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Original Research

Efficiency Assessment of 80MLD Activated Sludge-based Sewage Treatment Plant (STP) at Prayagraj, Uttar Pradesh, India

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Abstract

The treatment of wastewater is necessary to reduce the intensity of the water scarcity problem worldwide. In developing countries like India, wastewater treatment is also a challenging task due to a lack of essential services (energy, cost, and skilled manpower), which affects the efficiency of treatment plants. Therefore, in the present study, an attempt has been made to assess the efficiency of the sewage treatment plant (STP) located in Naini, Allahabad, India. The results of the current study revealed that the overall efficiency of STP for physical parameters was in the order of TSS (88.43%) > Turbidity (85.18%) > TDS (22.51%). On the other hand, the chemical parameters were in the order of Phosphate (89.47%) > Sulphate (87.12%) > COD (87.04%) > BOD (86.19%) > Nitrate (73.02%). Similarly, the efficiency for heavy metals was in the order of Fe (88.89%) > Cu (60.42%) > Cr (54.93%) > As (45.60%). The treated waste can be reused for irrigating the golf course, greenway, and the park, or for groundwater storage in a safe way. In order to improve the efficiencies of the STPs, the treatment systems must be properly operated and maintained, sources of raw sewage need to be identified, and existing facilities should be upgraded accordingly. In terms of proper operation and maintenance, trained and experienced workers are required within a defined period of time to assess treatment performance.

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Statement of Sustainability: The Activated Sludge-based Sewage Treatment Plant (STP) located in Naini of Prayagraj district of Uttar Pradesh is responsible for the treatment of sewage generated before its final discharge to the Ganga River ecosystem. Therefore, proper maintenance of the plant and its efficient working is a must to protect the health of the Ganga River water and its flora and fauna at Prayagraj. Thus, continuous monitoring of the plant is the need of the hour to ensure its efficiency and to tackle any upcoming major breakdown.

1. Introduction

Freshwater is an irreplaceable natural resource that plays a vital role in the sustenance of the human race on this planet. Urbanisation, industrialisation, and modern lifestyles are all responsible for generating a large amount of wastewater (Mara, 2013). Due to the lack of required infrastructure for the treatment of wastewater in developing countries such as India, proper treatment is a challenging task (Yadav et al., 2021). Therefore, the disposal practice of untreated and partially treated wastewater is common, which degrades the quality of fresh water as well as groundwater (Hernández-Sancho et al., 2015; Alizadeh et al., 2020). The untreated or partially treated sewage contains high quantities of nitrogen, phosphorus, and other crucial nutrients, which are responsible for algal blooms in water bodies, causing a threat to ecological systems. Contamination in groundwater is another threat that is responsible for several diseases and sometimes disease outbreaks in different parts of the world.

Efficient wastewater treatment is a necessity to provide the privilege of clean water for drinking and other purposes to mankind. STPs are an alternative that contains different processes to make municipal sewage harmless for dumping into surface and underground water bodies or on land to reduce hazards to both the environment and human health. The process also makes the effluent acceptable for reutilization. The idea behind the installation of STPs is to make the wastewater free from all types of pollutants, whether physical, chemical, or microbiological (Dehghani et al., 2018; Al-Obaidi, 2020). The wastewater treatment process has a key role in sustainable development as a tool for the protection of surface waters from anthropogenic pollution (Gargosova and Urminska, 2017).

Under the Namami Ganga Mission launched by the Indian Government, several Sewage Treatment Plants (STPs) and Effluent Treatment Plants (ETPs) were built in cities located on the banks of the River Ganga. To facilitate the effective collection of municipal waste, the Prayagraj city has been divided into 7 sewerage districts where STP has been set up by the government. The capacities of different STPs are Naini 80MLD, Numayadahi 50MLD, Salori 29MLD, Rajapur 60MLD, Ponghat 10MLD, Jhusi 16MLD, and Kodra 25MLD. Proper maintenance and assessment of wastewater treatment plants can play an important role in the protection of this natural resource, which we all know as the elixir of life. STPs play an impactful role in purifying wastewater, which results in reduced waterborne diseases. However, their mismanaged operation also results in the accumulation of pollutants, further accelerating the risks to the environment (Tiwari et al., 2024).

Therefore, in the current study, an attempt has been made to document the efficiency of the 80MLD STP located at Naini, Prayagraj, built under the Namami Ganga Mission and headed by the Adani group.

2. Materials and Methods

2.1. Study Area

To fulfil the objective of the current study, an 80MLD STP located at Naini in the Prayagraj city of Uttar Pradesh was selected (Figure 1). The plant's operation is based on the activated sludge process in combination with an aerator (60MLD capacity) and an air diffuser (20MLD capacity). The hydraulic retention time (HRT) of the plant during the sampling period ranged from 7 to 9 hours to provide sufficient time for microbes to digest the organic matter. Similarly, the sludge retention time (SRT) of the plant is maintained between 14 to 18 days to stabilize the microbial population. The mixed liquor suspended solids (MLSS) value was measured during each sampling, and it ranged from 3460 to 3512 mg/l, which is a good microbial load required for the treatment of wastewater. The food-to-microorganism (F/M) ratio of the plant was maintained between 0.25 to 0.50 kg BOD/kg MLSS/day. The aeration is provided in the form of diffused fine bubbles, and dissolved oxygen is maintained at a level of 3 to 4 mg/l, which is adequate for microbial degradation and oxidation.

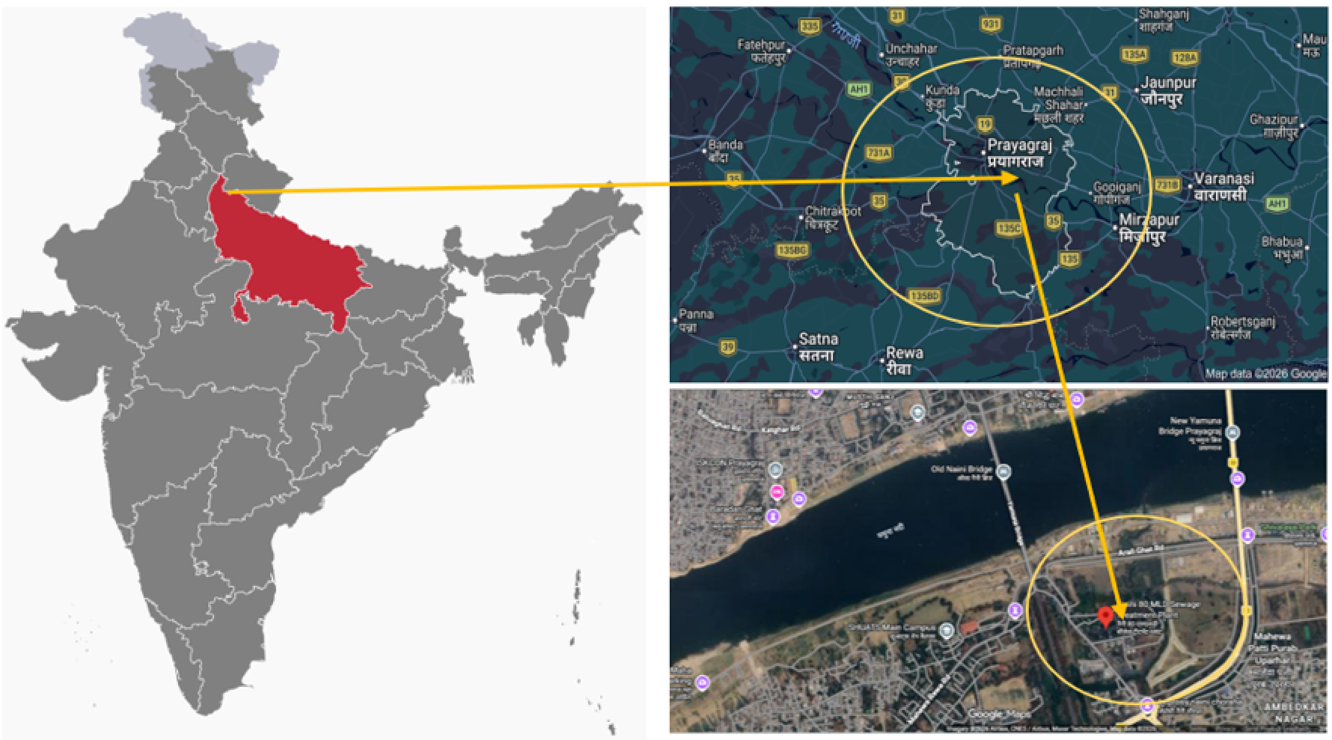

Figure 1. Location of the 80 MLD STP Plant in Prayagraj district of the Indian state of Uttar Pradesh (Source: The map was prepared using Survey of India topographic sheets and Google Earth imagery (2025 edition), referenced to WGS84 datum and projected in UTM Zone 44N, 1 cm = 50 Km).

2.2. Sample Collection and Analysis

The samples were collected from the inlet and outlet of the plant every month in a plastic can of capacity 2 litres. The samples were collected at around 05:00 PM following the grab method of sampling. The second half of the day was chosen for sampling, considering the high load of sewage in the evening. Samples for DO and BOD were collected in BOD bottles. The DO was immediately fixed at the site. pH and temperature were also measured at the site. The samples were then transferred to the laboratory for the analysis of the remaining parameters. The samples were analysed using the standard methodologies prescribed in APHA (2012) for total dissolved solids (TDS), total suspended solids (TSS), turbidity, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), phosphate (PO_4^{3-}), nitrate (NO_3^-), sulphate (SO_4^{2-}), iron (Fe), Chromium (Cr), copper (Cu), and arsenic (As).

2.3. Statistical Analysis

The data of inlet and outlet samples obtained during the study period were processed using MS Office Excel (2010) for the estimation of range, mean value, standard deviation (SD), and efficiency. Student's t-test was analysed using GraphPad software (https://www.graphpad.com/quickcalcs/ttest1/?format=SEM).

3. Results and Discussion

3.1. Efficiency of STP Plant for Physical Parameters

The presence of TDS in the wastewater is mainly due to the ions/salts added during the use of water (Salunke et al., 2014). The average TDS during the study period in the inlet and outlet was found to be 666.20 mg/l±19.03 and 516.40 mg/l±24.51, respectively (Table 1). Therefore, for TDS, the plant's reduction efficiency was observed to be 22.51%. The decrease in TDS may be due to oxidative degradation of dissolved solids. Student's t-test results indicate a significant reduction (p=0.0007, t= 4.8275) in the mean values of TDS. The lesser reduction in the TDS shows the insufficient utilization of chemicals required for precipitation, such as alum, lime, and ferric salts.

TSS is a measure of the floating particulate content of the wastewater and is an indicator of the clarity of the wastewater (Johal et al., 2014). The high value of TSS in the water reduces the transmission of light and therefore reduces the photosynthetic activity (Singh et al., 2021). The average TSS during the study period in the inlet and outlet was found to be 321.20 mg/l±13.74 and 37.20 mg/l±3.63, respectively. Therefore, for TSS, the plant's reduction efficiency was observed to be 88.43%. The decrease in total solids could be attributed to the sedimentation process occurring during the treatment. Student's t-test results indicate a significant reduction (p=0.0001, t= 19.9839) in the mean values of TSS. Muzaffar et al. (2022) observed an 84 to 97% reduction in different activated sludge-based STPs located on Malaysia's west coast. The outlet results of TSS confirm the suitability to discharge as per the MOEF&CC Discharge Standards (2017), which is <50 mg/l for metro cities and urban areas and <100 mg/l for nationwide.

Turbidity in water may be due to suspended solids and debris. The average turbidity during the study period in the inlet and outlet was found to be 347.00 NTU±3.54 and 51.40 NTU±6.39, respectively. Therefore, the plant's reduction efficiency for turbidity was 85.18%. Although the plant's efficiency was found to be good, the outlet was very turbid (51.40 NTU±6.39), which may be because the flocs formed above the water surface in the settling tank were not removed. Student's t-test results indicate a significant reduction (p=0.0001, t= 40.4924) in the mean values of turbidity.

Table 1. Showing the average values (n=6) of inlet, outlet, and % reduction of physical parameters.

Parameters		Minimum	Maximum	Average	SD	SE	Student's t-Test	
							t-Statistics	p-Value
TDS (mg/l)	Inlet	642.00	688.00	666.20	19.03	8.51	4.8275	0.0007
	Outlet	488.00	544.00	516.40	24.51	10.96		
	% Reduction	19.29	24.85	22.51	2.19	0.98		
TSS (mg/l)	Inlet	302.00	335.00	321.20	13.74	6.14	19.9839	0.0001
	Outlet	32.00	41.00	37.20	3.63	1.62		
	% Reduction	87.76	89.74	88.43	0.77	0.34		
Turbidity (NTU)	Inlet	341.00	350.00	347.00	3.54	1.58	40.4924	0.0001
	Outlet	42.00	58.00	51.40	6.39	2.86		
	% Reduction	82.99	87.97	85.18	1.92	0.86		

3.2. Efficiency of STP Plant for Chemical Parameters

pH is one of the important parameters in wastewater treatment, as it affects the secondary treatment process of the wastewater (Salunke et al., 2014; Singh et al., 2021). The average pH during the study period in the inlet and outlet was found to be 7.32±0.03 and 7.29±0.05, respectively. The nature of the effluent was observed to be near neutral before and after the treatment (Table 2). The outlet results of pH confirm the suitability to discharge as per the MOEF&CC Discharge Standards (2017), which is 6.5-9.0 for all the areas. Student's t-test results indicate the non-significant reduction (p=0.6181, t= 0.5145) in the mean values of pH.

DO is an important and critical parameter in the treatment of wastewater. As the plant under study is based on the activated sludge process, which is a biological process of wastewater treatment, and therefore value of DO in the inlet and impacts the microbial density and thus the treatment efficiency of the plant. The DO values in the inlet are out of the detection limit of the analytical procedure followed. Therefore, the DO in the inlet was found "not detectable." While in the outlet, the average DO values were 4.46 mg/l±0.40. Therefore, in the case of DO, the gaining efficiency of the plant was observed as 100.00%. Student's t-test results indicate the significant reduction (p=0.0001, t= 11.1500) in the mean values of DO.

The BOD is the quantity of oxygen required by microbes to degrade the unit quantity of organic matter present in the water (Bhutiani et al., 2016). The average BOD during the study period in the inlet and outlet was found to be 145.20 mg/l±8.53 and 20.00 mg/l±2.00, respectively. Therefore, for BOD, the plant's reduction efficiency was observed to be 86.16%. BOD removal is an indicator of the efficiency of biological treatment processes and is the most widely used parameter to measure wastewater quality. The reduction may be attributed to batch reactors, which allow more oxidation of organic matter. Wakode and Sayyad (2014) reported a 95.27 to 97.12% reduction in BOD using the SBR process. Student's t-test results indicate the significant reduction (p=0.0001, t= 14.2901) in the mean values of BOD. The outlet results of BOD confirm the suitability to discharge as per the MOEF&CC Discharge Standards (2017), which is <30 mg/l in general areas and <20 mg/l for metro cities and urban areas.

The COD is the amount of oxygen consumed in the oxidation process of organic and inorganic matter (Akan et al., 2008). The high value of COD indicates the availability of a high quantity of organic and inorganic matter, which, when disposed of in the freshwater bodies, impacts the concentration of DO (Singh et al., 2021). The average COD during the study period in the inlet and outlet was found to be 346.60 mg/l±5.46 and 44.91 mg/l±4.39, respectively. Therefore, for COD, the plant's reduction efficiency was observed to be 87.04%. Higher levels of COD in wastewater lead to drastic oxygen depletion once discharged into a water body and adversely affect the biota. The decrease may be linked to the aeration and digestion processes (Jafarzadeh Ghehi et al., 2014; Johal et al., 2014). Student's t-test results indicate the significant reduction (p=0.0001, t= 43.0681) in the mean values of COD.

Phosphorus is one of the important elements for the growth of algae, and its concentration in wastewater discharges has to be controlled/reduced in order to avoid noxious algal blooms. Orthophosphate, or inorganic phosphate, is often referred to as "reactive phosphorus." It is the form most readily available to plants and thus may be the most useful indicator of excessive plant and algal growth (Habibah et al., 2018). The raw sewage contains nutrient loads from various point and non-point sources, i.e., agricultural runoff and domestic sewage. Phosphate in sewage effluents arises from human wastes and domestic phosphate-based detergents and soaps (Ogunfowokan et al., 2005). The average phosphate during the study period in the inlet and outlet was found to be 9.12 mg/l±1.01 and 0.98 mg/l ± 0.37, respectively. Therefore, for total phosphate, the plant's reduction efficiency was observed to be 89.47%. The decrease in total phosphorus may be attributed to various phenomena such as adsorption, precipitation, and/or assimilation by microorganisms during the process of treatment (Rajeb et al., 2011). The result is consistent with the findings of Wakode and Sayyad (2016), who reported a phosphate removal efficiency from 57.62 to 83.33%. Singh et al. (2021) reported a 76.2 to 87.2% reduction efficiency of STPs located in Vasant Kunj and Najafgarh. Student's t-test results indicate the significant reduction (p=0.0001, t= 7.5676) in the mean values of phosphate.

The high level of nitrate in the wastewater released in the surface water bodies, such as ponds and lakes, results in eutrophication. The process results in loss of water quality as well as loss of aquatic diversity. Further, the conversion of ammonia into nitrogen reduced the toxicity level of the effluent (Tchobanoglous et al., 2003; Metcalf & Eddy, 2014). The average nitrate during the study period in the the inlet and outlet was found to be 16.18 mg/l±0.88 and 4.36 mg/l±0.24, respectively. Therefore, for nitrate, the plant's reduction efficiency was observed to be 73.02%. Student's t-test results indicate a significant reduction (p=0.0001, t= 12.9585) in the mean values of nitrate. Chanakya et al. (2022) studied the efficacy of a biological process model before the actual modification of STP and achieved the 75% reduction in the value of total nitrogen, showing the effectiveness of biological treatment processes. The low reduction of nitrogenous compounds from the wastewater is also interlinked with the temperature of the wastewater during the process (Reddy et al., 2017). Gautam et al. (2013) reported the 71% reduction in nitrate while studying the efficiencies of STPs located in different parts of Delhi.

The main source of sulphate in sewage is detergents used in the houses. The discharge of sulphate-rich wastewater in aquatic bodies impacts the level of salinity, dissolved oxygen, and microbial activities (Dong et al., 2017; Araújo et al., 2022). The average sulphate (SO_4^{2-}) during the study period in the inlet and outlet was found to be 134.00 mg/l±7.97 and 17.24 mg/l±1.54, respectively. Therefore, for sulphate, the plant's reduction efficiency was observed to be 87.12%. Gautam et al. (2013) reported that an increase in the values of sulphate in the treated water may be due to variable influent characteristics, low values of DO, and excess of sludge in the system. Student's t-test results indicate the significant reduction (p=0.0001, t= 14.3839) in the mean values of sulphate.

3.3. Efficiency of STP Plant for Heavy metals

Among all the heavy metals studied (Fe, Cr, Cu, and As), the plants show the highest reduction efficiency for Fe (Table 3). The average value of Fe decreased from 0.31 mg/l±0.02 to 0.06 mg/l±0.04, indicating a reduction efficiency of 88.99%. Student's t-test results indicate a significant reduction (p=0.0002, t=5.5902) in the mean Fe values. However, the plant's efficiency for the remaining

Table 2. Showing the average values (n=6) of inlet, outlet, and % reduction chemical parameters.

Parameters		Minimum	Maximum	Average	SD	SE	Student's t-Test	
							t-Statistics	p-Value
pH	Inlet	7.28	7.36	7.32	0.03	0.01	0.5145	0.6181
	Outlet	7.21	7.33	7.29	0.05	0.02		
	% Reduction	0.00	0.96	0.38	0.37	0.16		
DO (mg/l)	Inlet	ND	ND	0.00	0.00	0.00	11.1500	0.0001
	Outlet	3.90	4.80	4.46	0.40	0.18		
	% Reduction	100.00	100.00	100.00	0.00	0.00		
BOD (mg/l)	Inlet	136.00	156.00	145.20	8.53	3.81	14.2901	0.0001
	Outlet	18.00	23.00	20.00	2.00	0.89		
	% Reduction	83.92	88.16	86.19	1.52	0.68		
COD (mg/l)	Inlet	340.00	354.00	346.60	5.46	2.44	43.0681	0.0001
	Outlet	38.67	48.72	44.91	4.39	1.96		
	% Reduction	85.84	88.79	87.04	1.31	0.59		
Phosphate (mg/l)	Inlet	8.00	10.56	9.12	1.01	0.45	7.5676	0.0001
	Outlet	0.50	1.45	0.98	0.37	0.17		
	% Reduction	84.99	94.12	89.47	3.29	1.47		
Nitrate (mg/l)	Inlet	15.20	17.60	16.18	0.88	0.40	12.9585	0.0001
	Outlet	4.10	4.70	4.36	0.24	0.11		
	% Reduction	70.39	74.53	73.02	1.61	0.72		
Sulphate (mg/l)	Inlet	125.00	146.00	134.00	7.97	3.56	14.3839	0.0001
	Outlet	15.50	18.90	17.24	1.54	0.69		
	% Reduction	85.35	88.43	87.12	1.13	0.51		

ND = Not detectable.

studied metals (Cr, Cu, and As) ranged from 45.60% to 60.42%. The average Cr during the study period was 0.07 mg/l±0.01 at the inlet and 0.03 mg/l±0.02 at the outlet of the plant, indicating a 54.93% reduction in Cr. Student's t-test results indicate the non-significant reduction (p=0.1039, t= 1.7889) in the mean values of Cr.

Similarly, the Cu was reduced from 5.26 mg/l±0.48 to 2.06 mg/l±0.51, indicating a 60.42% reduction in Cu. Student's t-test results indicate the significant reduction (p=0.0010, t= 4.5691) in the mean values of Cu. The unrealistically high Cu values in the inlet may be due to mixing of industrial discharge with the sewage. On the other hand, the plant reduced the As from an initial value of 0.48 mg/l±0.05 to 0.26 mg/l±0.05, showing a reduction of about 45.60% in As values. Student's t-test results indicate the significant reduction (p=0.0110, t= 3.1113) in the mean values of As. Naini is the industrial hub of Prayagraj, consisting of many manufacturing industries such as electrical, electronics, steel, electroplating, and warehouses. The high values of the selected heavy metals in the inlet of STP are an indicator of serious anthropogenic activities in the area. The reduction in the values of the metals is due to the combination of physicochemical and biological processes, i.e., absorption, adsorption, sedimentation, and microbial degradation.

Table 3. Showing the average values (n=6) of inlet, outlet, and % reduction of heavy metals.

Parameters		Minimum	Maximum	Average	SD	SE	Student's t-Test	
							t-Statistics	p-Value
Iron (mg/l)	Inlet	0.29	0.34	0.31	0.02	0.01	5.5902	0.0002
	Outlet	0.04	0.09	0.06	0.04	0.02		
	% Reduction	70.00	100.00	88.89	12.36	5.53		
Chromium (mg/l)	Inlet	0.05	0.08	0.07	0.01	0.01	1.7889	0.1039
	Outlet	0.01	0.06	0.03	0.02	0.01		
	% Reduction	25.00	80.00	54.93	20.07	8.97		
Copper (mg/l)	Inlet	4.50	5.70	5.26	0.48	0.22	4.5691	0.0010
	Outlet	1.70	2.90	2.06	0.51	0.23		
	% Reduction	46.30	70.18	60.42	10.90	4.88		
Arsenic (mg/l)	Inlet	0.41	0.53	0.48	0.05	0.02	3.1113	0.0110
	Outlet	0.20	0.32	0.26	0.05	0.02		
	% Reduction	34.69	54.55	45.60	7.35	3.29		

4. Conclusion

The current study of efficiency assessment was carried out at Naini STP at Prayagraj in Uttar Pradesh, India. To fulfill the objectives of the study, monthly monitoring of the inlet and outlet was carried out for a period of six months. The results of the monitoring reveal the highest efficiency of the plant for TSS (87.76 to 89.74%) among physical parameters, while phosphate (84.99 to 94.12%) among chemical parameters, and for Fe (70 to 100%) among heavy metals. A significant reduction was observed based on the student's t-test values for all the parameters except pH and Cr. To improve the efficiencies of the STPs, the treatment systems must be properly operated and maintained, sources of raw sewage need to be identified, and existing facilities should be upgraded accordingly. In terms of proper operation and maintenance, trained and experienced workers are required. The plant is unable to reduce the TDS to a sufficient level and therefore requires advanced membrane technologies, effective chemical dosing, and process optimization. The major limitation of this study is its short monitoring span, unable to capture seasonal variations; therefore, a comprehensive long-term study is recommended, including seasonal variations in treatment efficiency and energy consumption.

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Author Contributions

Faheem Ahamad: Conceptualization, Investigation, Methodology, Software, Supervision, Writing – original draft; Ajay Singh: Data curation, Investigation, Resources; Mukesh Ruhela: Resources, Validation, Writing – review & editing; Sweta Bhardwaj: Visualization, Writing – review & editing.

Declarations

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