospheric water harvesting	T. Pradeep, A. Nagar, S. Seth	August 29,2022	
13	Graphene based nanomaterials derived from Drepanostachyum	Nanda Gopal Sahoo, Chetna Tewari, Gaurav Tatrari,	202111031289 30 March 2022	Granted

	falcatum for water Purification	Sandeep Pandey, Anita Rana, Himani Tiwari, Anirban Dandapath		

17. Other Achievements during the Period:

(i) Collaboration with CMWSSB

As part of the research and development activities, Water-IC for SUTRAM of EASY WATER has resolved to study the pressing problems related to water supply in Chennai city, in collaboration with Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB). A brainstorming session was conducted on how the academic consortium members can get involved with governmental agencies (CMWSSB, Tamil Nadu Water Supply and Drainage Board (TWAD), Public Works Department (PWD), Pollution control board, etc.) to come up with a Sustainable water management plan for Chennai city (on 19th July 2019). The session brought out the holistic planning and management of water taking into account short-term and long-term issues (emerging contaminants, increase in total dissolved solids in closed systems, climate change impact on surface and subsurface water sources, the impact of land use on inflows into the storage, impact on urban flooding, etc.).

In this regard, the center has provided specific recommendations on the appropriate location and technologies for sewage treatment, monitoring the quality of the recovered water, the impact of using existing lakes/quarries as storage facilities, and policy on source augmentation. In addition, the center is jointly working with CMWSSB for the quality analysis of water from various quarries around Chennai city regarding the source augmentation. The consortium also provides recommendations and strategies on how to access the amount of Non-Revenue Water and quantify losses in the distribution system. As part of this, the center is helping in identifying the appropriate choice of meters for measuring the quality of water supplied to consumers (including transmission and storage of the data). The center wishes to make the best efforts to provide knowledge and information to the decision-makers and public utilities, which would help them in their untiring efforts to provide safe drinking water to all.

The suggestions provided by Water-IC for SUTRAM of EASY WATER (Ligy Philip, IIT Madras) have been accepted and a new 30 MLD plant is going to be commissioned soon for tertiary treatment of wastewater. The treated wastewater will be stored and integrated with other sources of water in the water supply system.

(ii) Urban Drainage and Flood Risk in Chennai Metro

The ongoing works in flood mitigation aspects are being discussed by Anna University (Prof. L. Elango) with the "Advisory Committee on mitigation and management of flood risk in Chennai metro" for implementation.

Prof. Balaji Narasimhan is part of the apex body, advising the honorable Chief Minister of the State of Tamil Nadu on matters of drainage systems and flood protection. Many of the ideas regarding sustainable drainage systems being evolved as part of SUTRAM project are being discussed.

(iii) Book Publication

1. **Book "Waste strategies, challenges and future directions";** edited by Prof. Nanda Gopal Sahoo has been published by Nova Science Publishers, Inc. New York, ISBN: 9781685073947.

2. An edited book: **"Technological Solutions for Water Sustainability: Challenges & Prospects – Towards a water secure India"** (Editors: Ligy Philip; T. Pradeep and S. Murty Bhallamudi) has been accepted for publication by the **International Water Association (IWA).** All the faculty members from all the Institutes / Organizations associated with the **WATER-IC of SUTRAM for EASY WATER** are contributing to this book comprising 26 Chapters. The research outcome from the project are highlighted in this book. This book will be published before December 31, 2023.

(iv) Inter-Institutional Collaborative Work

- *Solvent knitted triptycene-based polymer-based adsorption study for pharmaceutical removal (IIT Madras & IISER Bhopal):* Solvent knitted triptycenes polymers (SKTP) were synthesized by the IISER Bhopal research group and the IIT Madras research group conducted the adsorption experiments for the removal of CBZ, a persistent pollutant. The experiments were conducted using 0.1 g/l of adsorbent dose and 50 mg/l of CBZ. The kinetic and equilibrium plots are shown in figure-3 and the model fitting parameters are tabulated in table-1.The PSO kinetics fitted with the highest regression coefficient inferring chemisorption and the rate constant was 7.48. The Freundlich isotherm fitted well for CBZ and the maximum adsorption capacity was 1046 mg/g. It indicates a heterogeneous surface with multilayer adsorption.

- *Synthesis of various agricultural waste-derived biochar for textile dye removal (IIT Madras & CSIR-CLRI Chennai):*
  Four different agricultural wastes were chosen such as coconut shell, tender coconut, banana flower, and sugarcane bagasse. All these materials were pyrolyzed and biochar synthesized and named CS, TC, BF, and SB respectively. The adsorption capacity was evaluated by adsorption studies

carried out for three textile dyes i.e., methylene blue (MB), and methyl orange (MO). The experimental data were fitted with different kinetic models and isotherm models.

- *Kumaun University (Prof. N. G. Sahoo)*

1. USERC Young Women Scientist Excellence Award 2022-2023: Uttarakhand Science Education and Research Center, Uttarakhand government, India.
2. Young Scientist award 2022: National Conference on "Environmental Challenges for Sustainable Development", S.L.P. Govt. College Morar, Gwalior, India, 26-27th March, 2022.
3. Best Poster award 2022 (1st Prize): Waste to wealth: A green and sustainable approach to develop carbon based nanomaterials for bioimaging and water purification". National Conference on "Environmental Challenges for Sustainable Development", S.L.P. Govt. College Morar, Gwalior, India, 26-27th March, 2022.
4. Prof. D.D. Pant Research Award, Kumaun University, Nainital 2022.
5. Prof. K.S. Valdiya Research Award, Kumaun University, Nainital 2022.

- *Kumaun University (Prof. N. G. Sahoo) and IIT-Madras (Prof. Ligy Philip):* Collaborative research is being carried out for better outcome of the project (SUTRAM). In this collaboration work, the organization "Kumaun University" worked on the development of carbon nanomaterials from various solid waste materials as well as its modification and optimization for water purification. The collaborated institute (IIT-Madras) is studying their performance for metals removal and other studies. IIT Madras facilitates characterizations facilities for the developed materials which will help to achieve target of the project timely.

- *Kumaun University (Prof. N. G. Sahoo) and PRIST University (Prof. Ashutosh Das):* Kumaun University is engaged in developing carbon nanomaterials and Prof Das group's is using our materials for their water research work. They used our material for development of polyaniline graphene impregnated cotton fabric electrode based low-cost Microbial Fuel Cell using mixed culture obtained from Canteen wastewater.

- *Kumaun University (Prof. N. G. Sahoo) and IITR-Lucknow (Dr. Satyakam Patnaik)*

  Collaborative work is being carried out for toxicology study of carbon nanomaterials from different sources. IITR is doing a toxicology study of waste plastic and agricultural waste derived graphene based materials (provided by Kumaun University) to ensure that the materials are safe in nature and can be utilised for water treatment.

- *Kumaun University (Prof. N. G. Sahoo) and CLRI-Chennai (Dr. S. Easwaramoorthi)*
They are exploring the possibility of developed waste derived graphene as a base for sensors as well as other applications.

- *Kumaun University (Prof. N. G. Sahoo) and CSIR (Dr. S. V. Srinivasan)*
Prof. Sahoo is working with Dr. S. V. Srinivasan (CSIR) for the development of graphene based materials from biochar provided by him. CSIR has sent different types of materials (as a carbon source) to KumaunUniversity and KU is trying to optimize all the parameters for their up conversion into carbon nanomaterials.

- *IITR Lucknow and IIT Tirupati*
They are working together on Chitosan-RGO-Ag nanocomposite films for disinfection of water. Cytotoxicity assay (MTT) is being carried out to determine the effective concentration of IC50 of the leachate sample.

- *IISER Bhopal*

  Recent work on ‘Cage-derived COF film for the separation of organic micropollutants’ was highlighted in leading Indian dailies like The Hindustan Times, The Hindu, The Free Press Journal, The Hindu Business Line, Careers360, Prabha Sakshi, Business World – Education.

18. Financial Status on the Day of Reporting:

18.1 Amount Sanctioned: Rs: **8,93,56,849/-**

18.2 Amount Received: Rs: **7,32,45,513/-**

18.3 Manpower Sanctioned: **SRF – 10, JRF – 2, Project Coordinator – 1**

18.4 Manpower in position: **SRF – 10, JRF – 2, Project Coordinator - 1**

19. Status of Shortfalls of all the preceding Reviews:

Activity	**Shortfall (*if any*) in Specific**	**Responsible Organization**

	Terms	
	All our technologies developed so far are installed at site. New sensors developed for fluoride will be used where CDI is used. More involvement with collaborators has been initiated.	IIT Madras

Signature of the PI:

Name of the PI: Prof. Ligy Philip

Place: IIT Madras

Date:25.4.2023

ANNEXURE

Appendix-A: Water Treatment

A1: Risk Dynamics of Emerging Contaminants and Heavy Metals in the River Ecosystems

The contamination of surface water with several micropollutants (MPs) having the potential of creating ecological and human health risks has been well verified (Patel et al. 2019, Quadra et al., 2017; Strenge and Chamberlain, 1995). In the country-specific scenario, no investigation has been carried out to understand the migration of PPCPs from surface water to drinking water or water supply and the risk associated. The toxicological risk evaluation of MPs is a viable approach to water safety and management plan. Such systematic investigation facilitates a better understanding of MPs' occurrence, fate, and transport at different water sources. At the same time, assessment of potential human health and ecological risk through the exposure of MPs aids the regular monitoring and regulatory processes in identifying target pollutants (Topaz et al. 2020). Accordingly, the present study was conducted to determine the ecological, human health, and microbial risks for MPs, including PPCPs and HMs. The risk evaluation was carried out for two seasonal variations at wastewater discharge points and freshwater intake points (Figure A1). Additionally, the migration of PPCPs to the food chain and the risk involved was assessed to estimate the potential hazards in the Cauvery River Basin and surrounding areas.

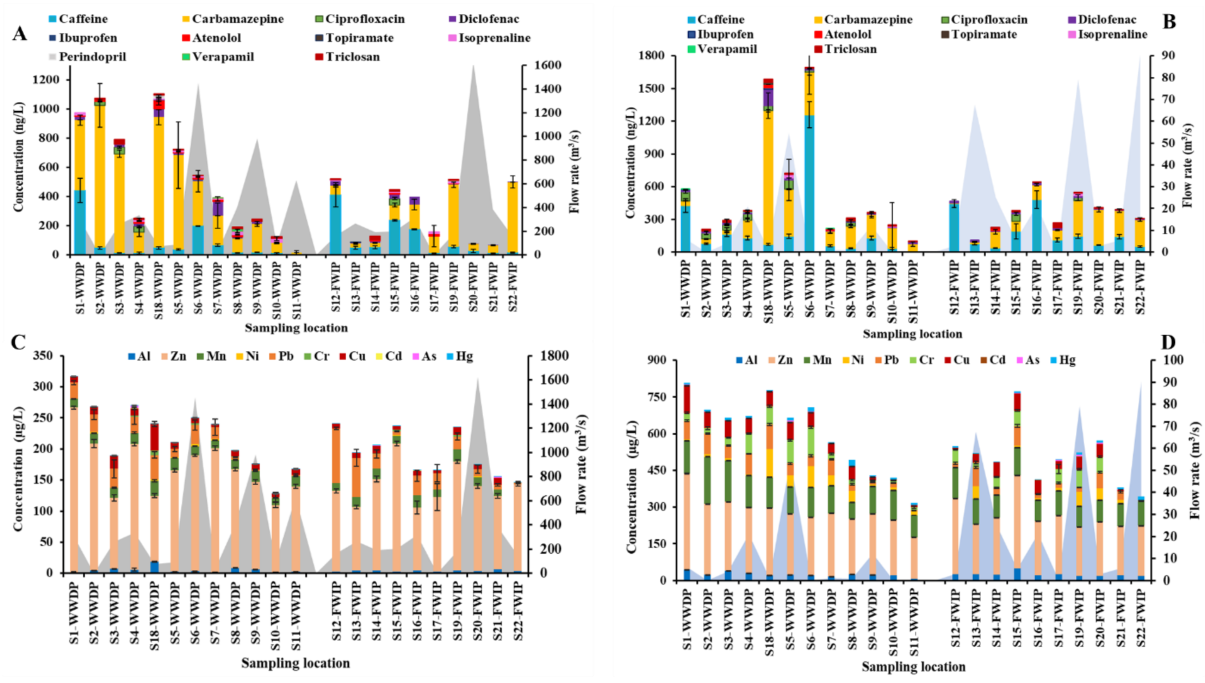


Figure A1. Spatial and Temporal Variation of PPCPs and HMs at various sampling sites. Panel (A) Pre Monsoon concentration of PPCPs with the area under the curve as flow rate, Panel (B) Post Monsoon concentration of PPCPs with the area under the curve as flow rate Panel, Panel (A) Pre Monsoon concentration of HMs with the area under the curve as flow rate, Panel (B) Post Monsoon concentration of HMs with the area under the curve as flow rate Panel water intake points FWIPS

A.2 Assessment of Adsorption of Pharmaceuticals and Personal Care Products on Carbonized Absorbent Derived from Waste

The study was conducted to synthesize low-cost carbonaceous adsorbent from waste litter. The synthesized adsorbent was explored to understand the translation of adsorbent properties that govern the removal of PPCPs. The synthesized material was characterized using FTIR, Raman, and XRD, surface area, point of zero charges to deduce the presence of organic functional group and crystal structure. The point of charge of 6.5 and extensive -OH functional groups aided the capture of PPCPs. The crystalline structure showed an exclusive peak of 24.3° representing the presence of graphene- graphite structure. The sorption studies in the initial stage were carried out as single component batch systems to estimate the adsorption capacity, equilibrium time, pH effect, and possible removal mechanism. The maximum adsorption capacity was found to be 61-24 mg/g, which varied based on the nature of adsorbate. The equilibrium time for removing all the four-target compound was obtained as 5 h in the pH range of 5-8 (Figure A2).

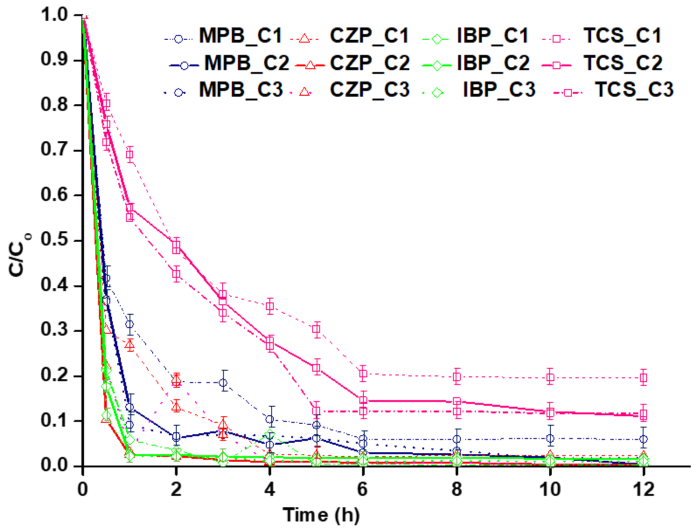


Figure A2. Kinetics study for the removal of target compounds at optimized environmental parameter

A.3 Selective Removal of Phosphate Using a Metal-Organic Framework-Based System

Metal-organic framework-based (MOF) electrodes were developed to remove phosphate ions selectively. MOFs are inorganic-organic hybrid materials assembled from inorganic building blocks as connectors and organic linkers. The properties of removal/ degradation using MOF depend on the central metal atom and organic linker. The central metal atom defines the structural stability, caging, and pore dimension. For our study, the MIL 101 (Fe)- NH2, MIL 101 (Al)- NH2, and UiO66- NH2 were identified as the best option for removing phosphate due to i) water stability, ii) selectivity toward phosphate adsorption and similar molecular diameter. The synthesized MOFs' surface morphology and functional groups were studied using FT-IR, XRD, and SEM analysis (Figure A3). The characteristic peak at 1575 cm^{-1} and 1657 cm-1 verified the presence of the 2-amino terephthalic acid as the linker. The peak at 767 cm, 978, and 576 cm^{-1} confirmed the presence of Fe-OH, Al-OH, and Zr-OH groups in MIL 101 (Fe)- NH2, MIL 101 (Al)- NH2, and UiO66- NH2, respectively. The batch scale adsorption study was carried out to understand the sorption behavior of phosphate on the MOFs. From kinetic and equilibrium study, it was confirmed that the adsorption of phosphate was fast and spontaneous (equilibrium time = 60 min), with Langmuir adsorption capacity as 90.6 mg/g, 81.2 mg/g, 82.0 mg/g for MIL 101 (Fe)-NH2, MIL 101 (Al)- NH2, and UiO66-NH2, respectively (Figure A4**)**. The effect of pH and co-existing ions showed that all three MOFs have high efficiency (removal: 92-85 %) and selectivity to capture phosphate in the pH range of 2-8. On the regeneration of the used adsorbent, it was found that only 1-3 % of the adsorbed phosphate was desorbed. Nonetheless, more than 80 % removal was still obtained by reusing the MOFs for the sorption. This indicates that the sorption of phosphate onto MOF was irreversible, and synthesized MOF has many active sites present that can aid in removing phosphate. To confirm this behavior of MOF, theoretical models, and density functional theory was used, whereby it was found that the bond energy of formation of MOF-phosphate bond is much higher, thus resulting in irreversible sorption of phosphate ions. To understand MOFs' behavior for electrosorption, electrochemical characterization was initially carried out. It was established that all three MOFs have poor conductivity (30-35 F/ g capacitance) and did not show any redox-active nature. Thus, the use of MOFs for the removal and recovery of phosphate ions during CD is not favorable.

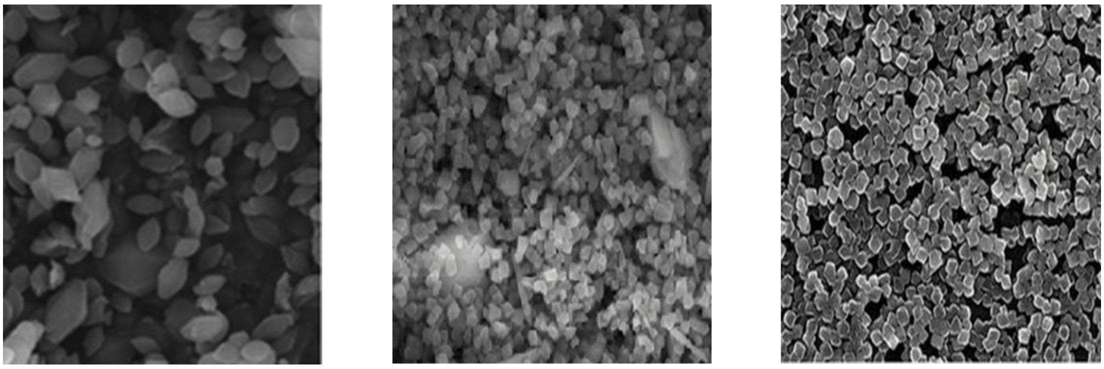


Figure A3. SEM micrograph to study the surface morphology of MIL 101 (Fe) -NH2, MIL 101 (Al) NH2, UiO66 NH2

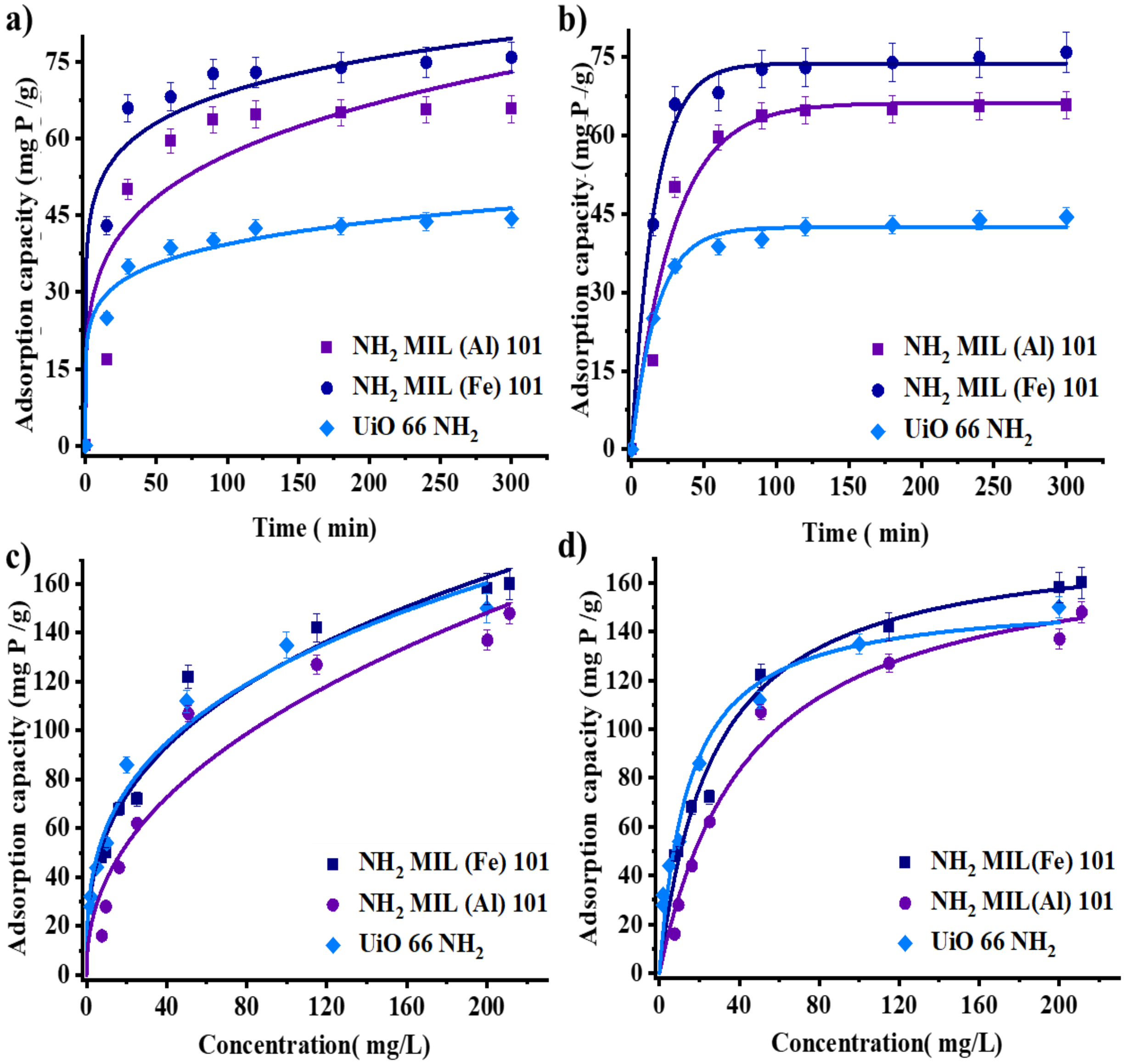


Figure A4. Adsorption kinetics (a, b) fitted to pseudo-first-order (a) and pseudo-second-order model (b), and equilibrium fitted to Freundlich (c) and Langmuir model (d).

A.4 Layered Double Hydroxide-Based Hybrid Capacitive Deionization System to Capture Phosphate

Generally, MOFs tend to have a solid structure and a smooth surface with little porosity, hindering the transmission of electrode materials and ions. Thus, it is not favorable for salt-ion adsorption during CDI. Layered double hydroxides (LDHs) have received increasing attention in electrochemical energy storage and conversion because of their facile tunability, high dispersion of active sites in layers array, and easy chemical modification (Zhao et al., 2017). Moreover, a series of Faraday reactions in the LDH layers due to metal ions like Co, Fe, and Ni contribute to high pseudocapacitance. Previously several LDH-based electrodes like Mg-Al (Hong et al.2019; Zhu et al., 2019), Mg- Fe (Zhu et al., 2019), Mg-Mn (Lai et al., 2019), Ni-Co (Hu et al., 2018) have been reported to capture phosphate ions. However, the major limitations in all the studies mentioned above were a) no discussion about the electrochemical behavior of electrodes, b) electrode materials (LDHs) were either calcinated, or a composite was made with activated carbon; subsequently, electrosorption corresponding to pure LDH was not known, c) sorption mechanism was not investigated d) electro-desorption studies were carried out in eluent like NaOH or NaCl, rather than reversing the potential. With these gaps, the current study is aimed to examine the behavior of Zn-Co-based LDH for the electrosorption of phosphate. The primary conclusion drawn from experiments till now is a) Synthesis of Zn-CO LDH with Cl as the interlayer ion was successful, b) Nearly 60% removal of phosphate (initial concentration 50 mg/L) (Figure A5). was noted at the potential of 1 V in 15 min, c) More than 70 % desorption was noted in 20 min, d) on increasing the potential sorption of phosphate was increased, d) the sorption of co-existing ions followed the order chloride> nitrate> sulfate> phosphate. The lowest removal for phosphate can be due to the small interlayer spacing of Zn-Co-Cl. Future work on a) improving phosphate removal, the effect of pH, and mechanistic investigation needs to be carried out.

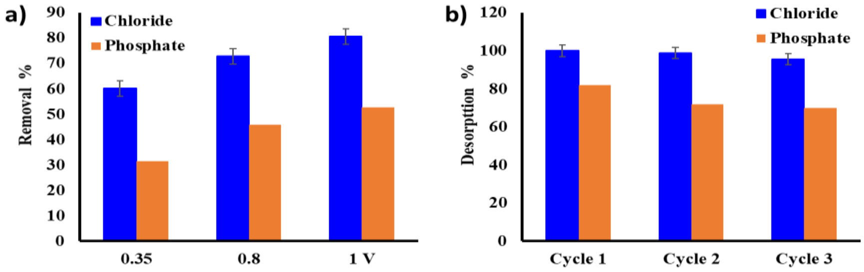


Figure A5. Electrosorption phosphate (50 mg/L) at a potential of 0.8 V (a), desorption of phosphate at 0V (b)

A.5 Performance Evaluation of Pilot Scale Pulse-Power-Plasma Treatment Systems for Pharmaceuticals Degradation

Effect of pulse power plasma on water quality parameters

The effect of plasma irradiation as a tertiary treatment technology is studied and compared with the raw feed water (SBR outlet) quality parameters such as pH, electrical conductivity, and nitrate concentration. The water quality parameters for influent and effluent are tabulated in table A1.

Table A1: Water quality parameters of influent and effluent of the pilot scale pulse power plasma reactor

Parameters	Influent	Effluent
pH	7.8±0.1	8.63±0.13
EC (mS/cm)	2.4±0.73	2.73±0.06
Nitrate (mg/l)	10.76±1.68	15.22±0.13
TOC-CBZ (mg/l) TOC-DCF (mg/l) TOC-CAF (mg/l)	8.63+14.66=23.29 8.63+12.43=21.06 8.63+7.86=16.49	4.90±1.09 7.39±0.94 5.98±0.63
CBZ (mg/l)	1	0.21±0.04
DCF (mg/l)	1	0.28±0.03
CAF (mg/l)	1	0.31±0.08

The pH of the treated water sample is found to be higher (8.63) than that of the influent (7.8) water to the reactors (Refer to fig-A6A). The rise in pH towards the alkaline range is mainly due to the reaction mechanism where hydroxyl radicals are produced which may recombine with the electrons and form hydroxyl molecules. Moreover, the atmospheric nitrogen gets electrons from the plasma and produces nitrate, and increases the nitrate concentration in the treated samples. There are an increase of 5 mg/l of nitrate concentration was found after the treatment (Refer to fig-A6C). Also, the electrical conductivity of the system was increased considerably from 2.4 mS/cm to 2.73 mS/cm (Refer to fig-A6B). The increase in EC of the system indicates the formation of reactive radical species in the system which is favorable for achieving a higher degree of degradation of the pollutants.

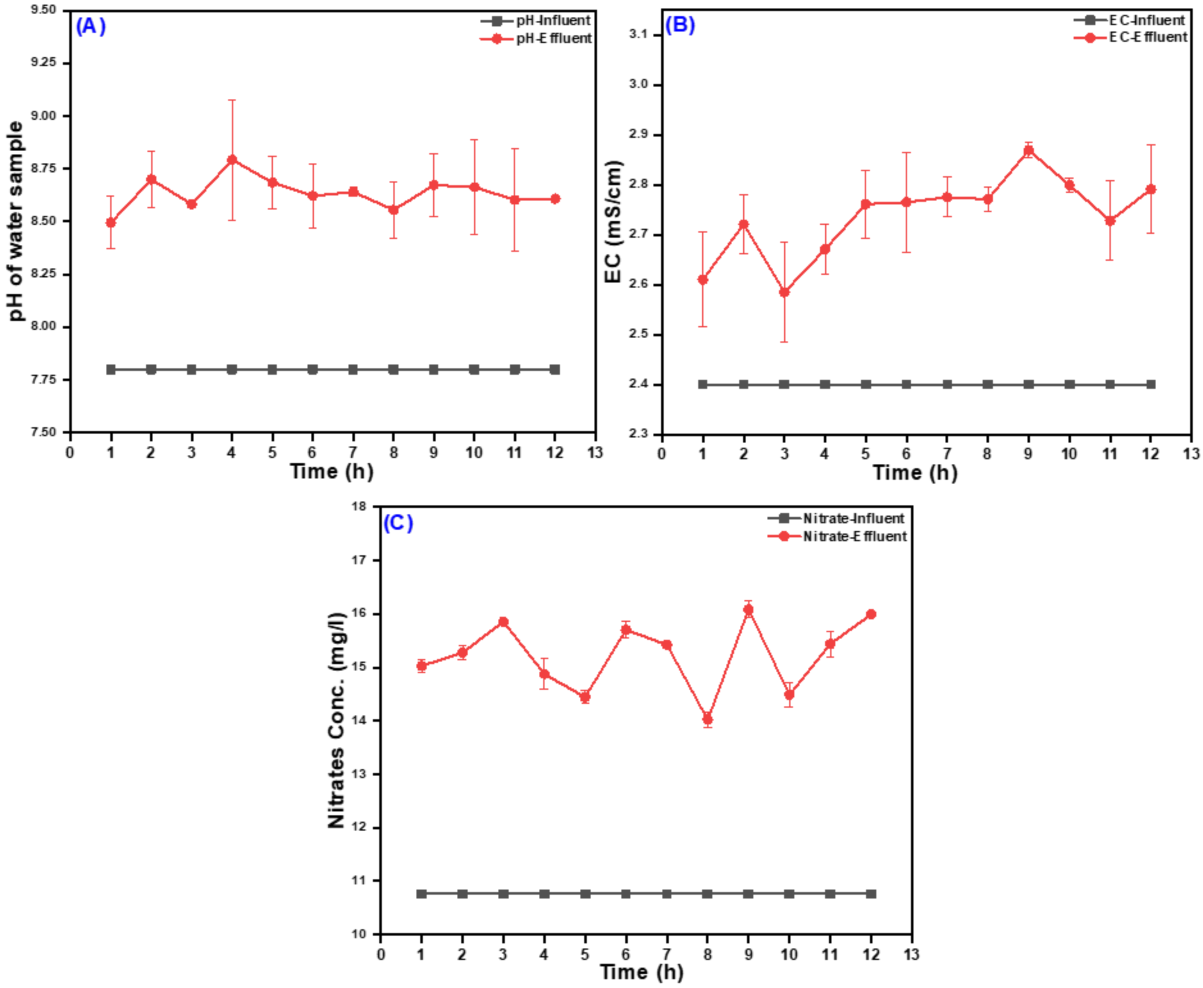
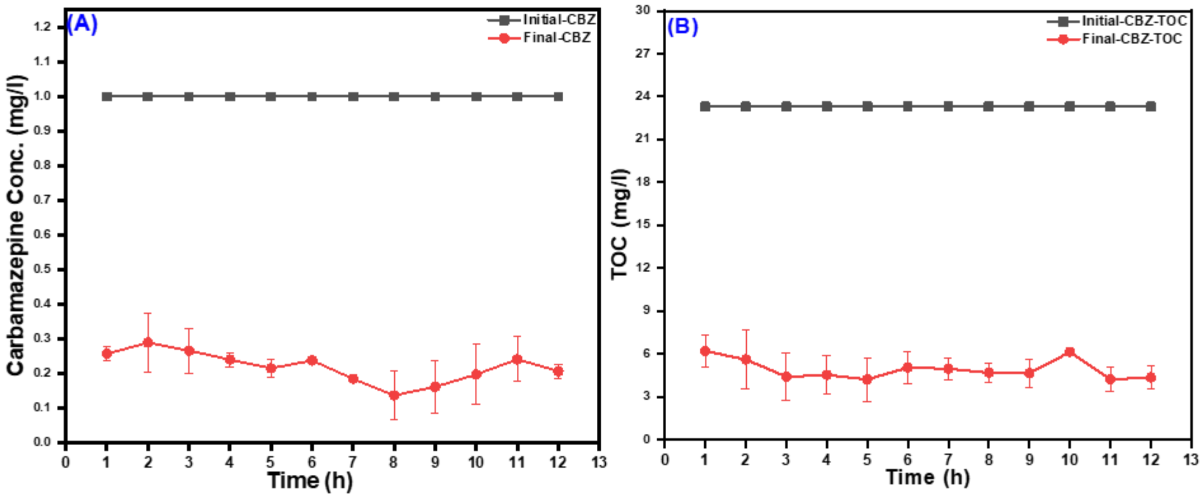


Figure A6: (A) Variation in pH profile of the system with time, (B) Variation of EC of the water samples at a different time of exposure, and (C) the accumulated concentration of nitrate in the sample at different sampling time

Carbamazepine degradation study



The degradation study of the carbamazepine is carried out in pilot-scale plasma reactors with an initial concentration of 1 mg/l in a single pollutant system. The flow rates were fixed at 20 l/h in one reactor while the input voltage and current were fixed at 23 kV and 1.5 kHz respectively. The samples were collected each hour from the effluent/recirculation tank and analyzed for the residual CBZ concentration and the corresponding TOC concentration. The plot for residual CBZ and TOC is shown in figure A7 (A) and (B) respectively. The average residual concentration of CBZ was 0.21 mg/l which is corresponding to ~79% degradation. On the other hand, the total TOC reduction (the SBR out and CBZ) was 78.96% and the average value of TOC reached 4.9 mg/l.

Figure A7: (A) Degradation profile of CBZ and (B) TOC reduction profile of CBZ

Diclofenac degradation study

The degradation study of the diclofenac is carried out in pilot-scale plasma reactors with an initial concentration of 1 mg/l in a single pollutant system. The flow rates were fixed at 20 l/h in one reactor while the input voltage and current were fixed at 23 kV and 1.5 kHz respectively. The samples were collected each hour from the effluent/recirculation tank and analyzed for the residual DCF concentration and the corresponding TOC concentration. The plot for residual DCF and TOC is shown in figure A8 (A) and (B) respectively. The average residual concentration of CBZ was 0.28 mg/l which is corresponding to ~72% degradation.

On the other hand, the total TOC reduction (the SBR out and CAF) was 64.9 % and the average value of TOC reached 7.39 mg/l.

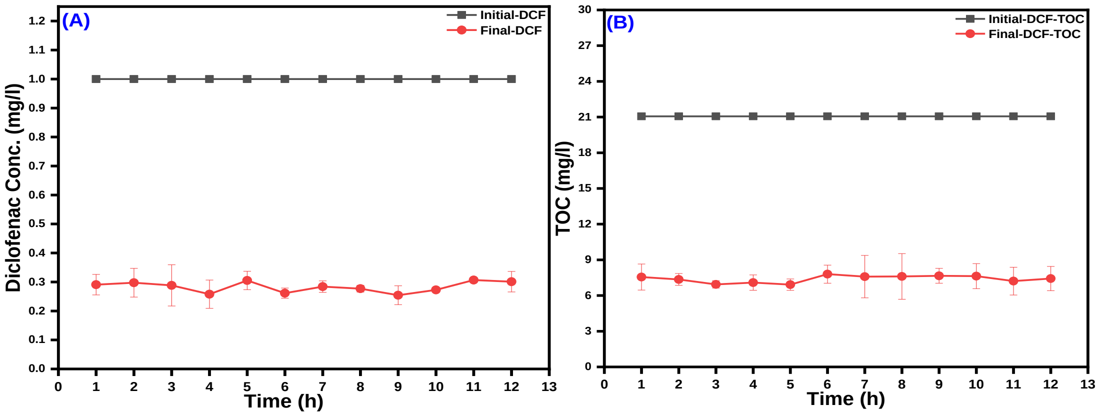


Figure A8: (A) Degradation profile of DCF and (B) TOC reduction profile of DCF

Caffeine degradation study

The degradation study of the caffeine is carried out in pilot-scale plasma reactors with an initial concentration of 1 mg/l in a single pollutant system. The flow rates were fixed at 20 l/h in one reactor while the input voltage and current were fixed at 23 kV and 1.5 kHz respectively. The samples were collected each hour from the effluent/recirculation tank and analyzed for the residual CAF concentration and the corresponding TOC concentration. The plot for residual CAF and TOC is shown in figure A9 (A) and (B) respectively. The average residual concentration of CAF was 0.31 mg/l which is corresponding to ~69% degradation. On the other hand, the total TOC reduction (the SBR out and CAF) was 63.73% and the average reached 5.98 mg/l.

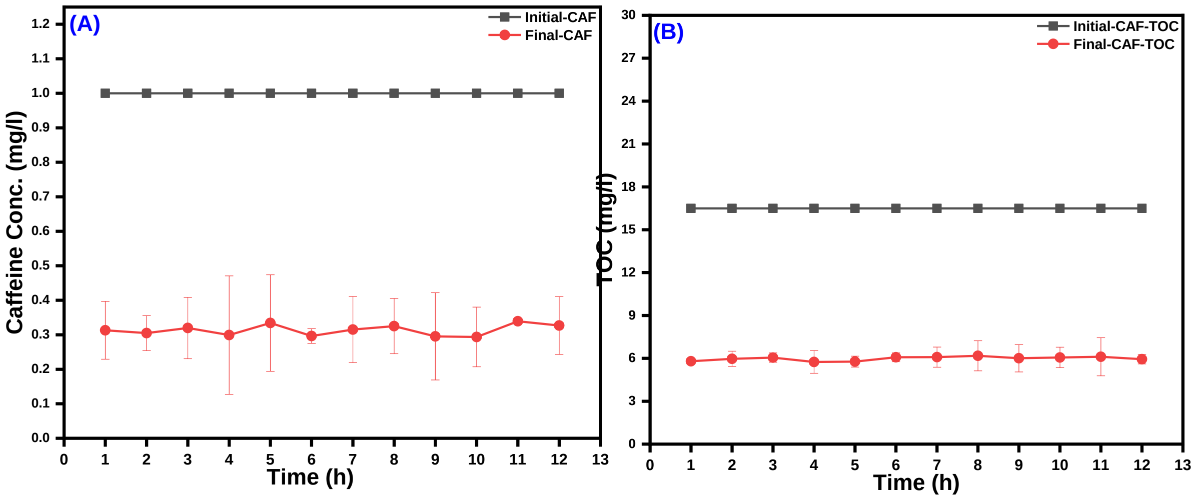


Figure A9: (A) Degradation profile of CAF and (B) TOC reduction profile of CAF

A.6 Design of portable online Nitrite sensing system

An extensive literature review was done to further understand the existing sensing techniques for nitrite detection. It was observed that in almost all studies, the accuracy of existing online monitoring systems is lower when compared to conventional systems. The range of pollutant concentration detected is also less. The one presented in Vellingiri et al (2019) tries to explore the use of colorimetric analysis for online monitoring of nitrite. The change in the colour of the basic fuchsin at different concentrations of nitrite was monitored at 543 nm (vide Fig. A.10.). However, a limitation of this study was that, visible colour differentiation was not seen beyond 0.98 mg/L nitrite concentration. Extending upon their work, a preliminary block diagram was developed based on colorimetric analysis involving 543 nm from an RGB light source .

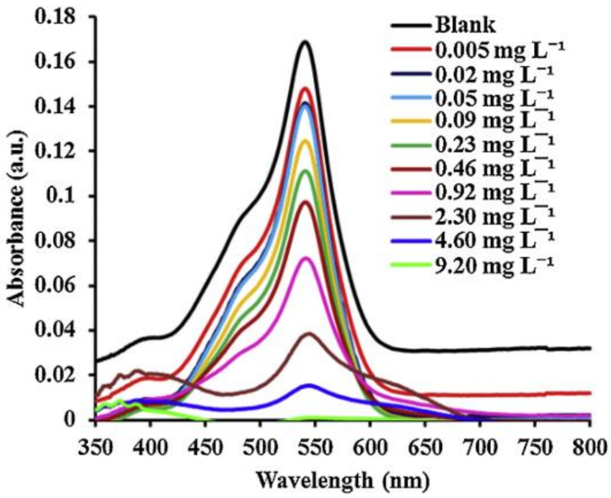


Fig. A10. Absorbance spectrum of basic fuchsin w.r.t concentrations of NO_2^- (Vellingiri et al., 2019)

To test this system, different concentration of standard nitrite solutions (0.05, 0.1, 0.2, 0.5, 1, 2, 3, 5, 8 and 10 mg/L) were prepared. Light of 543 nm was passed through each sample and the intensity of the transmitted light was measured using light sensor TCS34725. This data is then transferred to the micro controller. A calibration curve was plotted with the concentration and the digital average value from sensor. In this plot, irregularities were observed beyond the concentration of 2mg/L. In order to address this, an attempt was made to improve the sensitivity by focusing the transmitted light from the sample using a convex lens. This did not give a significant improvement.

A detailed block diagram of the system is shown in Fig. A.11. The water is filtered (basic filter to remove floating objects) and pumped to the detection chamber using pump 1. Using the pump 2, Basic Fuchsin (BF) and HCl was pumped into the detection chamber. Since the ratio of water, Basic Fuchsin and HCl is 27:2:1 (Vellingiri et al., 2019), the injection rate was adjusted accordingly. The sample (water) first gets acidified with HCl and then reacts with BF. An incubation time of 12 minutes is provided before passing the light. After this, light of 543 nm is passed through the detection chambers and the transmitted light is detected by the photodetector.

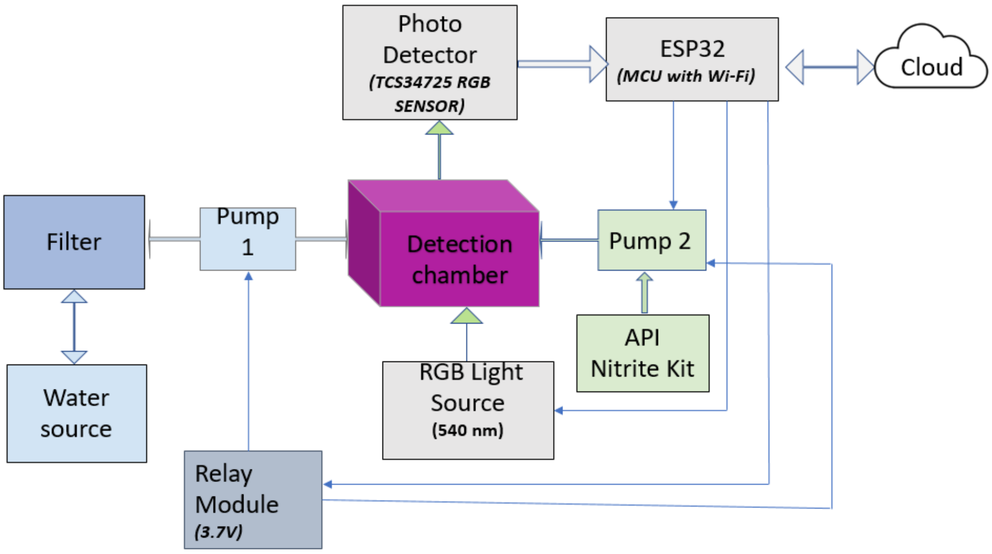


Fig. A.11. Modified block diagram for nitrite detection

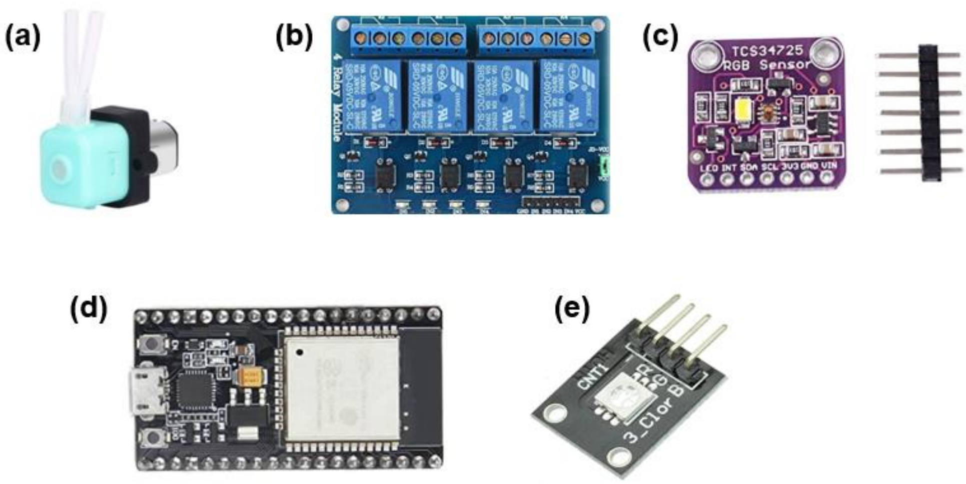


Fig. A12. (a) Kamoer 3.7V 0.1A 1-1.8ml/min Silicone Tube Liquid Pump; (b) 4-Channel 5V Relay Module with Optocoupler used to control the pumps 1 & 2; (c) TCS34725 is a digital Light-To-Digital converter; (d) ESP32 MCU with BLE and Wi-Fi; (e) KY-009 5050 PWM RGB SMD LED Module 3 Color Light source

Developed system and testing in the Laboratory

A photograph of the developed system is shown in Fig. A13. The pumps used, automatic mixing chamber developed, along with the electronic unit employed to regulate the operation are visible. The process flow is optimized, experimentally, and the same is given in Fig. A14. Results obtained for different concentrations are recorded and given in Fig. A15. The results are repeatable and it has high sensitivity in the low concentrations. The method and system are useful for such range. We are working further to enhance the range, while retaining the sensitivity.

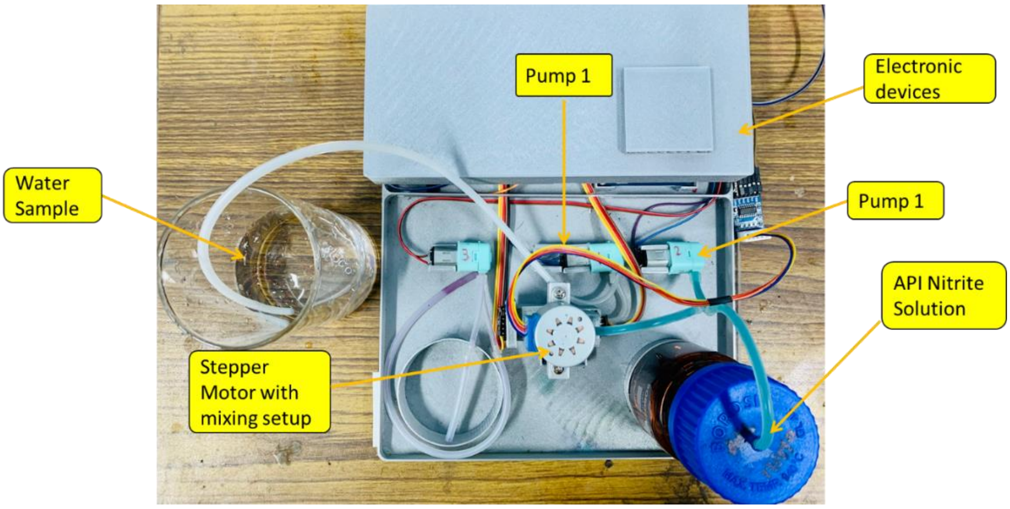


Fig. A13. Completed system, in the laboratory

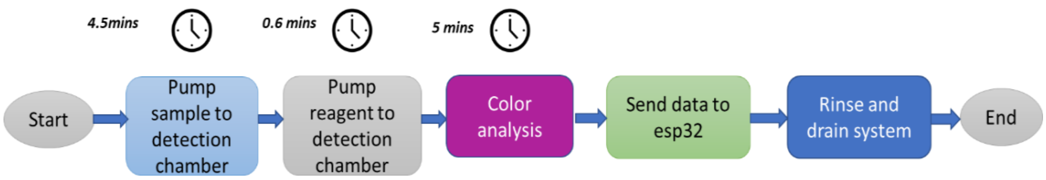


Fig. A14. Process flow

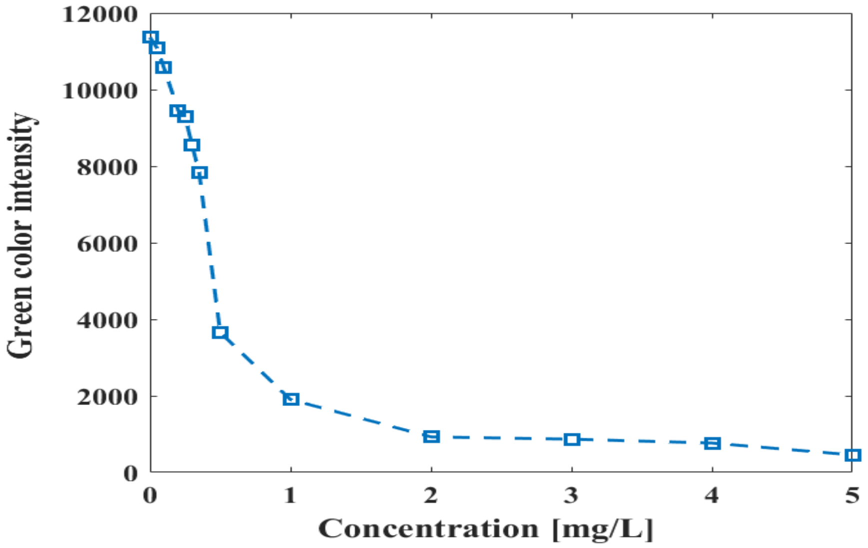


Fig. 15. Output from the system for different concentration levels

A.7 A Capacitive Cantilever-Based Flow Sensor

In this work, a new capacitive transduction mechanism for a cantilever-based flow sensor is developed. The sensor has a stainless steel cantilever attached inside the pipe. The cantilever is fitted in such a way that it bends depending on the flow rate and direction of the flow. The proposed sensing mechanism senses the bending angle of the cantilever using three specially shaped capacitive electrodes introduced outside the insulating water pipe. The capacitive sensor electrodes are connected to a measurement unit, but no electrical wiring is needed to the cantilever, ensuring a contactless bending angle read-out scheme. This method is new, and it helps to realize low-cost and easy-to-install flow sensors. The functionality of the sensing mechanism is first verified using finite element analysis (FEA). Later, a suitable sensor was developed in the laboratory and tested on a pipeline test bench. The change in capacitance due to the cantilever deflection with respect to fluid flow is obtained. A prototype sensor has been developed, and its performance for liquid flow measurement is evaluated. A suitable signal measurement circuity that obtains the difference in capacitance corresponding to the bending angle, and hence the water flow, is developed and employed for the experimental studies. The FEA and experimental test results showed that the proposed transduction and read-out mechanisms are suitable for the cantilever-based water flow sensor. Fig. A16 shows the diagram of the cantilever and the location of the proposed capacitive sensing electrodes introduced outside the pipe. A simplified 3D view of the same is available in Fig. A16 (b), which is the model used for the finite element analysis (FEA). A capacitive electrode, named receiver *R*, is introduced above the fixed end of the cantilever. The cantilever is made of stainless steel. A fixed coupling capacitance C_R is formed between the receiver electrode and the cantilever. There are two triangular-shaped capacitive electrodes, T_1 and T_2 introduced, on the pipe, at the free end of the cantilever. This forms three capacitances, one between the cantilever and the transmitter T_1, named C_{x1} and indicated in the simplified electrical equivalent circuit in Fig. A17. The second capacitance C_{x2}, is formed between the cantilever and T_2. The third one, not shown in the figure as we are not utilizing it for sensing, is present between the T_1 and T_2. As the cantilever bends, the capacitances C_{x1} and C_{x2} change in a push-pull manner for a certain range. This change in capacitance can be measured across the electrodes T_1 and R, and T_2 and R, and utilized to estimate the bending or deflection angle.

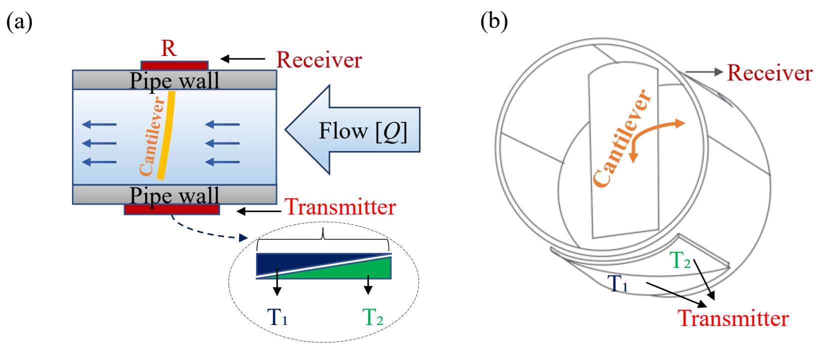


Fig. A16. (a) Schematic diagram of the proposed sensor. (b) Finite element model used in COMSOL Multiphysics tool.

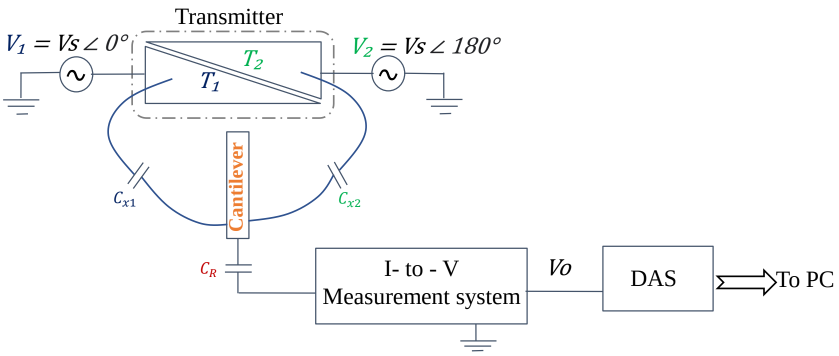


Fig. A17. An equivalent electrical circuit of the capacitive sensor with the cantilever (C^3S) in the vicinity of the electrodes. A Block diagram of the measurement system is also shown.

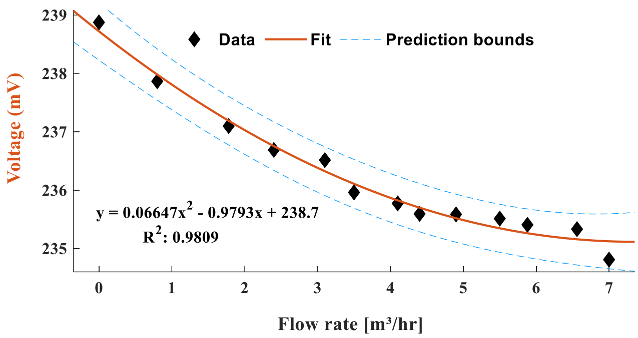


Fig. A18. Output voltage vs. flow rate characteristics plot of the capacitive sensor. This is for deflection in one direction.

The proposed proximity sensor has been developed and evaluated on a laboratory scale. The cantilever dimensions used were 50 mm × 20 mm, and it has a thickness of 0.15 mm. The prototype sensor is tested in a PVC pipe of 63 mm diameter. Different sets of readings were recorded, and measurements were repeatable with a maximum standard error of 0.2 mV. The result obtained from the prototype sensor is shown in Fig. A18. Similar trend is observed in the simulation.

A.8. Synthesis of 3D graphene nanoribbons from *Drepanostachyum falcatum* for dye removal application

A.8.1. Synthesis: The synthesis of 3D-GNR has been done using fiber part (remain after squeezing the extract) as the precursor. Briefly, sun-dried fiber pyrolyzed under the inert atmosphere of nitrogen at 300°C with a heating rate of 5°C/min (slow pyrolysis), which is mandatory to remove the bio-oil hydrocarbons from the material. After completion of the process, the black residue was obtained which was granulated using mortar-pestle and washed with acidic water (5% HCL) followed by multiple DDW washes until the wash water reaches a neutral pH range (~7). Then the residue was oven-dried at 90℃ overnight and named as 3D-GNR.

A.8.2: Kinetics study

The kinetic study was carried out to determine the contact time needed to reach an equilibrium state between adsorbate (MB) in dissolved and solid-bound. All experiments were conducted in batch mode using a 250 ml conical flask in which 0.5 g/L of adsorbent and 100 ml of 10 mg/L of MB dye solution were added. The mixture was given agitation by rotary shaker at a fixed speed (120 rpm) at room temperature. At different time intervals of 5, 10, 20, 30, 45, 60, 90, 120, 150, and 180 minutes, 5 ml of sample were collected and centrifuged at 4000 rpm for 10 minutes to separate the adsorbents. Then the samples were analyzed for residual dye concentration using UV-spectrophotometer at 665 nm wavelength. Also, all the experiments were conducted in duplication. The kinetic data were fitted with pseudo-first-order (PFO), pseudo-second-order (PSO), intra-particle diffusion (IPD), and liquid-film diffusion (LFD) models, and corresponding expressions are given in Table (1).

A.8.3 Equilibrium study

The equilibrium study was conducted by varying the initial concentration of target pollutant (MB) viz. 5, 10, 20, 40, 60, and 80 mg/L. The conical flask consisting of 100 ml target pollutant solution of above concentrations was given 0.5 g/L of adsorbent and kept for agitation in a rotary shaker (120 rpm) for equilibrium time based on kinetic experiment results. The final sample was collected followed by centrifugation and checked for the residual concentration of pollutants. The equilibrium data were modeled using Langmuir and Freundlich models. Also, using the Langmuir isotherm model, dimensionless equilibrium parameter (R_L) was evaluated as per the following equation (A1). The R_L describes the nature of adsorption isotherm such as favorable ($0<R_L<1$), unfavorable ($R_L>1$), and irreversible ($R_L=0$).

$$R_L = \frac{1}{1+K_L C_0} \qquad \text{Eq. (A1)}$$

Where C_0 is the initial concentration (mg/L)

A.8.4 Analytical methods

The MB concentration was quantified by UV Spectrophotometer (Agilent Cary 100). The standard calibration plot was made by scanning various known concentrations of MB solution at corresponding maximum absorbance (λmax) i.e., 665 nm, and used for quantifying the residual concentrations of experimental samples. To calculate the adsorption capacity (Q_e), equation (A2) was used.

$$Q_e\left(\frac{mg}{g}\right) = \frac{(C_0 - C_e)V}{m} \qquad \text{Eq. (A2)}$$

A.8.5 Kinetic study of MB dye removal

Pseudo-first-order and pseudo-second-order models were studied to evaluate the rate and order of adsorption of MB dye on 3D-GNR. Also, the diffusion mechanism of dye molecules was understood by intra-particle diffusion and liquid-film diffusion models. Different kinetic model constants and their linear regression coefficients (R^2) are presented in **Table A2.** The K_2 value (0.006 g/mg/min) indicates the removal of MB was best approximated by the PSO model with the highest R^2 value (0.9966). Moreover, the experimental equilibrium capacity (Q_{max}, Exp.) for MB dye (19.93 mg/g) was found to be very close to the sorption capacity calculated by using PSO kinetic model (20.62 mg/g). Adsorption equilibrium studies were carried out for MB dye over 3D-GNR. An equilibrium plot between equilibrium concentration (C_e) and corresponding adsorption capacity (Q_e) was made for MB dye and shown in **Fig.A19**.All the isotherm model parameters are tabulated under **Table A1.** It has been observed that the three-parameter model (The Toth isotherm) showed a better fit with higher co-relation coefficients (0.99) comparison to two-parameters isotherm, the Langmuir isotherm (0.98). Also, the t value less than 1 suggests the heterogeneous surface of the adsorbent which showed good agreement.

Table A2. Adsorption kinetic model parameters.

Kinetic Models	**Parameters**	**MB**	**Isotherm Models**	**Parameters**	**MB**
	Q_{max}, (Exp.)	19.93			
Pseudo-first-order	Q_e	13.67	**Langmuir**	Q_m	31.94
	K_1	-0.0319		K_L	44.71
	R^2	0.9663		R^2	0.9835
Pseudo-second-order	Q_e	20.62	**Freundlich**	K_F	22.1
	K_2	0.006		1/n	0.1187
	R^2	0.9966		R^2	0.8436
Intra-particle diffusion	K_{ID}	1.2142	**Elovich**	Q_m	3.383
	C	6.5061		K_E	$8.09*10^3$
	R^2	0.7912		R^2	0.8249
Liquid-film diffusion	K_{FD}	0.0319	**Temkin**	A_T	-57.97
	A	-0.3769		B	1.8897
	R^2	0.9663		R^2	0.862
			Toth	K_T	23.64
				α_T	81.6
				t	0.97
				R^2	0.99

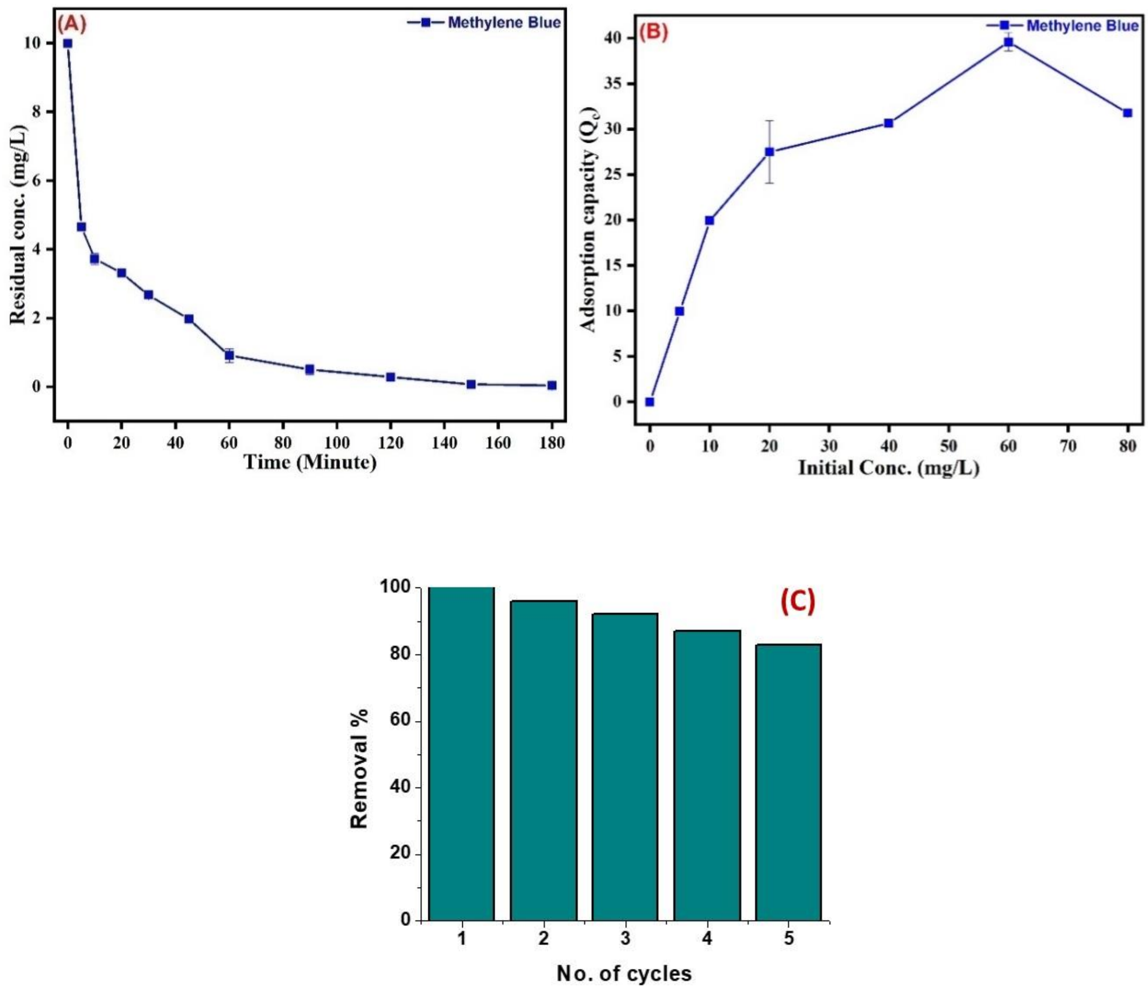


Fig. A19. A)Kinetic plot for MB dye adsorption using 3D-GNR; B) Equilibrium plot for MB dye adsorption using 3D-GNR**; C) Regeneration study for the adsorption of dye onto the 3D GNR.**

A.8.6 Regeneration and recyclability

Desorption and regeneration are the most significant characteristics for improved adsorbents in terms of economic and industrial applications. These two elements have the potential to considerably cut the material's cost. The regeneration adsorption study is carried out using 10 mg/L initial dye concentration and regeneration of material has been done by 1 M HCl solution as a regenerating. The regenerated adsorbent is employed in the next five cycles of adsorption. The removal percentage is determined for each cycle, and as shown in Fig. 1C, the adsorbent's removal effectiveness has fallen slightly from 100% to 83%. The dye cannot be completely removed from the cavities of 3D GNR after regeneration and due to this the drop in removal efficiency was observed. The adsorbed dye concentration in 3D GNR cavities is directly proportional to the number of cycles of regeneration, and the dye removal percentage will be reduced after each cycle.

A9. Synthesis of rGO-Fe3O4 for heavy metal removal

The Fe_3O_4 embedded rGO (rGO-Fe_3O_4) hybrid nanocomposite was synthesized and used in field heavy metal removal. Graphene oxide wassynthesized by the Improved Hummers technique. In a nutshell, a 1:6 ratio of 100 mm graphite flakes and potassium permanganate was mixed. After adding the prepared combination to an acid mixture containing 135 mL of 98 percent H_2SO_4 and 15 mL of 75 percent H_3PO_4, the mixture was stirred continuously at 50°C for 12 hours. Following that, the process was halted by the addition of DI water ice cubes, followed by hydrogen peroxide. The prepared solution was rinsed with DI water to remove any excess metal ions before being dried for 12 hours in a vacuum oven at 60°C and labeled as GO. The following approach was used to create Fe_3O_4 embedded rGO (rGO-Fe_3O_4) hybrid nanocomposite. In a nutshell, 0.3 g GO powder was dissolved in 60 ml of EG using an ultrasonic bath for 2 hours to make the rGO/Fe_3O_4 nanocomposite. After that, 0.12 g $FeCl_3.6H_2O$ and 0.37 g sodium acetate were added and stirred continuously for 30 minutes. To keep the pH of the produced solution basic, a few drops of ammonia solution were gradually added until the pH reached 10. In a Teflon-lined stainless steel autoclave, the resulting solution was sealed and heated at 180°C for 12 hours. The produced rGO/Fe_3O_4 nanocomposite was washed with water and ethanol, centrifuged for 10 minutes at 5000 rpm, and dried for 12 hours in a vacuum oven at 60 °C. The Compositional and morphological analysis such as FTIR spectroscopy, Raman spectroscopy, X-ray diffraction, and SEM-EDX of synthesized rGO-Fe_3O_4 nanocomposite confirmed the uniform distribution of Fe_3O_4 nanoparticles on rGO sheets. Because of its large surface area and magnetic behavior, this material is an ideal candidate for removing toxic heavy metals. The adsorption behavior of Pb (II) on rGO/Fe_3O_4 were investigated in different conditions. The batch adsorption experiments were conducted in a set of 250 ml of Erlenmeyer flasks containing 50 ml of Pb (II) (100, 200, 300, 400, 500 mg/L) solution with a predetermined amount of adsorbents. The flasks were agitated in an isothermal orbital shaker at 180 rpm until the equilibrium was reached. The concentration of the adsorbate was measured by a UV-Visible spectrophotometer. For maximum adsorption, various parameters like solution pH, adsorbent dosage, temperature, initial concentration, and adsorption time were optimized. The superior performance on eliminating toxic Pb(II) ion by rGO/Fe_3O_4 aqueous suspension was observed. The maximum adsorption capacities, kinetic behaviour, and isotherms for Pb(II) were evaluated. The adsorption process was best fitted to the Freundlich isotherm model and pseudo-second-order kinetic model with maximum adsorption capacity of 657.894 mg/g. The obtained results in this study demonstrate the effective removal of heavy metal pollutants, making this nanocomposite an effective and ecological absorbent with great potential in the field of water treatment.

A10. Removal of toxic organic, inorganic and pathogenic water pollutants using GO-modified PU granular composite

Synthesis of GO:

For the improved procedure, a 9:1 combination of concentrated H_2SO_4/H_3PO_4 (180:20 mL) was added to graphite flakes (2.0 g, 1 wt. equiv.) and $KMnO_4$ (12.0 g, 6 wt. equiv.), creating a mild exotherm to 35-40 °C. The reaction was agitated for 12 hours at 50-55°C. The reaction was placed over ice (400 mL) with 30% H_2O_2 (5 mL). The supernatant containing unoxidized manganese ion was decanted after the filtrate was centrifuged (8000 rpm for 30 min). The residual solid material was washed with 200 mL of water, 200 mL of 30% HCl, and 200 mL of ethanol. After each wash, the mixture was centrifuged (4000 rpm for 30 min), and the supernatant was decanted. The leftover substance was coagulated with 200 mL of ether and filtered through a 0.45 m PTFE membrane. The filtered solid was oven-dried overnight in a vacuum oven at 60 ºC. The final yield was around 1.57 g.

Fabrication of GOPU granules:

At first, the waste PU sponge was collected, chopped into $1cm^3$ pieces, and thoroughly cleansed with 100 ml water and acetone solution (1:1 ratio) before drying overnight at 60 °C in a hot air oven. After that, a Bajaj GX-1500-watt mixer grinder was used to reduce the PU sponge pieces to granules. 10 g of the PU granules that had been prepared were subjected to sonication in a 100 mL GO solution (5 mg/mL) for 5 hr at a frequency of 50 Hz and a temperature of 50° C. The sonication was done in 1 hr intervals, with a 30-min agitation in between. At the end of the sonication, the mixture had a paste-like consistency. Later, the GO-embedded PU granules were dried in a vacuum oven at 60 ºC overnight. The previous process steps were repeated to increase the thickness of the GO coating. Figure S1 schematically illustrates the chemical interaction between GO and PU during the development of GOPU.

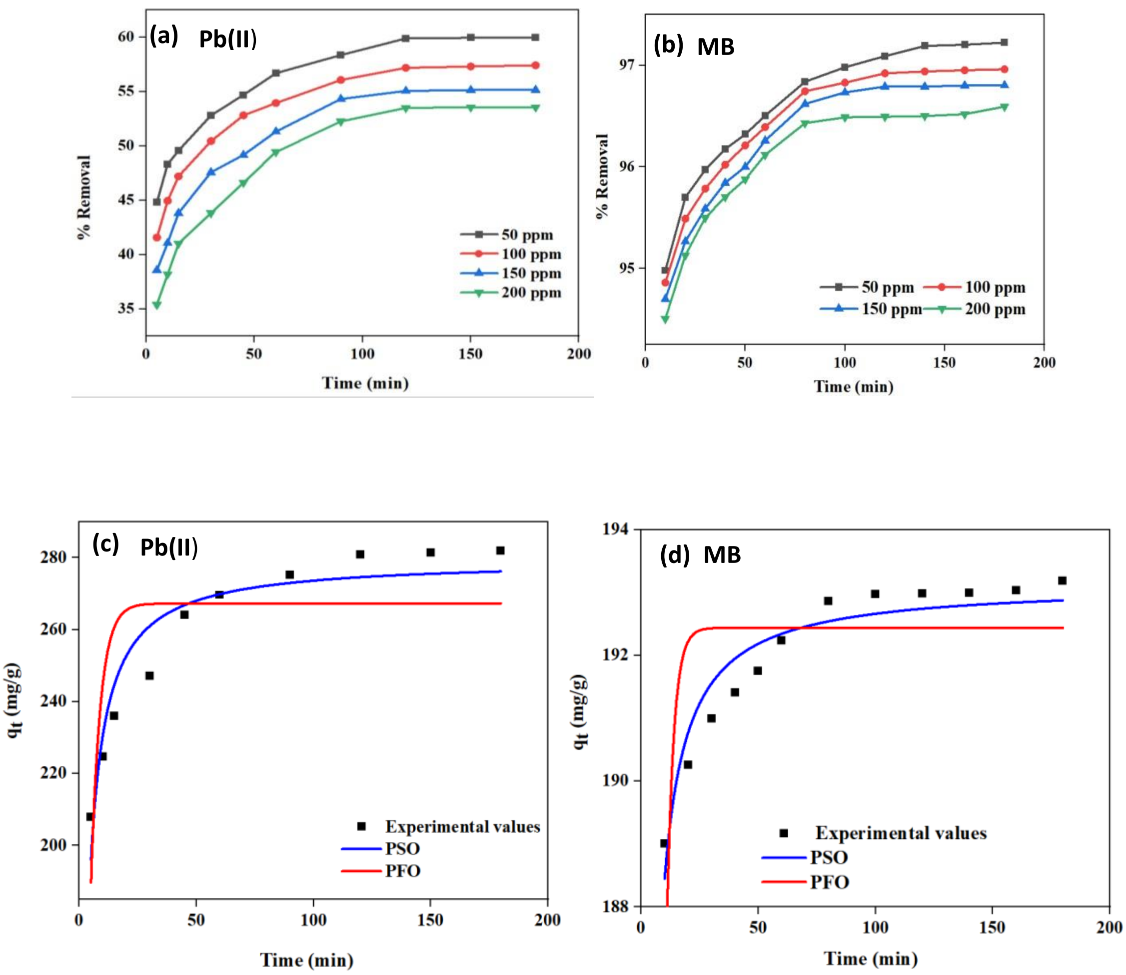
Kinetics study

Various kinetics and isotherm models are used to examine the adsorption behaviour, rate and process of GOPU granules involved in removing Pb(II) heavy metal ions and MB dye. Experimental results presented in figure A20 (a) and (b) show that the adsorption rate increases exponentially till 60 minutes, and it achieves an equilibrium gradually after 130 min. Initially, the adsorption rate was high due to the abundance of unoccupied active sites (-COOH, -OH, -COC, -COOH) to adsorb the different pollutant ions. Over time, the pollutant molecule occupied the active sites and gradually decreased the adsorption rate to a saturation point. The adsorption dynamics of Pb (II) and MB onto GOPU were studied by analysing adsorption observations with different kinetic models. Equations A3 and A4 present the pseudo-first-order and pseudo-second-order diffusion kinetic equations, respectively. The results are depicted in figures A20(c) and (d), respectively.

$$qt = (1 - e{-}k1t) \qquad \text{(A3)}$$

$$qt = (qe\ 2k2t\ 1{+}qek2t) \qquad \text{(A4)}$$

where qe and qt (mg/g) represent the amount of pollutant adsorbed onto GOPU granules at the equilibrium stage and at a given time (min), respectively. Pseudo-first-order and pseudo-second-order rate constants were denoted by k1 and k2, respectively.



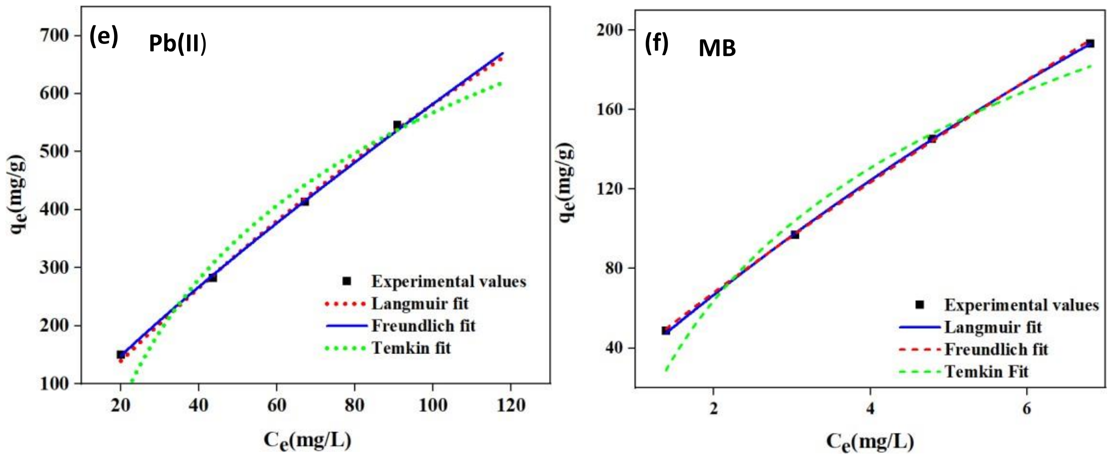


Figure A20: Percentage removal of (a) Pb(II) and (b) MB using GOPU granules. Nonlinear fitting of pseudo-first-order model and pseudo-second-order model for (c) Pb(II) and (d) MB. Nonlinear fitting of Langmuir, Freundlich, and Temkin model for the removal of (e) Pb(II) and (f) MB, respectively.

The resulting kinetic parameters of the pseudo-first-order model and the pseudo-second-order model for both Pb(II) and MB are summarised in table A3. Experimentally obtained values of adsorbed pollutants (Qexp) do not match well with the computed values (qcal,1) using the pseudo-first-order model (as listed in table A3), which leads to a small correlation coefficient (R2). However, the pseudo-second-order model's predicted values by (qcal,2) well approximate the experimental Qe (table A3) and show a high correlation coefficient (R2Pb> 83-91, R2Mb> 86-90).These observations confirmed that the pseudo-second-order model fits the sorption process of Pb(II) and MB onto GOPU granules better than the pseudo-first-order model; therefore, the adsorption of these pollutants onto the GOPU granules comes under the chemisorptions category. This chemisorption might occur due to the formation of hydrogen bonds, covalent bonds and ionic bonds between the pollutant particles and the functional groups present in GOPU granules. Furthermore, the rate of adsorption is dependent on the adsorption capacity of the GOPU.

Table-A3. Kinetic parameters of pseudo-first-order and pseudo-second-order are obtained from the nonlinear fitting of the adsorption process of Pb(II) and MB using GOPU granules.

	Pb(II)				MB			
Parameters /(ppm)	**50**	**100**	**150**	**200**	**50**	**100**	**150**	**200**
Q_{exp} (mg/g)	149.8	282.1	413.5	545.6	48.6	96.9	145.2	193.2
	Pseudo first order							
k_1 (min^{-1})	0.266	0.247	0.201	0.174	0.4	0.4	0.4	0.33
$q_{cal,1}$ (mg/g)	141.1	267.3	388.1	502.5	48.3	96.5	144.5	192.4
R^2	0.58	0.6	0.58	0.58	0.47	0.47	0.04	0.53
	Pseudo second order							
k_2 (g/mg.min)	0.003	0.001	0.0008	0.0005	0.079	0.04	0.026	0.02
$q_{cal,2}$ (mg/g)	147.2	279.5	409.3	535.1	48.6	96.9	145.2	193.1
R^2	0.89	0.91	0.87	0.86	0.87	0.88	0.86	0.90

Isotherm study

The experimental results are fitted with different kinetic models, such as Langmuir, Freundlich, and Temkin models, to understand the interaction process between pollutants and GOPU granules. In the field of sorption, the Langmuir isotherm model is often used to analyse the adsorption capabilities and efficiency of various adsorbents. The Langmuir model considers the monomolecular deposition of adsorbate on homogenous surfaces. Also, the Langmuir isotherm model deals with uniform sorption, no molecular transmission, and single-layer sorption. The nonlinear form of the Langmuir model is represented in equation (A5).

qe =qtkLCe 1+kLCe (A5)

qe represents the sorption capacity of the adsorbent at equilibrium conditions, KL is the Langmuir constant and C0 and Ce reflect the starting and equilibrium concentrations of contaminants, respectively. The separation factor (RL) is a dimensionless constant that determines favouritism of the adsorption process by the Langmuir model. The RL (RL = 1 1 + C0KL ⁄) values presented in table A4 are between 0.88-0.61 (<1) and 0.33-0.09 (<1) for Pb(II) and MB, respectively, confirming the adsorption of both pollutants onto GOPU granules is a favourable process. The Freundlich isotherm model is often used to model multilayer Pb(II) and MB adsorption on heterogeneous GOPU surfaces. The nonlinear form of the Freundlich model is represented in equation (A6).

$$qe = kF(ce)1/n \qquad (A6)$$

here, qe represents sorption capacity at equilibrium conditions. KF and 1 n ⁄ denote the Freundlich constants and dimensionless surface heterogeneity, respectively. Further, the Temkin model was used to understand the binding energy involved during the interaction between the adsorbate and adsorbent. This model presumes that the adsorption process is a multilayer process; the adsorption is distinguished by a uniform distribution of binding energies up to the highest binding energy. Equation (A6) presents a nonlinear form of the Temkin isotherm model.

$$qe = RT\ bT\ (\ln AT) + RT\ bT\ (\ln Ce) \qquad (A7)$$

where, bT is the heat of adsorption (Jmol-1), R is the universal gas constant (8.314J/mol.K), T is the temperature, KT represents the Temkin isotherm constant (Lg-1), and Ce represents the equilibrium concentration of the pollutants.

Table A4: Isotherm parameters of Langmuir, Freundlich, and Temkin isotherm models are obtained from the nonlinear fitting of the Pb(II) and MB adsorption process using GOPU granules.

Isotherm Models	Parameters	Values Pb(II)	Values MB
Langmuir	q_m *(mg/g)*	842.4	899.6
	K_L *(L/mg)*	0.0025	0.0413
	R_L	0.88-0.61	0.33-0.09
	R^2	0.998	0.999
Freundlich	k_F *(mg/g) (L/mg)*$^{1/nF}$	11.56	37.44
	1/n	1.17	0.9
	R^2	0.999	0.999
Temkin	b_T *(J/mol)*	8.165	26.621
	K_T *(L/mg)*	0.061	0.972
	R^2	0.973	0.977

The adsorption quantities of Pb (II) and MB were determined after 3 h for various initial concentrations. Figure 2 (e) and (f) depict the different isotherm models for the adsorption of Pb(II) and MB using GOPU granules, whereas table 2 lists the values of respective isotherm parameters. A comparison of the correlation coefficients (R2) of various isotherm models revealed that the Langmuir isotherm model best describes the adsorption of Pb(II), and the Freundlich isotherm model best describes the adsorption process of MB onto GOPU granules. The above results conclude that Pb(II) adsorption onto the GOPU granules is single-layer adsorption, whereas adsorption is multilayer for MB. Further, the maximum adsorption capacities of GOPU granules for Pb(II) and MB were calculated to be 842.4 mg/g and 899.6 mg/g, respectively, which confirms that the GOPU granules are efficient Pb(II) and MB adsorbent. Additionally, the positive value of KL indicates the favourability of the adsorption process, which is further supported by the values of n.

Appendix-B: Wastewater Treatment

B1. Performance evaluation of pilot scale Ceramic membrane as tertiary treatment systems for domestic wastewater

Performance evaluation of ceramic filters as a tertiary treatment system for water and secondary treated domestic wastewater was carried out. As a phase-1, and phase-2, studies, filtration experiments were carried out using 4 µm and 250 nm ceramic filters with water and wastewater. Compare to the 4 µm filter, the 250 nm filter clogs frequently and results in the frequent backwash. Performance comparison between 250 nm and 4µm shows that the 4µm ceramic filter performed better in terms of quantity of treated water and the 250 nm ceramic filter performed better in terms of quality of treated water and pollutants removal.

In the first part of the phase-3 study, the Performance of a pilot-scale ceramic membrane filter with a pore size of 4 µm was completed and in the second part of the phase-3 study, the performance of pilot scale ceramic membrane filter with a pore size of 250 nm (Fig. B1) was tested for treating secondary treated wastewater under different operating conditions. The filtration process was carried out to check the efficiency of the filter by fixing the flow rate between 2 to 9 m^3/h. For every cycle, the flux value has been calculated by using the volume of water treated (obtained from a digital rotameter) and the Transmembrane pressure (TMP) evolves during each cycle. Each filtration cycle was carried out at 20- and 10-min running times (duration). At the end of each cycle, Pneumatic pressurization Air + water Backwash was initiated to recover the nominal flux during the filtration operation. After Pneumatic pressurization air+water backwash, the filtration experiment was continued, when the transmembrane pressure reaches 1.5 bar. A flux monitoring study has been carried out by fixing a flow rate between 2 to 9 m^3/h for the continuous process by optimizing the air+water backwash and chemical backwash. During the operation, the flux was stated at 448 L/hr/m^2 and lasted 36 L/hr/m^2. The average volume of water treated in a set of cycles (until TMP reaches 1.5 bar) is 2500 to 6100 L.

The filtration process was stopped and the chemically enhanced backwash was initiated, when the air+water back was ineffective). Chemical Enhanced Backwash (CEB) was initiated in an efficient way by combining Caustic (NaOH) and Hypochlorite (NaOCl). The CEB was found to be effective when the transmembrane pressure was not reduced as much after the air and water backwash. The percentage of water used for backwash was found to be 3-15%. The removal efficiency of different pollutants such as turbidity, COD, and Fecal coliform ranged between 95-99%, 45-60%, and 80-90% respectively, (Fig B2) for 250 nm pilot scale ceramic filter. The quality of treated water from a 250 nm ceramic filter was found to be slightly higher than ultrafilter. Overall studies showed that the treated wastewater quality from ceramic filter (CF) was better than the existing ultrafiltration (UF) in IITM STP.

Fig B1: Picture showing 250 nm pilot scale ceramic membrane at STP, IITM.

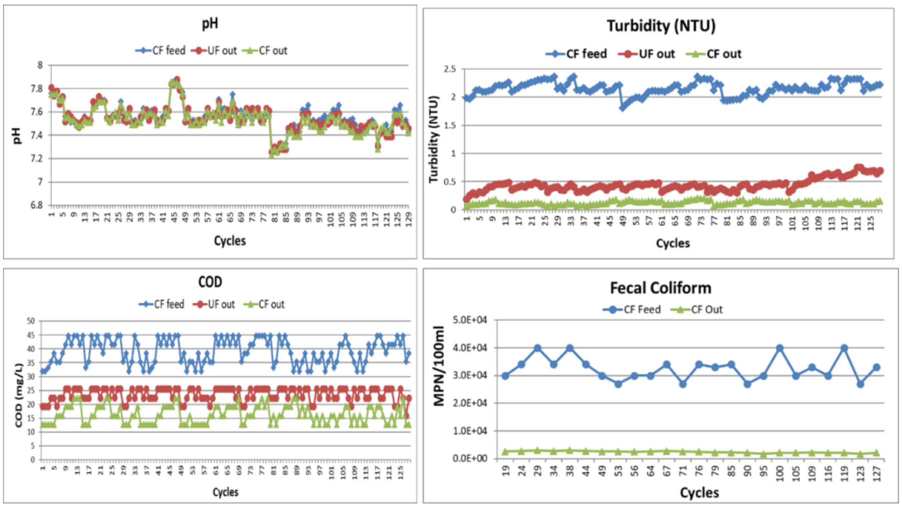


Fig B2: Quality comparison of the ceramic membrane with the UF membrane.

B2. Fate of carbamazepine and its effect on physiological characteristics of wetland plant species in the hydroponic system

The present study attempted to select an appropriate plant species for CWs, considering their characteristics and physiological response to PhACs. The primary objective of this study is to assess the removal, fate, and antioxidative response of CBZ in four wetland plant species (*Canna indica, Colocasia esculenta, Phragmites australis,* and *Chrysopogon zizanioides*) in exposure and recovery phases. These four plant species were screened for their well-developed root system, higher plant biomass, lipid content, etc. (Ayusman et al., 2020; Banerjee et al., 2016; Vymazal, 2013). In this regard, batch hydroponics studies were carried out to assess the removal, fate, and antioxidative response of carbamazepine (CBZ) in four wetland plant species.

The removal of CBZ from the nutrient medium by the selected plant species was monitored, and the result is given in Fig B3. The predominant CBZ removal mechanism includes photodegradation, root adsorption, plant uptake and accumulation, metabolism inside the plant tissues, and degradation by endophytic bacteria at the rhizosphere (Y. Hu et al., 2021; Matamoros et al., 2012). After 30 days, CBZ removal from nutrient solution by *C. indica, C. esculenta, P. australis, and C. zizanioides* was 72.3 %, 53.5 %, 63.6 %, and 45.4 %, respectively. Compared to the planted reactor exposed to CBZ, a lower removal of CBZ (2.87%) was observed by photolysis (under natural sunlight) in the unplanted control reactor.
It was reported that the capacity of different plant species to uptake and accumulate the same pollutant varies depending on their characteristics. At the end of 30 days, the concentration of CBZ in roots of *C. indica, C. esculenta, P. australis,* and *C. zizanioides* was 0.21, 0.24, 0.271, and 0.14 µg/g, respectively. The accumulation of CBZ in the leaves was 0.88, 1.20, 0.92, and 0.39 µg/g, respectively, for *C. indica, C. esculenta, P. australis, and C. zizanioides*. Interestingly, the accumulation of CBZ in aerial parts was relatively higher in *C. esculenta*, and it showed higher BCF_{leaf} (1.2L/kg) and TF (5.62) values than the other plants. It could be associated with its higher transpiration level (6.96 L) over the exposure period due to its larger leaf surface area than the selected plant species. Also, a positive correlation was observed between BCF_{leaf} and transpired water. On the contrary, *P. australis* showed higher accumulation in the root portion with a BCF_{root} value of 0.27 L/kg due to the higher root lipid content. From Pearson`s correlation analysis ($P < 0.05$), the accumulation of CBZ in the plant

tissues showed a positive correlation with root activity (r – 0.92), transpiration rate (r – 0.98), and chlorophyll content (photosynthetic activity) (r – 0.76) of the plant species.

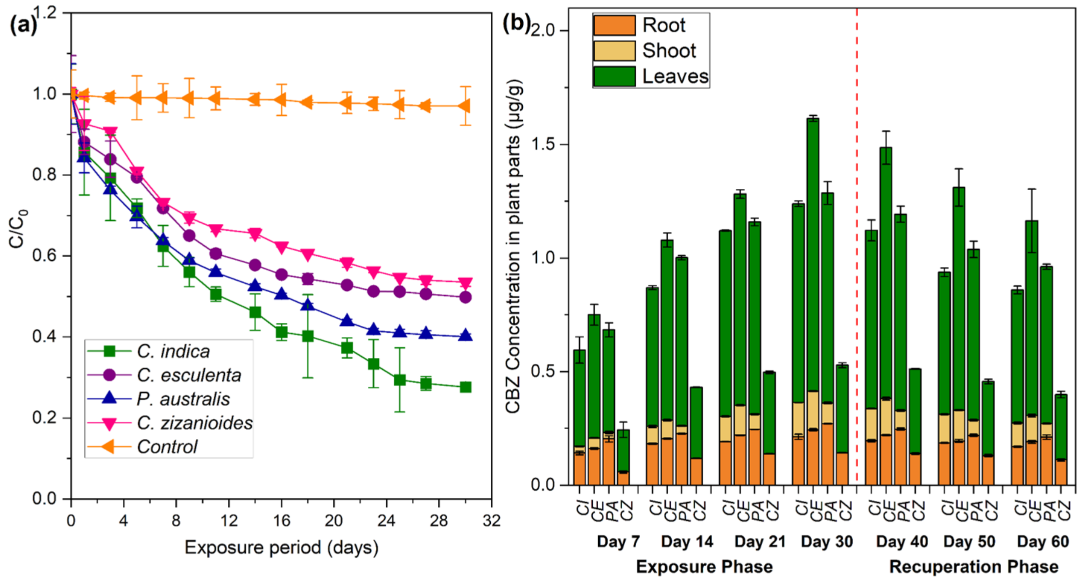


Fig B3. (a) Removal of CBZ from the nutrient medium in the hydroponic systems with different plant species and unplanted control system and (b) Accumulation of CBZ in the tissues of different plant species

The research work focused on the effect of CBZ on the physiological characteristics (chlorophyll content, root activity), accumulation of ROS, oxidative damages (lipid peroxidation and plasma membrane integrity), and antioxidant enzyme activities (ascorbate peroxidase and catalase) of the selected plants. Among the plant species selected in the present study, a lesser inhibition of photosynthetic activity was witnessed for *C. indica* (8.53±3.04%) and *P. australis* (8.79±4.36%) upon exposure to CBZ for 30 days. It might be attributed to the higher carotenoid content of these plants. Moreover, the exposure to CBZ adversely affected the plant root activity. Like the chlorophyll content, *C. indica* (7.55±2.07%) and *P. australis* (8.60±1.44%) showed a lesser inhibition in root activity upon the exposure to CBZ compared to the other selected plants (*C. esculenta* and *C. zizanioides*). Also, a higher concentration of H_2O_2 was noticed in the plants exposed to CBZ than in the control plants. The higher accumulation of ROS could (1) damage the integrity of thylakoid membranes, (2) hinder the activity of Calvin cycle enzymes, (3) inhibit the synthesis of photosystem II proteins, and (4) cause photoinhibition (Foyer and Noctor, 2011; Gomes et al., 2017). Further, it induces oxidative damage in the plant tissues. In the present work, the increase in the concentration of ROS accumulated was in the order of *C. zizanioides* (18-fold) > *C. esculenta* (15-fold) > *P. australis* (9-fold) > *C. indica* (6-fold), compared to the corresponding control systems.

Lipid peroxidation is an important indicator of plant stress responses and cellular damage, and it results in the production of MDA (Malondialdehyde). Thus, the concentration of MDA and Evan`s blue uptake was determined to assess the oxidative damages of CBZ (lipid peroxidation and plasma membrane integrity) in the plant species. The concentration of MDA and Evan`s blue gradually increased in the plant leaves over the exposure period. It could be associated with the increasing accumulation of ROS in the plant tissues. Besides, the antioxidant enzyme activities (catalase (CAT), ascorbate peroxidase (APX)) were measured to understand the accumulation of ROS and the response of the plant species. During the exposure period, the increasing trend of enzyme activities (CAT and APX) in each plant species was associated with the increasing amount of CBZ accumulated and the overproduction of ROS. Among the selected species, the increase in enzyme activities was found in the order of *C. zizanioides* (7 to 9-fold) > *C. esculenta* (7 to 9-fold) > *P. australis* (3 to 5-fold) > *C. indica* (2 to 3-fold). It can be associated with the accumulated ROS in the plant species.

Further, Multi-criteria decision analysis (MCDA) was adopted in the study to select the best plant species for the removal of CBZ. MCDA is the most critical tool to choose the best option among the alternatives. In MCDA, parameters of different units are linearly normalized, and weightage was assigned. In the present study, the weightage for the plant characteristics was given based on their significance observed in Pearson`s correlation analysis. The performance score of the selected plant species can be ordered as *C. indica* (0.93) > *P. australis* (0.84) > *C. esculenta* (0.74) > *C. zizanioides* (0.60).

Thus, apart from the pollutant removal and accumulation, the physiological characteristics and defense response of the selected plant species should be considered while choosing the plant species. The plant’s tolerance to PhACs is usually related to its ability to cope with ROS accumulation by activating enzymes and defense mechanisms. In the present study, all the selected plant species witnessed oxidative stress upon exposure to CBZ. However, *C. indica* showed lesser oxidative stress than the other plant species. Also, the selected plants could counteract the excessive ROS accumulated in the plant tissues and recover to a certain extent in the recuperation phase (reduction of ROS to 40-63%). At the end of the recuperation phase, a significant decrease in oxidative damages and CBZ accumulation was observed for *C. indica*. It indicates the capacity of *C. indica* to adapt to the PhACs environment. Moreover, higher root exudates could have also influenced their removal performance and growth. Thus, the order of preference of plant species is *C. indica* > *P. australis* > *C. esculenta* > *C. zizanioides*.

B3. Acclimatization of Microalgal Culture

For this study, microalgae were collected from the sewage treatment plant (STP) of IIT, Madras. To cultivate the microalgae, Modified BG-11 media is being used. The composition of the media can be found in Table B1. After being autoclaved at 121^{0}C for 30 min, the microalgal cells were added to it, and the pH was maintained at around 7.5. The algal culture was then exposed to conditions such as illumination of 6000-7000 lux (four 14W Philips LED bulbs) for 12:12 h light: dark periods, temperature ~30°C for two weeks. After reaching a certain cell density, the culture was used for the batch study. Aerobic activated sludge was collected from STP, IIT, Madras for bacterial culture. The same BG-11 media will be used for cultivation except for the organic carbon source (glucose). Aeration will also be provided for bacterial culture. The same culture will be exposed to different concentrations of antibiotics for acclimatization. The removal of antibiotics and nutrients will be compared between acclimatized microalgal culture and normal culture (figure B4).

Table B1: Composition of synthetic wastewater or culture media

Compounds	**Concentration (mg/L)**	**Compounds**	**Concentration (mg/L)**
$NaNO_3$	1500	**Trace metal solution (1 mL/L)**	
K_2HPO_4	31.4	H_3BO_3	2860
$MgSO_4$	36	$MnCl_2.4H_2O$	1810
$CaCl_2.2H_2O$	36.7	$ZnSO_4.7H_2O$	222
Na_2CO_3	20	$Na_2MoO_4.2H_2O$	390
Na_2 /Mg EDTA	1	$CuSO_4.5H_2O$	79
Citric acid	5.6	Co $(NO_3)_2.6H_2O$	49.4

			$CoCl_2.6H_2O$	
Ferric ammonium citrate	6	Can use glucose as an organic carbon source		

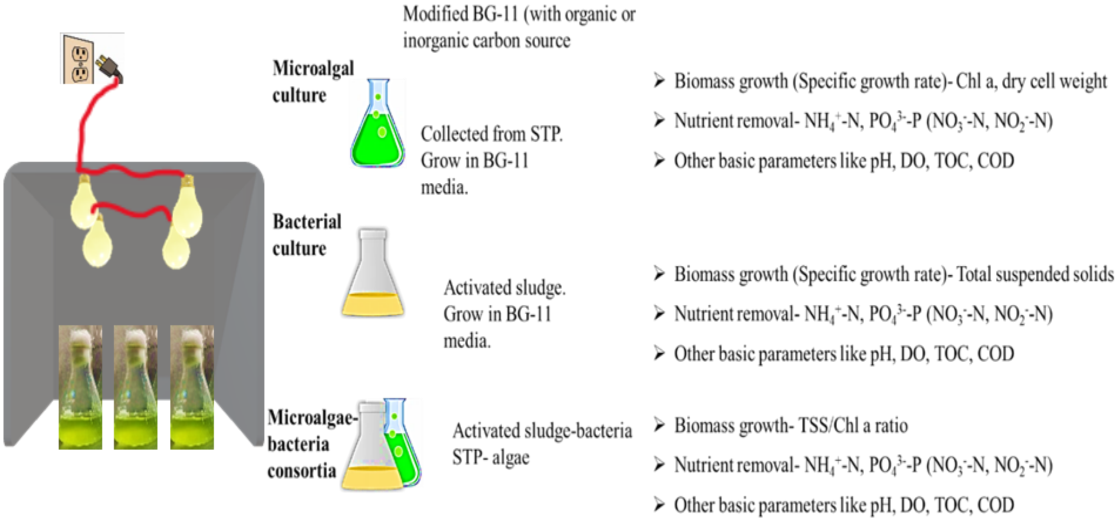


Figure B4: Batch study setup and approach for the study

Formation of microalgae-bacteria consortia:

For microalgae-bacteria consortia formation, different inoculum ratios of microalgae: activated sludge 10:1 and 5: 1 are being used. The conditions provided for the culture are mentioned in table B2.

Table B2: Conditions provided for the formation of microalgae-bacteria consortia formation

Carbon	~300 mg/L
Nitrogen	~70 mg/L
Phosphorous	~2-3 mg/L
pH	7-8
Agitation	100-120 rpm
Media for growth	BG-11 media (with organic carbon glucose)
Temperature	Room temperature

Source of biomass	STP, IITM (Activated sludge for bacteria)
Inoculation ratio (Algae: activated sludge)	5:1, 10:1

Below are given some microscopic images (Figures B5-B10) showing the growth of consortia with time in different ratios of microalgae and activated sludge.

WEEK 1:

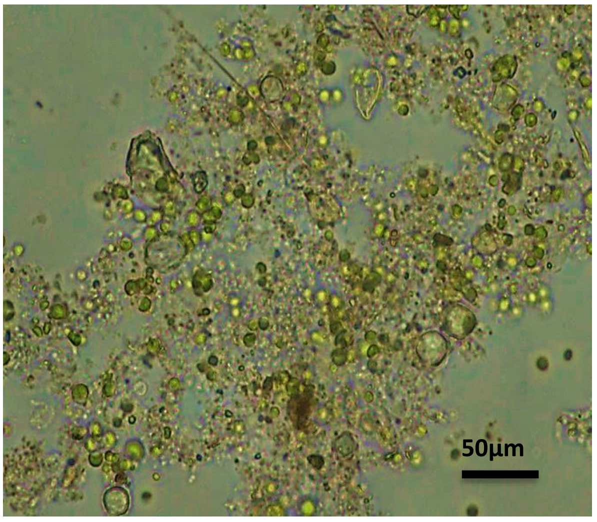


Figure B5: Microalgae: activated sludge 5:1

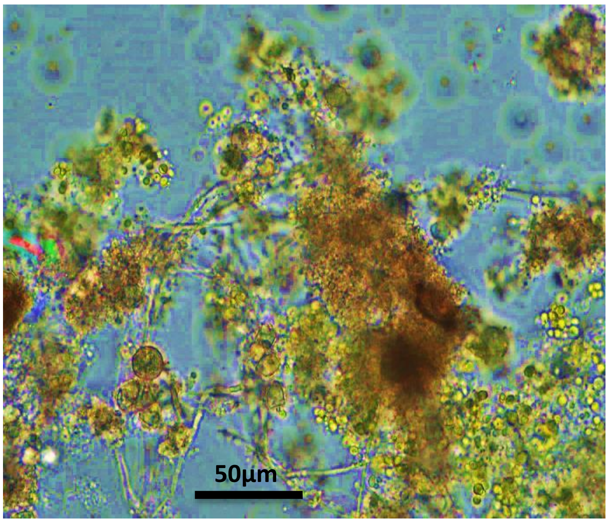


Figure B6: Microalgae: activated sludge 10:1

WEEK 2:

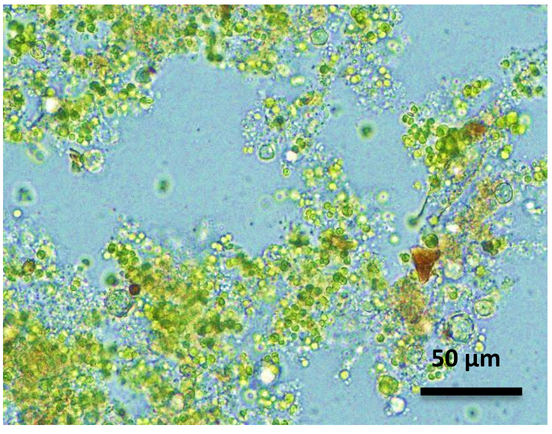


Figure B7: Microalgae: activated sludge 5:1

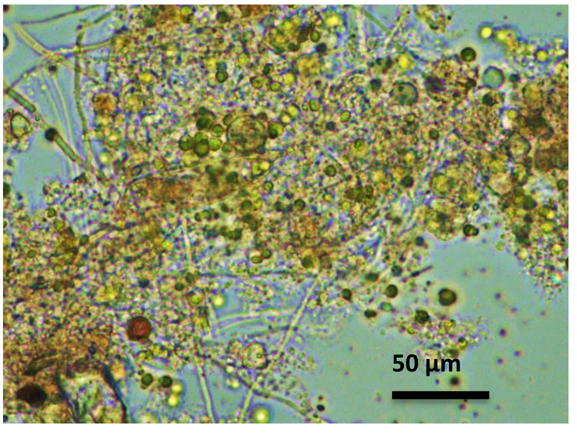
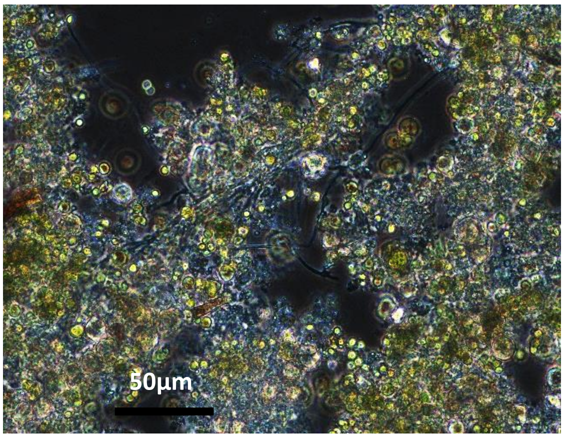


Figure B8: Microalgae: activated sludge 10:1

WEEK 3:



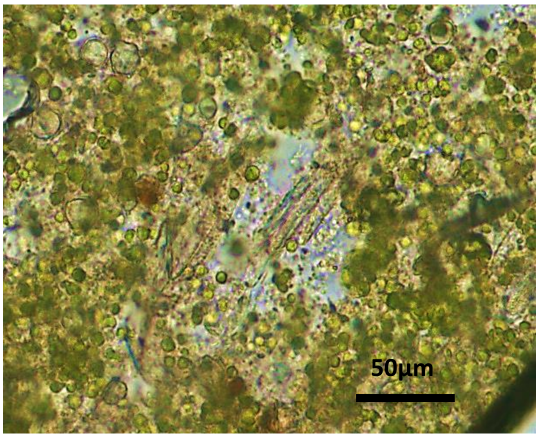


Figure B9: Microalgae: activated sludge 5:1 **Figure B10: Microalgae: activated sludge10:1**

<u>Inferences:</u>

In inoculum ration of 5:1 (microalgae: activated sludge), filamentous growth is more. In 10:1 inoculum ratio, microalgae and bacteria compete for the nutrients and microalgae outgrow the bacteria (filamentous or cyanobacteria) as we are adding more microalgae than activated sludge. Thus, 5:1 ratio of microalgae: activated sludge is suitable for consortia formation.

<u>Removal of nutrients using microalgae alone in the presence of antibiotics (ciprofloxacin):</u>

For this batch study, the same conditions were provided as mentioned in the previous section. The experimental setup is shown in table B3. There is an increase in the ammonia and phosphate concentration after a certain time which is due to the death of biomass (Figures B11-B14).

Table B3: Showing experimental setup for nutrient and antibiotics removal

S. No.	Biomass	Light	Antibiotics	Identity	Inference/outcome
1	+	+	+	Light control	
2	+	-	+	Dark control	Removal w/o photosynthesis (hydrolysis)
3	-	+	+	Indigenous system	Photodegradation
4	+	+	-	Blank light control	For growth parameters comparison

5	+	-	-	Blank dark control	For growth parameters comparison
6	-	-	+	Control	Hydrolysis

Below, there are many graphs showing the removal of nutrients with time in the presence of antibiotics.

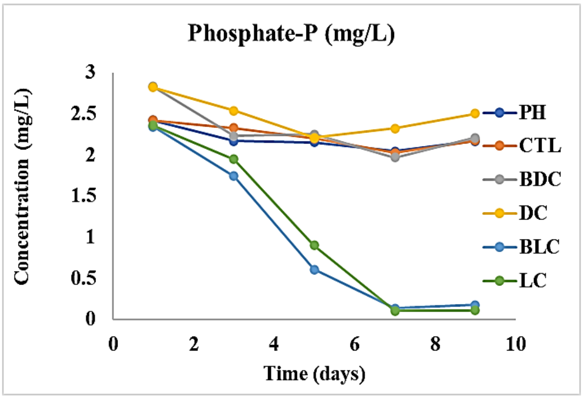


Figure B11: Removal of Phosphate-P

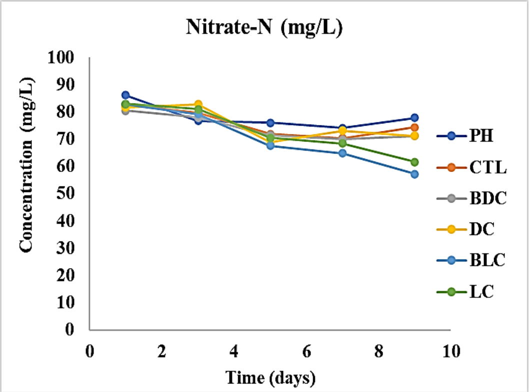


Figure B12: Removal of Nitrate-N

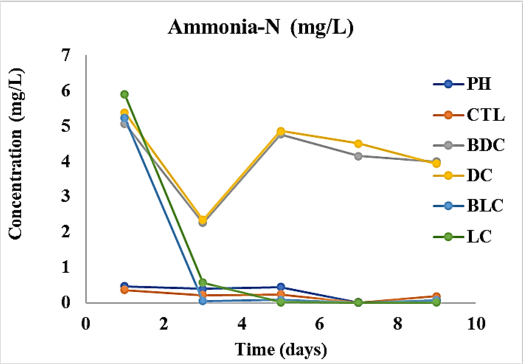


Figure B13: Removal of Ammonia-N

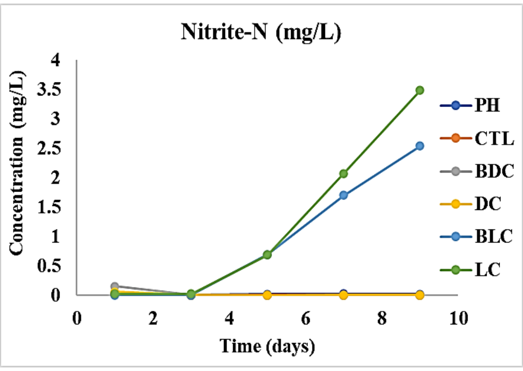


Figure B14: Removal of Nitrite-N

Nutrient removal is good in light control and blank light control due to biomass growth and photosynthesis. There is an increase in the nutrient concentration of some systems due to the absence of light. Biomass growth also is not affected in the presence of antibiotics as microalgae are not the target species due to less concentration of the contaminant. This study is still going on where proper removal mechanisms for antibiotics are needed to study.