

# A SUSTAINABLE APPROACH TO TREAT EFFLUENTS FROM SEAFOOD PROCESSING INDUSTRIES

Monisha V<sup>1</sup>, Swarnalatha K<sup>2</sup>, Lea Mathew<sup>3</sup>, Biju B<sup>4</sup>

## Abstract

This project focuses on implementing an efficient, sustainable technology to treat wastewater from seafood processing industries near Kappithodu, a small stream in Alappuzha Municipality, Kerala. The 14-kilometer stream drains into Pookaithayar, a tributary of the River Pamba, and is heavily polluted due to effluent discharges from prawn and fish peeling centres, hospitals, hotel waste, and sewage from households and educational institutions. The goal of the study was to identify the sources of pollution in Kappithodu and explore sustainable technologies to treat the effluents, particularly from seafood processing industries. Wastewater generated from seafood processing operations—such as those involving fish, shrimp, clams, and tuna is known for its high biodegradability. As per the EPA Seafood Processing Effluent Guidelines (440/1-74/041), the COD values in such effluents generally approximate the ultimate BOD, indicating that most of the organic matter present is easily degradable. This is typically reflected in a BOD/COD ratio well above 0.6, which further confirms the suitability of biological treatment methods. Considering the elevated levels of BOD and COD in the effluent, a hybrid treatment approach has been adopted. The system combines an Upflow Anaerobic Sludge Blanket (UASB) reactor for anaerobic degradation of organic matter, followed by phytoremediation using a constructed wetland. This sequential setup enhances overall treatment efficiency by coupling anaerobic digestion with natural polishing mechanisms provided by wetland vegetation and associated microbial activity. A laboratory setup, including a hybrid reactor, was established for this study. The combination of the UASB unit and a phytoremediation system using Vetiver zizanioides was found to be highly effective. The treatment achieved remarkable results, with BOD removal efficiency at 97.5%, COD at 98%, nitrate at 97.5%, and phosphate at 88.9%. This hybrid technology for wastewater treatment proves to be a promising, sustainable, and cost-effective solution, especially for handling high-strength wastewater, making it ideal for decentralised plants that benefit small-scale industries while protecting water bodies.

**Received:** 1 August, 2024

**Revised:** 2 February, 2026

**Accepted:** 1 April, 2026

<sup>1</sup>Department of Civil, Engineering, Government, Engineering College, Barton Hill, Trivandrum, India.

<sup>2,3</sup>Department of Civil Engineering, College of Engineering Trivandrum, Trivandrum, India.

<sup>4</sup>Kerala State Pollution Control Board Alappuzha, India.

**\*Corresponding author:**  
jayamonisha56@gmail.com

**DOI:** <https://doi.org/10.54552/v87i2.255>

## Keywords:

Open street map (OSM tracker), Phytoremediation, Sludge, Upflow anaerobic sludge blanket (UASB), Vetiverzizanioides

## 1.0 INTRODUCTION

Over the past few decades, water quality has significantly deteriorated due to rapid industrialisation and population growth. With increasing urbanisation and development, it is crucial to safeguard the environment from these growing threats. The need to address water pollution, a major factor in the decline of water quality, has become more urgent. Wastewater, particularly when discharged without proper treatment, can contaminate natural environments and sewer systems due to rising organic and inorganic pollutants. Effective industrial wastewater treatment is a critical step in environmental protection.

In fish peeling sheds and slaughterhouses, large amounts of water are used during processing, resulting in wastewater with high concentrations of suspended solids, nitrogen, phosphorus, oil, grease, and biochemical oxygen demand (BOD). Biological treatment methods, such as aerobic and anaerobic systems, are considered the most efficient for handling such waste. Anaerobic treatment, in particular, offers several advantages over aerobic methods, including lower land requirements, reduced construction and operating costs, minimal sludge production, the ability to adapt to changes in temperature, pH,

and influent concentration, and rapid biomass recovery after shutdowns.

Among various anaerobic treatment technologies, Upflow Anaerobic Sludge Blanket (UASB) reactors are widely favoured because of their ability to treat a broad range of polluted effluents. Research has shown that UASB reactors can achieve high removal efficiencies for COD, BOD<sub>5</sub>, total solids, total dissolved solids, total suspended solids, ammonium, phosphate, and nitrate—up to 97.31%, 96.91%, 57.61%, 47.91%, 96.3%, 73.11%, 83.61%, and 93.01%, respectively, with a hydraulic retention time (HRT) of 24 hours. However, the effluent from UASB reactors may still not meet permissible discharge limits and can be unsafe for direct disposal. To improve the quality of the effluent, phytoremediation can be effectively utilised as a sustainable post-treatment method. Phytoremediation involves the use of living plants to control contaminants in soils, surface water, and groundwater. This low-effort, sunlight-driven process has been shown to significantly reduce contaminants, with a 86.74% reduction in BOD, 92.88% reduction in COD, 74.55% reduction in TSS, and 71.44% reduction in TDS at a hydraulic retention time of three days. This study aims to combine the



electromotive force developed between a glass electrode sensitive to hydrogen ions and a reference electrode, which is directly related to the pH of the solution. The pH meter was first calibrated using standard buffer solutions of known pH, usually 4.0, 7.0, and 9.2. The electrode was then rinsed with distilled water and immersed in the sample, and the pH value was recorded once the reading stabilises. This method provides accurate and reliable results and is widely used in environmental, water, and wastewater analysis as per APHA and IS: 3025 standards.

### 2.3.2 Bio-Chemical Oxygen Demand

Winkler's method is a classical iodometric titration technique used to determine the dissolved oxygen (DO) content of water, which is essential for assessing water quality and for calculations such as biochemical oxygen demand (BOD). In this method, dissolved oxygen in the sample oxidises manganous sulfate added under alkaline conditions to form a brown precipitate of manganic hydroxide. Upon acidification with sulfuric acid, the manganic compound oxidises potassium iodide to liberate free iodine in proportion to the amount of dissolved oxygen present. The liberated iodine is then titrated with a standard sodium thiosulfate solution using starch as an indicator until the blue colour disappears. The amount of sodium thiosulfate consumed is directly proportional to the dissolved oxygen concentration, which is expressed in mg/L. Winkler's method is highly accurate and is widely used in laboratory analysis of natural waters, wastewater, and environmental monitoring as per standard methods.

### 2.3.3 Chemical Oxygen Demand

Chemical Oxygen Demand (COD) analysis using ferroin indicator is performed to determine the amount of oxygen required to chemically oxidise organic matter present in a water or wastewater sample. In this method, the sample was refluxed with a known excess amount of standard potassium dichromate solution in the presence of concentrated sulfuric acid, which provides the acidic medium, along with silver sulphate as a catalyst to oxidise organic compounds and mercuric sulphate to eliminate chloride interference. After refluxing for a fixed period, usually two hours, the excess unreacted dichromate was titrated against standard ferrous ammonium sulphate (FAS) solution using ferroin indicator. The end point was indicated by a sharp colour change from blue-green to reddish brown. The difference between the dichromate added and the amount reduced by FAS corresponds to the oxygen equivalent of the organic matter, and the COD value was calculated and expressed in mg/L, serving as a key parameter for assessing the pollution load of water and wastewater.

COD and BOD are high in shrimp industry effluent because: Shrimp contains organic-rich tissues (proteins, fats) Processing produces residues like shells, blood, and muscle debris. Cleaning and washing release large quantities of biodegradable matter (EPA Seafood Processing Effluent Guidelines 440/1-74/041). The volume of wastewater produced was determined by monitoring water consumption in the industry from January 7 to 14, 2019. Since the peeling shed unit operated on an intermittent basis, variations in wastewater

flow on a daily, weekly, and monthly basis were recorded. It was assumed that the wastewater generated accounts for 75-80% of the water consumed (Source: Metcalf & Eddy, 2002). The average wastewater production was calculated to be 1.52 MLD. Since the collected wastewater exhibited high BOD and COD values [Table 1].

Table 1: Characteristics of constructed wetland

Characteristics	Constructed Wetland
Flow pattern	Surface vertical flow
Bed dimension	0.30mx0.25 m
Bed depth	0.50m
Surface area	0.081m <sup>2</sup>
Loading rate	8L/d
Type of loading	Intermittent

Among the different anaerobic wastewater treatment innovations, Upflow Anaerobic Sludge Blanket (UASB) reactors have made impressive progress and these reactors have been connected to treat a wide scope of effluents, for example, sugar, mash and paper, dairy, chemical, potato starch, bean adjusting, soda pops, fish preparing, noodle handling, yeast generation, slaughterhouse, and coffee producing ventures. The effluent obtained from UASB do not have water quality parameter under the permissible limit, hence a post treatment was required for the effluent from UASB. Upflow Anaerobic Sludge Blanket (UASB) reactor is a wastewater treatment system that uses microorganisms to break down organic pollutants. It's a type of anaerobic digester that produces biogas. Wastewater enters the reactor from the bottom. It flows upward through a layer of granular sludge. Anaerobic microorganisms break down the organic pollutants in the wastewater. The process produces biogas. This method highly cost effective, energy efficient and handles high organic loads. Anaerobic treatment processes cannot achieve surface water discharge quality without post-water treatment. The UASB Reactor maintains a high concentration of biomass through the formation of highly settle able microbial sludge aggregates. The wastewater flows upwards through a layer of very active sludge to cause anaerobic digestion of organics of the wastewater. At the top of the reactor, three phase separation between gas-solid-liquid takes place. Any biomass leaving the reaction zone is directly recirculated from the settling zone. The process is suitable for both soluble wastewaters as well as wastewaters containing particulate matter.

Hence, a sustainable hybrid treatment system combining an anaerobic process (UASB) followed by phytoremediation (constructed wetland) was implemented L.C.Martin *et al.* (2009), K.P. Gosami *et al.* (2020). Phytoremediation is the immediate utilisation of living green plants for in situ, or set up, evacuation, debasement, or control of contaminants in soils, oozes, residue, surface water and groundwater. Phytoremediation is a minimal effort, sunlight based vitality driven clean up strategy. Most favourable at destinations with shallow, low degrees of sullyng. Helpful for treating a wide assortment of natural contaminants. Viable with, or sometimes, instead of mechanical clean up strategies. Phyto signifies plant

is a conventional term for the gathering of advances that utilise plants for remediating soils, sludge and water sullied with organic and inorganic contaminants. Phytoremediation can be characterised as the productive utilisation of plants to expel, detoxify or immobilise ecological contaminants in a development network (soil, water or sediments) through the natural biological, chemical or physical exercises and processes of the plant. Laboratory-scale reactors were set up accordingly. The UASB reactor was fabricated using a 3mm thick acrylic sheet and measured 0.47m x 0.15m x 0.15m, with a 60-degree hoppers bottom. An Organic Loading Rate (OLR) of 0.76 gCOD/m<sup>3</sup>/day was applied K.P. Gosami *et al.* (2020). The wastewater enters the tank from the bottom, and flows upward through the sludge bed, which gets formed during the process itself. The sludge bed develops micro-organisms capable of flourishing in an oxygen deficient environment. The sludge bed (blanket) traps the suspended organics of the upmoving wastewater. The suspended solids trapped in the sludge bed are degraded by the anaerobic and anaerobically working facultative bacteria, producing methane and carbon dioxide (i.e. biogas, which is a mixture of 65-70% methane, and 30-35% carbon dioxide). The biogas produced during the anaerobic decomposition helps in providing gentle mixing and stirring of the biomass, thereby increasing the efficiency of decomposition, reducing the BOD and suspended solids of the wastewater. The UASB, evidently operates as a suspended growth system, with no packing material in the reactor. The effluent from the UASB reactor was then directed to a constructed wetland (0.30m x 0.25m x 0.5m) (Source: Metcalf & Eddy, 2002). The design of the wetland followed the standards set by the Environmental Protection Agency (EPA) in 2000 and 2008. The characteristics of the constructed wetland were provided in Table 2. A post treatment option, constructed wetland system was adopted for the treatment of effluent from UASB, for the reduction of parameters to the discharge standards.

Table 2: Wastewater quality parameters of the effluent collected from sea food processing industries

Sampling Points	pH	BOD (mg/l)	COD (mg/l)
Source1	7.1	4.5	212
Source2	7.2	52	126
Source3	7.1	7.2	158
Source4	7.8	6.8	222
Source5	7.2	786	1220

### 3.0 EXPERIMENTAL SET UP (DESIGN OF CONSTRUCTED WETLAND)

The design procedure for the constructed wetland (CW) unit was adopted in accordance with the guidelines prescribed by the United States Environmental Protection Agency (EPA, 2000; 2008). The computing procedure for the design of a vertical subsurface flow constructed wetland was carried out as follows. Initially, the type of media, vegetation, and depth of the wetland bed to be used were selected. The porosity and effective hydraulic conductivity of the chosen media were assumed. The influent biochemical oxygen demand (BOD)

concentration and average daily wastewater flow rate were determined, and the desired effluent BOD concentration was assumed. Based on these parameters, the required bed surface area was calculated, followed by the determination of bed length and width for an assumed length-to-width ratio. The design was carried out based on first-order plug flow kinetics. The area required for pollutant loading was determined using the Kickuth equation, expressed as

$A_s = Q (\ln C_0 - \ln C_e) / (k_t d n)$ , where  $k_t = k_{20} \times 1.06^{(T - 20)}$ . Here, Q represents the average daily sewage flow (L/d), d denotes the depth of the water column (m), n is the porosity of the substrate medium, C<sub>0</sub> is the influent BOD concentration, and C<sub>e</sub> is the effluent BOD concentration. For the present study, the average daily flow rate was taken as 8 L/d, the bed depth as 0.5 m, and the porosity as 0.39. The influent BOD concentration was assumed as 219 mg/L, considering a 70% BOD reduction achieved by the upstream UASB reactor, and the desired effluent BOD concentration was fixed at 30 mg/L. Based on these values, the required surface area was calculated as 0.080 m<sup>2</sup>. A bed width of 0.25 m was assumed, and the corresponding bed length was obtained as 0.30 m. The hydraulic residence time (HRT) of the wetland was then calculated using the expression  $t = nLWd / Q$ , where L and W are the length and width of the bed, respectively. Substituting the design values, the HRT was obtained as 1.9 days, which was approximated to 2 days. The area loading rate (ALR) was calculated using the relationship  $ALR = Q C_0 / A_s$ , where Q is the average daily sewage flow rate (m<sup>3</sup>/d), C<sub>0</sub> is the influent BOD concentration (mg/L), and A<sub>s</sub> is the surface area of the wetland (m<sup>2</sup>). The area loading rate was determined as 38 g/m<sup>2</sup>-d, which satisfies the EPA-recommended criterion of being greater than 6 g/m<sup>2</sup>-d. The effluent BOD concentration was further verified using the first-order kinetic expression  $C_e / C_0 = e^{(-k_t t)}$ . Based on this relationship, the effluent BOD concentration was calculated as 19.78 mg/L, which is less than the permissible limit of 20 mg/L. Hence, the designed constructed wetland unit was found to be hydraulically and organically adequate as per EPA standards.

The substrate material used was M sand and aggregates of 12mm. The plant species selected for the study was Vetiver zizanoides considering excellent growth rate and their ability to remove pollutant from wastewater Farari Masinire *et al.* (2021). The schematic diagram and the experimental models are shown in Figure 3 and Figure 4 respectively. For the laboratory scale constructed wetland a ball type valve was provided at the outlet and treated effluent was collected. The efficiency of UASB & constructed wetland were monitored from the treated effluent collected from the reactors.

The wastewater from a sea food processing unit was collected and its water quality parameters like pH, BOD<sub>5</sub>, COD, Nitrate & Phosphate were analysed. (APHA 2005). Also to determine the efficiency of the UASB & constructed wetland, treated effluent of the system was collected and the water quality analysis was carried out frequently. For the laboratory scale constructed wetland a ball type valve was provided at the outlet and treated effluent was collected from that. The wastewater was initially stored in an overhead settling tank for 2 hours and wastewater was directed to the

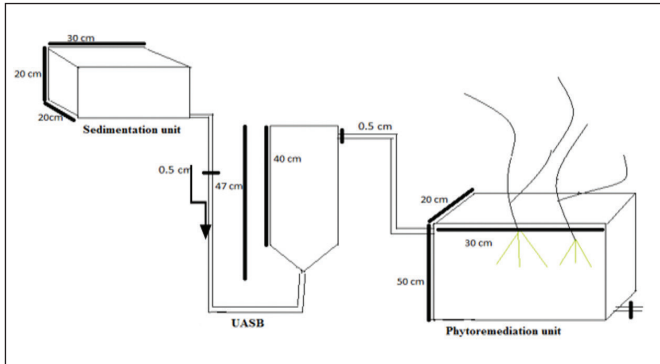


Figure 3: Schematic diagram of experimental setup



Figure 4: Laboratory scale set up

UASB reactor from the bottom, it was allowed to flow through granular sludge and kept for 10 hours and later directed to Phytoremediation unit having a Hydraulic retention time of 2 days.

The following standard analytical methods were used to identify the wastewater quality: - Dissolved oxygen demand was measured by Winkler's iodometric method. Chemical Oxygen Demand (COD) was estimated using the standard titration method. Phosphate and nitrate levels were determined using phosphate and nitrate analysers, respectively. Biochemical oxygen demand (BOD) was determined using the Winkler's five-day method, chemical oxygen demand (COD) was analysed by the open reflux titrimetric method, phosphate was estimated by the colorimetric method using a phosphate analyser, and nitrate was determined using the UV spectrophotometric/analyser method. For BOD analysis, reagents such as manganous sulphate solution, alkaline iodide–azide reagent, concentrated sulphuric acid, standard sodium thiosulphate solution (0.025 N), starch indicator, distilled water, and nutrient buffer solutions including phosphate buffer, magnesium sulphate, calcium chloride, and ferric chloride were used, and equipment such as 300 mL BOD bottles, an incubator maintained at 20 °C, conical flasks, burette, pipette, measuring cylinder, titration stand, and thermometer were employed. COD analysis utilised potassium dichromate solution, concentrated sulphuric acid, silver sulphate as catalyst, mercuric sulphate as a chloride masking agent, standard ferrous ammonium sulphate solution, ferroin indicator, and distilled water, with a COD reflux apparatus, heating mantle or hot plate, reflux condenser, conical flasks, burette, pipette, and measuring cylinder. Phosphate analysis was carried out using ammonium molybdate solution, potassium antimonyl tartrate, ascorbic acid, sulphuric acid,

phosphate standard solution, and distilled water, employing a phosphate analyser or spectrophotometer, sample cells or cuvettes, volumetric flasks, pipettes, and measuring cylinders. Nitrate analysis was performed using nitrate standard solution, analyser-specified buffer solution, and distilled water, with the aid of a nitrate analyser or UV–Visible spectrophotometer, sample cells or cuvettes, volumetric flasks, pipettes, and measuring cylinders.

The reagents used for BOD analysis include manganous sulphate, alkaline iodide–azide reagent, sulphuric acid, sodium thiosulphate, and starch indicator. COD analysis employed potassium dichromate, sulphuric acid, silver sulphate, mercuric sulphate, and ferrous ammonium sulphate. Phosphate was analysed using ammonium molybdate and ascorbic acid reagents, while nitrate was determined using nitrate standard solutions. Equipment used included BOD bottles, incubator, reflux apparatus, burettes, pipettes, and phosphate and nitrate analysers.

Reagents of analytical grade supplied by standard manufacturers namely Merck Life Science Private Limited, Plot No. EL-3, TTC Industrial Area, MIDC, Mahape, Navi Mumbai – 400710, India, and Sisco Research Laboratories Pvt. Ltd. (SRL), 68/69, MIDC, Dhatav Industrial Area, Roha, Raigad – 402116, Maharashtra, India were used for the analysis of BOD, COD, phosphate, and nitrate. Equipment including BOD bottles and glassware from Borosil and Tarsons, BOD incubator and heating devices from Labline Instruments Pvt. Ltd., Ahmedabad, Gujarat, India COD digester and reflux apparatus from Spectralab Instruments Pvt. Ltd., Mumbai, Maharashtra, India and phosphate and nitrate analysers/spectrophotometers from Systronics India Pvt. Ltd., Ahmedabad, Gujarat, India were employed for the experimental work.

## 4.0 RESULTS AND DISCUSSIONS

### 4.1 Water Quality Analysis

#### 4.1.1 Trend of BOD & COD after Treatment in UASB

The wastewater from Source5 was collected and characterized for water quality parameters like pH, BOD<sub>5</sub>, COD, Nitrate, Phosphate (APHA, 2005). Sedimentation tank with HRT 1 hour was used to remove the settleable solids initially, followed by treatment through UASB & Constructed wetland. Treated effluent from UASB was analysed for BOD, COD & Phosphates shown in Figure 5 & 6. The water quality parameters were checked daily.

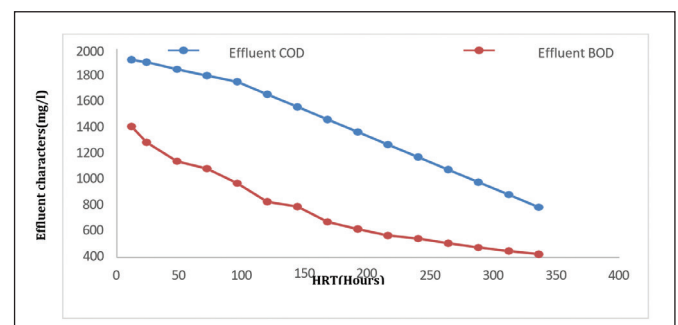


Figure 5: Variation of characteristics of effluent from UASB

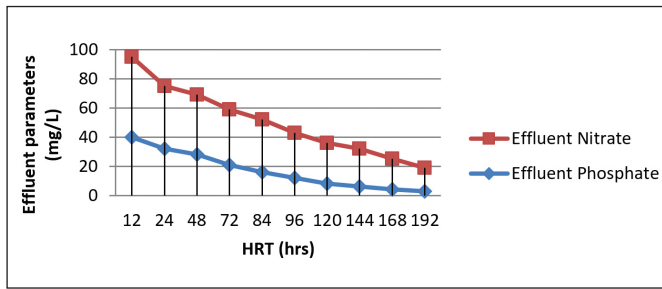


Figure 6: Variation of characteristics of effluent from UASB

Due to the presence of high organic content in the wastewater, high values of BOD and COD are present. The effluent from sedimentation tank having a high COD (1890 mg/l) was reduced to 480 mg/l after passing through UASB. This is due to the action of anaerobic degradation occurring in UASB. Similarly, BOD of 1252 mg/l reduced to 32 mg/l.

**4.1.2 Trend of Nitrate and Phosphate after Treatment in UASB**

After treatment in the UASB reactor, there was a significant reduction in the concentrations of BOD, COD, nitrate, and phosphate. Phosphate reduction was also observed in the UASB, which could be attributed to the presence of trace elements that enhance phosphate removal. Tchobanoglous *et al.* (Wastewater Engineering), Rao *et al.* (Bioresource Technology, 2008). Initially, the wastewater contained 35.1 mg/l of ammoniacal nitrogen. However, in the UASB reactor, there is minimal conversion of ammoniacal nitrogen to organic nitrogen and further to nitrite and nitrate due to the absence of oxygen. The treated wastewater from the UASB was then fed into the phytoremediation unit, and the effluent was collected for further analysis of BOD, COD, nitrate, and phosphate levels.

**4.1.3 Trend of BOD & COD after Treatment in Phytoremediation Unit**

There was reduction in BOD from 250mg/l to 32mg/l (Figure 7). The reduction in the Biological Oxygen Demand may be due to the degradation of complex organic matter into simpler matter by phytodegradation action of *Vetiver zizanoides*. There is the possibility of storing the pollutant in the aerial part of the plant by process known as phyto stabilisation. The BOD was reduced to 32mg/l which is not within the permissible limit, hence recirculation of effluent was done which further reduced the BOD value to 28mg/l which is acceptable. The Chemical Oxygen Demand was found to be reduced to significant level due to the degradation of organic matter by the plant shown in Figure 7. The plant has a property known as rhizofiltration with which plant root filter the wastewater by taking up the contaminants through roots.

**4.1.4 Trend of Phosphate and Nitrate after Treatment in Phytoremediation Unit**

Initially there was an increase in nitrate concentration to 15.6mg/l due to the aerobic condition existing, this nitrate concentration was reduced to 1.4mg/l due to the considerable uptake by the plant shown in Figure 8. A reduction in COD, BOD, and Nitrate & Phosphate was observed. There was an increase in nitrate concentration due to the aerobic conditions prevailing. This nitrate concentration was reduced due to the uptake by the plant. The aerobic environment favoured the microbial oxidation of ammonium to nitrate (nitrification), and the resulting nitrate was partially removed via plant assimilation. The values of different parameters in the influent and effluent of sedimentation tank, UASB reactor and CW are shown in Table 3.

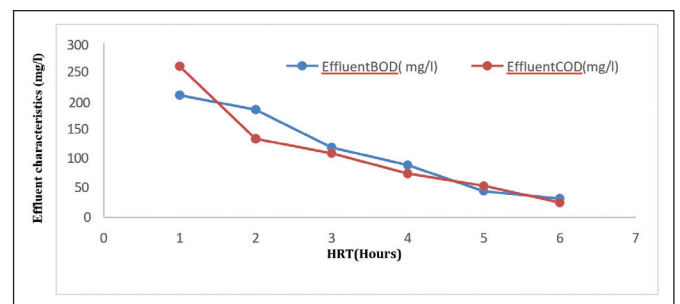


Figure 7: Variation of characteristics of effluent from Phytoremediation unit

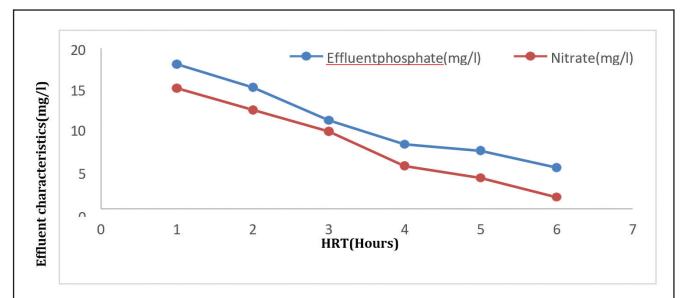


Figure 8: Variation of characteristics of effluent from constructed wetland

Table 3: Characteristics of treated effluents

Parameters	Process	Concentration of Various Parameters from Different Processes				
		Sedimentation	UASB	CW	Overall efficiency (%)	Effluent standards (mg/l)
BOD (mg/l)	Initial	1320	1280	250	97.5	30
	Final	1280	250	28		
	%removal	3	90.1	87.2		
COD (mg/l)	Initial	1840	1750	135	98	250
	Final	1750	135	36		
	%removal	4.8	74.5	95.1		
Phosphate (mg/l)	Initial	46	43	18	88.9	4
	Final	43	12	5.1		
	%removal	6.5	72	71.6		
Nitrate (mg/l)	Initial	58	55.5	9.6	97.5	45
	Final	55.5	15.6	1.4		
	%removal	4.5	71.8	85.4		



Figure 9:  
WW\* before  
treatment



Figure 10:  
Effluent from  
UASB



Figure 11:  
Effluents from  
constructed  
wetland

WW\* =Wastewater

There was also a reduction in COD, Nitrate and phosphate. Due to the necessity of a post treatment system after UASB phytoremediation unit helped in reducing the load by an appreciable percentage. A performance study of a sewage treatment system consisting of a settler followed by an UASB was reactor carried out by Seghezzeo *et al.*, (2002). In the study COD concentration averaged 224.2 and 152.6 mg/L, for raw and settled sewage, respectively. The effluent concentration was 68.5 mg COD/L. Total and suspended COD removal efficiencies were approximately 70 and 80%, respectively.

Fortunately, for this study there was an overall reduction of BOD by 97.5%, COD by 98%, Nitrate reduction by 97.5% and phosphate reduction by 88.9%. It is evident that how the wastewater turns to good quality water by referring the Figure 9, 10 and 11. Table 4 shows change in various parameters during the decomposition process. A quantitative measure in various water quality parameters can be easily recognised from Table 4. In this study BOD/COD removals ( $\approx 97.5\text{--}98\%$ ) are very high — higher than the study conducted by Abdullah Sanghir *et al.*; (2022) biological treatment example ( $\sim 89.5\%$ ) and somewhat higher than the phytoremediation case (BOD  $\sim 86.7\%$ , COD  $\sim 92.9\%$ ). That indicates that the treatment system/process achieved exceptional organic load removal compared with typical reported biological and phytoremediation. The Nutrient (nitrate, phosphate) removal (97.5%) is very strong and suggests either effective denitrification or uptake processes in your system. Phosphate at 88.9% is also high but slightly lower than the very best TP removals reported for specialised processes (some SBR/chemical/tertiary schemes report  $>95\%$  TP). This is consistent with the general literature: nutrient removal efficiency is more variable and more process-specific than BOD/COD. Results so obtained for UASB and constructed wetland were found to be compatible with previous studies (Azad *et al.*; (2018), Abdullah Sanghir *et al.*; (2022) and Neharika (2015).

## 5.0 CONCLUSION

The laboratory-scale hybrid treatment system combining a UASB reactor with phytoremediation showed high efficiency in treating high-strength wastewater, achieving removal efficiencies of 97.5% for BOD, 98% for COD, 97.3% for nitrate, and 87.5% for phosphate. Organic matter removal occurred mainly in the UASB reactor through anaerobic microbial activity, while the constructed wetland acted as a polishing unit to meet discharge standards. The system is more economical than conventional aerobic processes, with 70–80% lower operation

and maintenance costs due to low energy requirements, biogas recovery, and minimal maintenance in phytoremediation. While suitable for rural and semi-urban areas, the system has limitations such as dependence on wetland performance for nutrient removal, climatic sensitivity, and limited removal of emerging contaminants.

The laboratory-scale hybrid treatment system integrating an Upflow Anaerobic Sludge Blanket (UASB) reactor with phytoremediation demonstrated high efficiency in treating high-strength wastewater. Significant reductions in organic and nutrient loads were achieved, with overall removal efficiencies of 97.5% for BOD, 98% for COD, 97.3% for nitrate, and 87.5% for phosphate. Organic matter removal in the UASB reactor was primarily attributed to anaerobic microbial activity, while the constructed wetland served as an effective polishing unit, bringing effluent concentrations within permissible limits. Economically, the integrated system is more cost-effective than conventional aerobic treatment processes. The UASB reactor requires low to moderate capital investment and minimal energy input, with the added benefit of biogas recovery. Phytoremediation systems involve minimal capital and operational costs, with maintenance limited to periodic plant harvesting. Overall, operation and maintenance costs are estimated to be 70 – 80% lower than those of aerobic systems such as Activated Sludge Processes and Sequencing Batch Reactors. ■

## AUTHORS' CONTRIBUTIONS

<b>Monisha V</b>	Conceptualisation, study design, data collection, methodology, writing original draft preparation and literature review, writing review, editing.
<b>Swarnalatha K</b>	Supervision and formal analysis and final manuscript approval.
<b>Lea Mathew</b>	Supervision and formal analysis and final manuscript approval.
<b>Biju B</b>	Technical assistance and supervision.

## REFERENCES

- [1] Abdullah, S., & Hajjar, S. (2022). Biological treatment of slaughterhouse wastewater using upflow anaerobic sludge blanket (UASB)–anoxic–aerobic system. *Scientific African*, 16, e01236. <https://doi.org/10.1016/j.sciaf.2022.e01236>
- [2] Adhikari, J. R. (2019). Design, installation, and experimentation of septic tank–UASB wastewater treatment system. *Renewable Energy*, 143. <https://doi.org/10.1016/j.renene.2019.04.059>
- [3] American Public Health Association. (2005). *Standard methods for the examination of water and wastewater* (26th ed.).
- [4] Aziz, A., *et al.* (2018). Biological wastewater treatment (anaerobic–aerobic) technologies for safe discharge of treated slaughterhouse and meat processing wastewater. *Science of the Total Environment*, 686, 681–708. <https://doi.org/10.1016/j.scitotenv.2019.05.295>

- [5] Banerjee, R. (2017). Vetiver grass is a potential candidate for phytoremediation of iron ore mine spoil dumps. *Ecological Engineering*, 132. <https://doi.org/10.1016/j.ecoleng.2018.10.012>
- [6] Bustillo-Lecompte, C. F. (2015). Slaughterhouse wastewater characteristics, treatment, and management in the meat processing industry. *Journal of Environmental Management*, 161, 287–302. <https://doi.org/10.1016/j.jenvman.2015.07.008>
- [7] Fongsatitkul, P., Wareham, D. G., Elefsiniotis, P., & Charoensuk, P. (2011). Treatment of slaughterhouse wastewater: Effect of internal recycle rate on chemical oxygen demand, total Kjeldahl nitrogen, and total phosphorus removal. *Environmental Technology*, 32(15), 1755–1759. <https://doi.org/10.1080/09593330.2011.555421>
- [8] Gandhi, R. (2013). Design of upflow anaerobic sludge blanket (UASB) reactor for jam industry wastes. *Water Science and Technology*.
- [9] Ghangrekar, M. (2002). *Design of an UASB reactor*. Indian Institute of Technology Kharagpur.
- [10] Goswami, K. P., & Pugazhenthii, G. (2020). Treatment of poultry slaughterhouse wastewater using tubular microfiltration membrane with fly ash as key precursor. *Water Process Engineering*, 37, 101361. <https://doi.org/10.1016/j.jwpe.2020.101361>
- [11] Jensen, P. D., Yap, S. D., Boyle-Gotla, A., Janoschka, J., Carney, C., Pidou, M., & Batstone, D. J. (2015). Anaerobic membrane bioreactors enable high-rate treatment of slaughterhouse wastewater. *Biochemical Engineering Journal*, 97, 132–141. <https://doi.org/10.1016/j.bej.2015.02.009>
- [12] Jordan Standards and Metrology Organization. (2007). *Water – Industrial reclaimed wastewater (JS 202:2007)*.
- [13] Kumar, S., Pratap, B., Dubey, D., & Dutta, V. (2022). Integration of constructed wetland microcosms with available wastewater treatment technologies for the polishing of domestic wastewater and their potential reuses. *International Journal of Environmental Research*, 16, 99. <https://doi.org/10.1007/s41742-022-00485-8>
- [14] Liu, Y., Kang, X., Li, X., & Yuan, Y. (2015). Performance of aerobic granular sludge in a sequencing batch bioreactor for slaughterhouse wastewater treatment. *Bioresource Technology*, 190, 487–491. <https://doi.org/10.1016/j.biortech.2015.03.008>
- [15] Liu, Y., Wu, Z. Y., Peng, P., Xie, H. B., Li, X. Y., Xu, J., & Li, W. H. (2020). A pilot-scale three-dimensional electrochemical reactor combined with anaerobic–anoxic–oxic system for advanced treatment of coking wastewater. *Journal of Environmental Management*, 258. <https://doi.org/10.1016/j.jenvman.2019.110021>
- [16] López-López, A., Vallejo-Rodríguez, R., & Méndez-Romero, D. C. (2010). Evaluation of a combined anaerobic and aerobic system for the treatment of slaughterhouse wastewater. *Environmental Technology*, 31, 319–326. <https://doi.org/10.1080/09593330903470693>
- [17] Martin, L. C., das Neves, A., Converti, A., & Penna, T. C. V. (2009). Biogas production: New trends for alternative energy sources in rural and urban zones. *Chemical Engineering & Technology*, 32, 1147–1153. <https://doi.org/10.1002/ceat.200900051>
- [18] Masinire, F., Adenuga, D. O., Tichapondwa, S. M., & Chirwa, E. M. N. (2021). Phytoremediation of Cr(VI) in wastewater using vetiver grass (*Chrysopogon zizanioides*). *Minerals Engineering*, 172, 107141. <https://doi.org/10.1016/j.mineng.2021.107141>
- [19] Mayor, L. R., Camacho, J. V., & Morales, F. J. F. (2004). Operational optimization of pilot-scale biological nutrient removal at the Ciudad Real (Spain) domestic wastewater treatment plant. *Water, Air, and Soil Pollution*, 152(1), 279–296.
- [20] Mini, M., Claramma, R., & Sebastian, M. (2016). Effectiveness of vetiver system for treatment of wastewater from an institutional kitchen. *Procedia Technology*, 24, 203–209. <https://doi.org/10.1016/j.protcy.2016.05.028>
- [21] Nativ, D., & Tsion, I. (2018). Agronomic and economic evaluation of vetiver grass (*Vetiveria zizanioides* L.) as a means for phytoremediation of diesel-polluted soils in Israel. *Journal of Environmental Management*, 211, 247–255. <https://doi.org/10.1016/j.jenvman.2018.01.013>
- [22] Ruiz, I., Alvarez, J. A., Díaz, M. A., Serrano, L., & Soto, M. (2008). Municipal wastewater treatment in an anaerobic digester constructed wetland system. *Environmental Technology*, 29(11), 1249–1256. <https://doi.org/10.1080/09593330802296173>
- [23] Seghezzi, L. (2002). Removal efficiency and methanogenic activity profile in a pilot-scale UASB reactor. *Water Science and Technology*, 243–248. <https://doi.org/10.2166/wst.2002.0343>
- [24] Yihan, J., Guo, J., Zhang, Y., & Lian, J. (2018). Anaerobic granular sludge formation and perchlorate reduction in a UASB reactor. *Bioresource Technology Reports*, 4, 123–128. <https://doi.org/10.1016/j.biteb.2018.09.012>
- [25] Zeb, B. S., Mahmood, Q., Jadoon, S., Pervez, A., Irshad, M., Bilal, M., & Bhatti, Z. A. (2013). Combined industrial wastewater treatment in anaerobic bioreactor post-treated in constructed wetland. *BioMed Research International*, 2013, Article 957853. <https://doi.org/10.1155/2013/957853>

## PROFILES



**MONISHA V** is a Assistant Professor in the Department of Civil Engineering at the Government Engineering College, Barton hill, Trivandrum, affiliated with APJ Abdul Kalam Technological University, Kerala, India. She has served as Assistant Engineer in Kerala State Pollution Control Board, District Office, Trivandrum from the year of 2023 to 2025. She has extensive experience across various industrial domain. Also, she has 3 years of teaching experience in various areas of Environmental Engineering. Currently she is an Assistant Professor in Government Engineering College, Barton hill, Trivandrum. Her research interests include water pollution control, wastewater treatment, waste-to-energy technologies. She has also delivered many lectures to entrepreneurs, various government departments and also has hosted several awareness programs with the idea of protecting environment. Her current research focuses on rejuvenating the water bodies in Trivandrum District, Kerala.

Email address: monisha.v@gecbh.ac.in



**SWARNALATHA K** is a Professor in the Department of Civil Engineering at the College of Engineering Trivandrum, affiliated with APJ Abdul Kalam Technological University, Kerala, India. She has over 26 years of teaching experience in various areas of Environmental Engineering. She has published several research papers in national and international journals. Her research interests include water pollution control, wastewater treatment, waste-to-energy technologies, vehicular pollution, and bio-composting. Her current research focuses on resource recovery and sustainable environmental management.

Email address: swarnalatha@cet.ac.in



**LEA MATHEW** is a Professor in Microbiology under Civil Engineering Department, College of Engineering Trivandrum. She completed her doctoral degree in Biotechnology from University of Kerala and having 22 years of teaching experience. Her area of interests include Environmental Microbiology, Environmental Biotechnology, Waste management, Antimicrobial resistance, etc. She had undertaken several projects, organised training programmes, delivered expert lectures and have publications in reputed journals.

Email address: leamathew@cet.ac.in



**BIJU B** was an Environmental Engineer in Kerala state Pollution Control Board, District Office, Kottayam. He has immense experience in the field of environmental Engineering projects, organised training programmes, delivered expert lectures. Unfortunately, he passed away on 2023.