02 Days Workshop

Used Water Management: Navigating Challenges & Opportunities in Madhya Pradesh

June 26 - 27, 2025

Low-Cost Nature-Based Technologies for Liquid Waste Treatment, Recycling and Resource Recovery

Prof. Sanjeev Kumar Prajapati
Head
Department of Hydro and Renewable Energy
Indian Institute of Technology Roorkee
sanjukec@hre.iitr.ac.in, Mob: +917428640872

ACADEMIC PROGRAMMES @HRED IIT Roorkee

a) Undergraduate – B.Tech program in Energy Engineering with intake of 20 students through JEE Advance exam.
– Minor degree specialization in Renewable Energy Technology (5-6 courses) for other B.Tech students)
– Honours Courses of the Department (5-6 courses) for deptt. B.Tech students
– 06 Elective Courses per year

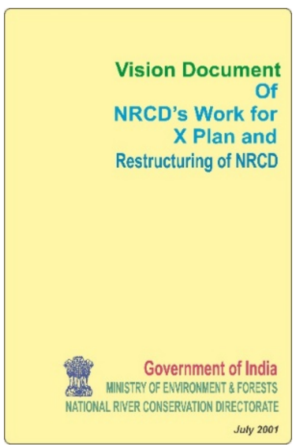
b) M.Tech.

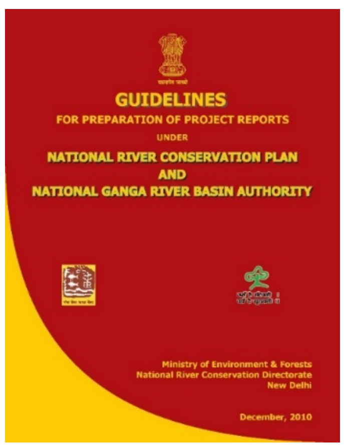
Area	Intake
M.Tech (Environmental Management of Rivers and Lakes) (Since 2004)	09 Regular GATE qualified **05 (Sponsored by Ministry of Jal Shakti) – covers Full tuition, hostel charges, contingency and travel etc** 05 (Sponsored by others) 10 Sponsored – through ITEC of MEA
M.Tech (Renewable and Hydro Energy) (since 1997)	15 Regular (GATE Qualified) 05 Sponsored – Govt. nominees 05 GATE Qualified (MNRE fellowship) 15 Sponsored – through ITEC of MEA

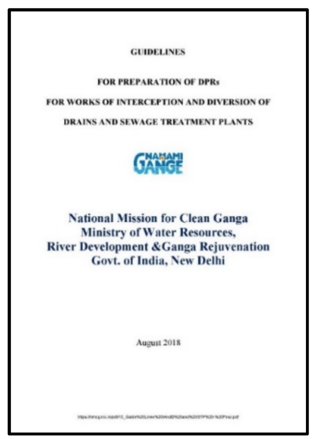
c) Ph.D. (RE/EMRL) : 69 registered, 86 scholars Awarded

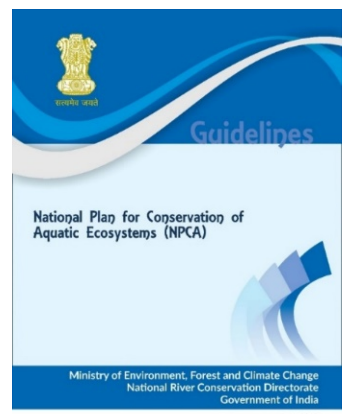
Guidelines prepared by HRED IIT Roorkee for NRCD/NMCG/MOEFCC

- Vision Document of NRCD's Work for X Plan and Restructuring of NRCD (2001)
- Guidelines for MOEFCC and NMCG for preparing the project proposals by implementing agencies (2010)
  https://nrcd.nic.in/writereaddata/FileUpload/Guidelines_for_Report_Preparation_under_NRCP_NGR_A_Dec%202010.pdf
  https://nmcg.nic.in/writereaddata/fileupload/40_Guidelines%20for%20Report%20Preparation%20under%20NRCP%20NGRBA%20Dec%202010.pdf
- Guidelines for interception diversion and STP works (2018) https://nmcg.nic.in/pdf/13_Guide%20Lines%20IAndD%20and%20STP%20-%20Final.pdf
- National plan for conservation of aquatic ecosystem (NPCA) (2019) http://moef.gov.in/wp-content/uploads/2019/09/NPCA-MOEFCC-guidelines-April-2019-Low-resolution.pdf
- Guidelines for Constructed Wetland systems for Treatment of sewage in India (2023)
  https://iitr.ac.in/Departments/Hydro%20and%20Renewable%20Energy%20Department/static/guidelines/Guidelines_constructed_wetlands_NMCG_HRED_IIT_Roorkee_2023.pdf



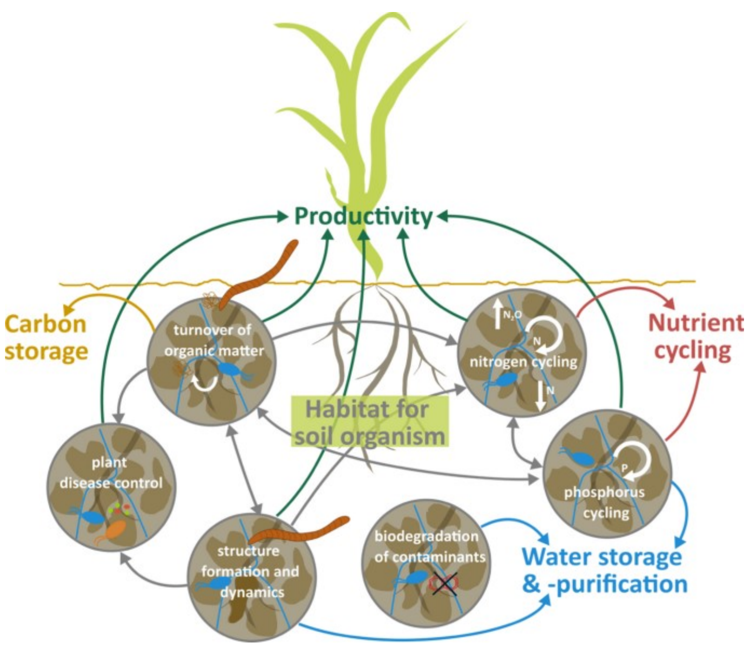


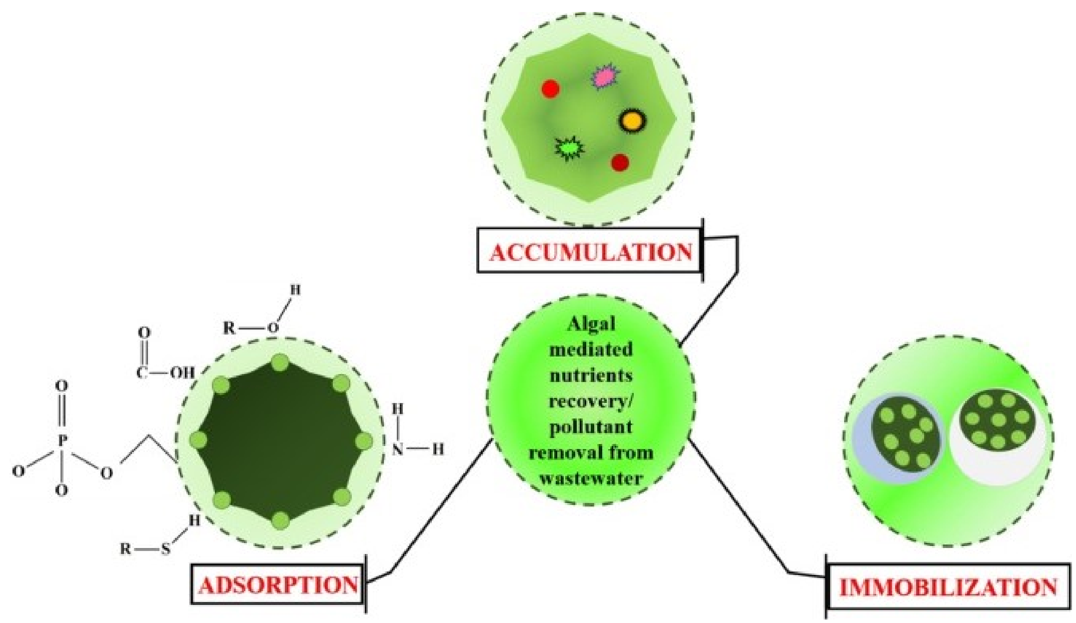




Introduction

❖ Nature-Based Solutions for wastewater treatment are engineered ecological systems that leverage biogeochemical processes driven by microorganisms, plants, soil matrices, and sunlight to remove organic and inorganic pollutants from liquid waste streams including sewage



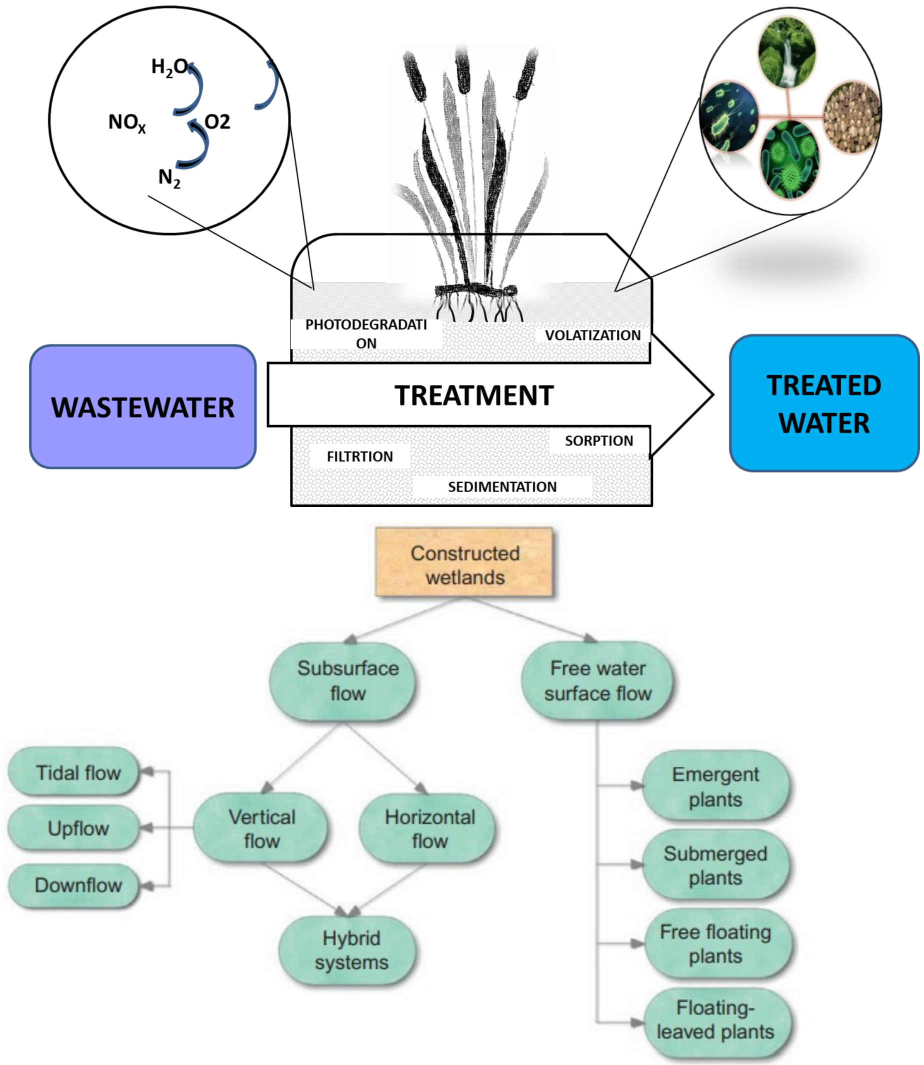


Key Low-Cost Nature-Based Wastewater Treatment Technologies

Technology	Key Features	Primary Pollutants
Constructed Wetlands	Subsurface or surface flow systems using macrophytes (e.g., Typha, Canna), media filtration, and microbial consortia	BOD, COD, TSS, nutrients
Waste Stabilization Ponds	Series of anaerobic, facultative, and maturation ponds relying on natural algae-bacteria symbiosis under sunlight	BOD, pathogens, nutrients
Algae-Based Systems	High-rate algal ponds, algal photo-granules or algal turf scrubbers using controlled algal growth for nutrient uptake and oxygenation	Nutrients (N, P), BOD, CO_2 absorption
Phytoremediation Units	Floating treatment wetlands or land-based plant systems for uptake and transformation of metals and nutrients	Heavy metals, nitrates, phosphates
Biofilters (e.g., Vermifilters)	Media beds (e.g., gravel, sand, organic matter) inoculated with earthworms and microbes for rapid solid-liquid separation and biological treatment	Organics, TSS, fecal coliforms, pathogens

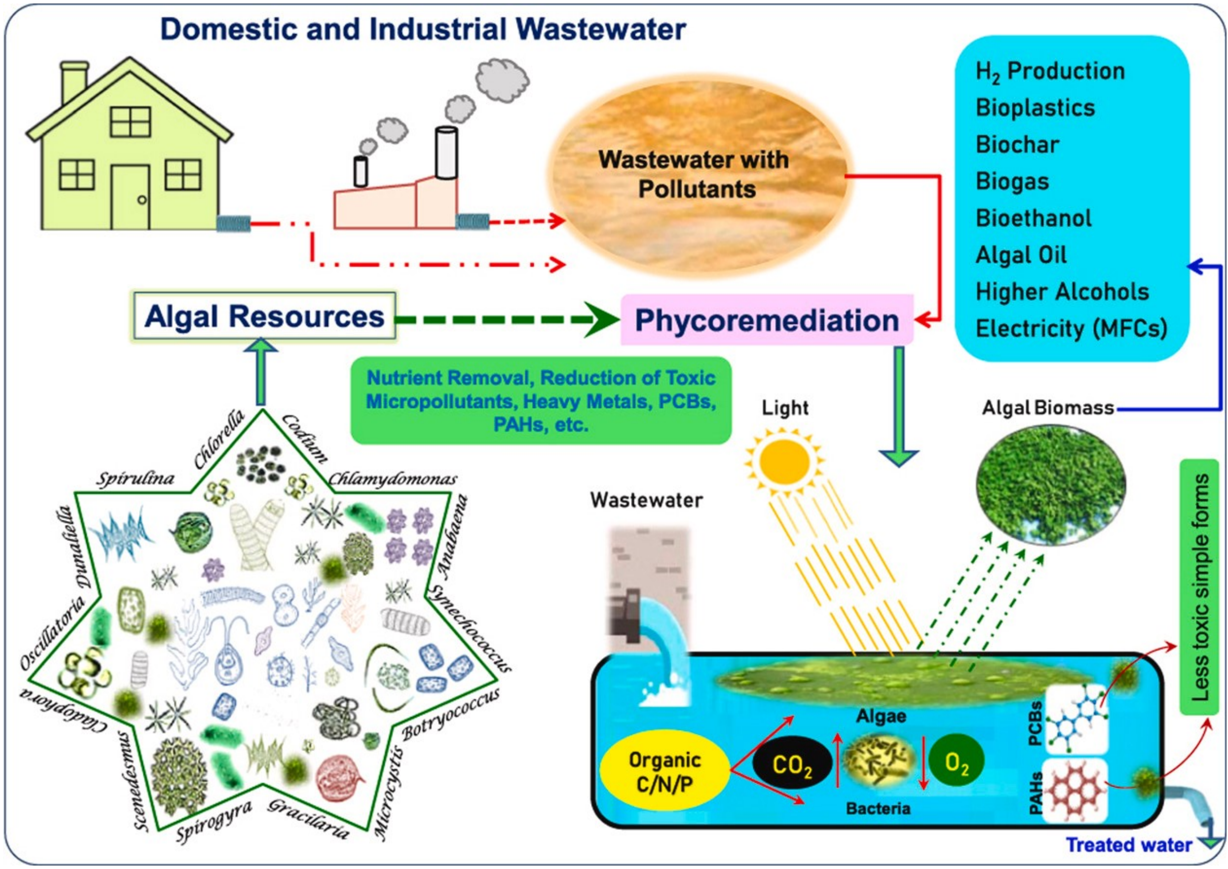
Nature-Based Wastewater Treatment Technologies

Constructed Wetlands are engineered, man-made ecosystems specifically designed to treat wastewater by optimizing biological, physical, and chemical processes occurring in natural wetland systems.



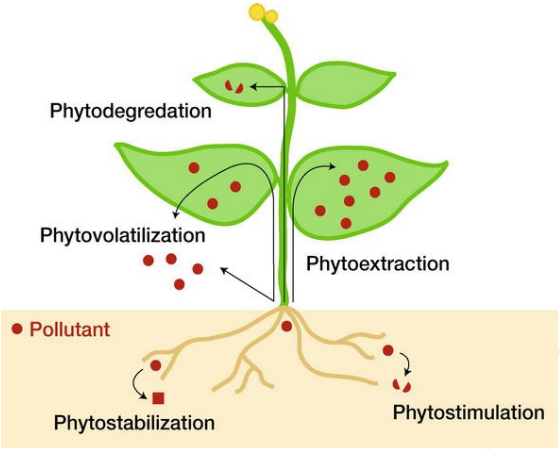
Phyco-remediation

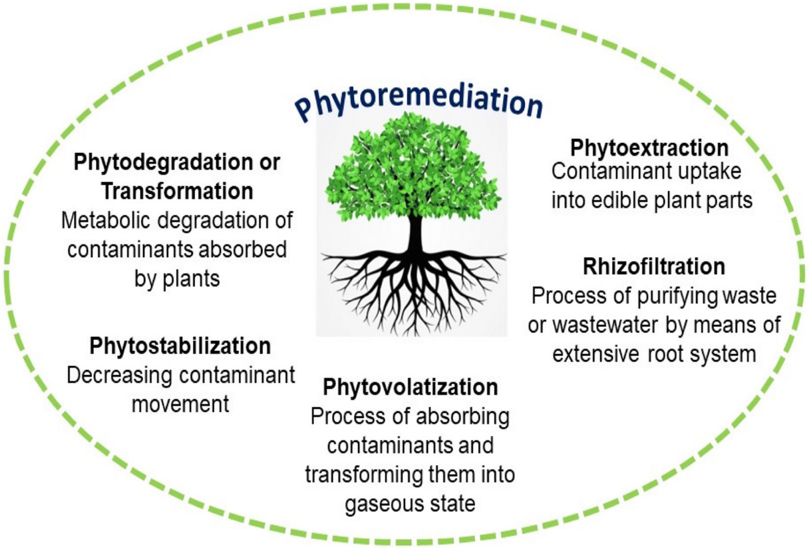
In this method algae are used to remove pollutants such as nutrients (nitrogen and phosphorus), heavy metals, and organic matter from contaminated water.



Phytoremediation

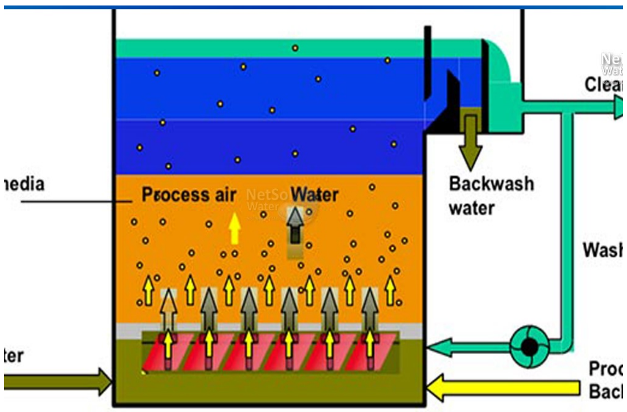
In phytoremediation green plants are used to remove, degrade, or stabilize contaminants from soil, water, and air. Plants absorb pollutants through their roots and either store, transform, or break them down, making the environment cleaner and healthier.



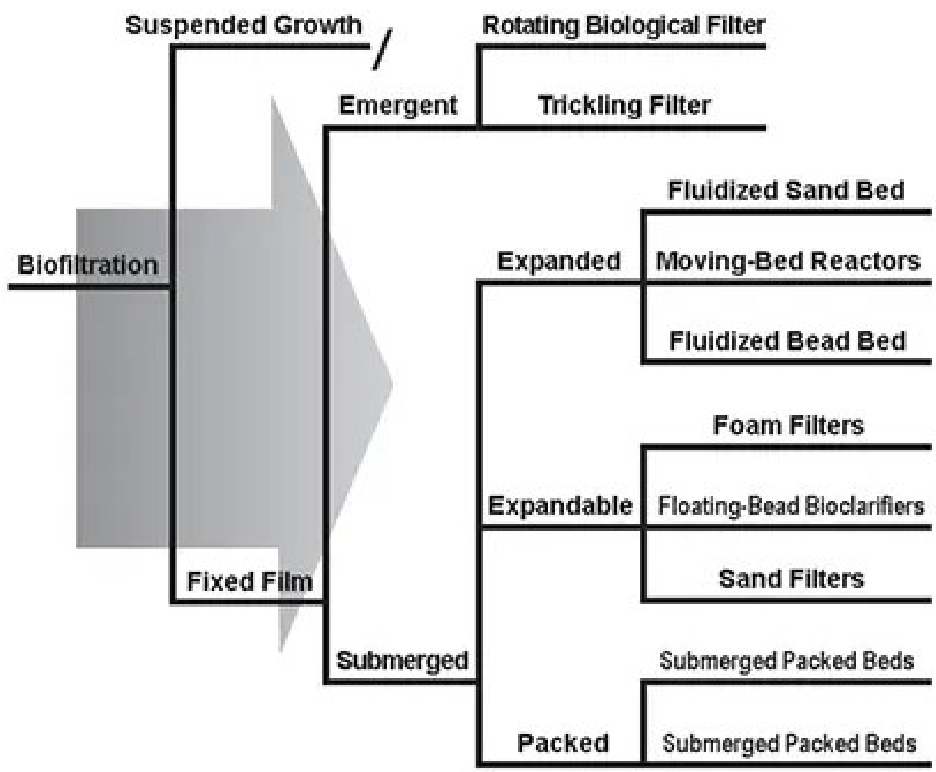


Bio-filters

Biofilters are natural or engineered systems that use a combination of filter media (such as gravel, sand, or compost) and microorganisms to treat contaminated water or air.

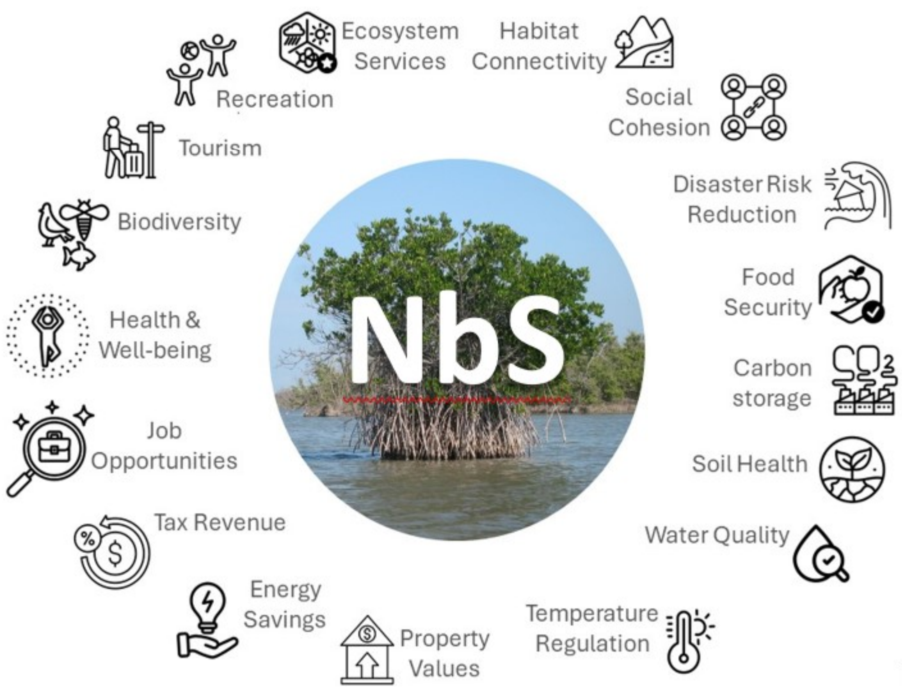


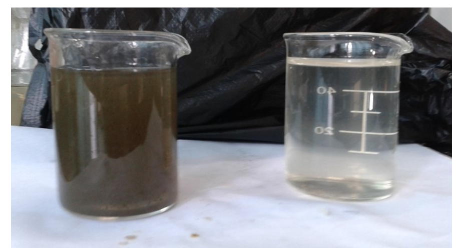
What is Bio-Filtration in Municipal WWT Plants



Benefits for Cities on adopting Low-cost NBS

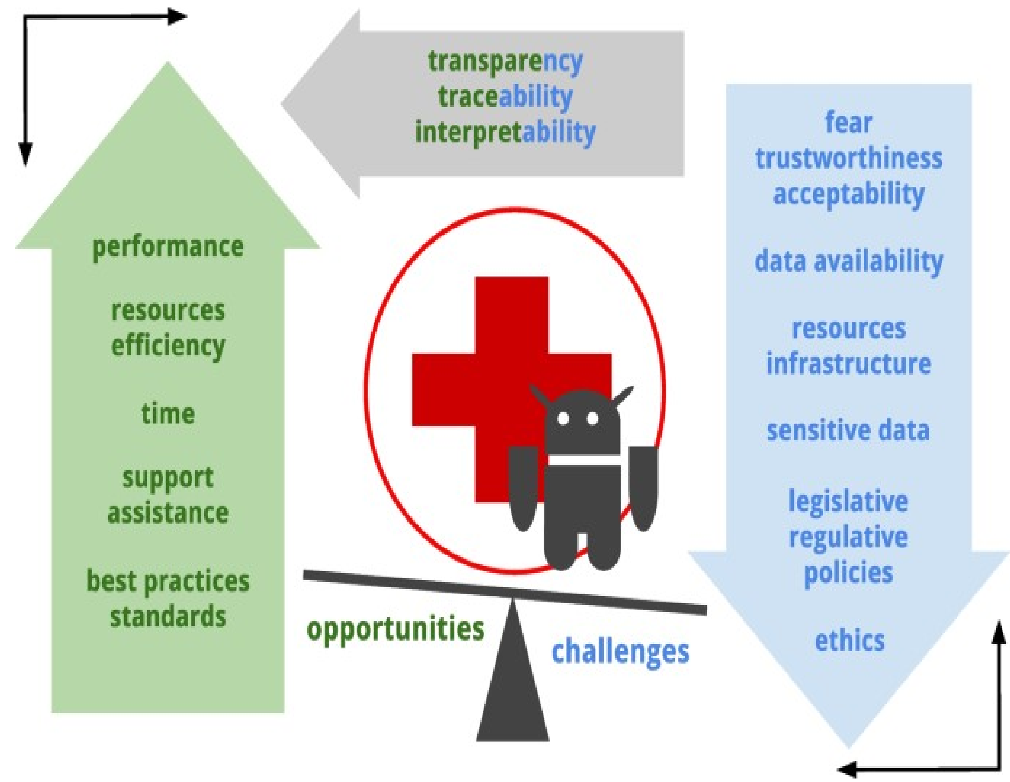
- **Benefits of Low-Cost Nature-Based Systems for Cities**
  - Minimal requirement of electricity, chemicals, & high-end machineries.
  - Low in operation & maintenance cost





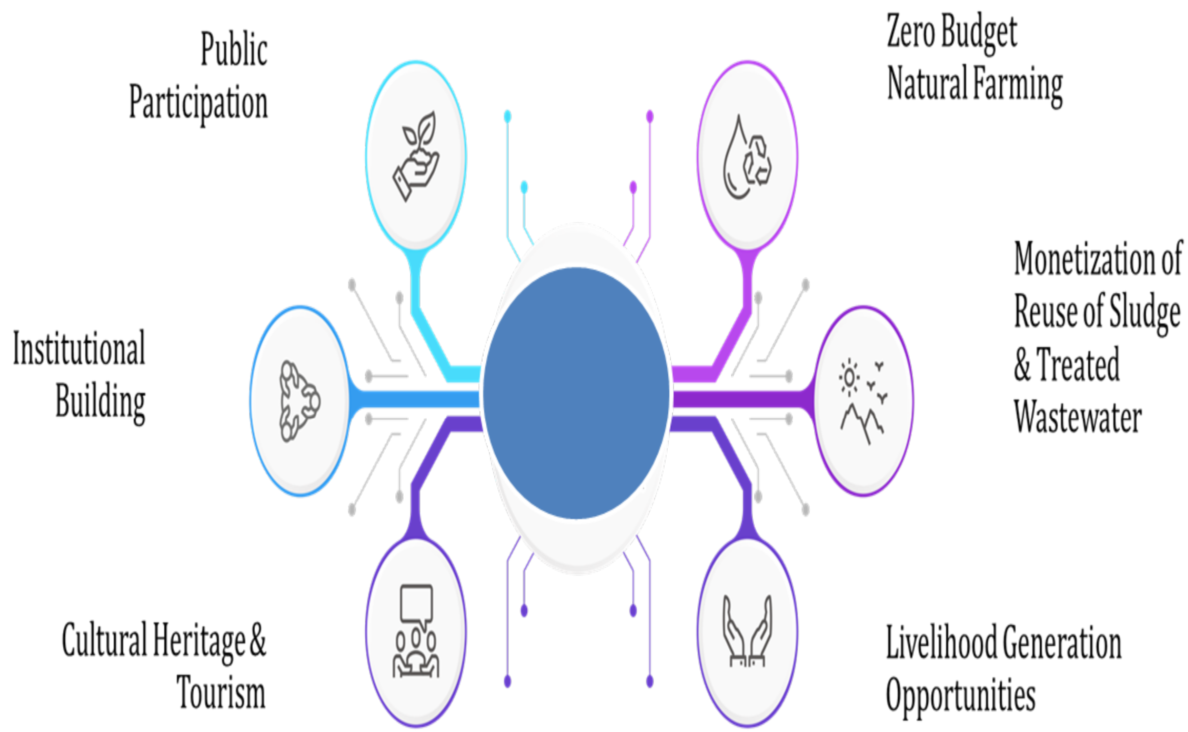
Challenges in Adopting Nature-Based Systems in Cities

- Space constraints in dense urban areas
- Public perception and odor concerns
- Inconsistent maintenance due to low technical oversight
- Seasonal variations affecting performance
- Policy and regulatory gaps for decentralized systems

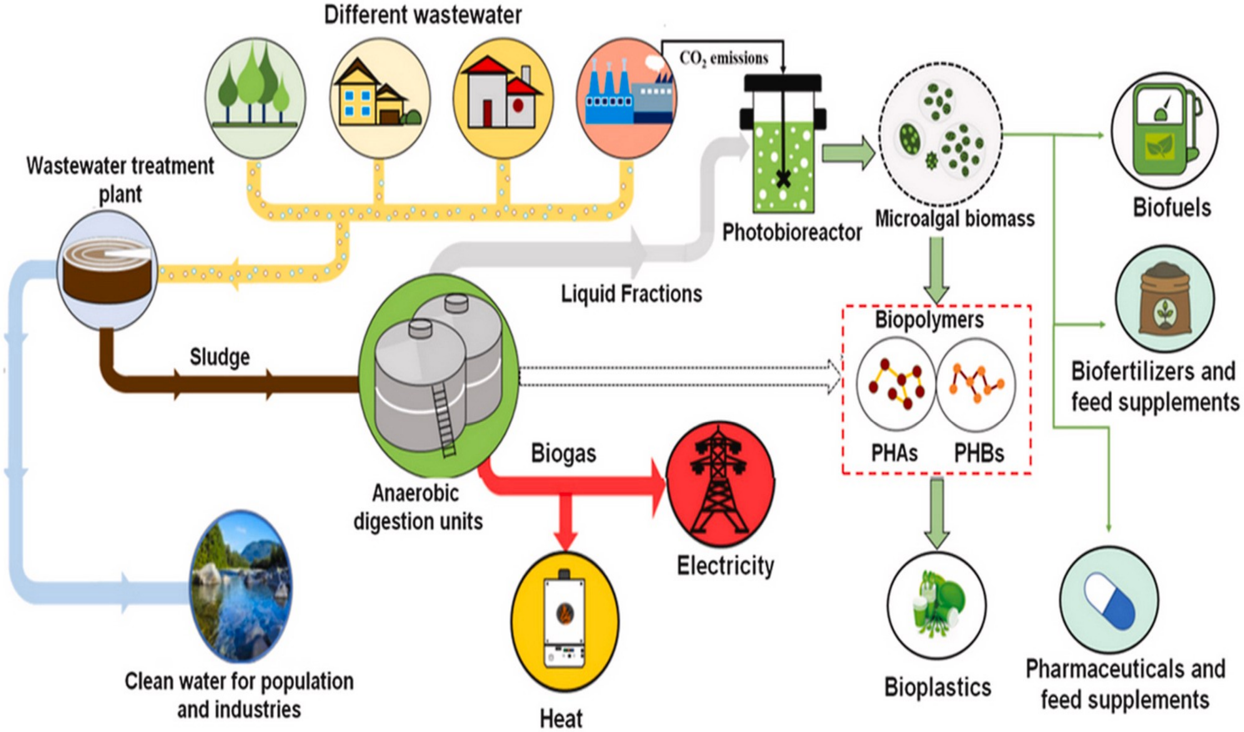


Sustainable Solutions and the Way Forward

- Awareness and knowledge creation
- Hybrid systems: Combining natural and mechanical units (e.g., primary sedimentation + Nature-based systems)
- Decentralized networks integrated into city planning
- Incentives for water reuse and sludge valorization
- **Capacity building**
- Mainstreaming NbS in policies



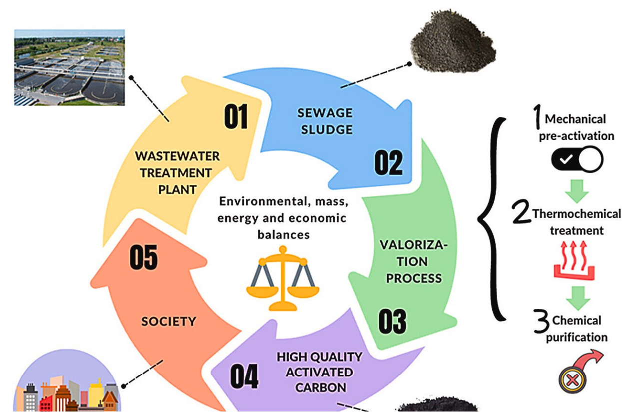
Wastewater treatment plants recoverable resources



Wastewater treatment plants recoverable resource

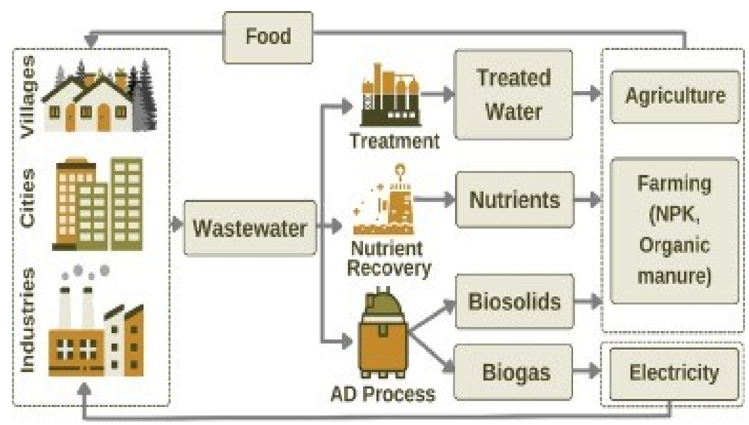
Key recoverable resources include:

- ❖ Water – the primary and most valuable resource for reuse.
- ❖ Energy carriers – such as methane (CH_4), hydrogen (H_2), and ammonia (NH_3), generated through anaerobic digestion, fermentation, or thermochemical processes.



Soil amendment and carbon-rich products:

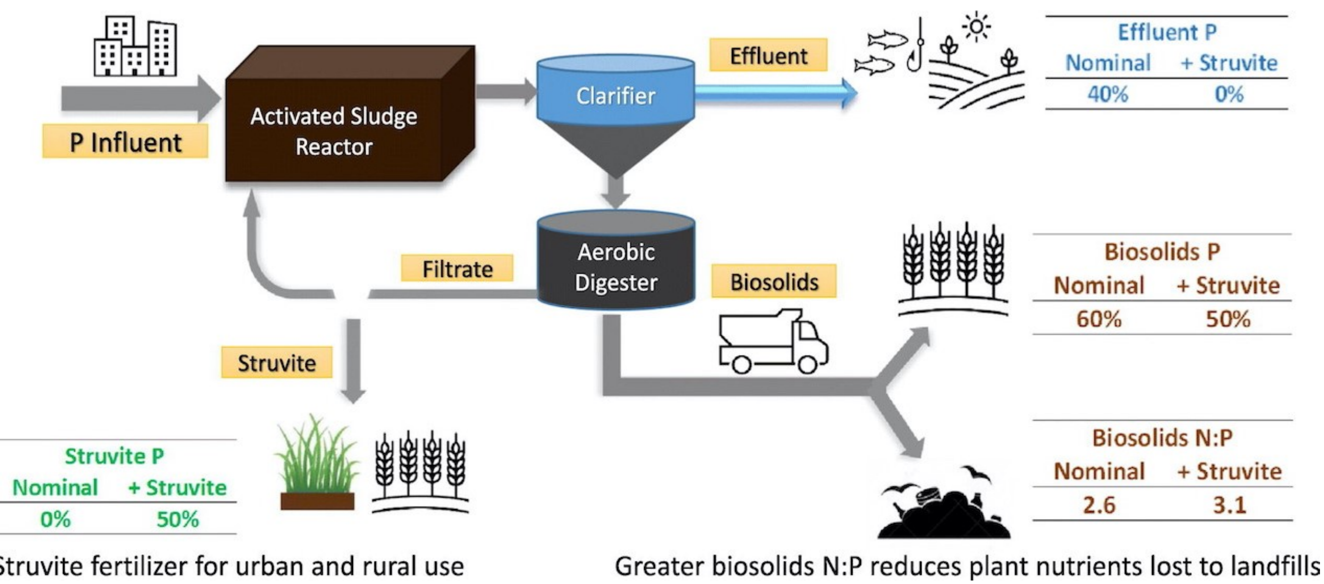
- ❖ Compost and biosolids for agricultural use.
- ❖ Biochar – produced through pyrolysis of sludge or organic matter; enhances soil health and sequesters carbon.



Nutrients

- ❖ Struvite ($MgNH_4PO_4 \cdot 6H_2O$) – a slow-release fertilizer.

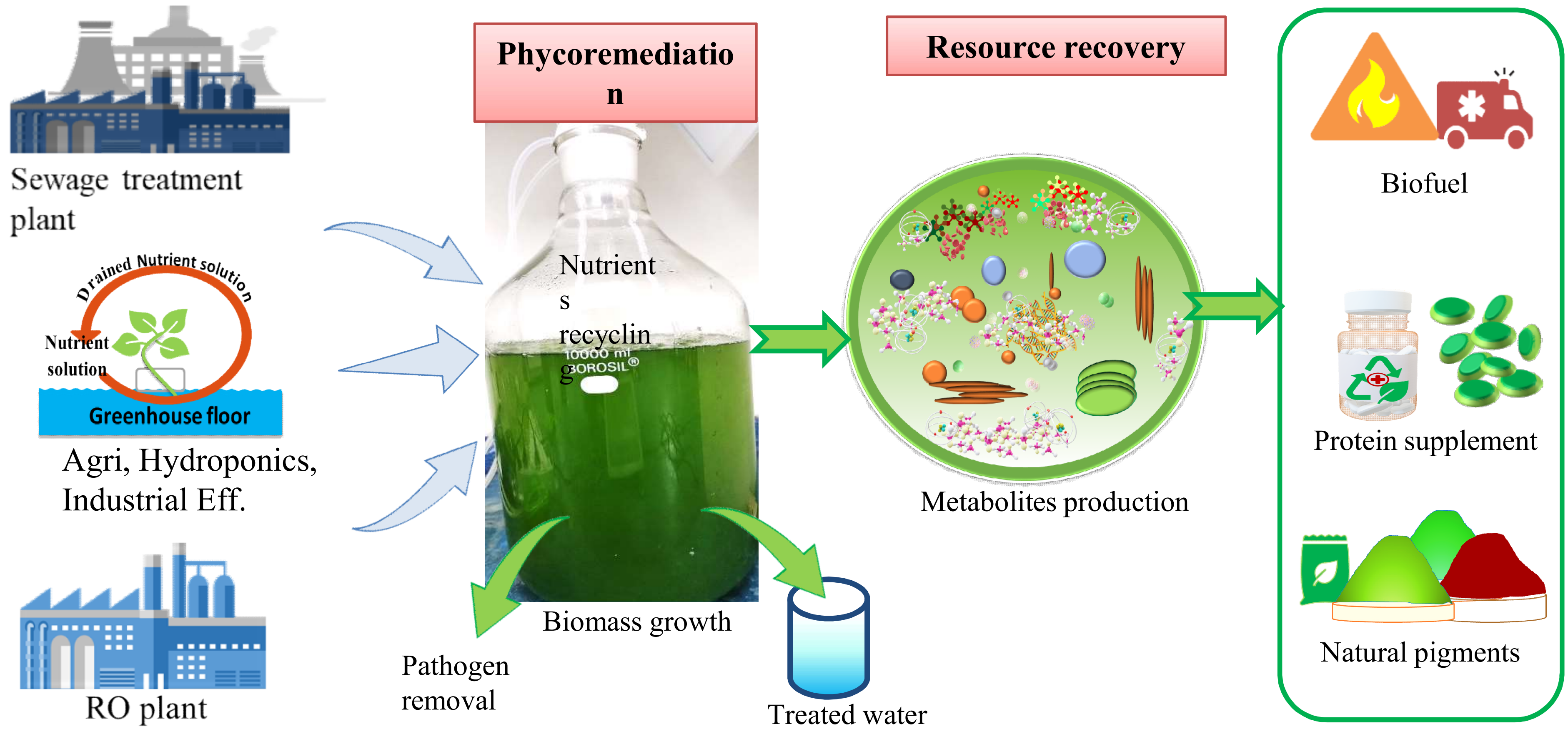
Process	Product	Nutrients recovered	Potential limitations	Reference
Struvite precipitation in (dewatered) sludge	Struvite ($MgNH_4PO_4$)	P: < 5-65% of total load [a]	Needs addition of Mg Only little N recovered [b]	Wollmann and Möller (2015)
Thermo-chemical MSS ash treatment with Na and/or K additives	Contaminant depleted NaCaP bearing ash	P: ca. 90% of total load [a] Cu, Zn	Cr and Ni not removed No N recovery High energy consumption	Herzel et al. (2016)
NH_3 volatilization + acid stripping	$(NH_4)_2SO_4$	N	Soluble fertilizer Use of sulfuric acid	Evans (2007)
Microalgal nutrient recovery	Microalgal biomass	N & P: up to 100% [a, b] Likely other nutrients	Pathogens and trace elements not investigated Unsuitable for cold climate Lab-scale development stage	e.g. Vasconcelos Fernandes et al. (2015)



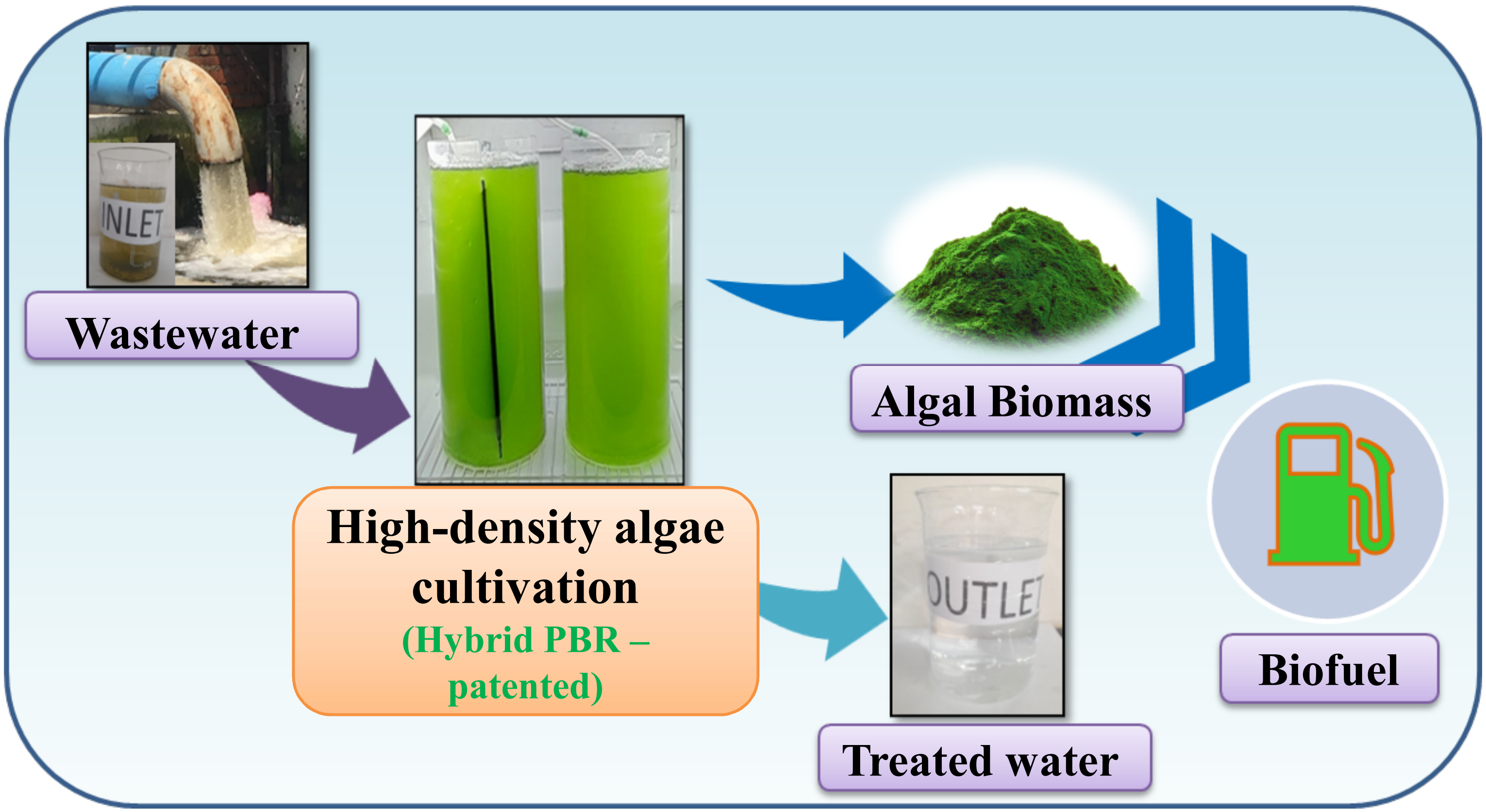
- ❖ Ammonia – recovered through stripping or distillation.
- ❖ Calcium phosphate – derived from chemical precipitation

Nature-based solutions developed @HRED IITR

Algae integrated processes for wastewater recycling and resource recovery



Algae cultivation and resources recovery from Sewage



ELSEVIER

Bioresource Technology Reports

Volume 25, February 2024, 101756

Bicarbonate-assisted microalgae cultivation for drinking water RO reject recycling and bioproduct generation

Mamta Bhandari [a], Shailesh Kharkwal [b, c], Sanjeev Kumar Prajapati [a]

ELSEVIER

Resources, Conservation and Recycling

Volume 188, January 2023, 106699

Recycling drinking water RO reject for microalgae-mediated resource recovery

Mamta Bhandari [a], Shailesh Kharkwal [b], Sanjeev Kumar Prajapati [a]

Show more

Indian Patent: A process for co-culturing microalgae with yeast in RO reject for protein-rich biomass

Industry Partner: Dr. Shailesh Kharkwal, H2O Mantra Pvt. Ltd.

ELSEVIER

Journal of Environmental Management

Volume 342, 15 September 2023, 118159

Review

An integration of algae-mediated wastewater treatment and resource recovery through anaerobic digestion

...alis Simsek [c], Ravinder Kumar [d],

npj | clean water

Explore content About the journal Publish with us

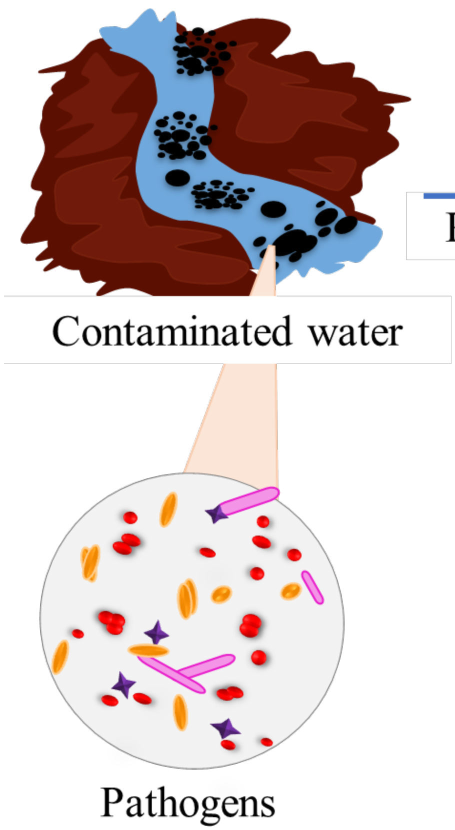
nature > npj clean water > articles > article

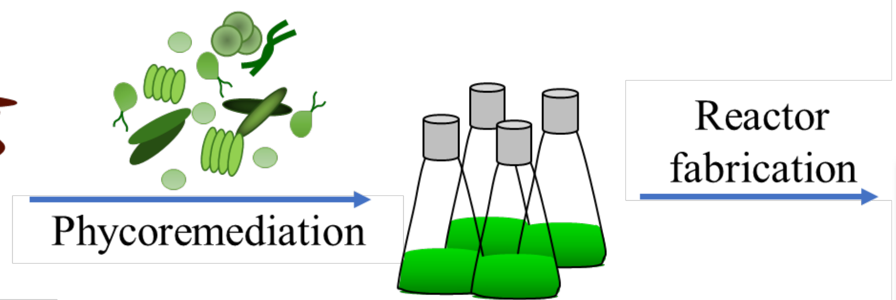
Article | Open access | Published: 22 November 2024

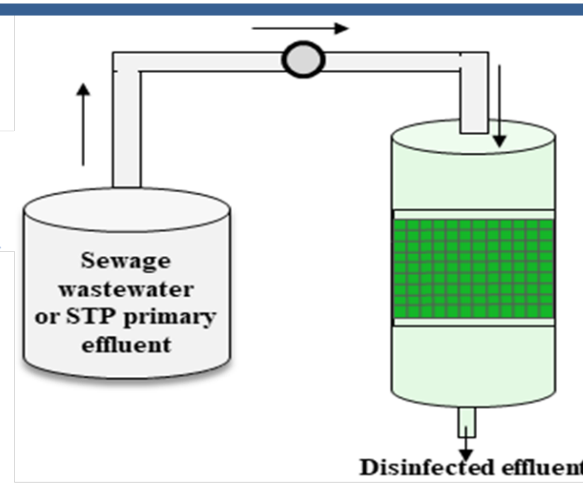
Unveiling mechanistic intricacies of *Chlorella pyrenoidosa*-mediated pathogen removal from sewage

Ankita Bhatt, Pratham Arora & Sanjeev Kumar Prajapati

Microalgae-mediated pathogen removal (MAPR)







- 90% *E.coli* removal in presence of *C.pyrenoidosa* within 3-4 days in synthetic wastewater
- 80-88% reduction in total bacteria in MAPR for real primary treated sewage
- Photooxidation, competitive interactions and attachment, identified as probable mechanisms

Biofilters for pathogen removal from sewage

Nature-based solutions developed @HRED IITR

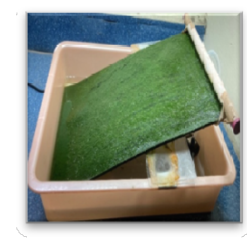
- **Constructed Wetlands: S**ludge free
- **Phycoremediation:** Algae based photosynthesis
- **Algal granules sludge process:** Nature-based, low-cost , resource recovery
- **Biogas:** Enhanced biogas recovery

Developed @HRED IITR

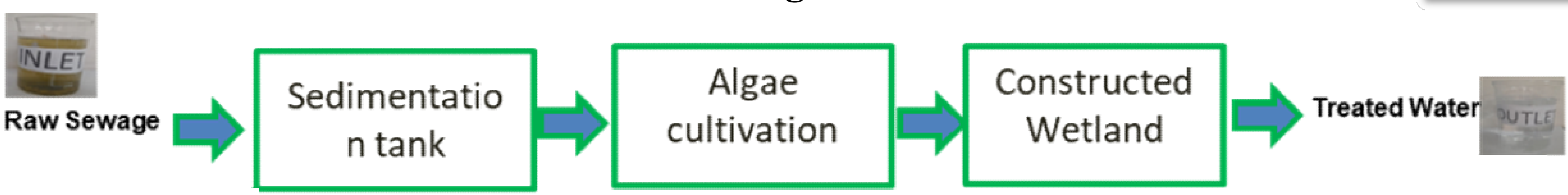
- Selection guidelines for constructed wetland systems for treatment of sewage in India
  https://iitr.ac.in/Departments/Hydro%20and%20Renewable%20Energy%20Department/static/guidelines/Guidelines_constructed_wetlands_NMCG_HRED_IIT_Roorkee_2023.pdf

- Microalgal biofilm reactor coupled constructed wetland

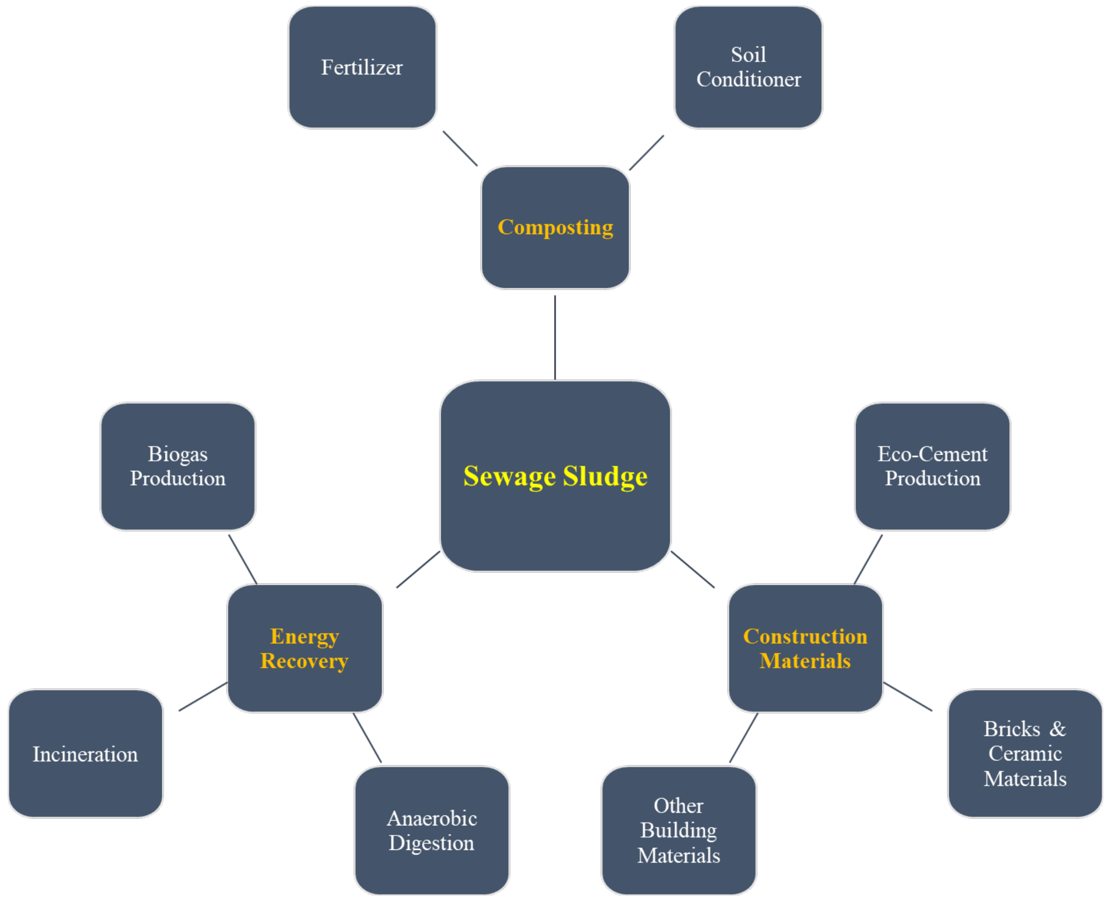
- Photobioreactor coupled constructed wetland systems
  (Doctoral Research Work)



Process validated with real sewage at Lab scale

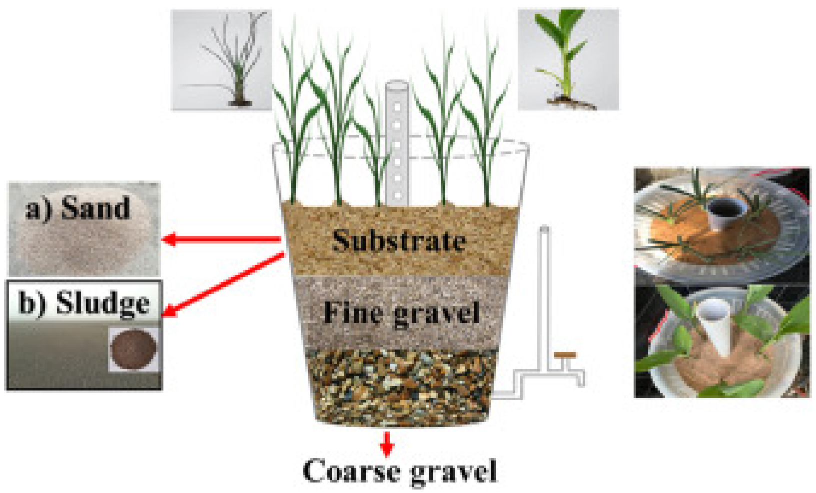


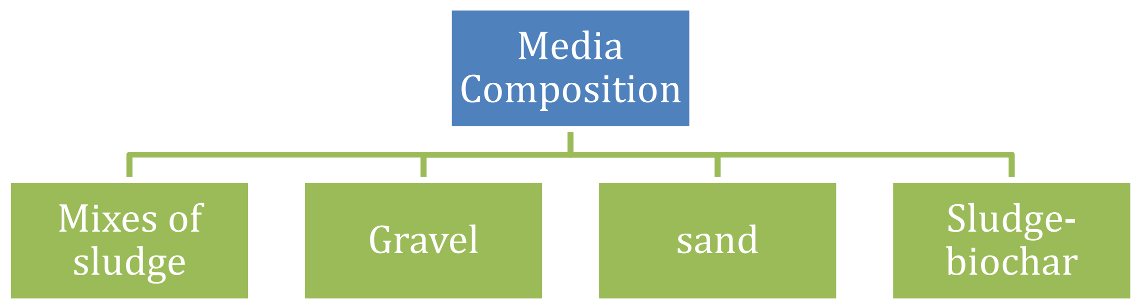
Resource Recovery from Sewage Sludge



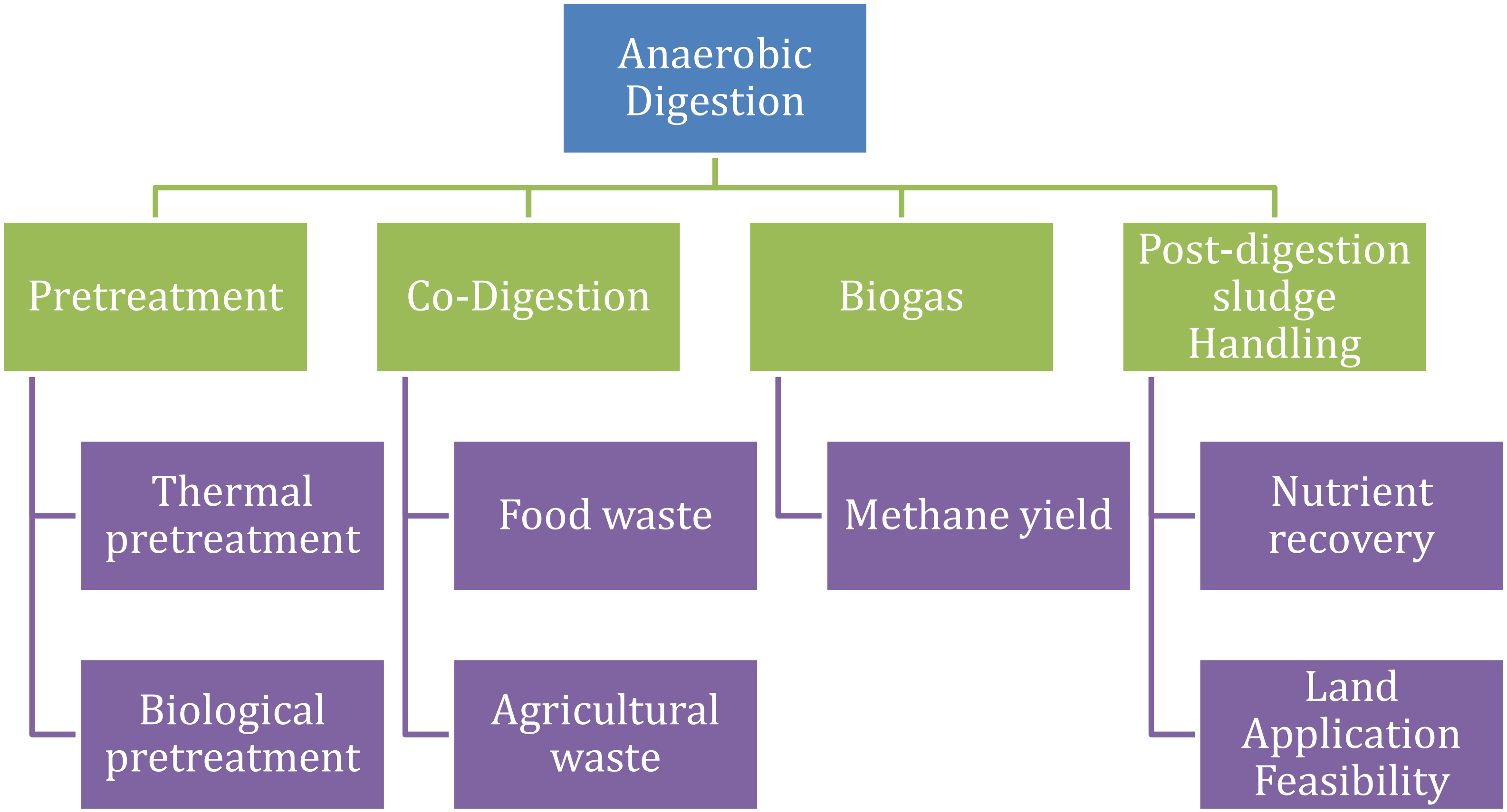
Use of Sludge as Substrate in Constructed Wetlands

Stabilized sewage sludge and biochar-blended sludge as a substrate material in constructed wetlands

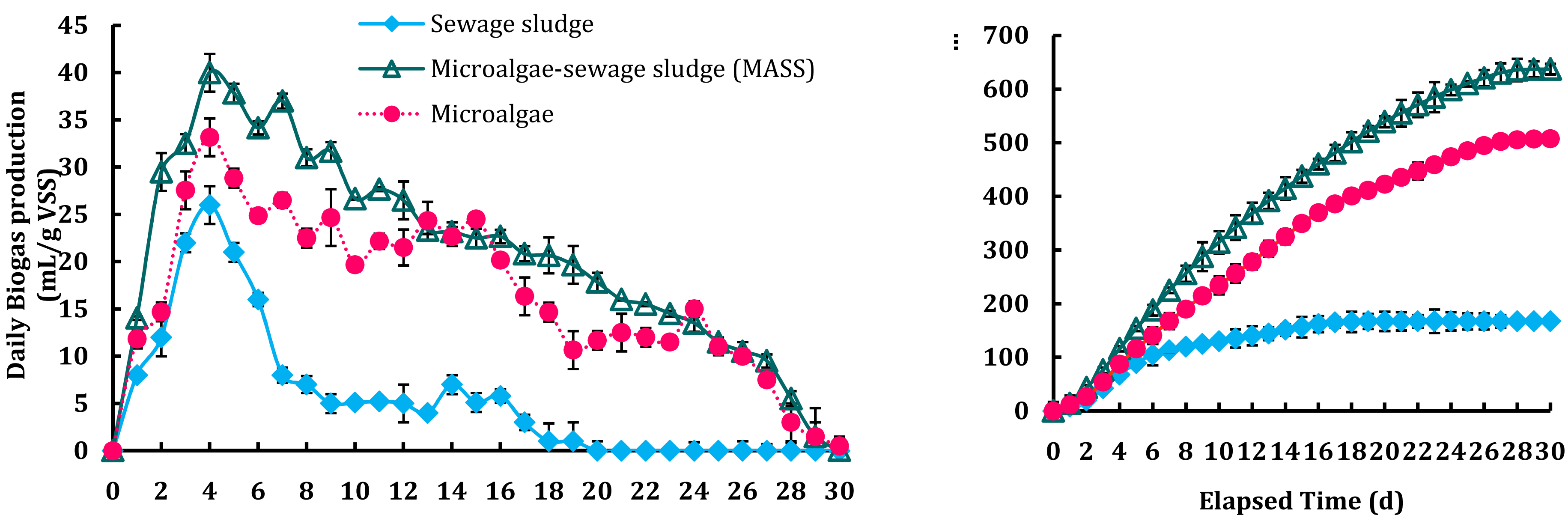




Sewage Sludge resource recovery @HRED IITR



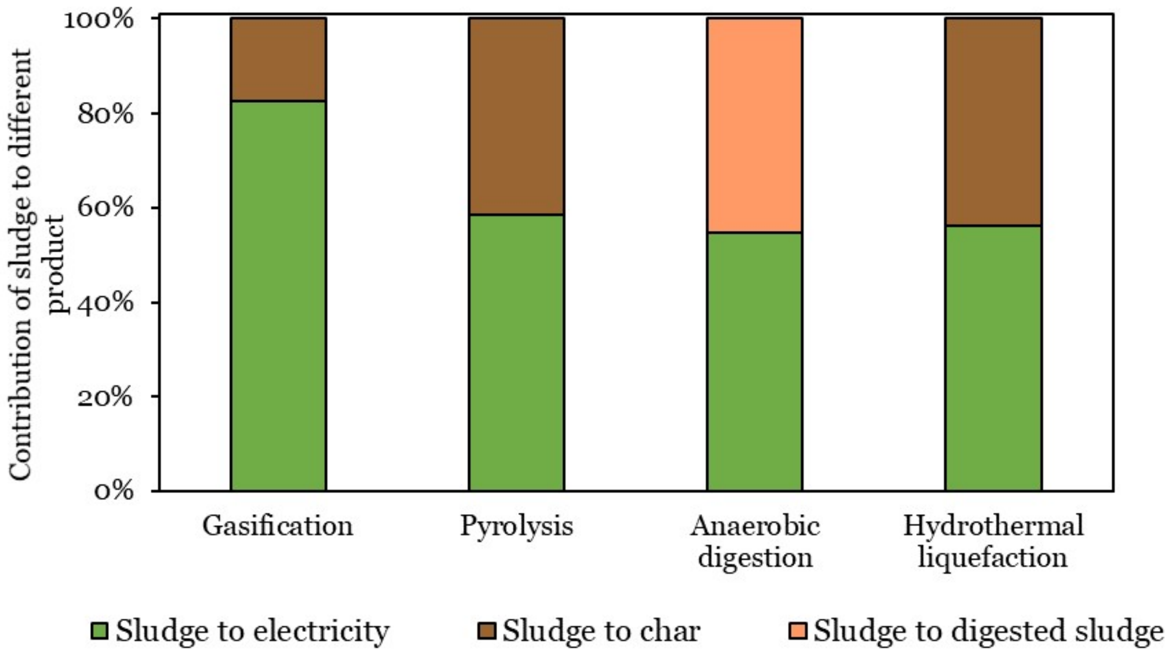
Biogas production potential of microalgae-sewage sludge biomass



Biomass	CEV (MJ Kg^{-1})	COD$_{th}$ (mg O$_2$ g^{-1}VS)	SMP (L CH$_4$ g^{-1}VS)	TMP (L CH$_4$ g^{-1}VS)	BMP (L CH$_4$ g^{-1}VS)	Digestibility $\left(\frac{BMP}{SMP}\right) \times 100\ \%$
Sewage Sludge	15.39	1,350	0.40	0.41	0.10	25.00
Microalgae	20.63	2,374	0.70	0.55	0.30	42.85
MASS	22.41	2,324	0.73	0.59	0.38	52.05

Assessment of Energy Recovery form Sewage Sludge

Used Aspen Plus to construct models of AD, pyrolysis, gasification, and HTL processes for a 100 MLD STP



- The gasification- highest electricity, utilizing approximately 80% of the sewage sludge but requires dried sludge
- The pyrolysis and HTL processes - utilize 60-70 % of the sludge for electricity generation.
- AD utilizes 50% of the sludge while producing 50% digested sludge

New Trends and Innovations

- Hybrid Treatment Systems (Constructed Wetlands + STPs)
- Wetlands + Biochar Media
- Algae-Based Granular Systems
- Solar-Assisted Wetlands
- Modular STPs

Plug-and-Play Nature-Based Wastewater Treatment System

- Johkasou

Type: Compact septic + biological reactor unit
Use: On-site treatment for homes, schools
Plug-and-play: Yes (comes preassembled)

KLARO containerized wastewater treatment plant

The mobile solution for wastewater treatment
Type: SBR-based container system
Use: Refugee camps, oil fields, rural settlements

- The Portable NBS™

https://ayala-aqua.com/

Kanha Santhi Vanam Kanha Village, Hyderabad

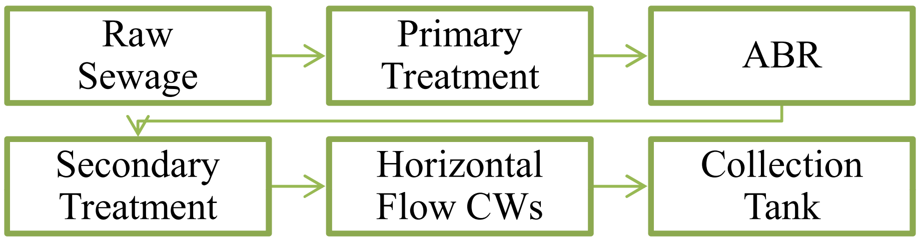
Treatment Facility 2.4 MLD CW-based wastewater treatment process

Raw Sewage → Primary Treatment → ABR → Secondary Treatment → Horizontal Flow CWs → Collection Tank

pH		DO (mg/L)		TSS (mg/ L)	BOD (mg/ L)	COD (mg/ L)	Ammonia (mg/L)
Influent	Effluent	Influent	Effluent	% Removal	% Removal	% Removal	% Removal
7.29	7.01	0.9	4.23	97.08	94.19	93.08	100

Kanha Santhi Vanam residence Hyderabad

Treatment Facility 1.2 MLD CW-based wastewater treatment process



pH		DO (mg/L)		TSS (mg/ L)	BOD (mg/ L)	COD (mg/ L)	Ammonia (mg/L)
Influent	Effluent	Influent	Effluent	% Removal	% Removal	% Removal	% Removal
7.67	7.61	0.1	3.76	97.74	92.07	89.34	96.54

Some Other CWs in India

IIT Gandhinagar
Gujarat (0.6MLD)

Surya Varsani Academy,
Bhuj, Gujarat (0.12 MLD)

Kanha Santhi Vanam residence
Hyderabad (1.2 MLD)

NCD Vivanta Central Court
Hyderabad (0.15MLD)

Dharamsala Cricket stadium,
Himachal Pradesh (0.65MLD)

Bhubaneshwar
Odisha

Devanahalli, Bengaluru,
Karnataka (0.006 MLD)

Indradhanushya Environmental Museum
Pune, Maharashtra (0.05 MLD)

Nature-Based Solution - International

Ecological wastewater treatment plant (Saint Louis, USA)

Ramat Hovav, power station, Israel
Constructed Wetland

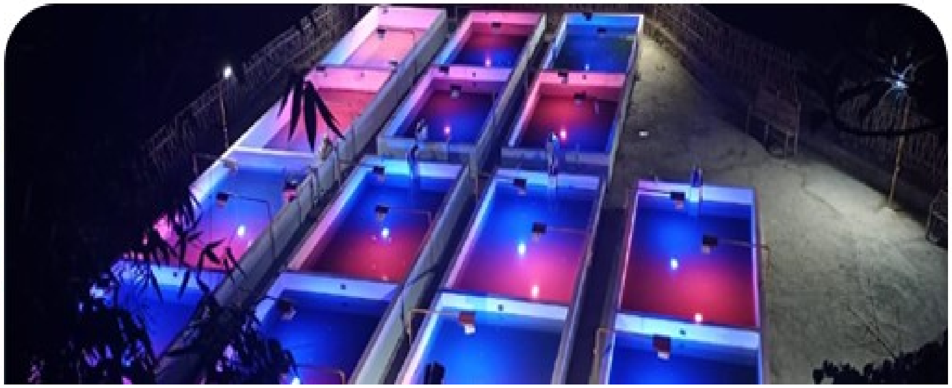
Lukha River – East Jaintia Hills – Meghalaya

Problem: Extremely Toxic large river due to metals and non metals. No bio life. High amount of Alumunium, Ferrous and Sulphur.

Result: This is an ongoing project and have been successful in removing the toxicity using micro algae consortia.

During the day time

During night time with LED lights



Source: https://www.trinityalgae.com/

Gujarat Agrochem Ltd
Panoli GIDC, Panoli, Ankleshwar, Gujarat 10 KLD
Zero Liquid Discharge Pilot Plant

Inlet Effluent Detail:

- pH: 4.5 to 13.5
- TDS: ~70,000 ppm
- COD: ~25,000 ppm
- NH3 - N – 50-300 ppm

Treatment given:
A pilot plant of 0.5 KLD was set-up which was further scaled-up to 10 KLD for processing of the effluent via micro-algal technology

Post-treatment:
The pH was neutralized in the range of 8 – 8.5, 77% of TDS was removed.

Source:
https://www.trinityalgae.com/

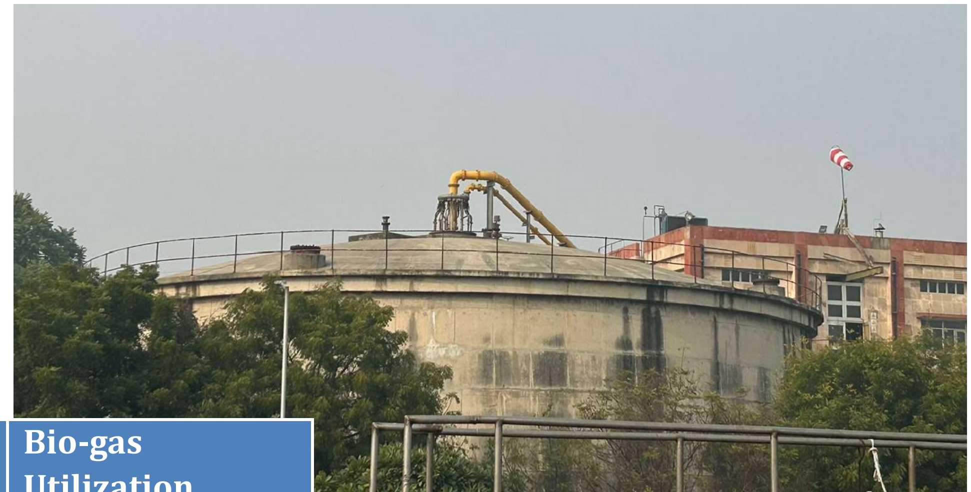
Algae-based Wastewater Treatment Solution

South Africa has been involved in a project at the Motetema wastewater treatment plant that utilizes algae to purify sewage in maturation ponds.

Source: https://www.csir.co.za/algae-based-wastewater-treatment-solution

Resource Recovery from Sewage sludge management at Okhla STP

The OKHLA Sewage Treatment Plant (STP), designed for a capacity of 30 MGD (136 MLD), is currently operating at 25.54 MGD (96.66 MLD). The plant produces 2425 m³ of sludge daily, creating significant challenges in sludge management. To address this, the STP employs anaerobic digestion for sludge treatment. This process generates approximately 75,000 m³ of biogas per month with a methane content of 60–65%, which is fully utilized in-house



Sludge produced (per day)	Biogas Production	Methane Content	Bio-gas Utilization
2425 m^3	75,000 m^3 per month	≈60 %	In-house
Infrastructure			
Anaerobic Digesters	Biogas Holders	Quantity of Digested Sludge	Sludge Drying Beds
4 units with a capacity of 8000 m^3 each (3 in operation, 1 on standby)	2 units with a capacity of 2100 m^3 each.	Monthly: 450 tons. Annually: Approximately 5000 tons.	114 units with a capacity of 120 m^3 per unit.

Thank You

Recovery, Reuse of Faecal Sludge in UP

FSTP capacity (in Kilo litre a day)	10
Number of planted drying beds	6
Size of planted drying bed (in square metre)	56
Total FSS loaded on 6 beds (in kilogram)	60,480
Since dry FSS / compost contains 25% moisture, total weight would be (in kg)	80,640
Assume 10% loss during filtration and handling, net compost available (in kg)	72,576 kg (72.6 tonnes)
At conservative side, selling price at the site is assumed	Rs 3,000 / tonne (Rs 3 / Kg)
Amount recovered by selling of total compost	Rs 217,800 / year

Source: https://www.downtoearth.org.in/rural-water-and-sanitation/excreta-as-resource-looking-at-recovery-reuse-of-faecal-sludge-in-up-71419

Resource Recovery from Faecal Sludge Treatment in Kampala, Uganda

- Dewatered faecal sludge can be co-processed with the Bioburn pelletizer into a pellet form at a moisture content ranging from 40 to 60%.
- In a pellet form, sludge dries faster than sludge on drying beds.

Drying beds at Lubigi Wastewater and Faecal Sludge Treatment Plant in Kampala, Uganda

Pellets produced from faecal sludge in Kampala, Uganda

Sourcehttps://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/publikationen/EWM/Treatment_Objectives/Production_Pellets_and_Electricity_from_FS.pdf

From Waste to Resource: from WWTP to Bio-factory

- ❖ The biofactory at the Guijuelo Wastewater Treatment Plant (WWTP) in Salamanca, Spain, is an innovative initiative in bio-waste biomethanisation and the use of bio-CNG.
- ❖ Applying the concept of circular economy makes it possible to transform bio-waste whose management has a high economic and environmental impact.

Source : https://www.globalwaterintel.com/articles/from-waste-to-resource-from-wwtp-to-biofactory-aqualia