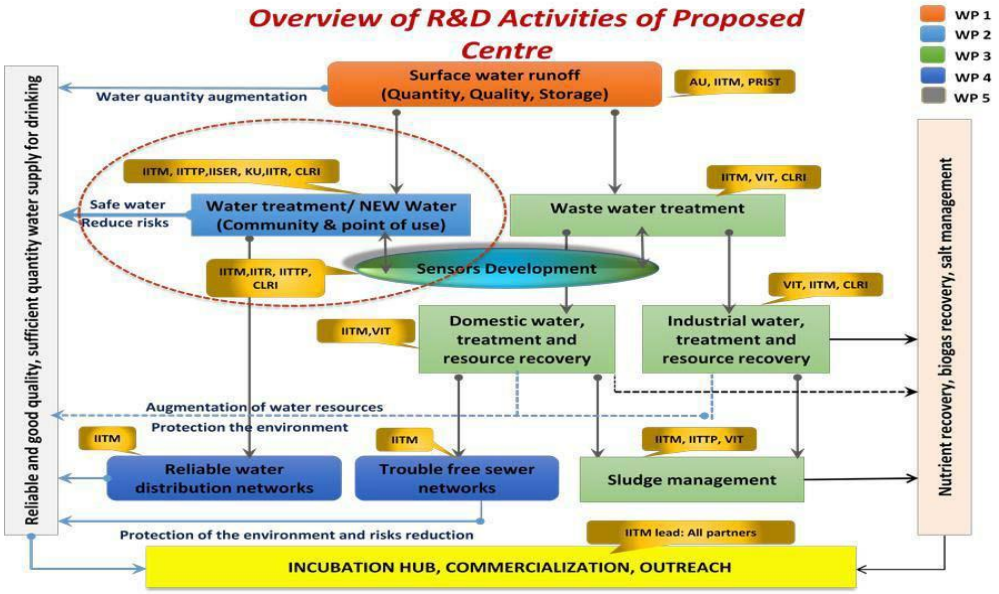
Water Technology Research and Innovation Centre

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

March 2022

ANNUAL PROGRESS REPORT

(*Five copies to be submitted)*

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: **23rd Oct 2018, 4th Sep 2020 and 26th Oct 2021**

6. Progress Report Serial No: **3**
7. Reporting Period: **April 2021 to March 2022**
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. Planning to analyze more samples from successive sampling	Anna University and IITM
	Sample evaporate residues preparation	Residues prepared for two quarry samples and yet to be analyzed to identify some rare trace elements	Anna University and IITM
	Development of research methodology to accomplish a regional level planning of SUDs as well as their impact assessment	Completed	IITM
	Determination of Soil hydraulic properties for IITM Campus	Completed	IITM
	Analyze the long-term performance of sustainable practices using SWMM and HYDRUS-1D coupled model.	Ongoing	IITM
	Integration of LID modules with SWAT sub-routines	Ongoing	IITM
	Water quality Analysis & collection of Secondary data on water quality (storm-water & runoff)	Secondary data on water quality as well as collection of samples and laboratory analysis have been carried out for Orathanadu taluk of Thanjavur, which was selected for exploration micro hydrological regime. Besides the University campus was explored to track run-off	PRIST

		pattern of stormwater, following which specific sampling points were identified for characterization and periodic assessment of hydro dynamic and hydro geochemical variations (both temporal and spatial) . Besides, the variation of rainfall patterns for the current year and their time series analysis for Thanjavur, Nagapattinam and Chennai were estimated and the previously developed rainfall prediction model was calibrated.	
	Estimation of significant parameters for each zone	Water quality characterizations of the two zones taken during the present study (namely Orathanadu taluk and University campus) were statistically assessed for the significant correlation among them. Successively principal component analysis (PCA; Rotated) were used to identify the dominant parameters and their groupings, using Eigen value >1. The selected factors were used for further geospatial analysis.	PRIST
	Zone-wise Water quality contours for dominant parameters	The water quality (WQ) parameters obtained from PCA were used for geospatial analysis wherein the contours for individual parameters as well as stormwater quality index (developed based on previous studies) were obtained.	PRIST
	Segregation of Cyclicity, Seasonality & Trend of Time Series Hydrological data of study area	Completed	PRIST
	Time & frequency domain-based modeling	Completed	PRIST
	Integrated Time Series Modeling for each storm-water zone	Ongoing	PRIST

WP2	Fabrication of portable colorimetric sensor based on Basic Fuchsine for the detection of nitrite ion in aqueous system	Finished	IIT Madras
	Assessment of competitive adsorption of pharmaceuticals and personal care product on carbonized absorbent derived from waste: Single and Multicomponent study	Finished (Manuscript submitted)	IIT Madras
	Colorimetric Sensors for the detection of phosphate	Finished	IIT Madras
	Risk Dynamics of Emerging Contaminants and Heavy Metals in the River Ecosystems	Finished	IIT Madras
	Adsorptive removal of plasticizers using composite biochar	Finished	IIT Madras
	MOF derived structure for capture of Phosphate	Experiments Ongoing	IIT Madras
	Synthesis of biochar derived from bamboo fiber (BDB)	Completed	Kumaun University
	Synthesis of biochar using wastewater treatment plant sludge (SDB)	Completed	IIT Madras
	Characterization of BDB and SDB	Going on	IIT Madras
	Sorption and sono-sorption of three textile dyes and its kinetic and equilibrium study using BDB	Going on	IIT Madras
	Textile dye degradation study in pulse power plasma	Completed	IIT Madras
	Effect of catalyst in pulse power plasma	Completed	IIT Madras
	Effect of the input voltage on the degradation of dyes	Completed	IIT Madras

	Effect of other parameters	Going on	IIT Madras
	Degradation mechanism study	Going on	IIT Madras
	Synthesis of triptycene based polymer	Completed	IISER Bhopal
	Adsorption study for pharmaceuticals using triptycene based polymers	Going on	IIT Madras
	Fluoride free drinking water	Lab-scale performance evaluation	IIT Madras
	Sensors and Kits for Water Quality Monitoring	Combining sensing moieties with detection techniques	IIT Madras
	Low-cost microfluidic platform for multi-analyte assessment of water quality	Detection of single contaminants	IIT Madras
	Atmospheric Water Capture	Completion of large area nano-engineered surface fabrication	IIT Madras
	CDI Prototype	Incorporation of ion exchange membranes Integration with electronic and photovoltaic system	IIT Madras
	Synthesis and characterization of affordable composite materials for the removal of heavy metals and microbes	Completed	IIT Tirupati
	Performance evaluation of the materials	Completed	IIT Tirupati
	Reuse/Recycle of spent materials	Completed	IIT Tirupati
	Prototype: design, development, and evaluation	On-Going	IIT Tirupati
	Field trials - household unit	On-Going	IIT Tirupati
	Documentation and data analyses: report making, manuscript preparation, patent filing	On-Going	IIT Tirupati
	Development of single probe multi-analyte sensor for	1. A simple, low-cost and sensitive multiplexed	CSIR-CLRI

	different metal ions with specific focus on Cr (III & VI), As (III & V), and Hg (II)	electrochemical sensor using dual functionalizatized graphene oxides. Evaluation of handheld electrochemical device. 2. Synthesis of L-Cysteine, L- Glutathione, Dithiothreitol on graphene oxide 3. Development of novel, low cost colorimetric and fluorescent probes	
	• Optimization of fabrication conditions for molecular cage- derived crystalline covalent organic framework based free-standing film for nanofiltration • Testing of pristine and sulfonated HCPs for real-time removal of pharmaceuticals found in Indian surface water • Optimization of ionic porous polymers for toxic metal anion removal • Manuscript writing and publication	• Optimization of the fabrication conditions for cage derived crystalline covalent organic framework based free-standing film through interfacial polymerization • Nanofiltration study using crystalline COF films • Pristine and sulfonated HCPs for the removal of pharmaceutical compounds from water (e.g., carbamazepine) • Optimization of fabrication conditions of triaminoguanidinium based porous organic polymers for dichromate, permanganate anion removal • Publication of manuscript on Nanostructured triptycene-based hypercrosslinked porous organic polymers for rapid separation of polar organic micropollutants	IISER Bhopal
	Synthesis of nanocomposites with agricultural waste/waste plastic derived graphene oxide for lead removal application	Completed	Kumaun University
	Characterization and Lead removal study	Under progress	KU and IIT Madras

	Toxicology assessment of synthesized materials	Under progress	IITR Lucknow
	Synthesis of graphene-based sponge for oil-water separation	Completed	KU and NIT Rourkela
	Synthesis of material for water purification membrane	Completed	Kumaun University
	Testing of material for water purification membrane	Under progress	Kumaun University
	Toxicity profiling of various materials/compounds	Preliminary *in vitro* experiments were performed on various cell lines to assess their toxic profile	CSIR-IITR and Kumaun University, Nainital
	1. Quantum Dots for Anticancer activity	Cytotoxicity assay (MTT), Quantum dots internalization through flow cytometry, and Fluorescent microscopy study are underway.	CSIR-IITR and Kumaun University, Nainital
	2. Carbon nanotubes for water treatment	Cytotoxicity assay (MTT) to determine the effective concentration of IC_{50} of the carbonaceous material is in progress.	CSIR-IITR and Kumaun University, Nainital
	3. Chitosan-RGO-Ag nanocomposite films for disinfection of water	Cytotoxicity assay (MTT) to determine the effective concentration of IC_{50} of the leachate sample is underway.	CSIR-IITR and IIT, Tirupati
WP3	Laboratory studies on identification of appropriate adsorbent materials for the removal of pharmaceutically active compounds and nutrients	Completed	IIT Madras
	Fabrication of large scale 4 µm pilot ceramic filter for the treatment of secondary treated wastewater.	Completed	IIT Madras
	Batch study with 4 µm pilot scale ceramic filter	Completed	IIT Madras

	membrane by fixing feed flow rate below 15 m^3/h with secondary treated wastewater as feed.		
	Quality analysis for the parameters like pH, COD, Fecal coliform, and Turbidity for Ceramic filter and it was compared with existing UF system.	Completed	IIT Madras
	Flux monitoring study along with Transmembrane pressure in batch process.	Completed	IIT Madras
	Modification work for continuous process with 4 µm pilot scale ceramic filter membrane.	Completed	IIT Madras
	Continuous experiments with 4 µm pilot scale ceramic membrane filter by fixing feed flow rate below 15 m^3/h with secondary treated wastewater as feed along with air plus water backwash.	Completed	IIT Madras
	Optimization of air plus water backwash timing.	Completed	IIT Madras
	Continuous filtration cycle with 4µm pilot scale ceramic membrane followed by air plus water backwash (1-90 cycles) with secondary treated wastewater along with chemical enhanced backwash (CEB).	Completed	IIT Madras

	Comparison of energy and chemical consumption for Ceramic and ultrafilter	Completed	IIT Madras
	Optimization of operation time and flow rate.	On going	IIT Madras
	Studies on decolorization of high concentration of azo dye-Methyl Red via denitrification pathway	Completed	VIT Chennai
	Batch studies on decolorization of model azo dyes (Orange G, Tartrazine, and Chrysodine Y) via denitrification pathway	Completed	VIT Chennai
	Gene expression studies on Nitrifiers, ammonia oxidizers and sulfur reducers (Oct 2020 - March 2021)	SBR and UASB studies have been restarted and the work is in progress. Subsequent to the stabilization and continued operation of SBR and UASB studies, the gene expression of the bacteria consortia will be carried out.	(CSIR-CLRI)
	Effect of COD loading and total nitrogen rates in tannery waste water (April 2021 – Sep 2021)	Removal of COD and TKN were evaluated with different loading rates in SBR.	(CSIR-CLRI)
	Effect of nitrogen loading rates in tannery wastewater with SBR	Removal of TKN and Ammoniacal nitrogen were evaluated with different loading rates	Central Leather Research Institute (CSIR-CLRI)
	Initial study of AD-MEC, system in continuous mode for COD removal, biogas generation and ammonia recovery	Based on the study of graphene coated electrode based microbial fuel cell (MFC) and subsequent optimization of the process parameters namely PEM (Salt bridge, varying length), Salinity (anode Chamber), pH (anode Chamber), Aeration (anode Chamber), Temperature (cathode chamber), Stirring speed (both cathode and anode	PRIST

		Chambers), Electrode (both cathode and anode Chambers) Light (both cathode and anode Chambers), anaerobic decomposition (AD) – microbial enzymatic cell (MEC) was initiated and a surveillance on the scale of COD reductions in the effluent, biogas generation at cathode and ammonia conversion efficiency were carried out in addition to electricity generations.	
	Fine tuning of AD-MEC, system in continuous mode	Ongoing	PRIST
WP4	scheduling for water distribution networks	Pure data driven methods demonstrated on laboratory network Heuristics for reducing computational effort for model based formulation developed Python based web application is being devloped and will be released	IIT Madras
WP5	Incubation Hub	Continuation and completion of process set up	IIT Madras

9. Accomplishment in Terms of Milestone for the Review Period:

Work Package	Milestones	Target month	Progress
WP1	Collection of data supporting the study (Lithologs, Toposheets, Soil, Rainfall, Water level, Satellite imageries)	March 2019	The basic data related to the study were collected and the maps were prepared by the target month mentioned. The Time series data like Rainfall, water levels have been collected till date.

	Preparation of thematic maps	July 2019	Completed
	Identification of pits/ quarries/ tanks	August 2019	Completed
	Assessment of quarry water, surface water and groundwater quality	Periodical collection up to June 2023	Sample collection and analysis have been completed until September 2021; next sampling will be carried out in February 2022
	Identification and assessment of various interventions	May 2022	Controlled reservoir operation has been planned and assessed using HEC-HMS software package and procured feasible results. Some hydrological interventions that facilitate flood mitigation and groundwater augmentation like additional check dams, interlinking waterbodies are under assessment using MIKE11 NAM and MIKESHE packages
	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 has to be continued with the projected rainfall. Integrated flow modelling of Adyar watershed have to be calibrated and validated.
	Data collection for the monsoon event 2020-2021 and data analysis	Nov 2021 – January 2022	Completed
	Preliminary coupled model SWMM-HYDRUS1D has been setup to access the	Dec 2021	Completed

	long-term hydrological behaviour of catchment.		
	Development of LID modules for designing sustainable drainage plans	Dec 2021	Completed
	Data collection for the monsoon event (Cyclone Nirvar)of Dec 2020 and analysis of data	January 2020	Completed
	Mapping/Modelling loss of water bodies and urban sprawl using satellite imagery(M.Tech thesis)	July 2021	Completed
	Water availibity modelling for Chennai basin using WEAP model.(M.Tech thesis)	July 2021	Completed
	Storm water management by using traditional water storage systems as flood control structures(M.Tech thesis)	July 2021	Completed
	Time Series Models for each zone (coupled deterministic & stochastic)	31-36 Months	1. Calibration of time series model developed for rainfall prediction at the study area for current year 2. Evaluation of variation of cyclicity, seasonality and trend of time series hydrological data of study area 3. Time and frequency domain-based modeling for estimating suitable ARIMA model for the study area 4. Development of water quality contours and flow-patterns (using SWAT) for selected study area

	Zone-wise Water quality contours for dominant parameters	25-30 months	1. Calibration of time series model developed for rainfall prediction at the study areas. 2. Collection of secondary data as well as primary data (through collection at site and analysis at lab) from a selected taluk (namely Orathanadu). 3. Ground surveillance of the University campus to explore hydrological and hydro geochemical characteristics and establishment of sampling locations catering to spatio temporal and hydrological resolutions for development of optimal water utilization masterplan. 4. Selection of dominant WQ parameters using PCA and successive development of WQ contours.
WP2	Fabrication of Capacitive deionization cell and development of material for deionization	June 2022	On going
	Synthesis of biochar derived from bamboo fiber (BDB)	April, 2021	Completed
	Synthesis of biochar using wastewater treatment plant sludge (SDB)	June, 2021	Completed
	Characterization of BDB and SDB	September, 2021	Completed
	Sorption and sono-sorption of three textile dyes and its kinetic and equilibrium study	August, 2021	Completed
	Lab-scale performance evaluation	Sept 2021	Complete
	Combining sensing moieties with detection techniques	Feb 2022	In progress
	Detection of single contaminants	Feb 2022	In progress

	Completion of large area nano-engineered surface fabrication	Feb 2022	Complete
	Incorporation of ion exchange membranes	Feb 2022	In progress
	Continuation and completion of process set up	Sept 2021	Complete
	Textile dye degradation study in pulse power plasma	October, 2021	Completed
	Effect of catalyst in pulse power plasma	November, 2021	Completed
	Effect of the input voltage on the degradation of dyes	December, 2021	Completed
	Synthesis of triptycene based polymer	December, 2021	Completed
	Effect of other parameters	February, 2022	In Progress
	Degradation mechanism study	March, 2022	In Progress
	Characterization of triptycene polymers	March, 2022	In progress
	Adsorption study for pharmaceuticals using triptycene based polymers	March, 2022	In progress
	Pilot-scale performance evaluation	Feb 2022	Completed
	Combining sensing moieties with detection techniques	Feb 2022	Nearly complete
	Detection of single contaminants	Feb 2022	Nearly complete
	Completion of large area nano-engineered surface fabrication	Sept 2022	Nearly complete
	Incorporation of ion exchange membranes Integration with electronic and photovoltaic system	Sept 2022	Nearly complete

	Continuation and completion of process set up	Sept 2021	Complete
	Long term performance of the antibacterial silver nanocomposite (AgNC) film	33-39 Months	Sustained release of silver ions from AgNC in distilled water, surface water, and groundwater was established
	Coating of the developed AgNC onto citrate-functionalized glass plates for making a reactor for disinfection applications	33-39 Months	We have optimized the protocol for the functionalization of glass plates. A coating methodology was developed, and the hydraulic stability of the coating was evaluated
	A protocol has been developed to recycle/reuse exhausted AgNC films	33-39 Months	We have recycled the spent AgNC and demonstrated its potential to repair micro-cracks in damaged concrete cubes. The repaired cubes were evaluated for their potential leaching of Ag via modified TCLP analysis, and the results show that the leaching of Ag from the cubes is around 150 times lesser than the permissible limits.
	Study on performance evaluation of self-combustion graphene-oxide (SCGO) for the removal of uranium (U) in water	33-39 Months	Batch adsorption studies like kinetics, pH, isotherms, Co-ions, ionic strength, and groundwater samples are performed
	Study on performance evaluation of Fe-chitosan-Phosphate (Fe-Cs-P) granular composite to remove U(VI).	33-39 Months	The composition of Fe-CS-P granular composite was optimized for achieving better hydraulic stability and U(VI) removal efficiency.
	Evaluation of the antibacterial activity of the prepared nanocomposite (AgNC) in the presence of various co-ions in water	26-32 months	The antimicrobial activity of AgNC in the presence of various co-ions, including hardness, alkalinity, chlorides, and humic acid, was studied.

	Long term performance of the antibacterial silver nanocomposite (AgNC) film	26-32 months	Sustained release of silver ions from AgNC in distilled water, surface water, and groundwater was established
	Synthesis of AgNC coated beads and development of a reactor for PoU disinfection of water.	26-36 months	We have optimised the composition and procedure for the synthesis of AgNC coated Fe-beads. We have optimised and evaluated the release of silver and disinfection performance of the prepared beads in a batch reactor
	Project initiation, identifying the structural motif's	6^{th} Month	Structural motifs are identified and are synthesized.
	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
		36 -49 Months	**Activity 1**: In vitro studies were performed and preliminary data regarding the toxicity of materials/ compounds were generated on various cell lines. A complete set of cytotoxicity data was generated using A549

			and Kera 308 was performed and communicated to PI. The second set of data on HaCaT and MCF 7 is in process.
		36 -49 Months	**Activity 2**: One set of data on Human keratinocyte cell line (HaCaT) for Cytotoxicity assay (MTT) to assess the effective IC_{50} concentration of the carbon nanotubes was generated which is further being confirmed for reproducibility.
		36 -49 Months	**Activity 3**: One set of data on Human keratinocyte cell line (HaCaT) for Cytotoxicity assay (MTT) to assess the effective IC_{50} concentration of the Chitosan-RGO-Ag nanocomposite films leachate was generated which is further being validated for reproducibility.
	Study on performance evaluation of self-combustion graphene-oxide (SCGO) for the removal of uranium (U) in water	26-32 months	We have optimised the individual ingredients for the preparation of SCGO and the screening of the prepared SCGO material for the removal of Uranium (U). Isotherm batch adsorption studies and the effect of pH in the removal of U(VI) were evaluated.
	Study on performance evaluation of Fe-chitosan-Phosphate (Fe-Cs-P) granular composite for the removal of U(VI).	26-32 months	The composition of Fe-CS-P granular composite was optimized for achieving better hydraulic stability and U(VI) removal efficiency.
	Project initiation, identifying the structural motif's	6^{th} month	Structural motifs are identified and are synthesized.

	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 picomolar level using optical methods
	Fabrication of functionalized graphene modified electrodes	36^{th} month	Functionalization of graphene suitable for the specific metal ions detection and optimization of detection methods, improving the limit of detection
	Standardizing gram scale protocol for HCP and testing with a wide range of micropollutants, Optimization of fabrication conditions for macrocycle and cage-based network polymers	30th – 35th month	1.Toluene-based HCP was synthesized in gram scale 2.Optimization of the fabrication condition for macrocycle/cage-based porous networks for nanofiltration applications 3.Optimization of the solution processable triptycene-based HCPs using flexible halogenated linkers
	Writing of the manuscript	30th – 35th month	Revision and further fine tuning of the manuscript for triptycene-based HCPs for broad spectrum micropollutant removal and elucidation of morphological impact on micropollutant removal
	Water samples collection from the lakes of Nainital region	0-6 months	Completed
	Examination and Identification of the collected samples	06-12 months	Completed
	• Synthesis of porous carbon nanomaterials/activated carbon black by using traditional precursors and waste plastic.	12-24 months	Completed

	• Research Paper		
	• Carbon nanomaterials /activated carbon black/nano-zeolite based polymer nano composites as filter membranes for water filtration unit. • Research Papers and patent	24-36 months	In progress
	In vitro studies were performed and preliminary data regarding the toxicity of materials/ compounds were generated on various cell lines	36 -49 Months	In progress
WP-3	Identification and characterization of low-cost adsorbent materials	Jan 2020	Completed
	Batch adsorption study for three pharmaceutical compounds and nutrients with the selected eight materials	Feb 2021	Completed
	Screening of materials through multi-criteria decision-making tool (MCDM)	June 2021	Completed
	SBR studies on model azo dyes (Tartrazine, Orange G, Chrysodine Y) under denitrifying conditions	32nd month	Completed
	Writing manuscripts for Journals using existing data and book chapters	34th month	Completed
	Setting up of laboratory-scale constructed wetland units at IIT-Madras	Jan 2021	Completed
	Performance monitoring of the laboratory-scale constructed wetland units with different substrate materials	Sep 2021	Completed

	Quantification of accumulation of PhACs in the plants and substrate materials	Oct 2021	Completed
	Batch biodegradation studies	Dec 2021	Completed
	Fabrication of large scale 4 µm pilot ceramic filter for the treatment of secondary treated wastewater at STP, IITM.	Mar-Apr	Completed
	Batch study with 4 µm pilot scale ceramic filter membrane by fixing feed flow rate below 15 m^3/h with secondary treated wastewater as feed and quality analysis study for CF and existing UF.	Sep-Oct	Completed
	Flux monitoring study along with Transmembrane pressure evolve in batch process and Modification work for continuous process.	Oct- Nov	Completed
	Continuous filtration cycle with 4µm pilot scale ceramic membrane followed by air plus water backwash (1-90 cycles) with secondary treated wastewater along with chemical enhanced backwash (CEB). Energy and chemical consumption per unit volume for Ceramic filter and existing Ultra filter system.	Nov- Dec	Completed

	Continuous experiments with 4 µm pilot scale ceramic filter membrane filter at fixed feed flow rate below 10 m^3/h and optimization of operation time and flow rate.	Dec- Jan	On going
	Decolorization of high concentration of azo dye Methyl Red in sequencing batch membrane bioreactor	39th Month	Completed
	Working models of AD-MEC in continuous mode	31-36 Months	1. Study of Anaerobic degradation (AD) of MFC/MEC with varying degree of anaerobic conditions 2. Estimation of optimized recirculation ratio and flow rate for continuous mode operation 3. Assessment of energy generation potential (voltage, current and power-density), water quality variation and sludge characteristics 4. Tracking bacteriological dynamics during MFC operation
	Quantitative real time (RT-PCR) data analysis of nitrifiers, denitrifiers and sulphur reducers	5th Half-yearly period (End of March 2021)	SBR and UASB studies have been restarted and the work is in progress. After stabilization of reactors, the consortia from SBR and UASB will be evaluated.
	CNS removal in SBR under different COD loading rates	6th Half-yearly period (End of September 2021)	CNS removal of Synthetic Tannery Wastewater has been carried at COD loading of 1.85 kg COD/m^3/d with SBR and UASB. Kinetic studies on removal of pollutants in SBR were performed.
	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 and UASB.
WP-4	Methodology for network mapping	Month 30	Network mapping methodology developed
	Software for network mapping and scheduling	Month 36	Scheduling software has been converted to python. Web app will be released shortly.
WP5	Continuation and completion of process set up	Sept 2021	Complete

10. Completed/ongoing activities during the review period: April 2021- March 2022 (WP 1 - WP 5)

S. No	Review Period	Completed Activities	Ongoing / Pending Activities
WP1	April 2021 – March 2022	• Identification of pits, quarries and lakes for water storage and recharge • Spatial and temporal 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. • 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 September 2021)	•Next set of water sampling has been planned for February 2022 and this will be the periodic process • Calibrated R-R model has to be used to simulate discharge using different scenarios • Integrated flow model of the entire Adyar basin is under refinement using calibration and validation • Prediction of changes in future runoff due to climate change
	September 2021	• Analysis of hydrological behaviour of existing drainage system to storm event.	

		• Collection of Rainfall data, Ground water levels, soil samples and measurement of soil hydraulic parameters.	
	June, 2020	• Assessment of the impact of SUDS on hydrological behaviour. • Calibration and validation of the SWMM model carried out for SUDS. • Design of SUDS for the study area	• Parameterization of SWMM LID module hydraulic properties for design storm event, antecedent moisture content and soil types.
	Feb, 2021	• Preliminary model to evaluate optimal placement and sizing of SUDs has been setup.	• Calibration and validation of the existing drainage network model is ongoing. • Effect of optimal scenarios of SUDs on hydrological response of study area is being analyzed.
	August, 2021	• Development of methodology for achieving river basin scale planning of SUDs	• Developing LID modules for improving the SWAT model formulation. • Development of methodology for site suitability analysis of LIDs.
	December, 2021	• The preliminary coupled SWMM-HYDRUS1D model has been setup to evaluate effect of design storm events, antecedent moisture content and soil types on performance of proposed LIDs components	• To develop the SWMM-HYDRUS-1D coupled model using pySWMM and phydrus.
	August, 2021	• Development of methodology for achieving river basin scale planning of SUDs	• Verification of the developed LID modules with HYDRUS 1D. • Development of methodology for site

			suitability analysis of LIDs.
	25-30 Months	Water quality Analysis & collection of Secondary data on water quality (storm-water & runoff)	Stormwater zonation study for two micro hydrological regions (Orathanadu taluk and campus)
	25-30 Months	Estimation of significant parameters for each zone	Development of zone-specific micro clustering of WQ parameters for optimal modeling and forecasting
	25-30 Months	Zone-wise Water quality contours for dominant parameters	Model calibrations (temporal, spatial and hydrological)
	31-36 Months	Time Series Model calibration & Assessment of Trend, cyclicity and Seasonality	Compilation of ongoing precipitation data and exploring potential variability
	31-36 Months	Time and Frequency domain modeling to develop ARIMA predictive models	Comparative assessment of optimized predictive models
	31-36 Months	Surface hydrological Modeling of Selected Zone (i.e., University campus)	Tracking the specific water-harvesting potential
WP2	Jan April 2021	Fabrication of Capacitive deionization cell and MOF derived structure for capture of Phosphate	Ongoing
	May-Dec 2021	Selective removal of Phosphate via electro sorption	Ongoing
	Feb, 2021 – Aug, 2021	Synthesis of biochar derived from bamboo fiber (BDB)	Finished
	July- Dec 2019	Fabrication of portable colorimetric sensor based on Basic Fuchsine for the detection of nitrite ion in an aqueous system	Finished
	July – Jan 2020	Assessment of competitive adsorption of pharmaceuticals and personal care product on carbonized absorbent derived from waste: Single and Multicomponent study	Finished

	July -March 2020	Colorimetric Sensors for the detection of phosphate and nitrate	Finished
	July-September 2020	Risk Dynamics of Emerging Contaminants and Heavy Metals in the River Ecosystems	Finished
	Jan Dec 2021	Selective removal of Phosphate via MOF	Finished
	Jan-June 2022	Fabrication of Capacitive deionization cell and LDH derived structure for the capture of phosphate	Ongoing
	Feb, 2021 – Aug, 2021	Textile dye degradation study in pulse power plasma	
		Effect of catalyst in pulse power plasma	
		Effect of the input voltage on the degradation of dyes	
		Synthesis of triptycene based polymer	
			Characterization of triptycene polymers
			Adsorption study for pharmaceuticals using triptycene based polymers
			Effect of other parameters
			Degradation mechanism study
	Feb, 2021 – Aug, 2021	Synthesis of biochar using wastewater treatment plant sludge (SDB)	
	Feb, 2021 – Aug, 2021	Characterization of BDB	

	Feb, 2021 – Aug, 2021	Sorption and sono-sorption of three textile dyes and its kinetic and equilibrium study	
	Feb, 2021 – Aug, 2021		Modification of BDB
	Feb, 2021 – Aug, 2021		Characterization of SDB
	Feb, 2021 – Aug, 2021		Manuscript writing initiated
	1-24 Months	Identification of structural motifs, their synthesis and characterization and evaluation of sensing activities.	Further studies on sensing are in progress.
	24-36 Months	Few target compounds were synthesized and demonstrated for sensing purposes	Further studies to improve the sensitivity and selectivity
	1^{st} -29^{th} month	Submission of Indian patent and writing of manuscript on triaminoguanidinium-based ionic porous organic frameworks (POFs) for heterogeneous catalysis and broad-spectrum antimicrobial application	Patent (ongoing) Application No. 201921010663 A
	1^{st} -29^{th} month	Multifunctional ionic porous frameworks for CO2 conversion and combating microbes	Chem. Sci. 2020, 11, 7910-7920
	30^{th} -35^{th} month	Manuscript revision on unfolding the morphological importance of triptycene-based hypercrosslinked polymers toward micropollutant removal	Submitted
	Sep 2020-July 2021	Preliminary toxicity screening	Toxicity assessment to understand the environmental impact of the tested materials/compounds
	Sep 2021-Jan 2022	Preliminary toxicity screenings on cell lines of different origins for the three different materials are performed to generate baseline data.	The initial data which were generated for the three activities are now being

			validated for reproducibility.
	1-36 Months	Identification of structural motifs, their synthesis and characterization and evaluation of sensing activities. Fabrication of functionalized electrodes, development of the handheld device developed by CSIR-CLRI for Cr(VI) sensing	Evaluation of the low-cost sensing device developed by SUTRAM for EAST Water and optimization process. Development of new sensor molecules
	36-42 Months	Synthesis of nanocomposites with agricultural waste/waste plastic derived graphene oxide for lead removal application	Characterization and Lead removal study
	36-42 Months	Synthesis of graphene-based sponge for oil-water separation	-
	36-42 Months	Synthesis of material for water purification membrane	Testing of material for water purification membrane
	36-42 Months	Synthesis of nanocomposites material	Toxicology assessment of synthesized materials
WP3	August 2021 – January 2022	Laboratory-scale constructed wetland studies for the removal of organics, nutrients and pharmaceutically active compounds (PhACs)	NA
	Jan 2021 – Jan 2022	Fabrication of large scale 4 µm pilot ceramic filter for the treatment of secondary treated wastewater at STP, IITM.	
		Batch study with 4 µm pilot scale ceramic filter membrane by fixing feed flow rate below 15 m^3/h with secondary treated wastewater as feed and quality analysis study for CF and existing UF.	
		Flux monitoring study along with Transmembrane pressure evolve in	

		batch process and Modification work for continuous process.	
		Continuous filtration cycle with 4µm pilot scale ceramic membrane followed by air plus water backwash (1-90 cycles) with secondary treated wastewater along with chemical enhanced backwash (CEB).	
			Continuous experiments with 4 µm pilot scale ceramic filter membrane filter at fixed feed flow rate below 10 m^3/h and optimization of operation time and flow rate.
	Month 34-39	Decolorization of high concentration of azo dye Methyl Red in sequencing batch membrane bioreactor and manuscript draft preparation	Completed
	October 2021 – January 2022	• COD & TKN removal in SBR with different nitrogen loading rates (0.101, 0.145, 0.178, 0.237 g/L/d) have been carried out. • Presence of Ammonia oxidizing genes were analyzed in the bacterial consortia.	• Removal and conversion of sulphates and sulphides in tannery wastewater • Meta genomic studies of microbial consortia from SBR and UASB
	Month 29-32	Operation of lab scale anoxic SBR under denitrifying conditions for simultaneous removal of color, COD, and TN	Completed
	Month 33-34	Prepared 3 new manuscripts and 2 invited book chapters; Addressed the revisions of 2 manuscripts that were under review which got published now	Completed
	April 2021 – September 2021	COD and TKN removal in SBR with different loading rates have been carried out. Performance of SBR followed by UASB was evaluated.	Microbial community from SBR and UASB has to be studied.

		Kinetic studies on removal of pollutants in SBR were performed.	Residual Sulphide from the UASB has to be removed.
	31-36 Months	Fine-tuning of AD-MFC/MEC system with optimization of process parameters (recirculation, anaerobic potential)	Exploration of graphene-electrode based AD-MEC system.
WP-4	Demonstration of leak detection methodology	Systematic methodology for leak identification using minimum valve operations & flow balance is demonstrated experimentally in a complex test network.	Web based application for leak detection is in progress
	Methodology for network mapping	Developed method for reconstructing networks from road layout and explainable AI	Web based application is in progress
	Algorithms for optimal operation	Robust optimization formulations developed to address uncertainty in data	Web based application will be released shortly
	Network calibration	Problem for network calibration has been formulated and demonstrated on small sized networks	Demonstration and extension to large scale networks is in progress
WP-5	Sept 2021	Continuation and completion of process set up	Complete

11. A Brief Description of Technical/Scientific Achievement for the period (April 2021 – March 2022):

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 modelled Chembarambakkam sub-catchment were used for distributing and storing the simulated discharge to achieve improved water storage, reduced inundation and better water supply.
- The flow model of Adyar watershed using MIKESHE 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
- Collection of real time data of river discharges at critical locations across Adyar River and Kosasthalaiyar River.
- Evaluation of the hydrological response of the catchment due to the application of different combinations of SUDS using SWMM.
- Vadose zone modelling using HYDRUS -1D to simulate the infiltration based SUDS to combat the limitations of SWMM in SUDS representation through SWMM-HYDRUS coupling.

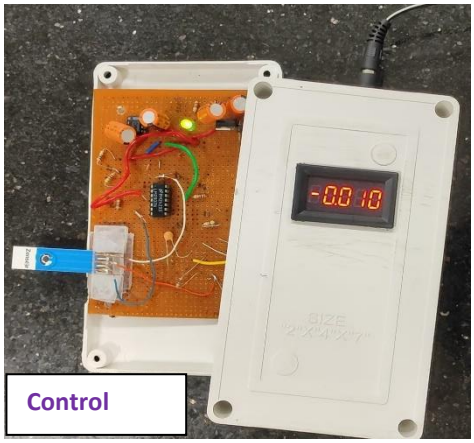
- Development of the SWMM-HYDRUS-1D coupled model using pySWMM and phydrus to simulate hydrological response of rainwater harvesting, permeable pavement, infiltration trench, infiltration basin and recharge shaft for IIT Madras campus, India.
- Formulation of methodology for strategizing a regional level planning of SUDS that would facilitate holistic water resource management for the basin.
- Development of modules for SWAT model formulation of LIDs using MATLAB to facilitate river basin scale decision making.
- LID modules for bio-retention cells, rain gardens, green roofs, permeable pavements, infiltration trenches and swales were formulated and the verification of the same is going on using HYDRUS 1D model.
- Conceptual model for recharge shaft was formulated and the development of the module is completed.
- Hydrological and hydraulic modelling to estimate the impact of traditional water storage tanks to control flood inundations in the Pallikaranai Marshland.
- Data sets that represent critical watershed parameters for site suitability analysis of LID components were collected from various sources.
- Methodology for site suitability analysis of LID components using Multi-Criteria approach was formulated.
- Thematic data layers viz., depth to bedrock, drainage density, geology, geomorphology, land use & land cover, lineament density, profile curvature, rainfall, slope, soil, Topographic Position Index (TPI), and Topographic Wetness Index (TWI) was created in GIS.
- Preliminary site suitability map of detention basin using Analytical Hierarchy Process (AHP) was prepared for Chennai basin using 11 of 14 thematic layers.
- Collection of rainfall data and calibration of time series predictive model developed at the study areas, and tracking the change in trend, cyclicity and seasonality
- Spatio-temporal hydrological modeling at University campus and estimation of water quality contours
- Assessment of water flow pattern variation through SWAT modeling and exploration of improved water utilization approach.

WP-2

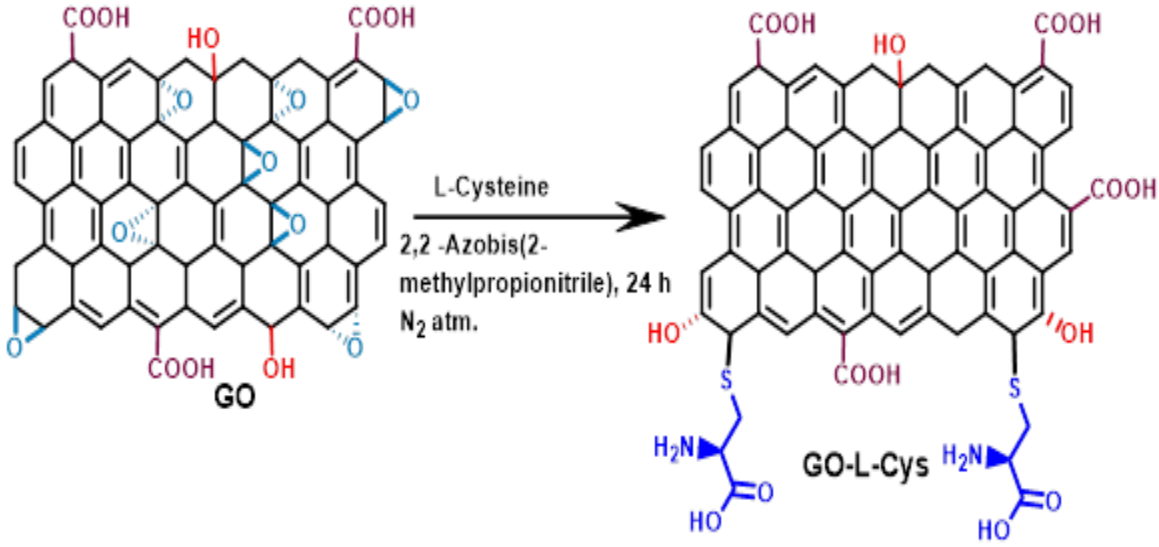
- Development of portable and low-cost techniques for detecting and removing trace pollutants. For this, a traditional method such as paper strip sensor and carbon-based adsorbents from waste have been tested. At the same time, two low-cost green adsorbents were made from agriculture and sewage sludge 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 for sorptive and electrosorption removal of phosphate was tested
-
- Degradation of three dyes (methylene blue, methyl orange and basic fuchsin) was studied in pulse power plasma technology was completed
- To utilize the pulse in activation of catalyst was studied to improve the efficiency of technology and to reduce the cost of the treatment process
- Effects of various parameters such as input voltage, initial dye concentration, treatment time etc was studied to find the optimized treatment condition
- The degradation mechanism and cost of treatment is being carried out to understand the feasibility of such process in dye degradation
- The synthesis of triptycene based polymers was completed to use for sorptive removal of pharmaceuticals (diclofenac and carbamazepine) from wastewater
- Adsorption studies and the effect of ultrasonication is being studied
- The model-based analysis will be carried out to optimize the various parameters involved
- Characterization of the polymers is carried out to find out the mechanism behind the sorption
- Nanocellulose reinforced organo-inorganic nanocomposite for synergistic and affordable defluoridation of water and an evaluation of its sustainability metrics
- Sensors and Kits for Water Quality Monitoring
- Scalable drop-to-film condensation on a nanostructured hierarchical surface for enhanced humidity harvesting

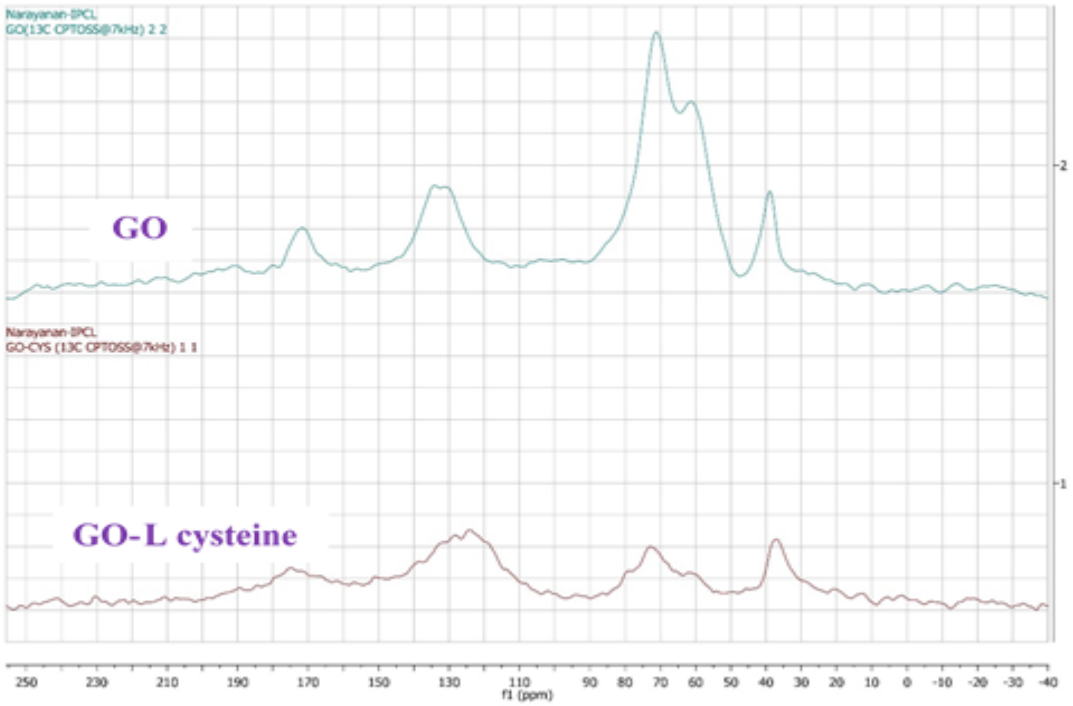
- The properties of the electrochemical cell (adopted with three-electrode configuration) was measured by Electrochemical impedance spectroscopy (EIS) and cyclic voltammogram (CV). This work is in progress now
- A Covalently Integrated Reduced Graphene Oxide–Ion-Exchange Resin Electrode for Efficient Capacitive Deionization
- Industrial Utilization of Capacitive Deionization Technology for the Removal of Fluoride and Toxic Metal Ions (As3+/5+ and Pb2+)
- Low-cost microfluidic platform for multi-analyte assessment of water quality
- The standalone AgNC film showed good stability in water, and the system could release silver ions of the required quantity till 500 cycles in distilled water and 250 cycles in surface and groundwater
- The AgNC films subjected to various water conditions were investigated with microscopic and spectroscopic tools
- The spent AgNC films were recycled to form composite termed as "G Plug," and it is disposed of as a sealant to heal micro-cracks in the concrete
- The G Plug has demonstrated excellent potential to seal the micro-cracks in the concrete and enhanced the compressive strength of the concrete cubes that are subjected to damage
- The interaction between G Plug and the cement were studied using spectroscopic and microscopic characterization tools
- The concrete cubes sealed with G plug was evaluated for the potential leaching of Ag ions via modified TCLP analysis, and the results showed that the release of Ag ions is around 150 times lesser than the permissible limits given by RCRA
- Based on the results, a manuscript titled "Chitosan-based nanopolymer composite as a sustainable point-of-use reservoir of silver ions: Water disinfection and safe disposal" is being prepared
- Methods of coating nanocomposite film on various surfaces for developing a PoU system were studied. Among various methods, (i) coating on a glass substrate after pretreatment at high temperature and pressure in the presence of Tri-sodium citrate and (ii) packed bed reactor employing nanocomposite beads were found to be feasible
- The coating of nanocomposite coated citrate-functionalized glass plates is found to be hydraulically stable
- The studies showed approximately 100% removal of U(VI) [5 mg/L]. Isotherm studies showed a maximum adsorption capacity of 183 mg/g at 30 oC
- An article titled "A critical review of uranium contamination in groundwater bodies: Treatment and safe disposal" is accepted with minor revisions in the Journal Science of Total Environment

- Article titled "Chitosan immobilized granular FeOOH-MnXOY bimetal-oxides nanocomposites for the adsorptive removal of lead from water" is accepted with minor revisions in the Journal of Environmental and Chemical Engineering
- The electronic components are procured locally and assembled. The instrument comprises of linear voltage regulator powered by a 12V battery, which has been fed into the switching voltage converted to 5V. This is to provide the differential voltage at the potentiostatic unit. An integrated circuit LM2902N has been used to connect the three electrode system comprises of working, counter, and reference electrode. An LED display is also integrated into the device, which indicates the changes in the potential and has been proportional to the concentration of metal ions present in the system. The electrode was constructed using the carbohydrazide and thymine functionalized graphene oxide drop cast on the screen-printed carbon electrode surface. Further, fabricated electrodes were used for the electrochemical sensor using the handheld device developed by us. Initially, the electrode was validated for sensing using the electrochemical workstation. The fabricated handheld device was evaluated for sensing chromium(VI) and control samples. The electrode senses the metal ions by indicating the potential changes corresponding to the specific metal ion. This handheld electrochemical device can use for on-site detection of chromium (VI) in an environmental water sample. Further, evaluation of the device is in progress and the total materials cost of the device is around Rs.1000/-.

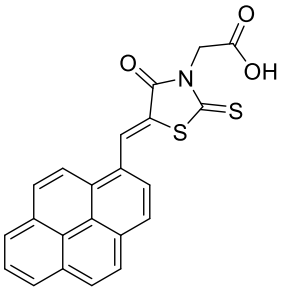
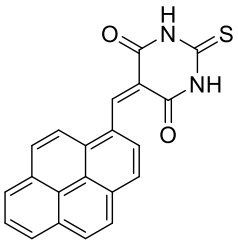
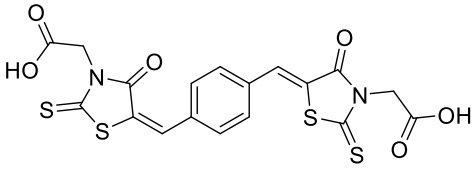
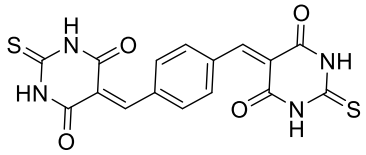


- Graphene oxide (GO) synthesized as a building block for the reporter and grafted are L-Cysteine functionalization. The grafted and graphene oxide are connected covalently via C-S conjugation. The solid-state nuclear resonance spectroscopy (ss-NMR) data shows the functionalization of graphene oxides (Figure 1). It confirms the attachment of L-cysteine on the graphene oxide layer. Further evaluation of the materials for sensing is in progress.


COOH
HO
COOH
O
COOH
OH
GO
L-Cysteine
2,2 -Azobis(2-methylpropionitrile), 24 h
N_2 atm.
COOH
HO
COOH
COOH
HO
OH
COOH
S
S
H_2N
H_2N
HO
O
HO
O
GO-L-Cys


Narayanan-IPCL
GO(13C CPTOSS@7kHz) 2 2
GO
Narayanan-IPCL
GO-CYS (13C CPTOSS@7kHz) 1 1
GO-L cysteine
250
230
210
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
f1 (ppm)

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

- The toxicity studies of the synthesized compounds were evaluated using MTT assay.
- Human skin origin, HaCaT and Kera cell lines as well as A549 and MCF 7 cancer cell lines were used for the study.
- Fabrication conditions for molecular cage derived crystalline covalent organic framework based free-standing film for nanofiltration.
- The recent research findings on broad-spectrum micropollutant removal from water published in ACS Appl. Mater. Interfaces has been shared with the media team. The news is going to be covered with frontline print media.
- Testing of pristine and sulfonated HCPs for real-time removal of pharmaceuticals found in Indian surface water in collaboration with Prof. Ligy Philip Group, IITM
- We have successfully developed a simple, greener, and cost-effective way to synthesize 2D and 3D GBM from the extract and fibre of Drepanostachyum falcatum. At low temperatures (150 °C), the 2D-MDGOs are extremely hydrophilic and readily bluish fluorescent under UV light of 365 nm. This material is biocompatible and nontoxic, whereas the synthesized 3D-GNR at high temperature (300 °C) is hydrophobic and has a 3D network-like structure. This 3D-GNR shows its excellent behavior for the removal of cationic dyes, i.e., MB. Therefore, the 3D-GNR can act as a promising candidate in the field of water purification.
- We have submitted the manuscript titled "Green and cost-effective synthesis of 2D and 3D Graphene-based nanomaterials from Drepanostachyum falcatum for Bio-imaging and Water purification applications" to a reputed journal, "Chemical Engineering Journal Advances." The manuscript is under revision.

- In addition, in this time frame, we successfully synthesized graphene-based sponge for oil water separation, and manuscript has been submitted.
- 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.

WP-3

- In this study, the fate of three PhACs – atenolol (ATL), carbamazepine (CBZ), and diclofenac (DCF) were investigated in each component of the CW.
- The hydroponics study with *Canna indica* removed 19.3 to 31.2% without substrate materials (initial PhACs:100 µg/L each).
- The breakthrough and sorption capacity of unplanted CW followed the order: natural zeolite (1.6-2.15µg/g) < Light-weight expanded clay aggregate (LECA) (5.37-8.27µg/g) < waste autoclaved aerated concrete (AAC) block (9.27-10.79µg/g) < wood charcoal (24.1-26.4µg/g), according to their surface and textural properties.
- Eventually, four laboratory-scale CW units with enriched microbes, *C. indica*, and different supporting materials were monitored for the removal of organics, nutrients, and PhACs.
- The synergistic interaction among AAC blocks, macrophytes, and microbial population in the system exhibited higher removal of COD, TN, TP, and PhACs as 88.6%, 81.6%, 77.6%, and 95.3%, respectively.
- Owing to the highly porous nature of waste AAC blocks, higher microbial activity was observed in the CW unit with AAC as substrate material.
- Performance of pilot scale ceramic membrane filter with pore size of 4 µm was tested for treating secondary treated wastewater under different operating conditions.
- Study showed that the filter was able to achieve desired treated wastewater quality with respect to pH, Turbidity, COD and Fecal coliforms.
- Removal efficiency of different pollutants such as turbidity, TSS, COD, and Fecal coliform ranged between 94-98.5%, 86-100%, 45-60%, and 80-85% respectively for 4µm pilot scale ceramic filter.

- Batch process was carried out to check the efficiency of filter by fixing the flow rate below 15m^3/h till the pressure reaches 1.5 bar.
- For every cycle, the flux value has been calculated by using volume of water filled in the permeate tank w.r.t time and the Transmembrane pressure evolve 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.
- After modification work for continuous process, Flux Monitoring study has been carried out by fixing flowrate below 15m^3/h for continuous process.
- Air + water Backwash was initiated for 30sec at the end of each cycle and the volume along with percentage of water used for backwash also estimated for every cycle.
- Optimization of running time by 20 minutes and 25 minutes was carried out for every cycle and flux also calculated.
- Chemical backwash was found to be effective in flux recovery Chemical washing was initiated to clear the blockage due to fouling when the transmembrane pressure not reduced as much after the air + water backwash.
- Chemical backwash was initiated in an efficient way by combining Caustic and hypochlorite and found to be effective.
- Overall cumulative net treated water and backwash water volume for 90 cycles was 2,53,718 L and 11,240 L, respectively. Percentage of water used for backwash was found to be below 5.
- Overall studies showed that the treated wastewater quality from ceramic filter (CF) was as same as the existing ultrafiltration (UF) outlet in IITM STP.
- The feasibility of decolorization of high concentration of azo dye Methyl Red (MR) in the presence of sucrose and NO_3^--N was evaluated in a laboratory scale membrane bioreactor operated in sequencing batch mode. Mixed microbial culture, which was previously enriched in a simple sequencing batch reactor under anoxic and static conditions, was used as seed biomass to decolorize high concentrations of MR (500 mg/L) using NO_3^--N as electron acceptor during start-up. After successful start-up, the reactor performance was assessed in increasing loading rates by decreasing the Hydraulic Retention Time (HRT) in different phases of reactor operation. Results indicate an effective decolorization of MR. Maximum removals of color (93%), COD (85%), and TN (81%) were achieved in phase I at a HRT of 16 d. On increasing the loading rate, the average removals obtained in phase III at a HRT of 4 d were color (77%), COD (78%), TOC (76%), and TN (95%). This

process may help in treating dye effluents cost-effectively using hybrid technologies (biological treatment followed other advanced techniques) because around 75% of dye could be treated in anoxic conditions without external aeration.

- A review paper published based on nutrients recovery from wastewater to promote circular economy and sustainable agricultural practice in India
- A book chapter (Springer) published titled 'Hybrid Bioreactors for Dye Biodegradation'
- A mini review paper published based on preliminary results of bio solids management using nano-scale oxides of Iron
- Fine tuning AD-MEC unit and optimization of nitrogen flow rate as well as recirculation ratio (and flow rate)
- Estimation of energy harvesting and water quality purification potential of the MFC/MEC system along with accompanying efficient sludge utilization approach
- Inoculum development (SBR) – Development of bacterial consortia for the removal of carbon and nitrogen removal in Sequential batch reactor.
- Batch studies were performed to evaluate the efficiency of bacterial consortia.
- After acclimatization process, Sequential batch process was performed to study the efficiency of inoculum for the aerobic process (C & N removal) with the cycle time of 36 and 24 hrs was evaluated over a period of 240 days.
- Inoculum development (UASB) – Cultivation and enrichment of sulfur reducing bacteria (SRB) using three different medium
- The acclimatization of bacterial consortium for the removal of Sulphur and Nitrate and residual COD from the synthetic tannery wastewater.
- The initial concentration of COD in UASB was 830 (±165) mg/L which got reduced to 270 (±80) mg/L. The maximum removal efficiency of Sulphate was found to be 58.8 % with the initial concentration of 1028 (±86) mg/L and the sulphide concentration in the final effluent was 315 (± 58) mg/L.
- The performance of the SBR for three different COD of loading rates (1.36, 1.85, and 2.45) has been evaluated.
- SBR Kinetic studies has been performed to find the complete cycle and its treatment efficiency
- Degradation kinetics were performed based on the experimental data obtained from SBR and found that Monod and first order model fits well.
- The performance of the SBR for four different nitrogen of loading rates (0.101, 0.145, 0.178, 0.237 g/L/d) has been evaluated over a period of 30 days at each loading rate and TKN removal efficiencies were found to be 83.3, 87.7, 83.3 and 80.9 respectively.
- Gene amplification was performed in the Bacterial sludge from SBR and confirmed the presence of ammonia oxidizing and nitrifying bacteria using PCR.
- Preliminary studies with Combined De-Sulfurization, De-nitrification and conversion of sulphide into elemental sulfur showed enhanced performance in the UASB with microaerophilic process.

WP-4

- Model based operation of water networks require 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.
- 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 will be released for public use shortly.
- 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 reconstrucitng 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.

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

IIT Madras

- Prototyping of smartphone-based fluoride sensor in progress.

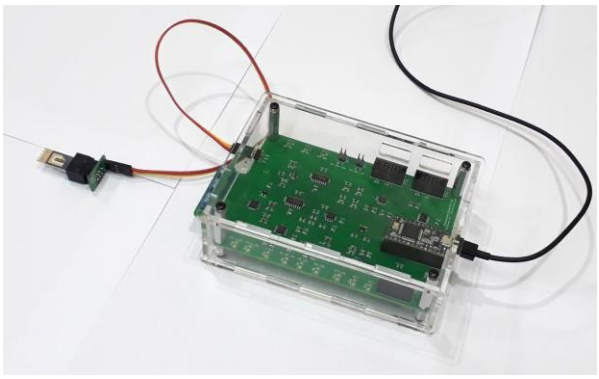


Figure: A hand-held electrochemical sensor system developed in the lab, output goes to a mobile phone

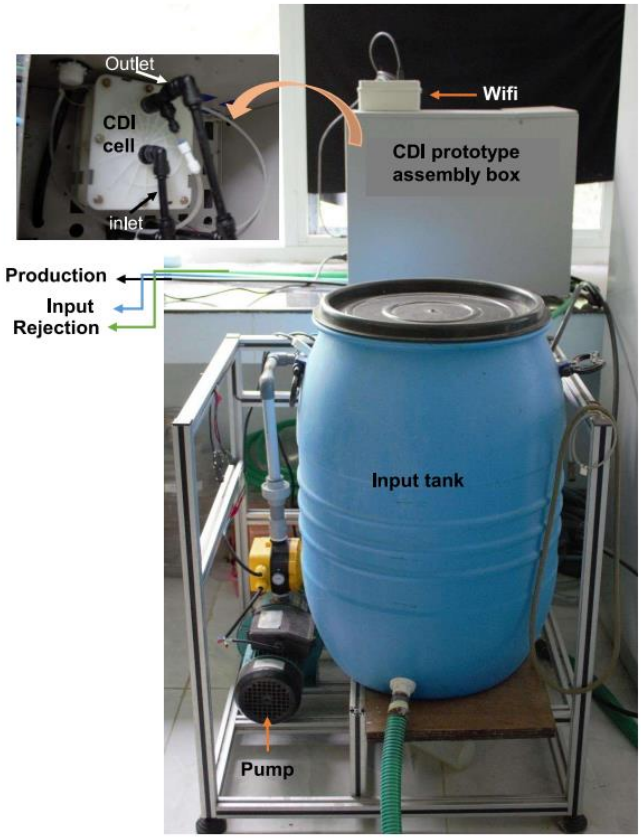


Figure. Prototype of CDI experimental setup, developed in the lab

Figure . An integrated sensor assembly for fluoride sensing.

IIT Tirupati

- A safe disposal protocol for the AgNC composite was developed
- AgNC coated chitosan beads were developed, and it produced a complete 3 log reduction within 30 min
- The reactor packed with AgNC coated beads are being developed
- A protocol for coating of AgNC on citrate-functionalized glass plates for fabricating the PoU reactor is developed, and its hydraulic stability is evaluated
- A synthesis protocol for large scale SCGO was optimized, developed, and used for U(VI) removal
- A stable Fe-CS-P granular composite that showed an enhanced U(VI) removal capacity was developed for making a small household point-of-use (POU) filter for the removal of U(VI)

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**
Sample collection	As funds for travel was not sanctioned, field work could not be completed as planned	Anna university

Running the reactor for extensive studies Dynamic column studies related the performance evaluation of heavy metal removal media	• The previous JRF was resigned from the project during February 2021, and the new JRF was recruited during August 2021 • The studies were affected due to the suspension of lab activities from April 2021 to June 2021 due to the second wave of COVID-19 lockdown. • Due to lockdown, the consumables required for some of the essential instruments (ICP-MS) were not accessible; Also, we could not address some of the equipment service issues on time due to restrictions.	IIT Tirupati
Mixed dye continuous decolorization studies	Unable to start due to lockdown	VIT Chennai
Feasibility studies for recovery of nutrient	Unable to start due to lockdown	VIT Chennai
Quantitative real time (RT-PCR) data analysis of nitrifiers, denitrifiers and sulphur reducers	Gene expression studies on Nitrifiers, ammonia oxidizers and sulfur reducers after stabilization of SBR and UASB could not be completed and will be initiated shortly.	Central Leather Research Institute (CSIR-CLRI)
	CoVID induced disruptions, closure of laboratory facilities has affected the progress of the work. However, we have made full attempts to make up for shortfall by optimizing resources and time.	IIT Madras
Manpower recruitment	Funds allocated are too small for the purpose. Need to release more funds in this head	IIT Madras

Environmental Impact Assessment	Delay in manpower recruitment due to COVID-19.	CSIR-IITR

14. Journal publication during the period:

Title of the paper	Journal, Issue, etc.	Authors
Spatio-temporal analysis of rainfall, meteorological drought and response from a water supply reservoir in the megacity of Chennai, India	Journal of Earth System Science / 2021	Anandharuban P, Elango L
A box model approach for reservoir operation during extreme rainfall events: A case study	Journal of Earth System Science / 2019	Anandharuban P, Michele La Rocca, Elango L
Organic micropollutants in groundwater of India – A Review	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
Sustainable Agro Landuse Evaluation through Life Cycle Assessment for Sugarcane Cultivation in Cauvery Deltaic Regions of India	Research Journal of Chemistry and Environment Volume 25, Issue 4, Pages 214 – 219 April 2021	Parthiban, P., Alagar raj, K., Das, A
Removal and risk assessment of pharmaceuticals and personal care products in a decentralized greywater treatment system serving an Indian rural community (2021)	Journal of Envionmental Chemical Engineering	Ravichandran M.K, Yoganathan.S and Ligy Philip
Stable paper-based colorimetric sensor for selective detection of phosphate ion in aqueous phase (2021)	Microchemical Journal	Choudhary, V and Ligy Philip
Enhanced degradation of complex organic compounds in wastewater using different novel continuous flow non – Thermal pulsed corona plasma discharge reactors (2021)	Environmental Research	Nippala N, Kamaraj Ramakrishnan and Ligy Philip
Spatio-temporal distribution of pharmaceutically active compounds in the River Cauvery and its tributaries, South India (2021)	Science of The Total Environment	Jayakumar Renganathan, Insamam Ul Huq S, Kamaraj Ramakrishnan,

		Ravichandran M.K, and Ligy Philip
Insight into the uptake, fate and toxic effects of pharmaceutical compounds in two wetland plant species through hydroponics studies (2021)	Chemical Engineering Journal	Ravichandran M.K, and Ligy Philip
Potential nanomaterials-based detection and treatment methods for aqueous chloroform (2021)	Environmental Nanotechnology, Monitoring and Management	Choudhary, V., Vellingiri, K., Ligy Philip
Performance evaluation of solar thermal systems as an alternative for human waste treatment (2021)	Sustainable Energy Technologies and Assessments	Krithika, D, Sharon, H, Reddy, K.S and Ligy Philip
Continuous flow pulsed power plasma reactor for the treatment of aqueous solution containing volatile organic compounds and real pharmaceutical wastewater (2021)	Journal of Environmental Management	Jerin Jose, and Ligy Philip
Sorption of pharmaceutical compounds and nutrients by various porous low-cost adsorbents (2021)	Journal of Environmental Chemical Engineering	Manthiram Karthik.R, and Ligy Philip
Comparative study of degradation of toluene and methyl isobutyl ketone (MIBK) in aqueous solution by pulsed corona discharge plasma (2021)	Journal of Environmental Sciences (China)	Jerin Jose, and Ligy Philip
Removal of antibiotics from aqueous solutions by electrocatalytic degradation (2021)	Environmental Science: Nano	Choudhary, V., Vellingiri, K., Thayyil, M.I., Ligy Philip
A Cantilever-based Flow Sensor for Domestic and Agricultural Water Supply System (2021)	IEEE Sensors	Harija H., George B. and Tangirala A
Assay of Inductive-Capacitive Probe for the Measurement of the Conductivity of Liquids (2021)	IEEE Transactions on Industrial Electronics	Tejaswini K. K., George B. and Kumar V. J.,
Analysis of a Direct Microcontroller Interface for Capacitively-Coupled Resistive Sensors (2021)	IEEE Transactions on Instrumentation and Measurement	Areekath L., George B. and Reverter F
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.202100533)	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
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	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	Ankit Nagar, Ramesh Kumar, Pillalamarri Srikrishnarka, Tiju Thomas and Thalappil Pradeep
A covalently integrated reduced graphene oxide-ion exchange resin electrode for efficient capacitive deionization	Adv. Mater. Interfaces, 2020	Md Rabiul Islam, Soujit Sen Gupta, 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	Sritama Mukherjee, Manav Shah, Kamalesh Chaudhari, Arijit Jana, Chennu Sudhakar, Pillalamarri Srikrishnarka, Md Rabiul Islam, Ligy Philip and Thalappil Pradeep
Dissolved arsenic in groundwater bodies: A short review of remediation technologies in "Pollution Control Technologies: Current Status and Future Prospects"	Pollution Control Technologies, June 2021, Pages 75-111,	M. S. V. Naga Jyothi, Gayathri S., T. Pushparaj Gandhi, S. M. Maliyekkal
Advanced Oxidation Processes: A Promising Route for Abatement of Emerging Contaminants in Water in "Pollution Control Technologies: Current Status and Future Prospects"	Nanomaterials and Nanocomposites for Environmental Remediation, August 2021,	Divya Kusuma T., M. S. V. Naga Jyothi, Chebrollu Pulla Rao, S. M. Maliyekkal
A critical review of uranium contamination in groundwater: Treatment and sludge disposal	Science of Total Environment, (Accepted with minor revisions)	T. Pushparaj Gandhi, S. Venkata Sampath. S. M. Maliyekkal

Chitosan immobilized granular FeOOH-MnXOY bimetal-oxides nanocomposites for the adsorptive removal of lead from water	Journal of Environmental and Chemical Engineering (Accepted with minor revisions)	M. S. V. Naga Jyothi, Afrah Harafan, Gaurav Singhal, Neethu Nalini, Soujit Sen Sengupta, B. Janaki Ramaiah, and S. M. Maliyekkal
Nanoscale silver-based point of use drinking water disinfection system	Book chapter submitted for publication in the book titled "Nanoremediation," Elsevier (in Press)	Uthradevi Kannan, Gayathri Pullangott, Swatantra Pratap Singh, and S. M. Maliyekkal
Application of plasma-assisted advanced oxidation processes for removal of emerging contaminants in water	New Trends in Emerging Environmental Contaminants, 333-370, Springer, 2022. DOI: 10.1007/978-981-16-8367-1_15.	S. M. Allabakshi, P.S.N.S.R. Srikar, R. Gangwar, S.M. Maliyekkal
Hydrogen Bond Assisted Julolidine-Barbiturate for Colorimetric Picomolar Level Detection of Hg^{2+} and Ag^{+} ions in 100% Aqueous Solution.	ACS Sustainable Chem. Eng. 2021, 9, 30, 10309–10317	Palani Yuvaraj, Joseph Ajantha, Shanmugam Easwaramoorthi, Masiyappan Karuppusamy, Venkatesan Subramanian, and Jonnalagadda Raghava Rao
Nanostructured hypercrosslinked porous organic polymers: morphological evolution and rapid separation of polar organic micropollutants	ACS Appl. Mater. Interfaces 2022, DOI:10.1021/acsami.1c24393	Arkaprabha Giri, Subha Biswas, MD. Waseem Hussain, Tapas Kumar Dutta, and Abhijit Patra*
Nanospheres to Nanosheets: Unfolding the Morphological Influence of Microporous Organic Polymers on Micropollutants Removal	Manuscript submitted (DOI: 10.26434/chemrxiv.14333936.v1)	Arkaprabha Giri, Subha Biswas, Tapas Kumar Dutta, MD. Waseem Hussain, and Abhijit Patra*
Agricultural Waste Derived Metal Doped Graphene Oxide for Selective and Visual Detection of Iron(III) in Water: Experiment and Theory	Sustainable Chemistry and Pharmacy	Chetna Tewari, Boddepalli SanthiBhushan, Anurag Srivastava, Nanda Gopal Sahoo
Waste Plastic Derived Graphene Sheets as Nano fillers to Enhance Mechanical Strength of Concrete Mixture: An Inventive Approach to Deal with	Cleaner Engineering and Technology, https://doi.org/10.1	Gaurav Tatrari[1], Chetna Tewari[1], Bhashkar Singh Bohra, Sandeep Pandey, Manoj Karakoti, Sumit

Universal Plastic Waste Inventive Approach to Deal with Universal Plastic Waste	016/j.clet.2021.100275	Kumar, Himani Tewari, 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, ISBN: 9781685073947)	Chetna Tewari, Sandeep Pandey, Sumit Bhardwaj, Nanda Gopal Sahoo*
A review on metal oxide (FeOx/MnOx) mediated nitrogen removal processes and its application in wastewater treatment	Reviews in Environmental Science and Bio/Technolgy (2020)	Swathi Desireddy Sabumon P. C
Development of aerobic granulation system for simultaneous removal of C, N, and P in sequencing batch airlift reactor	Journal of Environmental Chemical Engineering 9 (2021) 106100	Swathi Desireddy Sabumon P. C
Recovery of struvite from wastewaters as an eco-friendly fertilizer: Review of the art and perspective for a sustainable agriculture practice in India	Sustainable Energy Technologies and Assessments, ***Vol. 48,*** 101573, 2021 https://doi.org/10.1016/j.seta.2021.101573	Tejas N Vasa, Sabumon Pothanamkandathil Chacko
A mini review on effect of nano particles of Fe in the anaerobic digestion of waste activated sludge	materialstoday:PROCEEDINGS, 2022 https://doi.org/10.1016/j.matpr.2021.10.265	Ragasri S, Tejas N Vasa, P.C. Sabumon
Hybrid Bioreactors for Dye Biodegradation	https://link.springer.com/chapter/10.1007/978-981-16-5932-4_10	Swathi Desireddy, Sabumon Pothanamkandathil Chacko

Control Release of Adenosine Potentiate Osteogenic Differentiation within a Bone IntegrativeEGCG-g-NOCC/Collagen Composite Scaffold toward Guided Bone Regeneration in a Critical-Sized Calvarial Defect	ACS Biomacromolecules, 2021 22, 3069-3083	Verma NK, Kar AK, Singh A, Jagdale P, Satija NK, Ghosh D, Patnaik S∗
pH-responsive eco-friendly chitosan modified cenosphere/ alginate composite hydrogel beads as carrier for controlled release of Imidacloprid towards sustainable pest control	Chemical Engineering Journal, 2021, 131215	Singh A, Kar AK, Singh, D, Verma R, Shraogi N, Zehra A, Gautam K, Anbumani S, Ghosh D, Patnaik S*

Communicated and under review

Title of the paper	**Journal, Issue, etc.**	**Authors**
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.
Process optimization of conventional MFC through factorial design approach	Environmental Science and Pollution Research (Submitted)	Sathiskumar P., N. Baskar., Bharathirajan S., Nilavu B., Parthiban P., and Das, A
Evaluation of dephenolation capacity by column adsorption studies	Desalination and Water Treatment (Submitted)	Srihari V., Subramanyam B., and Das, A
Parametric Optimization and performance assessment of graphene impregnated polyaniline coated electrode based Microbial Fuel Cell using mixed culture obtained from Canteen wastewater	Suwam 2022 (Conference) (Abstract submitted)	Ponmani P., Nilavu B., Parthiban P., Mahesh R., Sivanantham M., Tewari C., Sahoo N.G and Das, A
Steady-state Assessment of Hydraulic Potential at Agniyar River Basin, India using GMS-MODFLOW	Suwam 2022 (Conference) (Abstract submitted)	Sugam Verma, Ravikumar K, IC Das and Das A
Hydrogen Bond Assisted Julolidine-Barbiturate for Colorimetric Picomolar Level Detection of Hg^{2+} and Ag^{+}	Analytical Chemistry (to be submitted)	Palani Yuvaraj, Joseph Ajantha, Shanmugam Easwaramoorthi, Masiyappan Karuppusamy, Venkatesan Subramanian, and Jonnalagadda Raghava Rao

ions in 100% Aqueous Solution.		
Multiplex Electrochemical Sensor for Metal Ions using Covalently Dual Functionalized Graphene Oxides	Manuscript under review	J. Narayanan, Shanmugam Easwaramoorthi, and Jonnalagadda Raghava Rao
Performance Evaluation of Novel Non-Thermal Pulsed Corona Plasma Reactors for the Degradation of Pharmaceutical Compounds	Journal of Separation and Purification	Nippatla n and Ligy Philip
Sustainability assessment of acid-modified biochar for sorptive removal of pharmaceuticals and personal care products from secondary treated wastewater	Journal of Environmental Chemical Engineering Journal	Choudhary, V., & Philip, L.
A comprehensive review on catalytic removal of paraben from water: Insight into experimental and theoretical evaluation	ACS ES&T Water	Vellingiri, K., Choudhary, V., Boukhvalov D., & Philip, L.
Sorptive removal versus catalytic degradation of aqueous BTEX: A comprehensive review in the perspective of life-cycle assessment	Environmental Science: Water Research & Technology	Vellingiri, K., Choudhary, V., Kumar, S., &Philip, L.
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	Sumit Kumar, Chetna Tewari, Nanda Gopal Sahoo, Ligy Philip
Simultaneous detection of Cr(VI), Hg(II) at ppb level using functionalized graphene	Manuscript under preparation	J. Narayanan, Shanmugam Easwaramoorthi, and Jonnalagadda Raghava Rao
Green and cost-effective synthesis of 2D and 3D Graphene-based nanomaterials from *Drepanostachyum falcatum*	Submitted	Chetna Tewari, Gaurav Tatrari, Sumit Kumar, Sandeep Pandey, Anita Rana, MintuPal, Nanda Gopal Sahoo

for Bio-imaging and Water purification applications		
Waste Plastic Derived Graphene Sheets as Nano fillers to Enhance Mechanical Strength of Concrete Mixture: An Inventive Approach to Deal with Universal Plastic Waste	Cleaner Engineering and Technology (Under revision)	Gaurav Tatrari1, Chetna Tewari1, Bhashkar Singh Bohra, Sandeep Pandey, Manoj Karakoti, Sumit Kumar, Himani Tewari, Nanda Gopal Sahoo* 1 Authors contributed equally to this work
Plastic derived graphene impregnated polyaniline coated electrode based Microbial Fuel Cell using mixed culture obtained from Canteen wastewater	Communicated	Ponmani P., ParthibanP.,MaheshR.,SivananthamM.,Nilavu B., Tewari C., Sahoo N.G and Das, A*
Development and long term operation of aerobic granular system for simultaneous removal of COD, nitrogen, and phosphorous in a simple conical SBR	Under review in Environmental Engineering Research	Swathi Desireddy, Sneha Madhavan, Sabumon P. C.
Development and long term operation of aerobic granular system for simultaneous removal of COD, nitrogen, and phosphorous in a simple conical SBR	Under review in Journal of Environmental Chemical Engineering	Swathi Desireddy, Sneha Madhavan, Sabumon P. C
Feasibility studies on decolorization of high concentration of azo dye Methyl Red in sequencing batch membrane	communication to Environmental Technology and Innovation	Desireddy Swathi Sabumon P. C
Effect of pH, salinity, dye and biomass concentration on decolorization of azo dye methyl orange in denitrifying conditions	communication to Environmental Technology and Innovation	Aditi Trivedi Swathi Desireddy, Sabumon P. C
Book Chapter: Emerging contaminants removal from wastewater by nanotechnological methods	Under review in New Trends in Emerging Environmental Contaminants	Desireddy Swathi Sabumon P. C
Book Chapter: Advances in Nano Filtration (NF)	Under Bio-membrane Filtration in Industrial	Desireddy Swathi Sabumon P. C

	Wastewater Treatment - Innovative Approaches	
Biological treatment of tannery wastewater using sequential batch reactor and its kinetics.	Manuscript will be communicate shortly	V. Nagabalaji, S. Karthick Shankar,. Nishanthi, R. Suthantharajan, S. V. Srinivasan*
Effect of initial inoculum in symbiotic bacterial – microalgal system and its optimization for the treatment of tannery wastewater	Communicated	V. Nagabalaji, P. Maharaja, R. Nishanthi, G. Sathish R. Suthantharajan, S. V. Srinivasan*

15. Presentations in Symposia/ Conferences during the period

Title of the paper presented	Symposium/ Conference	Dates of the Symp/Conf.	Authors
Quarries encompasses a fast-growing metropolitan city in India – retrospect and prospect, an approach for water sustainability	International Conference on Innovative technologies for clean and sustainable development by Chitkara University & NITTR, Chandigarh	14-15 October, 2021	Rinisha Kartheeshwari M and Elango L
Significance of reservoir operation during extreme rainfall event in flood mitigation and water demand management in a metropolitan city of India: a case study	EGU general Assembly 2020	4 – 8 May, 2020	Anahdharuban P, Michele La Rocca and Elango L
Groundwater quality assessment in the urbanized city, Chennai, Tamilnadu, India	Indian National Groundwater Conference (INGWC-2020) at CWRDM, Kozhikode	18 -20 February, 2020	Merin Sackaria 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 (Abstract submitted)	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	First International Conference on Circular Economy for Sustainable Water Management	March 2022 (Abstract submitted)	K. Modi and B.Narasimhan

HYDRUS-1D coupled model			
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 (Abstract submitted)	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 (Abstract submitted)	Sreethu, S., Narasimhan, B., and S. Murty Bhallamudi
Challenges and opportunities for storage and infiltration based LIDs in coastal catchments of Chennai, India.	12th Urban Drainage Modelling Conference, California	January 2022 (Abstract submitted)	B.Palanisamy, R. Borkar, K. Modi, S.Sreethu, S. Shaurabh and B.Narasimhan.
Colorimetric affordable test strips	Atal innovation mission and Innovation Centre Denmark water challenge	2021 Next Generation Water Action initiative	Choudhary, V. Vellingiri, K, & Philip, L
Interpretation of the risk associated with emerging contaminants in the aquatic systems of BRICS nations	EWRI, American Society of Civil Engineers	7-11 June, 2021	Choudhary, V. & Philip, L (2021)
Gas phase electrical discharge induced degradation of single and mixed VOCs in aqueous solution	14th International Conference on Eco materials, CSIR-NIIST Trivandrum	Feb 5-7, 2020	Jerin Jose, Ligy Philip
Occurrence and fate of antimicrobial agents in a hybrid flow constructed wetland treating greywater	Aqua 360 water for all – Emerging Issues and Innovations	31st August – 2nd September 2021	Manthiram Karthik Ravichandran and Ligy Philip
Exploration of socio-economic factors affecting the implementation of zero liquid discharge system in peri-urban and rural households of metropolitan city	Aqua 360 water for all – Emerging Issues and Innovations	31st August – 2nd September 2021	Krithika Delhiraja, Prema Rajagopalan and Ligy Philip
Spatial and temporal variations in the concentrations of	Aqua 360 water for all – Emerging Issues and Innovations	31st August – 2nd	Jayakumar Renganathan, Insamam

pharmaceutically active compounds in a south Indian river		September 2021	UlHuqS,KamarajRamakrishnan, Manthiram Karthik Ravichandran and Ligy Philip
Fe-Mn binary oxides granules for mercury removal from water	First InternationalConference on Circular Economy for Sustainable Water Management (SuWaM-2022)	23-25th March 2022, IIT Madras (Abstract accepted)	M. S. V. Naga Jyothi, and S. M. Maliyekkal
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 (Abstract accepted)	T. Pushparaj Gandhi, S Gomosta, S Sengupta, S. M. Maliyekkal.
When Macrocycle Meets Porous Organic Polymer (POP): Resorcin[4]arene-based POPs for Selective Molecular Separation (#MatChem_MC10)	ChemSci2021 Twitter poster organized by JNCASR	Virtual poster presentation: 10th Dec., 2021	Arkaprabha Giri, Abhijit Patra
Self-assembly of π-Conjugated Molecules and Nanoporous Organic Polymers	7th International Conference on Advanced Nanomaterials and Nanotechnology (ICANN 2021), IIT Guwahati	Online seminar 15th Dec., 2021	Abhijit Patra
Porous Organic Polymers for Sequestration of Organic Micropollutants from Water	Workshop entitled "Functional Polymeric Materials; Exploring towards Green and Sustainability (FPMGS-2021)" University of Melbourne and Rubber Technology Centre, IIT Kharagpur	Online seminar 7th Oct., 2021	Abhijit Patra
Porous Organic Polymers for Size and Charge Selective Sequestration of Organic Micropollutants from Water	160th Birth Anniversary Celebration of Acharya P. C. Ray and Recent Advances in Chemistry and Material Science 2021 (RACMS2021)	Virtual oral presentation: Indian Chemical Society, Aug. 2021	Arkaprabha Giri, Subha Biswas, Abhijit Patra [Best oral presentation Award (2021)]
One-pot green synthesis of 3D nanomaterial using plant of the Himalayan region for	International Conference on Environment and Energy Materials	29-31st July, 2021	Chetna Tewari, Nanda Gopal Sahoo

water purification application	(INCEEM): Innovation of Tomorrow.		
A mini review on effect of nano particles of Fe in the anaerobic digestion of waste activated sludge	second International Conference on (SESBT 2021),VIT Chennai in collaboration with ESRIG, University of Groningen, Netherlands	23-24 July, 2021	Ragashree Srinivas, Tejas N Vasa**,** Sabumon P. C.
"Algal-bacterial symbiotic system for the tannery wastewater treatment".	International conference on (ASREEM-2021) conducted by Sardar Vallabhbhai National Institute of Technology, Surat,India	August 06-08th, 2021	V. Nagabalaji, P. Maharaja, R. Nishanthi, G. Sathish R. Suthantharajan, S. V. Srinivasan*
Network reconstruction	AIAA –Graphs and complex structures	Feb 28, 22 (to appear)	Anish Diwan and Sridharakumar Narasimhan

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

Sl.no	**Title**	**Inventors**	**Filed on**	**Granted**
1	Turbidometer	Ashutosh Das, Kannan TTM, Parthiban P		340684-001 (Granted)
2	Solar and wind augmented composter	Ashutosh Das, Kannan TTM, Parthiban P		341584-001
3	Permeameter	Ashutosh Das, S. Amuthavel, Sugam Verma, K. Alagar Raj, P. Parthiban		342746-001
4	Recording Seepage Meter	Ashutosh Das, P. Parthiban, S Amuthavel, Sugam Verma, K. Alagar Raj		350262-001
5	Colorimetric sensors of Detection of Eutrophying pollutants **(Under Review)**	Vaishali Choudhary, Kowsalya Vellengiri, Ligy Philip		IDF2070
6	Simple direct microcontroller interface for capacitively-coupled resistive sensors	Lakshmi A., Boby George, and Ferran R	22/05/2020	202041021691
7	A Planar Coil-Based Water Level and Quality Monitoring System	Gaurav L., Subham K. S., and Boby George, Subhas C.	24-July-2019	201941021491

		Mukhopadhyay and Ligy Philip		
8	A smartphone integrated fluoride-specific sensor for rapid and affordable colorimetric detection,	Thalappil Pradeep; Sritama Mukherjee; Kamalesh Chaudhari; Manav Shah	June 20, 2020.	202041026054
9	An Integrated CDI Electrode US Patent no.: US20200331778A1	T. Pradeep, Md R. Islam, S. S. Gupta, P. Srikrishnarka, S. K. Jana	October 22, 2020.	
10	An Integrated CDI Electrode PCT patent no.: WO2019130355A1	T. Pradeep, Md R. Islam, S. S. Gupta, P. Srikrishnarka, S. K. Jana	July 4, 2019	
11	A point-of-care (POC) ampherometric device for selective arsenic sensing 202041023576	T. Pradeep, S. K. Jana, K. Chaudhari, and Md R. Islam	June 5, 2020	
12	A compact, modular and scalable continuous-flow greywater sink for potable and non-potable uses. 202141054715	T. Pradeep, A. Nagar, Md R. Islam	November 26, 2021	
13	HYDRO-SOLVO THERMAL GRAPHENE OXIDE SYNTHESIS METHOD	Nanda Gopal Sahoo,Chetna Tewari,Sandeep Pandey ,Manoj Karakoti ,Sunil Dhali ,Himani Tiwari , Gaurav Tatrari Anand B. Melkani	17/03/2020	Revised Indian patent application No. 202011011434, PCT application No. PCT/IB2021/052158
14	Process of preparation of naturally doped Silicon, Magnesium and Calcium Graphene nanosheets from Paper Waste for Energy Applications (Australia Innovation Patent)	Sandeep Pandey ,Manoj Karakoti , Sunil Dhali, Chetna Tewari ,Nanda Gopal Sahoo	28/01/2021	2021100550 Granted
15	Triaminoguanidinium-based ionic porous organic frameworks (POFs) for heterogeneous catalysis	A. Patra, A. Chande, MD. W. Hussain and V. Bhardwaj	19/03/2019	Application No.201921010663 A

	and broad-spectrum antimicrobial application'			

17. Other Achievements during the period:

(New Facilities created, HRD, Demonstrations, Social Benefits, Notable Service Rendered)

Anna University

- The work carried out in connection with this project, in flood mitigation aspect suggests that the flood peak can be minimized with the controlled reservoir operation. And, a Ph.D thesis was submitted on this using integrated modelling approach
- One M.Sc dissertation was submitted, which focused on the efficiency of check dams in the Adyar river.
- Two Ph.D works are ongoing in connection with this project.
- The ongoing works in flood mitigation aspects are being discussed with the "Advisory Committee on mitigation and management of flood risk in Chennai metro" for implementation

PRIST University

- Collaborative Venture with other co-investigator of SUTRAM, (namely, Kumaun University, Nainital) for using graphene-based electrode for better performance of MFC. A research paper has been communicated to this effect

Kumaun University

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

IITR Lucknow

- The toxicity studies of the synthesized compounds were evaluated using MTT assay.
- Human skin origin, HaCaT and Kera cell lines as well as A549 and MCF 7 cancer cell lines were used for the study.

IIT Madras

- New facilities were purchased and installed. Several lectures at national/international conferences. Several visits and visitors

18. Financial Status on the Day of Reporting:

18.1 Amount Sanctioned: Rs: **4,46,56,222/-**

18.2 Amount Received: Rs:**2,58,96,930/-**

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 Terms**	**Responsible Organization**
Environmental Impact Assessment	Delay in manpower recruitment due to COVID-19.	CSIR-IITR

Appendix – 1

WORK PACKAGE – 1

1.1 Hydrogeological Interventions for Flood Mitigation and Augmentation of Groundwater Recharge

Introduction

Frequent floods, water scarcity, contaminated environment has become the new signs of Chennai city in recent past. Erratic monsoon, urbanization, improper water management and population seems to be the major cause for Chennai's current situation. Adopting favourable surface and sub-surface interventions like links, diversions and deepening of water bodies, percolation ponds can facilitate to improve the existing scenario. The study mainly focused on Adyar and Kovalam basins, where numerous hydrological units for interventions like reservoirs, quarries, lakes, temple tanks are available. The prime objectives are

- To identify measures to use storm water to improve groundwater recharge and assess feasibility through pilot study by constructing percolation pond with recharge shafts
- To identify the exiting pits/quarries to use them as storage zones to conserve storm water
- To identify ways to divert storm water to improve water storage and reduce inundation through modelling.

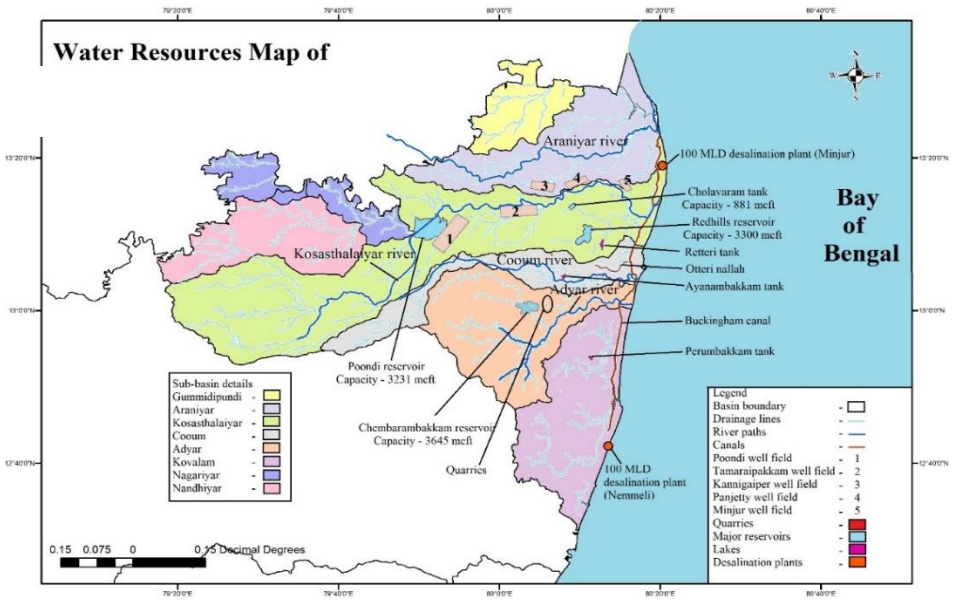


Fig 1 Water resources map of Chennai basin

Work done

- The maps of Topography, soil, geology, drainage and stream order, existing surface water bodies for the Adyar and Kovalam basins were prepared using the appropriate sources. Elevation & characteristics of various water bodies and the dimensions of abandoned quarries were assessed both in field and through satellite imagery. The land use land cover map was prepared using LISS III (May, 2017) imagery by supervised classification. The Thiessen polygon was also prepared and the rainfall analysis using the precipitation data for different rain gauge stations were carried out.
- The volume of the three major set of abandoned quarries in Adyar basin were estimated as 0.81, 0.11 and 0.24 TMC and graphs were plotted for better understanding of depth to volume relationship of different quarries. The abandoned quarries can perform as additional water storage structures, among them Sikkarayapuram is the most promising one. The water quantification and budgeting was performed for balanced water tapping without draining of quarries.
- The water samples were collected and analysed periodically to identify the locations that are likely to be affected by surface source of contaminants. The quality of water in Trisoolam quarry (Kovalam basin) is of poor quality. In surface water's case, the water samples are Ca-Na-HCO_3 group and Na-HCO_3 group and the dominant cation and anion are Na and HCO_3 respectively. In groundwater's case most of the samples are Na-Cl group and Ca-Mg-HCO_3 group. And the dominant cation and anion are Na and Cl respectively. Also the mechanism controlling the groundwater chemistry is noted as the combination of evaporation and rock-water interaction using Gibb's plot.
- The surface water quality of the lakes that are to be used to augment groundwater resources by discharging treated sewage water were assessed periodically. Next sampling campaign will be commenced by this month (September, 2021). The results obtained were checked for the ion balance error, and the error percent is maintained within plus or minus 10 for all the samples collected and analyzed. Since, they are surface water bodies and having inhabitants nearby, the water quality seems to be affected by contaminants.
- The water diversion works are focused towards Adyar basin as of now. The water diversion studies for Chembarambakkam (219.39 Km^2) & Sikkarayapuram (7.32 Km^2) sub-catchments of Adyar basin were carried out. The rainfall and evaporation from the

influencing rain gauge stations of the two sub-catchments were collected. The rainfall runoff modelling was performed initially using MIKE11 NAM for the catchments by assigning nine surface and root zone parameters for the catchment area and validated using observed discharge data measured in Chembarambakkam (2005 to 2020).

- The modelling of Adyar watershed using MIKESHE is being carried out. Calibration and validation are in progress by incorporating various surface and root zone parameters. After validation with business asusual, the model will be used to understand the variation in the depth of overland flow and the water balance for the entire catchment.

FUTURE WORK

- Water quality of surface water (quarries, lakes, ponds and river) and groundwater were assessed till date and this work will be carried out periodically once in three months
- Feasibility of various interventions like diversions, check dams on augmenting groundwater and reduced overland flow will be assessed by modelling using MIKE software
- The impacts of hydrogeological interventions in groundwater recharge, water quality and runoff reduction in terms of different scenarios will be studied further.

1.2: Sustainable Urban Drainage Systems

The issue of water scarcity and flooding in urban setting poses major challenges for efficient water management. For tackling this issue, many cities of world are trying to adopt sustainable water management system which includes sustainable urban drainage, water distribution and groundwater management. Most often conventional storm drainage systems fail during circumstances of increased peak runoff flow and decrease time of concentration which are mostly associated with urban floods. This issue associated with conventional storm drainage systems was addressed by replacing it by more effective and sustainable practices namely Sustainable Urban Drainage System. Sustainable drainage mimics the natural processes such as infiltration, evaporation, and transpiration by providing storage-based or infiltration-based components by capturing the generated runoff at site to catchment level. This study attempts to evaluate the effect of sustainable urban drainage (SUDS) system on urban flood mitigation and groundwater recharge for Indian condition. However, effective implementation of Sustainable urban drainage system (SUDS) mainly depends on placement, design, construction, and maintenance. These factors are influenced by amount of runoff generation, infiltration capacity of soil, groundwater level of region, aquifer characteristics, availability of material and area. Hence, the characteristics of the region in terms of soil profile, soil retention characteristics, and land-use will decide the choice and location of options for sustainable drainage systems. To evaluate impact of these critical factors on hydrological behaviour of SUDs different studies have been carried out during review period.

The review of literature suggests vegetation-based SUDS such as green roofs and swales are effective source control solutions. However, design of SUDS is exclusive to the site conditions they are intended for and the hydrological behaviours vary based on the characteristics of the precipitation. Hence, the limitations and challenges in the implementation of SUDS for a coastal city like Chennai, with irregular rainfall and long dry weather periods have been identified through the study. Topographic Wetness Index, derived from digital elevation model of the study area was used to determine areas which were likely to be saturated. A catchment scale and pilot scale assessment on the impact of non-infiltration-based SUDS was done using SWMM. The research findings recommended managed aquifer recharge for the study area due to the low hydraulic conductivity in the region and widely sparse rainfalls. Flat topography, ground water levels, land

encroachments were also identified as factors posing hindrance to the implementation of SUDS in the region. The study also emphasized the use of SUDS in establishing the lost hydraulic interconnectivity in the region. The pertinence of a regional level study by incorporating modelling and optimization of combination of SUDS was also recognized in the study.

To enrich the study, impact of SUDs techniques was assessed at local scale for case study of IIT Madras campus. The hydrological behaviour of SUDs for different design storm, antecedent moisture conditions and soil profiles have been evaluated using SWMM and Hydrus-1D model. SWMM SUDS component does not adequately consider the existing soil and aquifer properties to simulate infiltration-based SUDS. Hence, groundwater / vadose zone modelling was carried out in HYDRUS-1D model which solve the one-dimensional Richard's equation incorporating time varying soil moisture characteristics and aquifer properties. HYDRUS-1D vadose zone simulations of SUDs soil profiles used to parameterise the SWMM SUDs component hydraulic properties for different inflow volume, antecedent moisture conditions and soil composition. the hydraulic parameter tables will be developed to access the site suitability and to design the various SUDs techniques.

In addition, the assessment of different combination of SUDs techniques have been carried out to assess the optimal placement and combination based on peak runoff, total runoff volume, cost and groundwater recharge using mean weighted method, standard deviation method, Shannon entropy method and CRITIC method. The hydrological analysis and cost analysis of different combinations of SUDs such as rain barrel, infiltration trench, permeable pavement, rain garden and bio-retention cell have been simulated in SWMM SUDs module. The SUDs combination of rain barrel and infiltration trench was the least effective and the permeable pavement, infiltration trench and bio-retention cell combination was most effective in reducing the peak runoff and total runoff. The optimal scenario was evaluated using TOPSIS assessment.

Effectiveness of SUDS in capturing the runoff at small spatial scales has been widely studied and experimented. The translation of SUDS to a regional scale is still a fertile area in research. For evaluating the impact of SUDS on the hydrological flow regimes of the river basin, the impending question of representation of SUDS in an apt hydrological model needs to be addressed. SWAT model with existing BMP features, sub hourly routines and newly developed computational modules for some SUDs can be used for a regional scale assessment. Green –Ampt infiltration

model was developed in view of this for estimating the process of infiltration in SUDS using MATLAB. SUDS modules for bio-retention cell, rain garden, green roof and infiltration trenches have been developed in MATLAB to improve the existing SWAT model formulation of SUDS. Furthermore, development of SUDS modules is designed in the study so as to meet the wider objective of regional level planning and optimization in combination of SUDS.

1.3. Storm water characterization (both, qualitative & quantitative), surveillance, modelling and forecasting

Approved Objectives:

1. To delineate the storm-water quality zonation of selected regions (based on their landuse-landcover, litho-topography, hydrogeology, micrometeorology and occupancy patterns)
2. To develop a depth-duration-frequency hydrological model for each of the delineated storm water zones, and its validation (with primary data).
3. Development of integrated predictable model using both deterministic and stochastic variants, with simulation for varying scenario-both region specific and interactive.

Executive Summary of the Work

1. Calibration of time series model developed for rainfall prediction at the study areas.
2. Collection of secondary data as well as primary data (through collection at site and analysis at lab) from a selected taluk (namely Orathanadu).
3. Ground surveillance of the University campus to explore hydrological and hydro geochemical characteristics and establishment of sampling locations catering to spatio temporal and hydrological resolutions for development of optimal water utilization masterplan.
4. Selection of dominant WQ parameters using PCA and successive development of WQ contours.

Work Package – 2

WP2-WATER TREATMENT

2.1. Fabrication of Portable Colorimetric Sensor Based on Basic Fuchsine for The Detection of Nitrite Ion in Aqueous System

The low-cost and straightforward colorimetric paper strip-based method for the detection of NO_2^- is aqueous systems was developed. The colorimetric probe was developed using triarylmethane dye i.e., Basic Fuchsine (BF). Initially, the study was carried out in the liquid phase to understand the practicality and selectivity of the proposed sensor for NO_2^- detection. The minimum detection limit was found out to be 0.005 mg/L and 0.92 mg/L using spectrophotometry and naked eye respectively. The probe was highly selective to NO_2^-, crucially the selective detection of NO_2^- corresponded to diazotization reaction. To, improve the portability of the sensor for onsite measurement, a low-cost colorimetric strip-based sensor was developed by immobilizing BF on Whatmann filter paper (W) (BF@W). The strip suffices visual detection of 0.005- 0.92 mg/L The surface properties of the prepared strips were characterized using FT-IR, Raman, UV-DRS, and XRD. Results confirmed that diazotization reaction as mechanism for the specific colour change (pink to colourless). The leaching test reported no leachable fraction from the coating, Cost analysis confirmed that the synthesized BF@W strip is a low-cost (0.01$/strip) and a portable colorimetric sensor for the detection of aqueous NO_2.

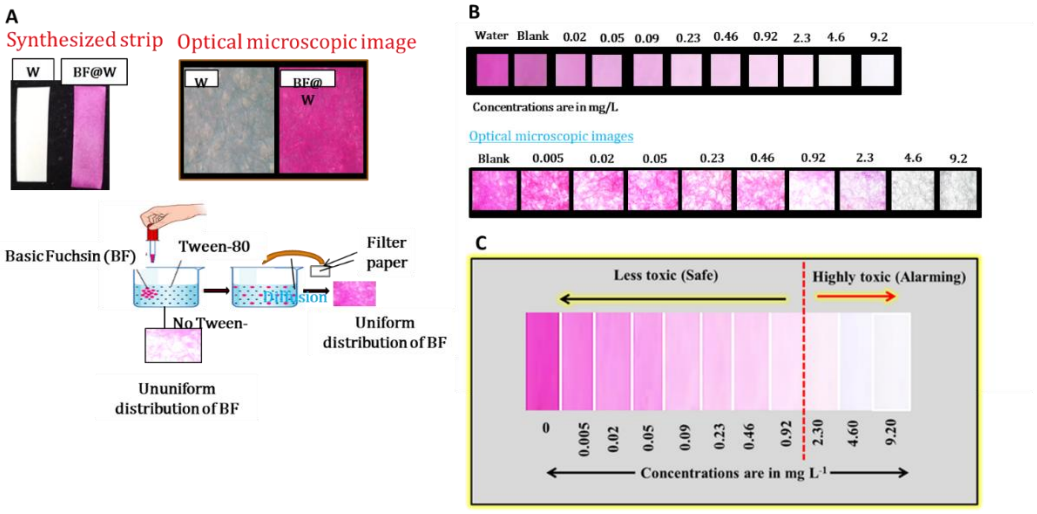


Figure . 2.1.1 Synthesis of portable colorimetric probe (B) Sensing of nitrite using portable colorimetric strips in at various concentration range (C) Colour pallet for selective nitrite sensing

2.2. Development of Dip Strip Based Colorimetric Sensor for Phosphate Detection.

Based on the previous study pattern (for nitrite sensor), the study was designed to develop a portable colorimetric sensor for phosphate ion (Pi). The presence of Pi in the environment is a decisive parameter for the quality of water resources and its available applications. For instance, a limited amount of Pi in the soil can adversely affect the growth of flowers, nitrogen fixation etc (Pinyorospathum et al., 2019). Along with it, the excess of Pi can lead to eutrophication. Henceforth, the development of sensitive, facile, selective, reliable, cost-effective and robust sensors is highly crucial. Colorimetric detection is the most common detection method in PADs due to its relatively simple operation and visual observation (Nagul et al., 2015). The color change observed is proportional to analyte concentration and allows for direct analysis by the naked eye, digital camera or smartphone, with no personal scientific skill needed. With this background, Brilliant green was selected as a probe for detection. The detection of Pi was carried out in the liquid phase for the concentration range of (13.6-0.1 mg/L). The naked eye detection is possible at a level of 0.13 mg/L, which is below the MCL, as suggested by USEPA (0.5 mg/L). Also, from the UV spectrum, it can be found that there is a yellow shift with a decrease in the concentration that validated the observations. Hence the naked eye susceptibility of the sensor can be 0.13 mg/L. Furthermore, kinetic and inference studies were conducted to understand the adaptability of the sensor in the real field. No interference from various cations and anions were reported. The developed paper strips to enhance the portability were stable at various tested pH, time and temperature. Also, the naked eye detection was in correspondence with liquid testing i.e. minimum detection level of level of 0.13 mg/L **(Fig.2.2.1)**.

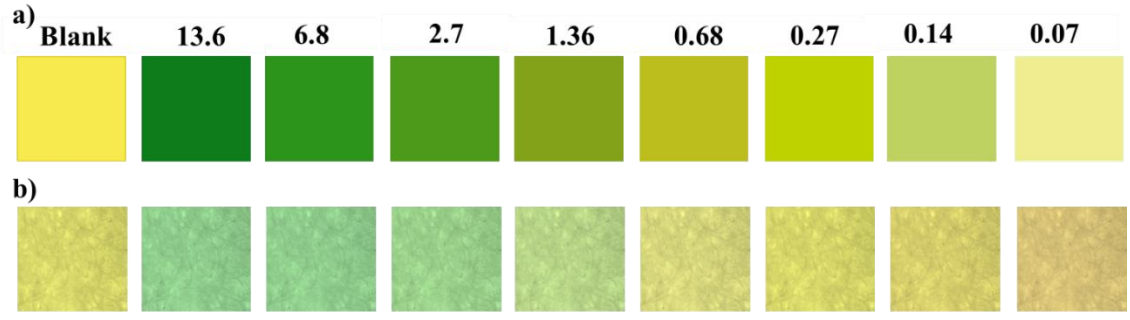


Figure.2.2.1 Optical and microscopy mage of various concentrations of phosphate (13.6 -0.1 mg/L) using developed paper strips

2.3 Risk Dynamics of Emerging Contaminants and Heavy Metals in The River Ecosystems

The contamination of surface water with several micropollutants (MPs) having potential of creating ecological and human health risks have been well verified (Patel et al. 2019, Quadra et al. 2017, Strenge and Chamberlain 1995). Broadly MPs can be classified in four groups as i) metal, metalloids, radioactive elements, ii) hormones iii) organic MPs (solvents, hydrocarbon, etc.), iv) pharmaceutical and endocrine disruptors (Rosenfeld and Feng 2011). Various sources involved in the dissemination of the MPs in the various environmental matrices are the discharge from municipal wastewater treatment plants (WWTPs), industries, hospital effluent, aquaculture, natural mines and ores (Yang et al. 2017). In the country specific scenario, the presence of MPs has been reported in (as discussed in work package 1, section 1), however, no investigation has been carried 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 for water safety and management plan. Such systematic investigation facilitates better understanding of occurrence, fate and transport of MPs at different water sources. At the same time, assessment of potential human health and ecological risk through 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 risk and microbial risk for MPs including both PPCPs and HMs. The risk evaluation was carried out for two seasonal variation at wastewater discharge points and freshwater intake points. 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.

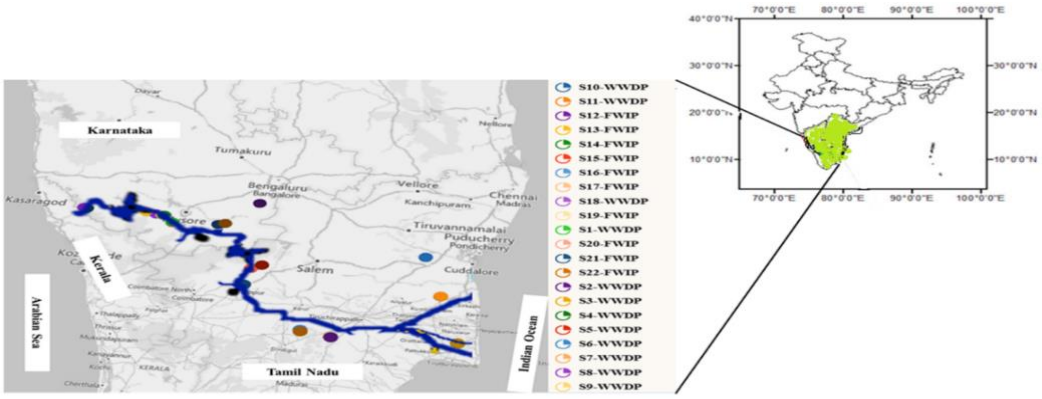


Figure. 2.3.1 Location of sampling sites along the Cauvery river stretch. Wastewater discharge points (WWDP) and fresh water discharge points (FWIP)

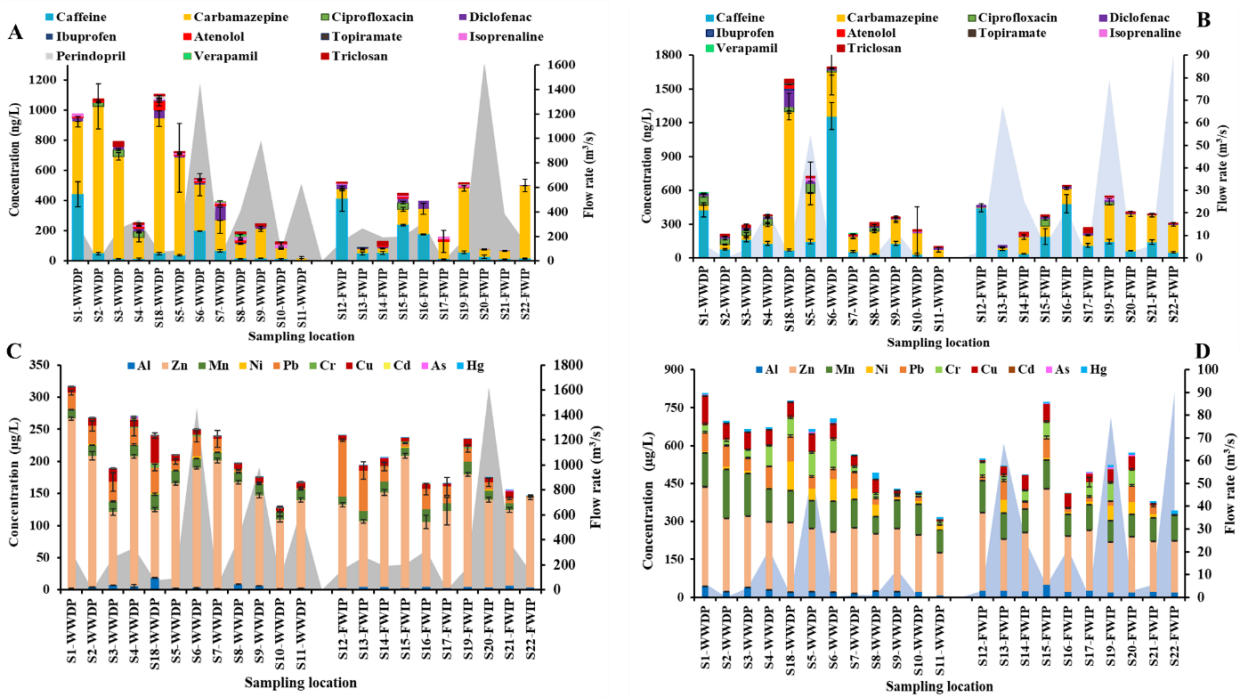


Figure 2.3.2. Spatial and Temporal Variation of PPCPs and HMs at various sampling sites. Panel (A) Pre Monsoon concentration of PPCPs with area under the curve as flow rate, Panel (B) Post Monsoon concentration of PPCPs with area under the curve as flow rate Panel, Panel (A) Pre Monsoon concentration of HMs with area under the curve as flow rate, Panel (B) Post Monsoon concentration of HMs with area under the curve as flow rate Panel water intake points FWIPS

2.4 Assessment of Adsorption of Pharmaceuticals and Personal Care Product on Carbonized Absorbent Derived from Waste

For the study efforts were laid down to develop remediation methods for the removal of emerging contaminats. In detail, the low cost and robust treatment approach of adsorption were used to remove targeted PPCPs. The continuous addition of PPCP in different environmental matrices has resulted in the degradation of natural resources like water, soil as well as an adverse effect on the biota. Hence, using economically feasible techniques like adsorption is a possible solution. For these several carbonaceous products obtained after the biomass thermochemical conversion finds its potential use in waste management, water filtration, carbon sequestration, soil fertility enhancement, and soil immobilization (Genç and Dogan 2015, Lima 2018). On the same line, the study was conducted to synthesis 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 presence of extensive -OH functional groups aided the capture of PPCPs. The crystalline structure showed an exclusive peak of 24.3° representing 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, effect of pH and possible mechanism of removal. The maximum adsorption capacity was found out to be 61-24 mg/g which varied based on the nature of adsorbate. The equilibrium time for removal of all the four-target compound was obtained as 5 h in the pH range 5-8 **(Fig.2.4.1)**.

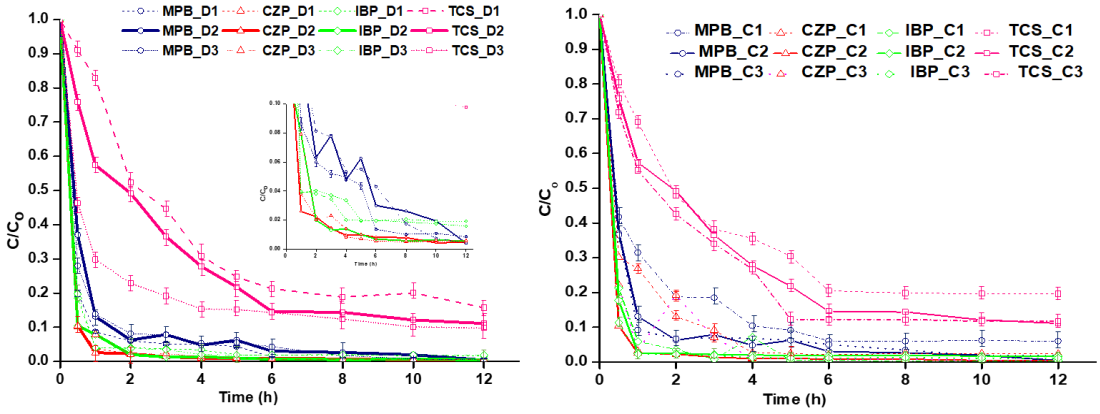


Figure 2.4.1. Dose and concentration kinetics study for the removal of target compounds at optimized environmental parameter

2.5 Selective Removal of Phosphate Using Metal-Organic Framework-Based Electrode

Capacitive deionization (CDI) has experienced dramatic growth over the past decades because of its promising prospects of brackish water desalination. The electrode materials are critical to the performance of CDI. Hence efforts for high-performance CDI electrodes have mainly focused on increasing the electrode adsorption capacity (Zhang et al. 2017), enabling long-term stability (Liu et al. 2019), introducing selectivity by modifying the surface chemistry (Bian et al. 2019), and enhancing charge efficiency by Faradaic reactions (Zhang et al. 2017). Accordingly, to selectively remove phosphate ions, we develop metal-organic framework-based electrodes **(Fig 2.5.1)**. For our study, the MIL 101 (Fe)- NH2 was identified as the best option for removing Pi due to i) water stability, ii) selectivity toward Pi adsorption, and similar molecular diameter. From the initial electrochemical characterization (cyclic voltammetry), it was established that MIL 101 (Fe)- NH2 has poor conductivity (30-35 F/ g capacitance) (**Fig 2.5.2)**. eaction). Also 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. Thus, layered double hydroxides (LDHs) can be utilized as a growth material for extending MOFs. This growth of LDHs on MOF can significantly improve EDL adsorption because of the increase in the specific surface area provided by the hollow structure after growth. Moreover, a series of Faraday reactions in the LDH layers contribute to high pseudocapacitance. Overall, the assessment of the role of these modifications onto MOF is an interesting way to increase electrosorption capacity.

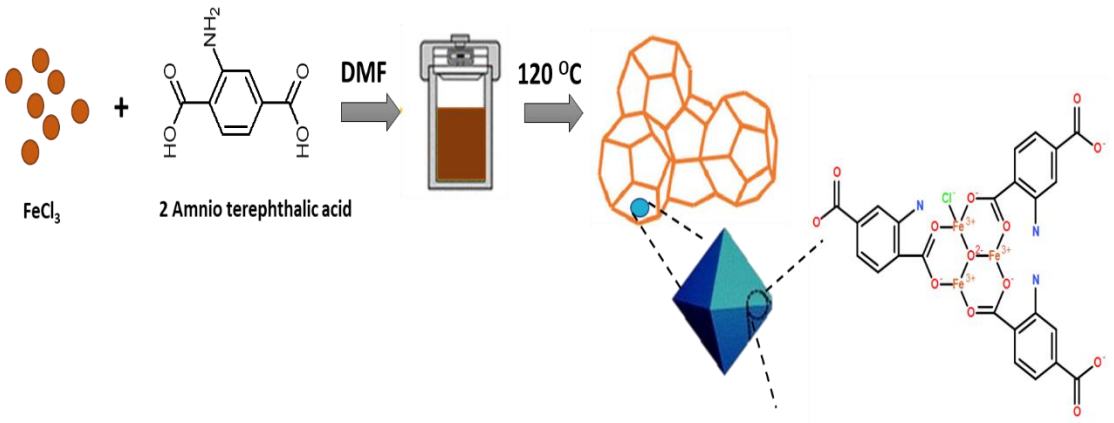


Fig 2.5.1. Schematic for the synthesis of MIL -101 (Fe)- NH_2

2.6 Simultaneous removal of three textile dyes in adsorptive and ultrasound assisted sorptive system using bamboo derived biochar

In order to reduce the cost of carbonaceous adsorbent, utilization of bamboo fiber could be potential precursor. The bamboo derived biochar (BDB) was synthesized via thermal pyrolysis and used for sorptive removal of the textile dyes. Since disposal of untreated dye loaded wastewater leads to many detrimental effects in aquatic eco-system. Therefore, removal of such toxic and recalcitrant dye pollutant before disposal would be environmental benign solution. In this regard, low-cost carbonaceous material i.e., BDB were synthesized studied for its potential towards sorptive removal of dyes in single and multi-component system with and without ultrasound assisted sorption system. BDB was characterized under XRD, FT-IR, BET, FE-SEM, HR-TEM and PZC for its structural, morphological and functional analysis. The synthesized BDB possesses considerably better functionality compared with other biochar materials. The reaction kinetics study showed the equilibrium time 120 minutes for sorptive removal while in case of ultrasound assisted sorption equilibrium time reduced to 10 minutes and shown in figure (2.6.1).

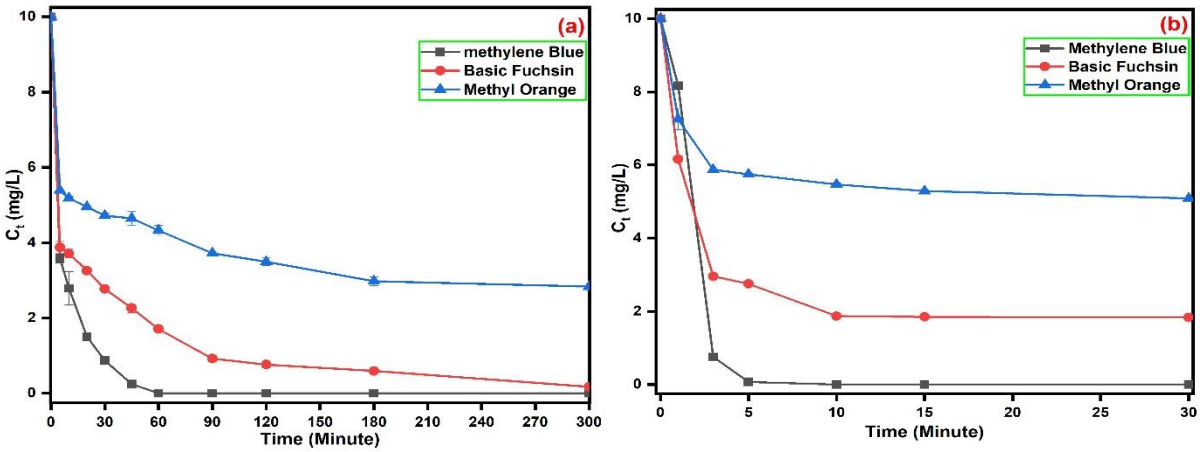


Figure 2.6.1(a)kinetic plot for sorptive removal and (b) kinetic plot for ultrasound assisted sorption for MB, BF and MO dye

2.7 Low cost yet efficient measurement system for water quality monitoring in a pipe

In this work, the conductivity of a water column in an insulating tube (e.g. PVC pipe) is determined without exposing the measurement electrodes to the water, thereby avoiding the possibility of errors in the measurement due to corrosion and formation of layers of contamination on them. As illustrated in Fig. 2.7.1(a), the electrode, the insulating pipe, and the water layer directly below the electrode and in contact with the insulation form a coupling capacitance. The resistance of the water column of interest can be measured, through this coupling capacitance. In the case of the conductivity measurement of water, the resistance of sea water (55000 μS/cm) in an insulated cylindrical column of length 10 cm and diameter 2.5 cm is in the range of a few hundred ohms, but that of a drinking water outlet (diameter ¼ inch or 6.35 mm pipe could be sufficient) is a few hundreds of kohms. The conductivity of drinking (tap) water varies from 50-800 μS/cm. For the capacitively-coupled measurement of higher resistances, a simpler scheme is preferred. This would be very promising in the water quality monitoring to determine the potability of drinking water and the quality of river water. In this work, a detailed study and evaluation of a simple and effective direct microcontroller interface suitable for the measurement of the resistance (of the water column) and coupling capacitance of a capacitively-coupled resistive sensor are conducted. The estimated resistance is independent of the variation in the values of the coupling capacitances, the charging capacitor, the power supply voltage, and the preset threshold voltage. Similarly, the measured value of the coupling capacitance is not a function of the change in the sensor resistance. The proposed scheme is simple in design, consumes low power, and carries out the measurement in a few milliseconds. It does not use any expensive part and can hence realize a low-cost measurement system. The feasibility study of the proposed circuit for resistance and coupling capacitance measurement, exhibits a maximum error of 0.28% and 0.96%, respectively, when evaluated without considering the non-idealities of the microcontroller. In the practical setup, maximum error noted for resistance measurement is 0.91%, (refer to Fig. 2.7.2) and that for the coupling capacitance is 2.94%. Higher accuracy can be achieved by selecting a microcontroller with more appropriate specifications. The proposed scheme uses only a simple microcontroller and a few passive components and hence can realize a low-cost, low-power measurement system. Owing to these attractive features, the proposed measurement circuit is expected to be extensively used in non-intrusive sensing and monitoring applications based on capacitively-coupled resistive sensors.

So far it was a laboratory study to develop the system and characterize it. Future work is to integrate the sensor in a water pipe in use and perform long time online monitoring and compare the results. Based on the results, fine tuning will be done if required, and retested in the site.

Repeatability experiment was carried out for several resistance values between 50 kΩ and 800 kΩ. The output was recorded for a data length of a hundred measurements, for each resistor, and the corresponding SD was computed. As presented in Table I, SD was very similar for the different resistance values under test. Later, the experiment was continued for the 100 kΩ case for 12 hrs, with the aim of testing any potential time drifts. In this, the microcontroller was powered all the time and a hundred measurements recorded for every one hour. The corresponding computed SD is presented in Table II. Again, the values of SD of the measured outputs remained very similar through the course of the day

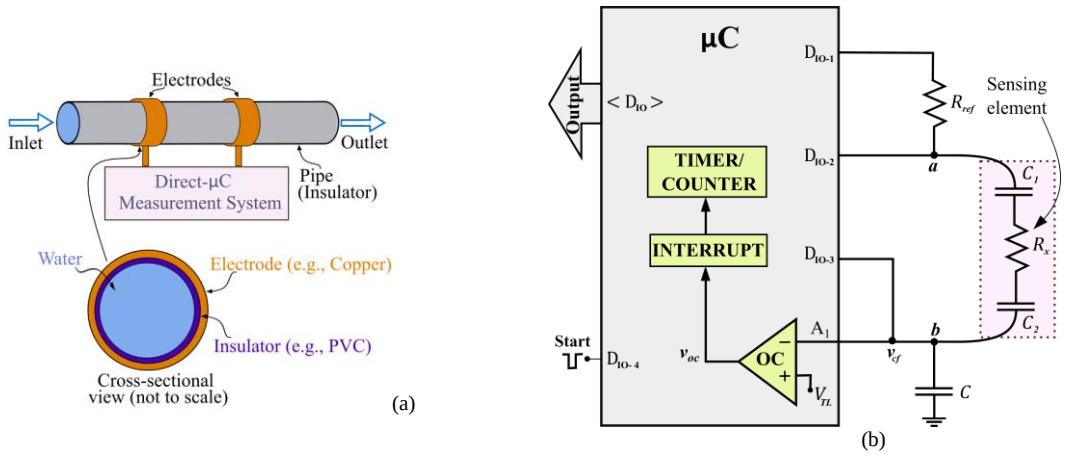


Fig. 2.7.1. (a) Illustration of non-contact conductivity measurement of water in an insulating pipe. (b) Block diagram of the proposed direct microcontroller interface for capacitively-coupled resistive sensor.

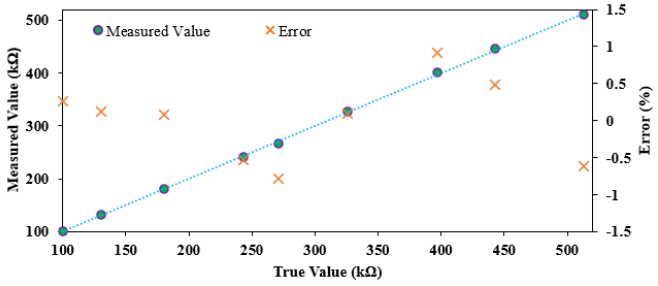


Fig. 2.7.2. Results from the prototype for a range of resistance R_x. This prototype was implemented using microcontroller.

TABLE I
STANDARD DEVIATION (SD) FOR A WIDE RANGE OF R_x

R_x [kΩ]	50	100	200	300	400	500	600	700	800
SD [kΩ]	0.303	0.303	0.304	0.305	0.304	0.305	0.305	0.301	0.305

TABLE II
SD FOR 100 kΩ MEASUREMENT AT 12 INTERVALS

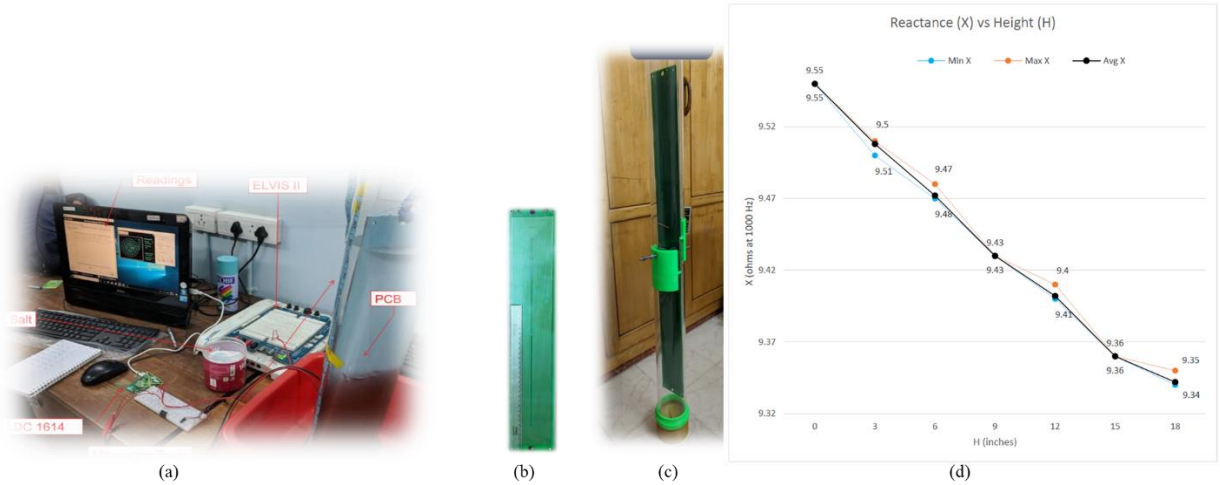
Time [hr]	1	2	3	4	5	6
SD [kΩ]	0.302	0.301	0.304	0.302	0.304	0.304
Time [hr]	7	8	9	10	11	12
SD [kΩ]	0.304	0.305	0.303	0.300	0.301	0.301

A Planar Coil-Based Water Level and Quality Monitoring System

Water level sensing and water quality monitoring is the need of the day in every household and in industries. Many situations exist in which it is desirable to accurately determine and display the level and quality of a liquid, for instance, chemicals stored in a tank, water stored in reservoirs or the level of water in canals, rivers and the lake. Often the environment may be corrosive, filthy and even explosive. There are several prior-arts in this space that detect the quality of water and also the level of water in the specified area.

The present research relates to a remote water level sensing device using planar printed circuit boards (PCBs) that indicates the end user with the data on water level and also the conductivity level. The present work (refer Fig. 2.7.3) has been designed and developed with improvement and novelty comprising of a single remote liquid level sensor unit for measuring the depth of the liquid in a variety of reservoir with 1 cm resolution and evaluating the quality of liquid, simultaneously, in terms of its conductivity.

Following are the few advantages of the new sensor: 1. single sensor is sufficient to measure level of the water and to indicate the quality., 2. Real-time continuous measurement, 3. Adjustable height configuration – the current system is of 1 m height. It can be varied up to a height of 1.5 m as per the requirement, 4. Debris proof – the encasing is made using robust acrylic pipes having stiff 3d printed connectors, 5. Multiple usages - Can be used in manholes, roof water tanks, water tankers, 6. Cost - The device can be made available at an affordable price. It would cost approximately ₹5000, 7. Modular product design - The device made is easily operable. All joints are made using wing nuts which ensures complete assembling within 5 minutes. Moreover, there are no moving parts in the entire setup, 8. Corrosion – the probe does not corrode over time.



(a) (b) (c) (d)

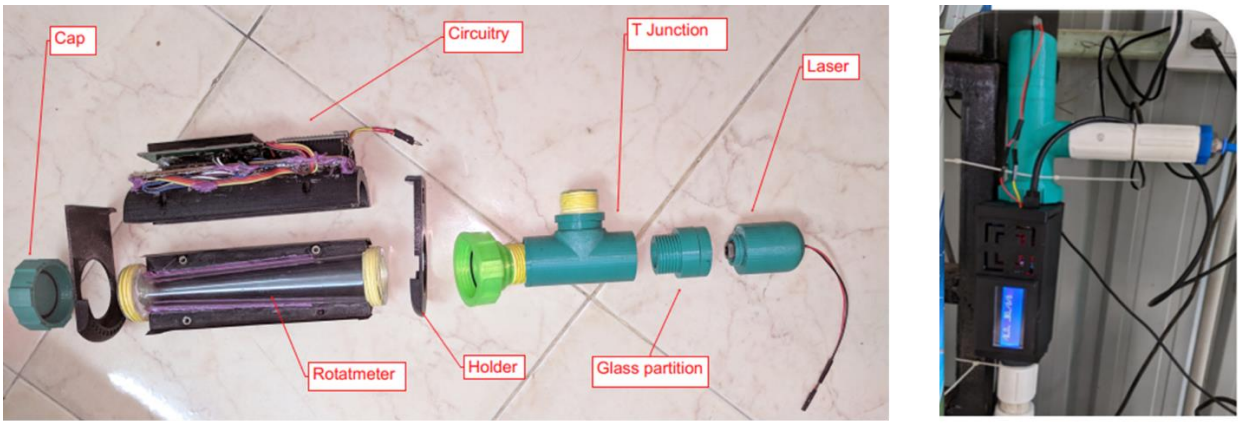
Fig.2.7 3. (a) Initial test setup of the planar PCB based level sensor, (b) the developed modular PCB, (c) two PCBs connected together along with enclosure and (d) change in the reactance of the PCB with respect to water level for repeated measurements. Measurement of the inductance at a higher frequency is utilised to know the conductivity level of the fluid.

Sensor system for Monitoring of the Quality of Recycled Water

Water is essential to human life and the health of the environment. Water quality is important not only to protect public health, is used for farming, fishing and mining, and contributes to recreation and tourism. Water quality issues influence human and environmental health, so the more we monitor our water the better we will be able to recognize and prevent contamination problems.

Monitoring helps ensure that the water source is being properly protected from potential contamination, and that an appropriate treatment system is selected and is operating properly. This will assist us in making informed decisions about the water, ensure us that it is suitable for the intended agricultural use, or drinking purpose, etc.

Online monitoring of water quality is required to address such issues. The output should specify the quality of water and turbidity. The project deals with design and development of a low cost but reliable system for monitoring water quality. Its operation is based on the principle of scattering of light due to the suspended matter and its concentration. A prototype (refer Fig. 4) of the design has been developed and tested in the laboratory. Test results validate the efficacy of the technique. During the test, the samples using the nephelometric method were successfully distinguished into different classes and the turbidity of the samples were predicted. The device is of low cost and easy to use.



(a) (b)

Fig.2.7 4. (a) Developed online turbidity and color monitoring unit, (b) installation of the same in an actual site.

2.8 An online Nitrite sensing system

Most of the existing Nitrite sensor systems are offline. In this work, we propose to convert a recently developed, low-cost, offline Nitrite sensor to an online one. The basic sensing is based on calorimetric principle. A precalculated amount of specially made regent is added to a predefined volume of water, wait a couple of minutes and then if we perform spectrophotometer measurement, maximum absorbance is observed at 550 nm wavelength. The amount of absorption varies as a function of the amount of the Nitrite present in the water under test. In order to get an electrical output corresponding to this phenomenon we have used an LED source at 550 nm and a suitable detector as shown in the block diagram in Fig. 2.8.1. The detector is connected to an i-v converter whose output is digitized and shared to internet using a suitable microcontroller.

In the second stage of this work, a pumping-in and pumping-out arrangement for the water sample and an injection port for automatically adding the reagent to the test sample will be added. The same microcontroller will be programmed to synchronise these operations and the output will be recorded. This cycle will be performed in a regular interval to perform online monitoring.

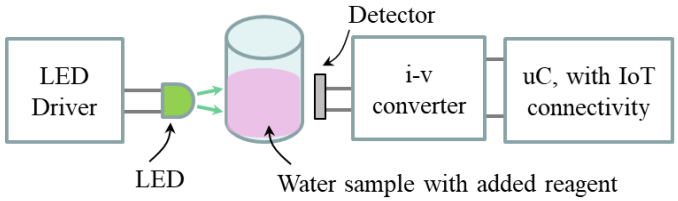


Fig. 2.8.1. Simplified block diagram of the electrical part of the sensing unit

A complete diagram of the circuit developed to perform the first level of studies is shown in Fig. 2.8.2. In this we have employed measurement at two wavelengths, one at 550 and another at red. At red, the change in absorption due to the presence of the Nitrite is very small. Hence this is used to get the reference or base line. The system is designed in a way that it takes power from the USB port, convert to the required voltage and use to power the entire circuit, including the uC. A photograph showing the prototype implementation is shown in Fig. 2.8.3.

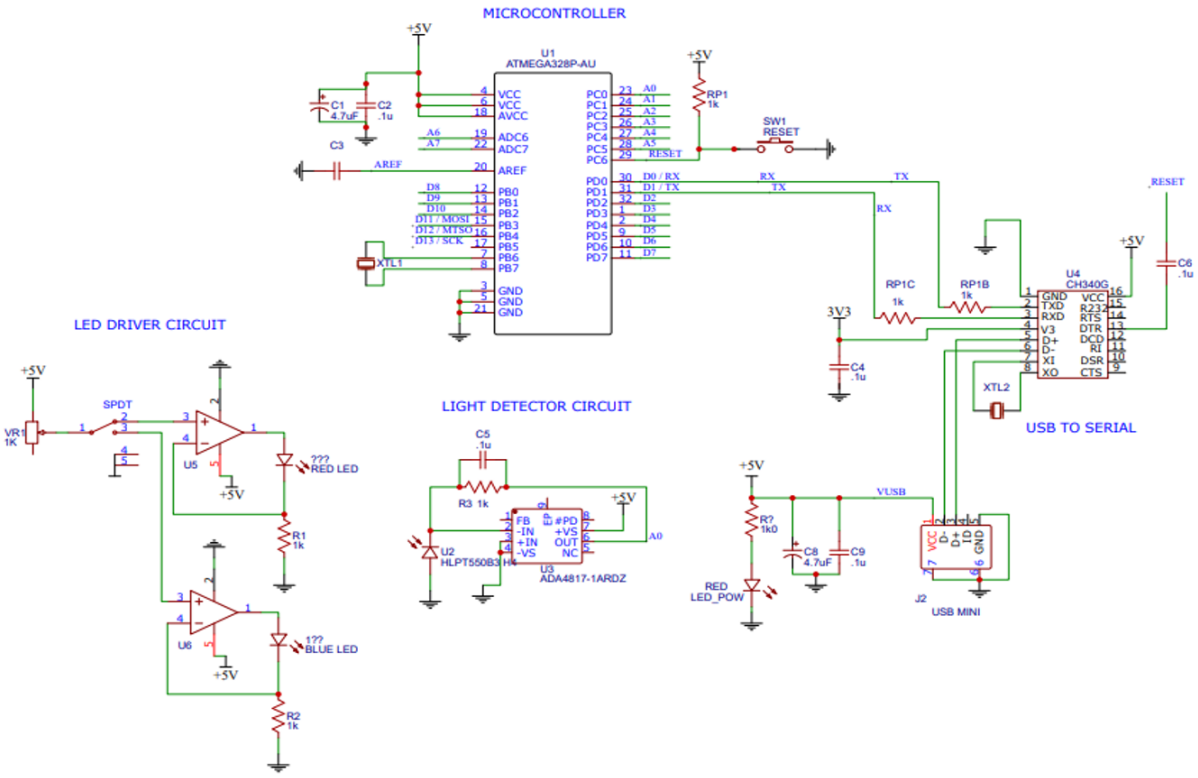


Fig. 2.8.2. Complete circuit diagram

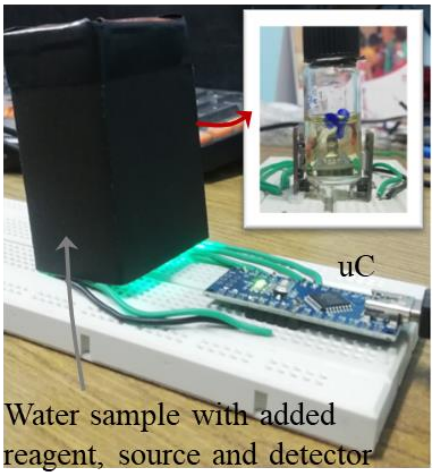


Fig. 2.8.3. Prototype of the measurement and digitization part

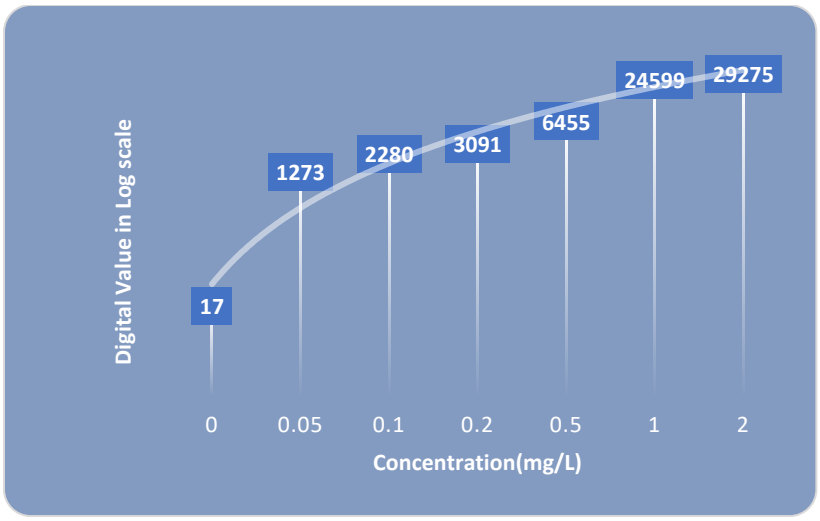


Fig. 2.8.4. Concentration of Nitrite vs. digital value observed from the protype. The values as well as the trend line are shown. The output is not scaled and hence it is in arbitrary unit.

This development is in the preliminary stage. Initial results from the laboratory protype developed is promising. Results obtained for different concentrations of Nitrite is recorded. The results were repeatable. More studies and further development of the prototype is in progress.

2.9. Concentrated Solar Thermal Reactor System for the disinfection of secondary-treated sewage effluent.

Team Members:
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Prof. Ligy Philip, IIT Madras.

A tiny amount of radiation from the Sun continually falls on the surface of the Earth, and in the process, heating the surrounding atmosphere. Solar energy is the only renewable source of energy that is available in abundance across India. Tapping this endless energy source in any shape or form is bound to positively impact our society as a whole, primarily due to its low carbon footprint. Several engineering devices have been designed and developed, mainly in the last decade, to capture and transform this energy from the Sun into heat or electrical energy. However, the diffuse nature of the solar energy source presents several challenges that prevent the widespread adoption of such technological innovations.

There are primarily two ways of tapping solar energy. One involves direct conversion into electrical energy using photovoltaic cells. The other involves transforming solar radiation into heat energy. The radiation from the Sun can be collected and concentrated to a point or along a line using parabolic collectors. This process can magnify the potency of radiation received from the Sun by a factor of ~50, which yields a natural source of intense radiation across the spectrum. This intense solar radiation can be directly employed to disinfect air/water or as a source of heat energy. There are several techniques to improve (or maximise) the performance of such devices by focusing primarily on improving (or maximising) their ability to capture and concentrate solar radiation through smart designs combined with advanced manufacturing processes. Here we present a novel, efficient, portable, scalable and low-cost design of a concentrated solar thermal reactor system. The critical design and developments aspects are listed below.

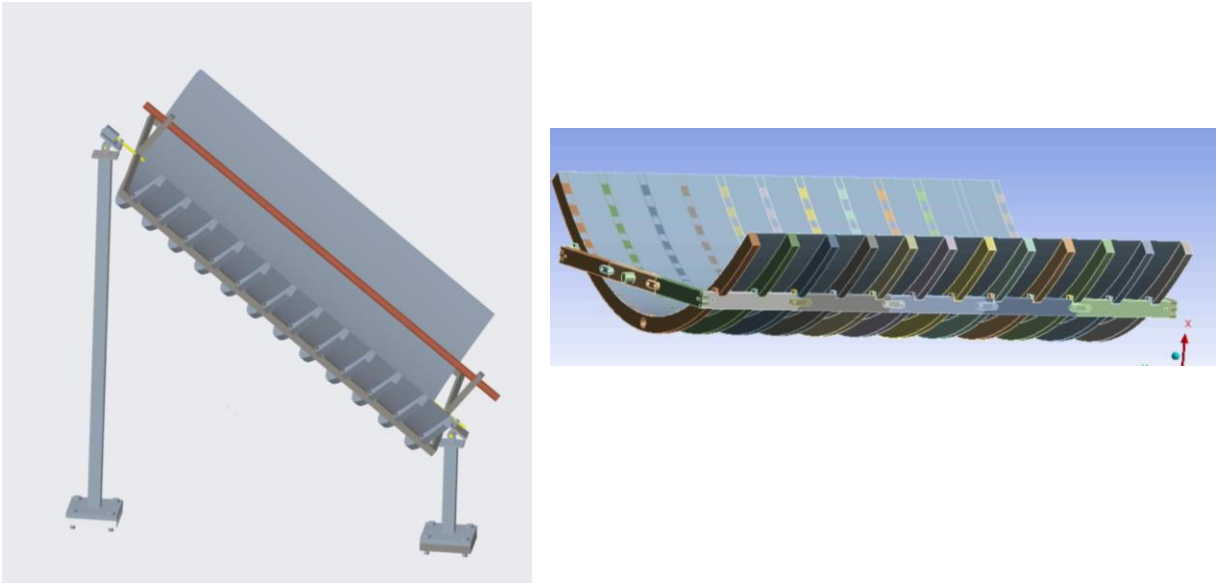


Figure 2.9.1: Concentrated solar thermal reactor system.

1) The concentrated solar thermal reactor proposed here employs an ultra-thin, foldable and all-wavelength reflective mirror sheet of thickness ~0.5 mm (i.e. 500 microns) or less to secularly reflect a broad range of electromagnetic spectrum (solar) radiation directly falling on it. This mirror sheet reflects >95% of the total solar radiation incident on its surface. Another reflective mirror sheet to primarily reflect ultraviolet wavelengths will also be tested as part of this project. The flexible mirror sheets can be easily removed and replaced; hence several different sheets can be tested to benchmark their performance.

2) This flexible mirror sheet is supported on all-composite, precision manufactured, parabolic-shaped frames. The parabolic-shaped frames guide the sheet to take on a parabolic shape. These lightweight supporting frames are portable, just like the flexible mirror sheet placed on top of them. The composite frames are arranged in a rib-like structure reinforced using precision-cut aluminium bars assembled in a rectangular shape. The number of frames and distance between them is optimised through rigorous Finite Element Analysis using Ansys workbench. These frames lose their parabolic shape due to deformation under the influence of inertial loads (i.e. self-weight + weight of mirror sheet), which affects its focusing performance. A way to mitigate this effect is to prebend the frames to ensure that they attain a parabolic shape after deformation under inertial loading conditions. The design tolerance is limited to ±10 microns, and the final prebent shape is found through Ansys Finite Element Method (FEM) simulations.

3) The modular aluminium bars, cut to a tight tolerance from Aluminum plates using wire Electron Discharge Machining (EDM), is assembled in a rectangular shape. These aluminium bars are also designed with a prebent profile to ensure that they become straight under the influence of inertial load from parabolic-shaped frames, a flexible mirror sheet and also due to their self-weight. Extensive Ansys analysis was employed to find the final prebent geometry. These aluminium bars and parabolic-shaped frames are designed and manufactured for ease of assembly.

4) The Sun rises in the east and sets in the west. It is possible to precisely calculate the Sun's position in the sky on any day of the year and at any instant in time during the day. Thus, we circumvent the need for a solar tracker by having a pre-programmable precision motor to steer the entire assembly and ensure that the mirror sheets always face the Sun. As the Sun's orientation in the sky changes over time during a year, these orientation changes need to be considered in the design stage to maximise our solar concentrator's performance. This is accomplished in the design by using a second mechanism - a precision linear slide - to change the tilt angle of the entire solar collector assembly.

5) The entire unit is placed inside a clear glass enclosure to insulate it from the outside environment, thus protecting it from wind, dust and rain. An air-conditioned unit helps to maintain the temperature inside the enclosure at ~25 C. The entire unit will be assembled and operated at 25 C - care is taken to minimise the effects of thermal expansion on the solar concentrator's performance

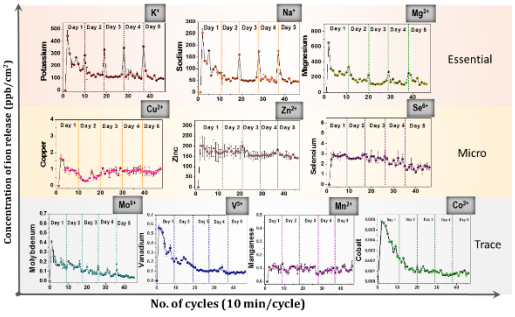
6) The system will be employed for the disinfection of secondary-treated sewage effluent.

2.10 Progress of Prof.T.Pradeep IIT Madras

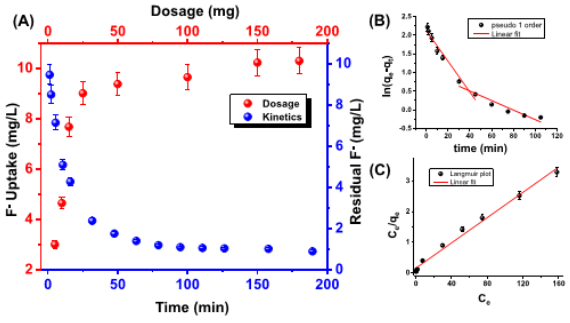
Activity	Progress
Fluoride free drinking water	Synthesis and lab scale performance evaluation completed, publication published, patent granted, synthesis for pilot-scale performance evaluation in progress.
Sensors and Kits for Water Quality Monitoring	Testing of the nanomaterial-dye sensing system for colorimetric detection of analyte (F^-) using visual and spectroscopic techniques is in progress.
Low-cost microfluidic platform for multi-analyte assessment of water quality	Optimization of process parameters is completed, Detection of single contaminants in progress.
Atmospheric Water Capture	Large area nano-engineered surface fabrication is completed, paper published.
CDI Prototype	Completion of fabrication of cells, incorporation of ion exchange membranes in progress.
Incubation Hub	Process Setup is completed.

Publications:

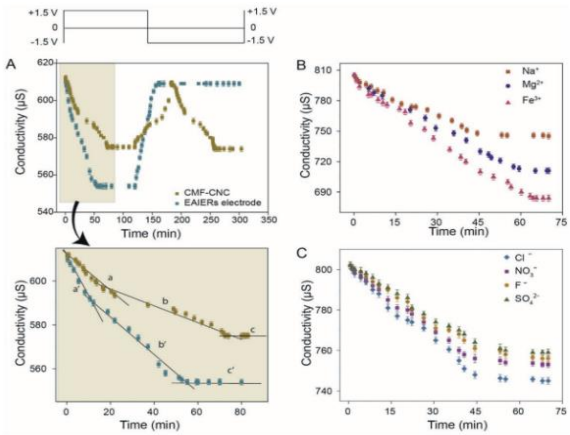
1. *Geologically-inspired monoliths for sustainable release of essential minerals into drinking water*, Swathy Jakka Ravindran, Ananthu Mahendranath, Srikrishnarka Pillalamarri, Anil Kumar Avula, Md Rabiul Islam, Sritama Mukherjee, Ligy Philip, and Thalappil Pradeep, *ACS Sustain. Chem. Eng.*, 2019, 7, 11735-11744 (DOI: 10.1021/acssuschemeng.9b01902)



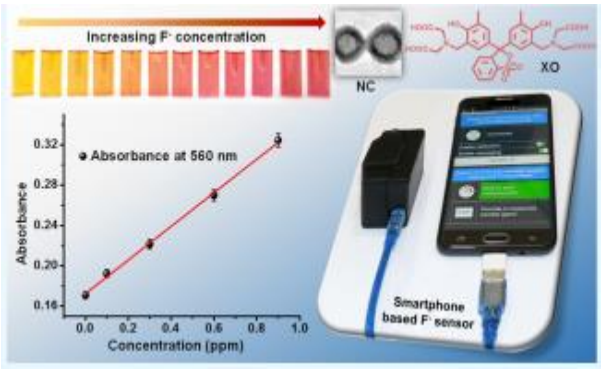
2. *Nanocellulose reinforced organo-inorganic nanocomposite for synergistic and affordable defluoridation of water and an evaluation of its sustainability metrics*, Sritama Mukherjee, Haritha Ramireddy, Avijit Baidya, A. K. Amala, Chennu Sudhakar, Biswajit Mondal, Ligy Philip, and Thalappil Pradeep. *ACS Sustain. Chem. Eng.*, 2020, 8, 1, 139-147 (doi: 10.1021/acssuschemeng.9b04822)



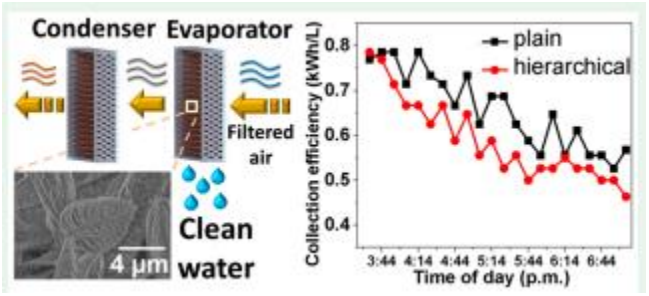
3. *A covalently integrated reduced graphene oxide-ion exchange resin electrode for efficient capacitive deionization*, Md Rabiul Islam, Soujit Sen Gupta, Sourav Kanti Jana, Pillalamarri Srikrishnarka, Biswajit Mondal, Sudhakar Chennu, Tripti Ahuja, Amrita Chakraborty and Thalappil Pradeep, Adv. Mater. Interfaces, 2020 (DOI: 10.1002/admi.202001998)



4. *A smartphone-based fluoride-specific sensor for rapid and affordable colorimetric detection and precise quantification at sub-ppm levels for field applications*, Sritama Mukherjee, Manav Shah, Kamalesh Chaudhari, Arijit Jana, Chennu Sudhakar, Pillalamarri Srikrishnarka, Md Rabiul Islam, Ligy Philip and Thalappil Pradeep, ACS Omega, 5 (2020) 25253–25263 (DOI: 10.1021/acsomega.0c03465).



5. *Scalable drop-to-film condensation on a nanostructured hierarchical surface for enhanced humidity harvesting*, Ankit Nagar, Ramesh Kumar, Pillalamarri Srikrishnarka, Tiju Thomas and Thalappil Pradeep, ACS Appl. Nano Mater., 2021 (DOI: 10.1021/acsanm.0c03032).



2.11 Synthesis of 3D graphene nanoribbons from *Drepanostachyum falcatum* for dye removal application

1.1 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.

1.2: 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).

1.3 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 (1). The R_L describes the nature of adsorption isotherm such as favorable ($0<R_L<1$), unfavorable ($R_L>1$), and irreversible ($R_L=0$).

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

Where C_0 is the initial concentration (mg/L)

1.4 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 (2) was used.

$$Q_e\left(\frac{mg}{g}\right) = \frac{(C_0 - C_e)V}{m}$$ Eq. (2)

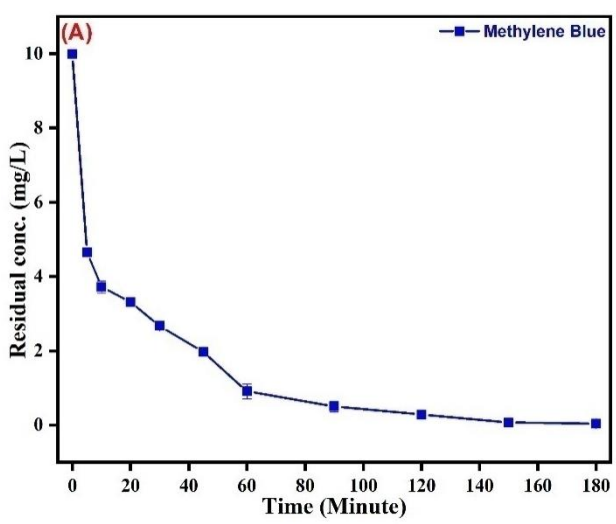
1.5 Kinetic study of MB dye removal

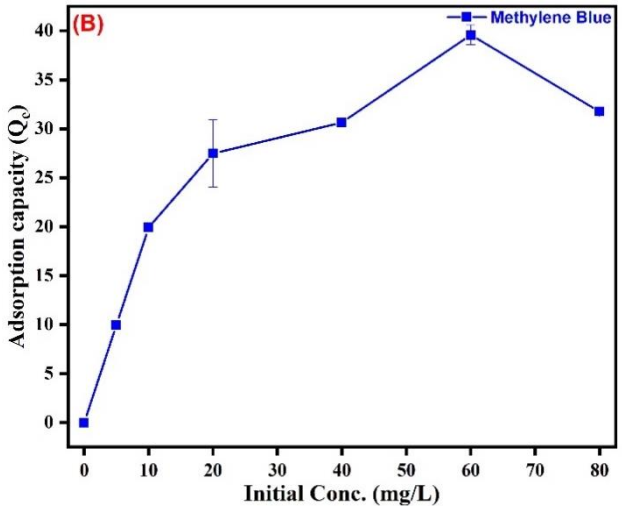
Pseudo-first-order and pseudo-second-order models were studied to evaluate the rate and order of adsorption of MB dye on 3D-GNR. Also, the diffusion mechanism of dye molecules was understood by intra-particle diffusion and liquid-film diffusion models. Different kinetic model constants and their linear regression coefficients (R^2) are presented in Table 1. 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.1.All the isotherm model parameters are tabulated under Table 1. 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 1. 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





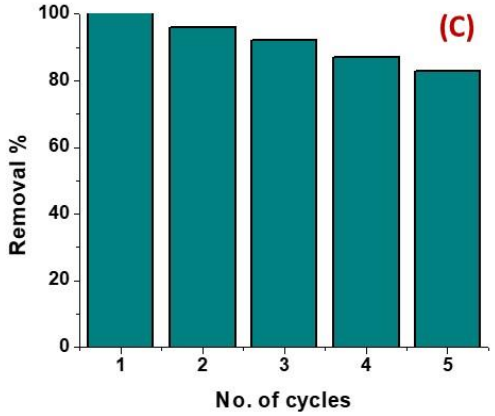


Fig. 1. A) Kinetic plot for MB dye adsorption using 3D-GNR; B) Equilibrium plot for MB dye adsorption using 3D-GNR; C) Regeneration study for the adsorption of dye onto the 3D GNR.

1.6 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.

1. 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 was synthesized 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-Fe3O4 nanocomposite confirmed the uniform distribution of Fe3O4 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/Fe3O4 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/Fe3O4 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.

Work Package – 3

WP3 WASTEWATER TREATMENT

3.1 Laboratory studies on identification of appropriate adsorbent materials for the removal of pharmaceutically active compounds and nutrients

In this study, the fate of three PhACs – atenolol (ATL), carbamazepine (CBZ), and diclofenac (DCF) were investigated in each component of the CW. Four identical CW units were established in the Indian Institute of Technology Madras campus. Each unit consists of three horizontal PVC pipes (diameter of 110 mm and length of 1 m) interconnected subsequently to form a plug flow reactor, as shown in Fig 1. The total length of the reactor was 3.8 m, and the volume of the reactor was 36.11 L. Each unit was provided with 24 numbers of perforation (diameter of 7.62 cm) on the top surface for planting *C. indica*. The units were fed with the synthetic wastewater from the inlet tank under gravity flow. The treated water from the units was collected at the outlet in acrylic containers. In the present study, the EBCT (5 days) is considered as the HRT for the performance evaluation. Based on our previous studies, the materials such as waste AAC blocks, LECA, wood charcoal (WC), and natural zeolites (NZ) exhibited better removal of pollutants under various operating conditions. Thus, these four materials were employed for the laboratory scale constructed wetland studies.

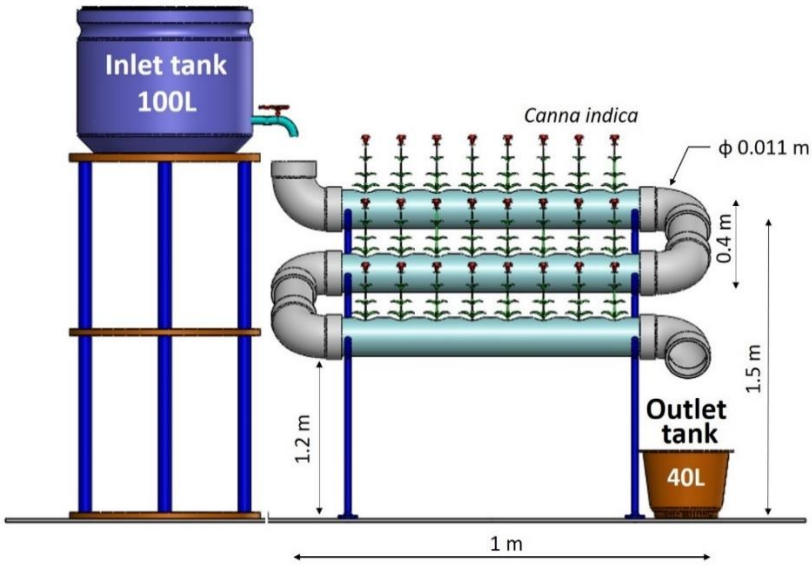


Fig 1. Schematics of the lab scale mesocosms

The mean removal of COD was observed as 88.56%, 76.07%, 73.76%, and 74.82% for AAC, LECA, WC, and NZ, respectively (Table 1). The statistical analysis (n = 52) showed significant differences (significance level, $p<0.05$) among the evaluated substrates systems. In phase 3, as the HRT increased from 5.01 to 10.03 days and OLR decreased from 98.86 to 47.83 g COD/cu.m./day, the effluent COD concentrations were considerably reduced from 43.46 to 22.99mg/L, 95.46 to 74.42 mg/L, 107.23 to 88.45 mg/L, and 101.25 to 86.11 mg/L, respectively with AAC, LECA, WC, and NZ units. AAC witnessed a higher TOC removal of 87.14% than the other materials - LECA (73.22%), WC (71.86%), and NZ units (72.61%). It could be due to the higher microbial activity observed in the AAC units. The microbial biomass (total protein content) attached to the substrate materials such as AAC, LECA, WC, and NZ was 52.59±1.68 mg/g, 31.56±2.42 mg/g, 34.06±1.11 mg/g, and 41.03±2.73 mg/g, respectively. The reason attributed to the observed higher biomass in AAC units could be its porous nature, which would have facilitated a higher growth and attachment of microbial biomass. Further, the COD values of treated water from AAC blocks were found to comply with the discharge standard (50 mg/L) suggested by the central pollution control board (CPCB) of India (Table 1).

In the present study, the superior performance of natural zeolites in NH_4-N and TN removal was witnessed at 84.7% and 84.2%, respectively ($p<0.05$). In addition, waste AAC block was spotted with an average ammonia removal of 81.3% with an average effluent concentration of 5.2mg/L. TN removal had a similar trend with NH_4-N reduction. Interestingly, the addition of enriched aerobic and anoxic bacteria into the CW units significantly increased the nitrification and denitrification efficiency of the systems. Consequently, the nitrate concentration in the treated effluent of the CW units was relatively lesser. Thus, TN concentration in the treated effluents of all CW units met the discharge standard of 10 mg/L suggested by CPCB. In the case of phosphate removal, the average efficiency of AAC, LECA, WC, and NZ was marked at 74.45±6.21%, 60.19±6.5%, 55.48±5.7%, and 63.6±7.31%, respectively ($p<0.05$). The phosphorus removal in CWs is mainly achieved by the sorption and deposition over the substrate, plant uptake, assimilation, and metabolism by microbes (Xiao et al., 2020). A higher level of Al, Ca, and Fe oxides enhanced the phosphate removal with AAC blocks and zeolites (Wang et al., 2013). In phase 3, as HRT increased, the nitrogen and phosphorus removal were elevated. The performance monitoring of the CW units was carried out in the summer season (March to May 2021) with minimum and maximum temperatures of 27.4 and 36.3℃. Thus, the higher temperature favoured the removal of organics and nutrients in the CW units, which agrees with an earlier study (Ramprasad et al., 2017).

The average removal efficiency of ATL was noted as 95.73% (AAC), 93.40% (LECA), 92.49% (WC), and 94.71% (NZ). Among the selected PhACs, ATL has shown higher removal in the CW systems. ATL is highly water-soluble, has a low log K_{ow} value (0.16), and undergoes rapid metabolization by plants and microbes (Ávila et al., 2014). For CBZ, the mean removal with AAC, LECA, WC, and NZ was noticed as 93.85%, 89.69%, 89.68%, and 90.86%, respectively. The predominant removal mechanisms of CBZ include sorption over the substrate and microbial degradation. The CW units were operated at a higher OLR of 85.4 to 112.3g COD/m^3/d, which enhanced the attenuation of CBZ in the units (He et al., 2018a). Besides, the hydrophobic nature of CBZ facilitated its sorption over the substrate materials (Hijosa-Valsero et al., 2010; Yan et al., 2016). Moreover, CBZ, a neutral compound, is more likely to be up-taken by the roots. Similarly, CW units employing different supporting materials marked DCF removal was above 90%. The effluent DCF concentration was observed as 6.29 to 10.03µg/L. DCF was reported to be degraded under various redox conditions (Ávila et al., 2013). As observed in the batch biodegradation studies, DCF could be degraded under aerobic and anoxic conditions. In addition, the hydrophobic nature of DCF facilitated higher sorption to the substrate materials and biofilm (Hijosa-Valsero et al., 2010). The statistical analysis delineated a notable variation in the removal of PhACs concerning the substrate materials ($p<0.05$).

Table 1. Characteristics of the synthetic raw and treated wastewater from the CW units

	Raw WW	AAC Outlet	LECA Outlet	WC Outlet	NZ Outlet
pH	6.4 ± 0.5	7.9 ± 0.1	6.8 ± 0.1	7.2 ± 0.3	7.10 ± 0.21
EC (µS/cm)	890.5 ± 10.7	762.5 ± 16.9	523.5 ± 36.3	472.5 ± 27.7	513.1 ± 34
Turbidity (NTU)	49.7 ± 1.7	2.8 ± 0.9	29.0 ± 0.5	34.4 ± 2.8	15.9 ± 0.5
TSS (mg/L)	96.7 ± 4.7	7.5 ± 3.5	42.5 ± 3.5	52.0 ± 5.6	28.8 ± 5.3
TS (mg/L)	750 ± 2.3	440 ± 6.2	365 ± 5.1	350 ± 4.9	340 ± 4.8
COD (mg/L)	402.3 ± 31.1	46.3 ± 19.7	96.3 ± 18.5	105.3 ± 14.1	101.1 ± 12.7
TOC (mg/L)	101.8 ± 9.0	13.3 ± 5.0	27.4 ± 5.9	28.7 ± 4.4	27.8 ± 3.8
TN (mg/L)	28.6 ± 2.7	5.5 ± 0.9	8.1 ± 1.2	5.9 ± 1.0	4.5 ± 0.9
NH3-N (mg/L)	27.8 ± 2.6	5.2 ± 0.9	7.8 ± 1.2	5.3 ± 0.7	4.2 ± 1.0
TP (mg/L)	10.4 ± 1.7	2.7 ± 0.7	4.1 ± 0.8	4.6 ± 0.7	3.8 ± 0.8
ATL (µg/L)	100.3 ± 7.0	4.3 ± 1.6	6.6 ± 1.3	7.5 ± 1.4	5.3 ± 1.9
CBZ (µg/L)	100.7 ± 7.7	6.2 ± 1.7	10.3 ± 1.5	10.3 ± 1.7	9.1 ± 1.3
DCF (µg/L)	101.6 ± 7.3	6.3 ± 1.8	10.0 ± 1.9	9.4 ± 1.5	7.9 ± 2.0

The biodegradation studies with the acclimatized microbes (identified as *Proteobacteria, Sphingobacteria, Arcobacter, Actinobacteria,* and *Chryseobacteria*) showed effective degradation of PPCPs under different redox conditions. The adsorption breakthrough studies with four

substrate materials showed their sorption capacities as natural zeolite (1.6-2.15µg/g) < light-weight expanded clay aggregates (5.37-8.27µg/g) < waste autoclaved aerated concrete (AAC) block (9.27-10.79µg/g) < wood charcoal (24.10-26.40µg/g), according to their surface and textural properties. Four laboratory-scale CW units with enriched microbes, *C. indica*, and supporting materials were monitored to remove organics, nutrients, and PPCPs. Eventually, the synergistic combination of AAC, enriched microbes, and *C. indica* notably witnessed an enhanced removal of pollutants.

3.2 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 4µm and 250 nm ceramic filters with water and wastewater. Compare to 4 um filter, 250nm filter clog frequently and resulted in frequent backwash. Performance comparison between 250 nm and 4µm shows that, 4µm ceramic filter performed better in terms of quantity of treated water and 250 nm ceramic filter performed better in terms of quality of treated water and pollutants removal.

As a first part of phase-3 study, Performance of pilot scale ceramic membrane filter with pore size of 4 µm Fig.1 was tested for treating secondary treated wastewater under different operating conditions. Batch process was carried out to check the efficiency of filter by fixing the flow rate below $15m^3/hr$. For every cycle, the flux value has been calculated by using volume of water filled in the permeate tank w.r.t time and the Transmembrane pressure evolve during each cycle. Initially, as a batch study run was carried out till the pressure reaches 1.5 bar. At the end of each cycle Air + water Backwash was initiated to recover the original flux during each cycle of operation. After modification work for continuous process, Flux Monitoring study has been carried out by fixing flowrate below $15m^3/h$ for continuous process by optimizing the operation time as 20 and 25 minutes. During the operation, the average flux and yield found to be 800± 146 $L/hr/m^2$ and 148 L/min for 20 minutes and 817 ± 76 $L/hr/m^2$ and 142 L/min for 25 minutes respectively**.**

Chemical enhanced backwash (CEB) was initiated in an efficient way by combining Caustic (NaOH) and hypochlorite (NaOCl) and found to be effective when the transmembrane pressure not reduced as much after the air + water backwash. Overall cumulative net treated water and backwash water volume for 90 cycles was 2,53718 L and 11240 L, respectively. Percentage of water used for backwash was found to be below 5. Removal efficiency of different pollutants such as turbidity, TSS and COD ranged between 94-98.5%, 86-100% and 45-60%% respectively Fig 2 and Fig 3 for 4µm pilot scale ceramic filter. Energy and chemical consumption of 4µm pilot scale Ceramic filter was found to be slightly higher than existing Ultrafilter system but comparing with the yield ceramic filter 4µm pilot scale found to be

slightly higher than ultrafilter. Overall studies showed that the treated wastewater quality from ceramic filter (CF) was as same as the existing ultrafiltration (UF) in IITM STP.

Fig 1: Picture showing 4 um pilot scale ceramic membrane at STP, IITM.

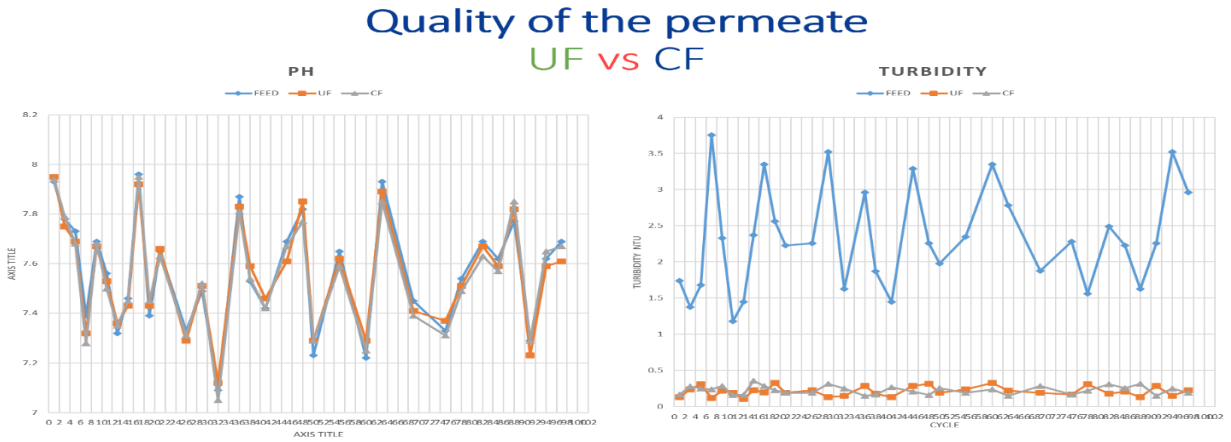


Fig 2: quality comparison of ceramic membrane with the UF membrane.

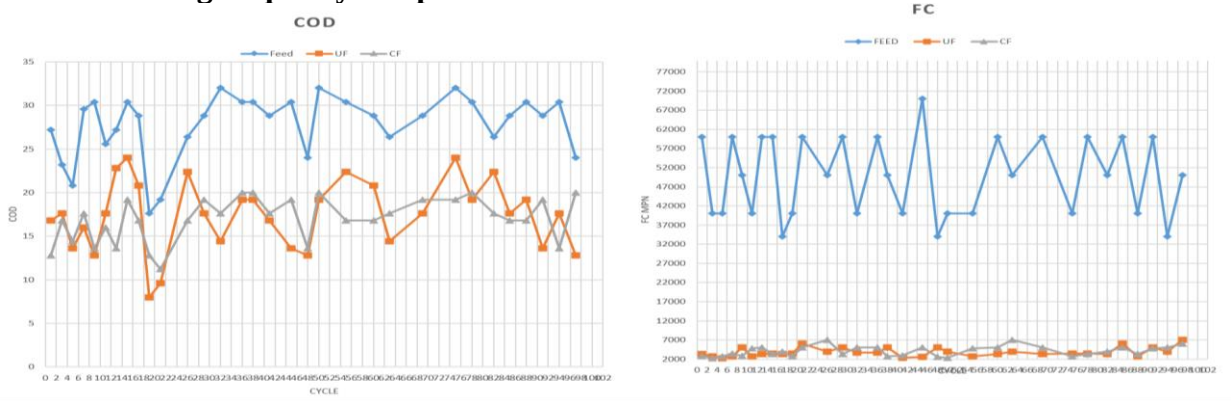


Fig 3: quality comparison of ceramic membrane with the UF membrane.

3.3: N, P, Biogas recovery from wastewater using bio-electrochemical systems (bio-refinery)

1. Continued optimizations of process parameters of MFC using Response Surface Methodology (RSM).
2. Design and installations of lab scale AD-MEC unit and optimization of process parameters (in line of MFC studies carried out earlier).
3. Assessment of biogas generation, Ammonia recovery and COD reduction potential of the system

Overall progress

- Collection of rainfall data and calibration of time series model developed for rainfall prediction at the study areas.
- Procurement of secondary data and collection of water samples (followed by lab analysis) from a selected taluk (namely Orathanadu).
- Ground surveillance of the University campus to explore hydrological and hydro geochemical characteristics and establishment of sampling locations catering to spatio temporal and hydrological resolutions for development of optimal water utilization masterplan.
- Estimation of inter parametric correlation followed by estimation of dominant WQ parameters using PCA.
- Development of WQ contours for the selected parameters at zone levels.
- Optimizations of process parameters of MFC using Response Surface Methodology (RSM).
- Engineering design and subsequent installations of lab scale AD-MEC unit and optimization of process parameters (in line of MFC studies carried out earlier).
- Estimation of potential for biogas generation, Ammonia recovery and COD reduction potential of the system

Other Achievements during the period:

Collaborative Venture with other co-investigator of SUTRAM, (namely, Kumaun University, Nainital) for using graphene-based electrode for better performance of MFC. A research paper has been under revision

3.4 Decolorization of high concentration of azo dye Methyl Red in sequencing batch membrane bioreactor

The feasibility of decolorization of high concentration of azo dye Methyl Red (MR) in the presence of sucrose and NO_3^--N was evaluated in a laboratory scale membrane bioreactor operated in sequencing batch mode. Mixed microbial culture, which was previously enriched in a simple sequencing batch reactor under anoxic and static conditions, was used as seed biomass to decolorize high concentrations of MR (500 mg/L) using NO_3^--N as electron acceptor during start-up. After successful start-up, the reactor performance was assessed in increasing loading rates by decreasing the Hydraulic Retention Time (HRT) in different phases of reactor operation. Results indicate an effective decolorization of MR. Maximum removals of color (93%), COD (85%), and TN (81%) were achieved in phase I at a HRT of 16 d. On increasing the loading rate, the average removals obtained in phase III at a HRT of 4 d were color (77%), COD (78%), TOC (76%), and TN (95%). This process may help in treating dye effluents cost-effectively using hybrid technologies (biological treatment followed other advanced techniques) because around 75% of dye could be treated in anoxic conditions without external aeration.

Nutrient recovery from wastewater to promote circular economy – a Review

The limited rock phosphate deposits present in the earth's crust are being used at a fast rate and therefore phosphate fertilizers use will be restricted in the future. Hence, there is an urgent need of conserving the use of phosphorous (P) and recover/reuse of P from wastewaters to the maximum extent. Struvite ($MgNH_4PO_4$) is a crystalline mineral composed of magnesium, ammonium, and phosphate, and is considered as an adequate source of nutrients especially P. Struvite can be used as raw material for fertilizer production or as slow-release fertilizer. Recently, there were a lot of researches carried out to explore the possibility of recovering the struvite from wastewater streams. This work reviews the potential sources of P in wastewater streams and the techniques of struvite recovery available in the literature for practical applications. Anaerobic digester supernatant, urine from livestock and humans are identified as potential wastewater sources of P in India. Continuous stirred tank reactor technique can be easily adopted to recover P, which is known to recover 80-90% P in wastewater. Currently, India is the second largest consumer of P due to the low P in soil and depends on imported sources for
meeting her demand on fertilizers. Therefore, the work presented in this review would help India to formulate suitable policy guidelines to meet a part of the P demand by recovering struvite from wastewater streams and apply in agricultural field as an eco-friendly fertilizer. Such an effort significantly contributes to promote circular economy and sustainable agriculture. More details are in: https://doi.org/10.1016/j.seta.2021.101573

Hybrid Bioreactors for Dye Biodegradation

Pollution due to dye effluents is a raising concern worldwide. The release of partially treated or untreated dye effluents into the environment is a major source of water pollution leading to eutrophication, death of aquatic species, and aesthetic problems. Dyes and their degradation components are recalcitrant in nature and subsequent bio-accumulated toxic components are carcinogenic, mutagenic, and teratogenic in nature. Several physicochemical and biological treatment methods were employed to treat dye containing wastewaters. However, none of the techniques were able to completely mineralize recalcitrant dyes. Application of any single technique to the wide range of dye effluents seems to be impractical and hence it is vital to develop hybrid systems by combining biological systems with other suitable and promising treatment methods to achieve efficient dye degradation. This work gives a review of hybrid bioreactors (i) integrating physicochemical and biological processes, (ii) integrating advanced oxidation processes and biological processes, (iii) integrating various biological processes, and (4) novel bioreactors. These hybrid bioreactors are beneficial in terms of technical and economic feasibility to achieve efficient dye degradation and expected to make more footprints in future. More details are in: https://link.springer.com/chapter/10.1007/978-981-16-5932-4_10

Effect of nano particles of Fe in the anaerobic digestion of waste activated sludge

Anaerobic digestion is seen as one of the most preferred method for sludge treatment in wastewater treatment plants. The process is attractive as it is a net energy gain process by collecting and utilizing the biogas produced from anaerobic digestion. Though it is widely used because of its potential to generate renewable energy (biogas), there are some limitations in its efficient operation. For example, the solubilization of sludge is identified as a very slow rate reaction and because of that higher volume of sludge digester is required for sludge treatment. This problem has been addressed by various pre-treatment approaches to reduce the time of sludge solubilization. Nano materials-based pre-treatment was also attempted to enhance the solubilization of sludge and ultimately to improve the bio-methanation efficiency of sludge digesters. Recent studies have showed that nano particles of metallic oxides have aided in enhancing the methane generation and nano particles of iron oxides and hydroxides have shown a positive effect on the methane generation rate. This work aims to review and summarize the recent advancements in nano particles of iron oxides and hydroxides as an additive, elucidate the various effects of parameters affecting the sludge treatment and thereby enhance the bio- methanation. This work is also supported with a preliminary study to examine the effect of nanoparticles of Fe in the sludge solubilization rate and overall effect on the sludge digestibility of a lab scale anaerobic reactor fed with waste activated sludge. The treated samples were analyzed for pH, volatile fatty acids (VFA), alkalinity, and SCOD. The results showed a positive impact of nanoparticles of Fe in the sludge solubilization and subsequent anaerobic digestion. The work

presented in this review would help to advance the knowledge and ultimately helps in improving the bio-methanation efficiency of anaerobic digesters. More details are in: https://doi.org/10.1016/j.matpr.2021.10.265

Work Package – 4

WP-4 Water Distribution and Sewerage Networks

- **Optimal operation of urban water networks**: Optimal operation of water networks can be posed as a scheduling problem where the objective is to meet the time varying consumer demands at required pressure. The resulitng problem is a nonlinear integer programming problem which can be computationally demanding. In the past, we have reformulated it as a mixed integer linear program which can be solved to global optimality using commerical and freely available software/solvers. However, in order to improve the computational efficiency, we have develop heuristic approaches that result in significant computational savings with marginal increase in optimal cost. A python based sofware package is being devloped for deployment and will be released shortly.

- **Simulation of water distribution networks.** Model based analysis (e.g, design, operation, monitoring) of water networks requires solution of a large number of nonlinear equations. We have developed fast solution techniques for simulating branched water distribution networks that exploit the structural properties of the network. The advantage is that the custom built solver can be interfaced with the other modules under development. Wegstein acceleration was used to improve computational efforts.. The results of simulations of different networks (ranging from 5 node to 50 nodes) were compared to EPANET and were found to be in agreement.

- **Network calibration**: Model based operation of water networks require 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 (pipe roughness coefficients and emitter coefficients of demand nodes) Network parameters are guessed in an outer loop while the hydraulic simulation is carried out in the inner loop. The methodology was demonstrated using data from the experimtal lab network and simulations of real world rural water supply and distribution networks.

- **Data driven scheduling of water distribution networks**: 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. The advantage of the proposed method is that no hydraulic or network models are necessary.

- **Network reconstruction**: We have formulated and demonstrated a methodology for reconstrucitng 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