Assessing the Efficiency of Effluent Treatment Plant in comparison with Traditional Sand Filtration System

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Abstract

Effluent Treatment Plants (ETPs) play a crucial role in managing wastewater generated from healthcare facilities and protecting the surrounding environment. This study evaluates the performance of a hospital-based ETP by examining its infrastructure, operational efficiency, maintenance practices, and overall treatment effectiveness. A comparative assessment of water quality parameters was conducted using both historical records and present operational data. Wastewater samples were collected from seven designated sampling points within the treatment system over five different days at varying time intervals. These points included the raw influent at the equalization tank, the SAFF reactor, the outlet from the mechanical treatment unit, and the outlet of the traditional sand filtration system. Key water quality parameters analyzed in the study were pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), turbidity, Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD). The influent pH ranged from acidic to neutral, while the treated effluent exhibited alkaline characteristics. The average removal efficiencies were recorded as 34.39% for TDS, 69.78% for TSS, 23.27% for turbidity, 64.59% for COD, and 79.23% for BOD. The mechanical treatment system showed an overall efficiency of 60.83%, slightly higher than the traditional sand filtration system, which achieved 57.96%. Comparison with historical data from 2053 BS indicated a gradual decline in treatment performance by 2081. Removal efficiencies for TSS, turbidity, COD, and BOD decreased by 2.66%, 9.34%, 4.08%, and 2.06%, respectively. Although the ETP remains effective, the reduced efficiency highlights the need for improved maintenance and operational management to restore its long-term performance.

Keywords: *Effluent Treatment Plant (ETP); Hospital Wastewater; Treatment Efficiency; Water Quality Parameters;*

1. Introduction

Water is one of the most important natural resources for human life, ecosystems, and economic activities. However, rapid population growth and increasing urbanization have placed significant pressure on water resources. As cities expand and industries develop, the amount of wastewater generated from households, industries, and healthcare facilities continues to increase. When this wastewater is discharged into the environment without proper treatment, it can contaminate water bodies and pose serious risks to both human health and the environment. Therefore, proper wastewater treatment has become an essential part of sustainable water management.

Wastewater treatment systems are designed to remove harmful substances before water is released back into the environment. Among the commonly used treatment methods are Effluent Treatment Plants (ETPs) and sand filtration systems. ETPs are widely used to treat wastewater that contains complex pollutants from industrial, domestic, or medical sources. These systems involve several treatment stages that help reduce organic matter, suspended solids, and harmful microorganisms. In contrast, sand filtration is a simpler and more economical treatment method that mainly removes suspended particles from water. It is often used for small-scale treatment systems because it requires less technology and operational cost.

In Nepal, wastewater treatment practices started several decades ago. One of the earliest treatment facilities was the Guheswori wastewater treatment plant, which was established in the 1970s. Later, sand filtration systems were introduced in 2002 for household and institutional water treatment purposes. Since then, both systems have been used in different settings depending on the type and complexity of wastewater. While ETPs are commonly applied in industries and hospitals, sand filtration is mostly used for basic filtration and water polishing.

Many researchers have studied the effectiveness of different wastewater treatment systems. For example, pointed out that centralized wastewater treatment systems may not always be cost-effective, especially when different types of wastewater are combined in a single treatment facility. The study suggested that distributed treatment systems could be more suitable under certain conditions (Wang & Smith, 1994). Similarly, Ramteke (2010) examined a common effluent treatment plant used in the tannery industry and found that the activated sludge process was effective in reducing Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). However, the treated effluent still contained chromium levels above the allowable limits, which indicated the need for cleaner production practices (Ramteke et al., 2010).

Another study conducted by Desai (2011) on a textile industry effluent treatment plant reported that the system successfully reduced BOD and COD levels in wastewater. However, the removal of Total Dissolved Solids (TDS) was limited, showing that some pollutants remain difficult to remove even after treatment (Desai & Kore, 2011). These studies show that while effluent treatment plants are effective in removing many pollutants, they still face certain limitations in achieving complete treatment.

More recent research by Md. Anowar Hossen further highlighted the challenges of conventional wastewater treatment methods. The study found that traditional biological treatment processes are often not capable of completely removing emerging pollutants such as pharmaceuticals, heavy metals, and other chemical compounds present in pharmaceutical wastewater. Although the treatment processes achieved high removal efficiency for parameters such as Total Suspended Solids (TSS), BOD, and COD, the treated water still exceeded regulatory limits for several pollutants. This was mainly due to metal–ligand interactions that reduce the overall efficiency of treatment systems (Hossen et al., 2024).

Despite the importance of effluent treatment plants, their actual performance in healthcare facilities in Nepal has not been widely studied. Hospitals produce wastewater that contains not only domestic waste but also chemicals, pathogens, and pharmaceutical residues. If this wastewater is not treated effectively, it can cause serious environmental pollution and public health problems. In Pokhara, a major hospital operates an effluent treatment plant to treat both medical and domestic wastewater before discharge. However, there is limited information about the current operational condition and treatment efficiency of this system (Bhuvaneshwari et al., 2022).

Given this situation, it is important to evaluate how effectively the treatment system is functioning and whether it meets environmental standards. In addition, it is useful to compare the performance of advanced treatment systems such as ETPs with simpler methods like sand filtration to understand their relative efficiency. Such comparisons can help identify practical and cost-effective wastewater treatment options.

Therefore, the main objective of this study is to assess the efficiency of an effluent treatment plant and compare its performance with a traditional sand filtration system. The study evaluates key water quality parameters by analyzing influent and effluent samples from the hospital treatment system during its initial and present operational stages. It also examines the effectiveness of conventional and mechanical sand filtration systems, determines whether the treated water meets discharge standards, and evaluates the possible environmental impact of the discharged effluent on the Seti River. The results of this research are expected to contribute to improving wastewater management practices and supporting better operation of treatment systems in Nepal (Ahmad et al., 2021; Khan et al., 2024).

2. Methodology

2.1 Study Area

The Effluent Treatment Plant (ETP) is located in Ward 11 of Pokhara Metropolitan City, Kaski District, Gandaki Province, Nepal, and has been in operation for 20 years. Positioned in the northwestern part of the ward, the plant serves municipal and industrial effluents. Fig. 1 shows the study area.

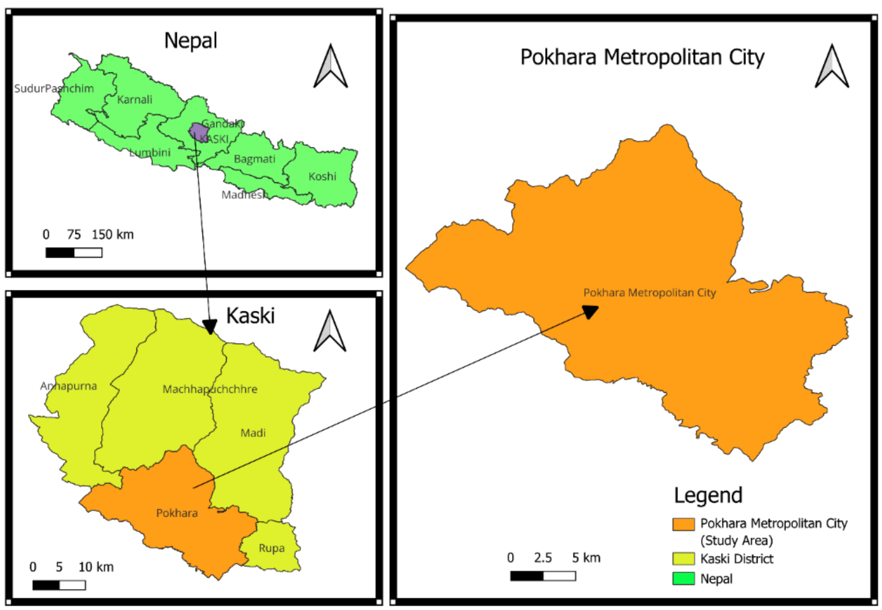


Fig. 1: Study area of ETP Plant of Pokhara Metropolitan City

2.2 Research Method

The treatment process of the effluent treatment plant (ETP) was examined by observing each operational unit and its role in wastewater purification. Initially, the raw effluent passes through a bar screen chamber, where large solid materials are removed to prevent damage or blockage in downstream treatment units. The screened wastewater then flows into an oil and grease trap, which separates floating oil and grease from the effluent.

After this preliminary treatment, the wastewater is collected in an equalization tank. This unit helps maintain a uniform flow and balances fluctuations in pollutant concentration. The tank is equipped with coarse bubble aeration, which ensures proper mixing and prevents the settling of suspended solids.

From the equalization tank, the wastewater is pumped to Parallel Plate Separator–I (PPS-I), where suspended solids settle and are removed, contributing to the reduction of biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

The clarified effluent from PPS-I flows by gravity into a Submerged Aerated Fixed Film (SAFF) reactor for biological treatment. In this unit, aerobic microorganisms break down dissolved organic matter present in the wastewater. Oxygen required for microbial activity is supplied through diffused aeration using air blowers. The biological solids produced during this stage are subsequently separated in Parallel Plate Separator–II (PPS-II).

The treated supernatant then passes through an online mixer, where hypochlorite is added for disinfection to eliminate remaining microorganisms. The disinfected effluent is collected in a filter feed tank and further treated through a dual media filter followed by an activated carbon filter. These filtration units provide final polishing of the effluent before its safe disposal or potential reuse.

The sludge generated from PPS-I and PPS-II is transferred to a sludge sump for further treatment. A dewatering polyelectrolyte (DWPE) is added and mixed with the sludge to improve thickening. Finally, the conditioned sludge is pumped into a filter press, where mechanical dewatering is carried out before final disposal and details is shown in Fig. 2.

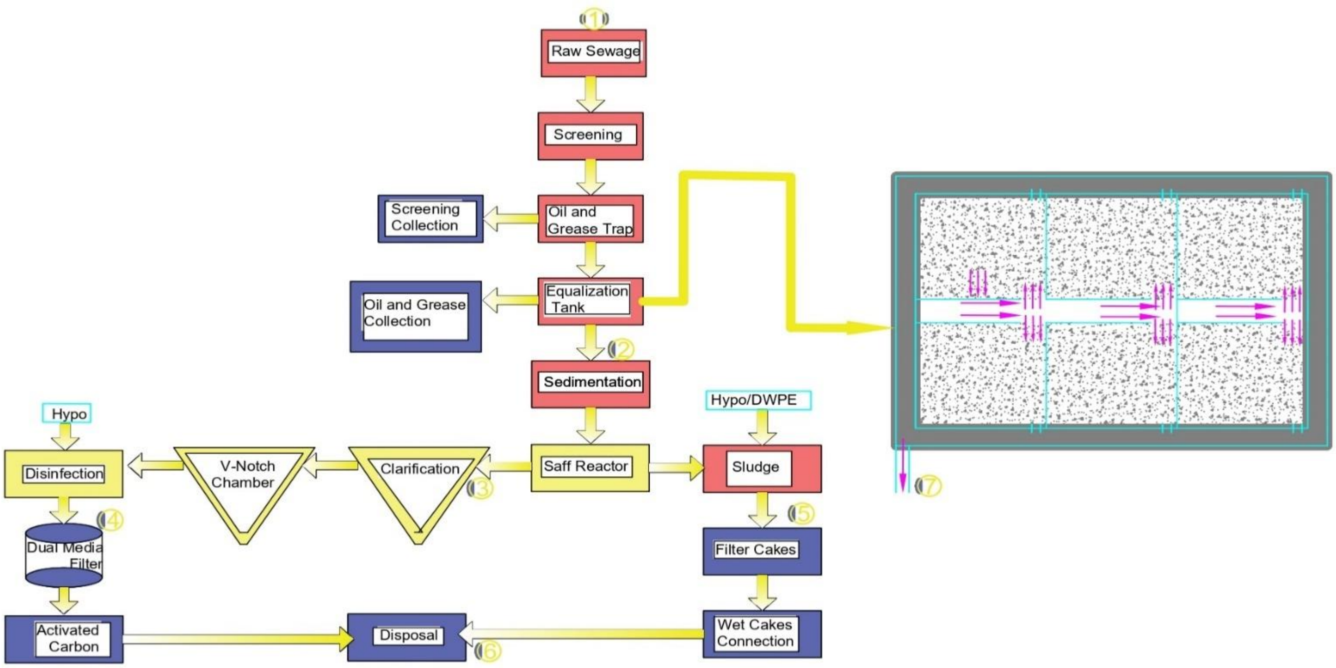


Fig. 2: Flow Diagram of ETP Plant

Table 1: List of Parameters to be checked in different Sampling Point

SN	UNIT	Parameters to Check	Sampling Point
1	Raw Sewerage (Entry Point)	PH, TDS, TSS, COD, BOD	Inflow
2	Equalization Tank	PH, TDS, TSS, COD, BOD	Outflow
3	Staff Reactor	PH	Out Flow
4	Disinfection	COD, BOD, PH	Outflow/ aeration basin
5	Hypo/ DWPE	COD, BOD, PH	Outflow to Equalization Tank
6	Disposal	PH, TDS, TSS, COD, BOD	Outflow
7	Traditional Sand Filtration	PH, TDS, TSS, COD, BOD	Outflow

2.3 Testing Point

As shown in Fig. 3, sampling points were designated based on the parameters affected by each treatment component. At the equalization tank (sampling point 2), aeration reduces suspended solids. In the SAFF reactor (sampling point 3), BOD and COD levels decrease. After disinfection (sampling point 4), bacterial counts are reduced, and at sampling point 5, chemicals are added to further treat COD and bacteria. By the outlet, all parameters as shown in table 1 have been addressed.

While mechanical treatment handles most of the wastewater, this study also evaluates sand filtration. At sampling point 7, the effluent after sand filtration is analyzed. Overall, the efficiencies of both the mechanical treatment outlet and the sand filtration system are assessed. Component-wise sampling allows the performance of each treatment stage to be individually evaluated and the results examined.

Fig. 3: Sampling points were designated based on parameters affected by each treatment unit.

2.4 Sampling Process

Effluent sampling is essential to assess wastewater quality and the performance of each treatment unit. Samples must be representative; otherwise, laboratory results may be inaccurate. Sampling points should be chosen where the wastewater is homogeneous, and care must be taken to prevent extraneous materials, such as scum or floating debris, from entering the sample bottles as shown in Fig. 4. Grab samples are collected when concentration changes are expected that could affect treatment, and these should be analyzed within 2–3 hours. Composite samples are used to evaluate the overall performance of treatment units and are typically collected over 12–24 hours. A volume of 1–2 liters is sufficient for process control parameters. Samples should be promptly transported to the laboratory for analysis, and since they cannot be treated before testing, they are often kept on ice during transport to preserve their integrity.

Fig. 4: Sampling from different points of the treatment system.

3. Results and Discussion

The assessment of the Effluent Treatment Plant (ETP) provided important insights into its operational performance and treatment efficiency. Field observations and data analysis helped develop a clear understanding of the plant’s treatment units and operational processes. Analysis of major water quality parameters showed considerable improvement after treatment, with noticeable reductions in biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and turbidity (Desai & Kore, 2011). Although some mechanical and civil components showed signs of wear, the treated effluent generally complied with local discharge standards. Therefore, improvements such as equipment upgrading, regular maintenance, and operational optimization are recommended to enhance long-term treatment efficiency and environmental sustainability.

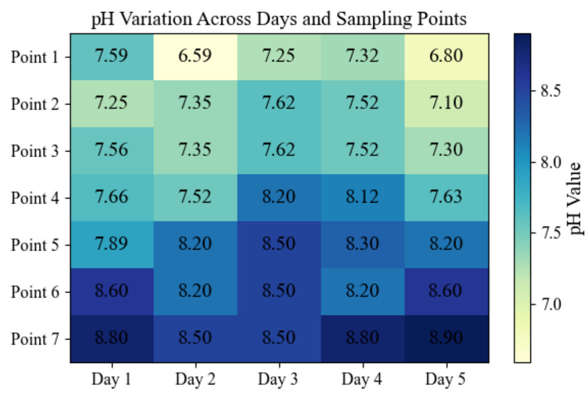


Fig. 5: pH Variation Across Days and Sample

The variation of pH values across sampling points (Points 1–7) over the monitoring period showed that influent pH ranged from 6.8 to 7.59, indicating slightly acidic to neutral conditions as shown in Fig. 5. After treatment, the effluent showed an alkaline tendency. Both the Mechanical Treatment Plant and the Traditional Sand Filtration system effectively regulated pH and maintained acceptable discharge conditions.

For Total Dissolved Solids (TDS), the average removal efficiency during the monitoring period was 34.92%. Influent TDS concentrations ranged from 720–850 mg/L. The lowest concentration was recorded at Point 6 (420 mg/L), corresponding to the Mechanical Treatment Plant, while the Traditional Sand Filtration system recorded 475 mg/L. The mechanical system achieved slightly higher efficiency (39.32%) compared to sand filtration (35.65%) as shown in Fig. 6.

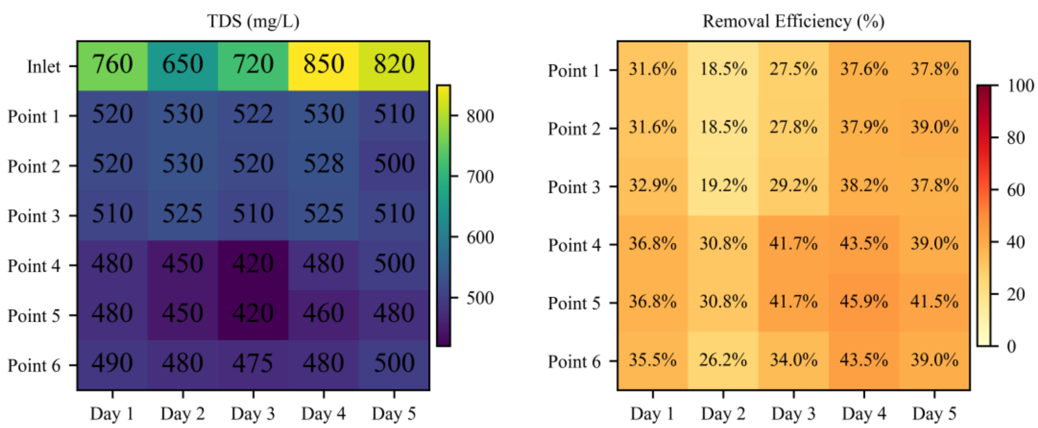


Fig. 6: TDS Value and Removal Efficiency

The analysis of Total Suspended Solids (TSS) showed an average removal efficiency of 69.78%. Influent concentrations varied between 410.2 mg/L and 562.8 mg/L. The lowest TSS value (76.04 mg/L) was observed at Point 6, while sand filtration recorded 75.01 mg/L on the same day. Overall, the mechanical treatment unit showed marginally better removal efficiency (79.49%) compared to sand filtration (78.58%) as shown in Fig. 7.

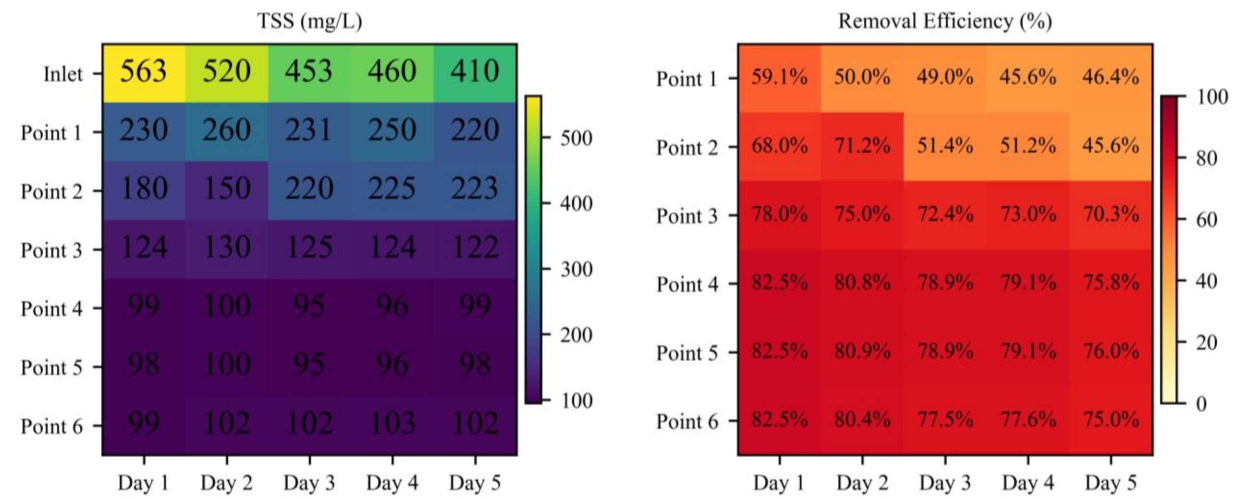


Fig. 7: TSS Value and Removal Efficiency

Similarly, turbidity analysis indicated an average removal efficiency of about 23–27%, with influent values ranging from 650–750 NTU as shown in Fig. 8. The lowest turbidity value (500 NTU) was observed at Point 6. Mechanical treatment achieved 27.25% efficiency, slightly higher than sand filtration (26.08%).

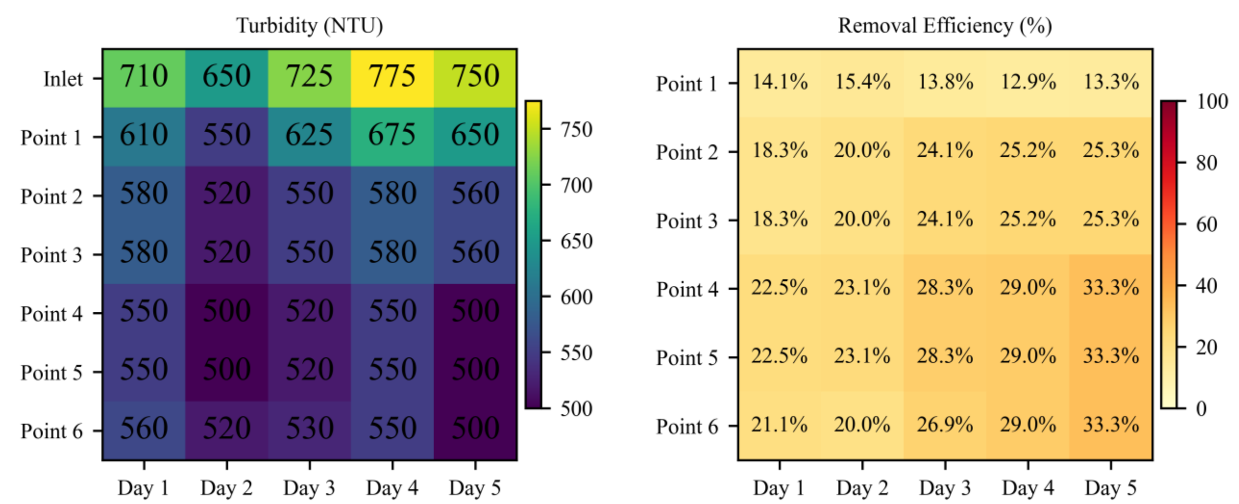


Fig. 8: Turbidity Value and Removal Efficiency

For Chemical Oxygen Demand (COD), the average removal efficiency was 64.59%, with influent concentrations ranging from 820–850 mg/L as shown in Fig. 9. The lowest COD value (200 mg/L) was recorded at Point 6, whereas sand filtration showed 231.52 mg/L. Mechanical treatment achieved higher removal efficiency (74.86%) compared to sand filtration (72.32%).

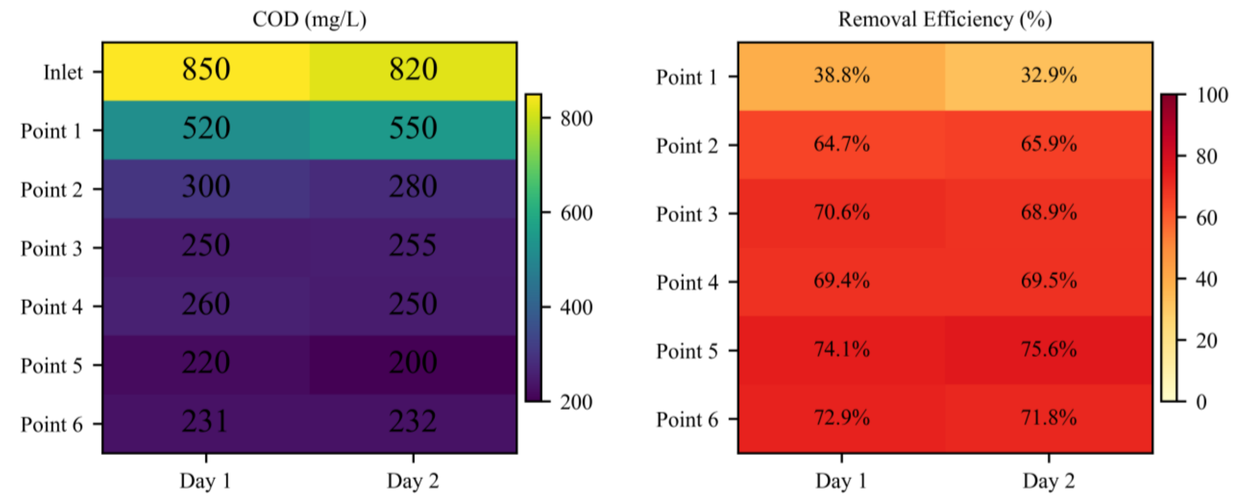


Fig. 9: COD Value and Removal Efficiency

In the case of Biochemical Oxygen Demand (BOD), the average removal efficiency was 79.23%, with influent concentrations between 310–312 mg/L as shown in Fig. 10. The lowest BOD value (28 mg/L) was observed in the mechanical treatment unit, while sand filtration recorded 35.1 mg/L. The removal efficiency of the mechanical system (90.67%) was higher than that of sand filtration (88.70%).

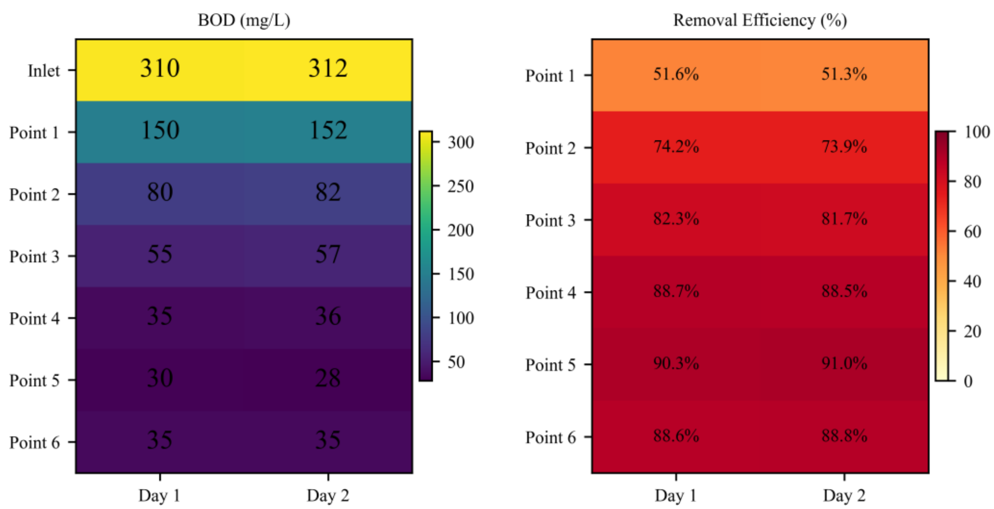
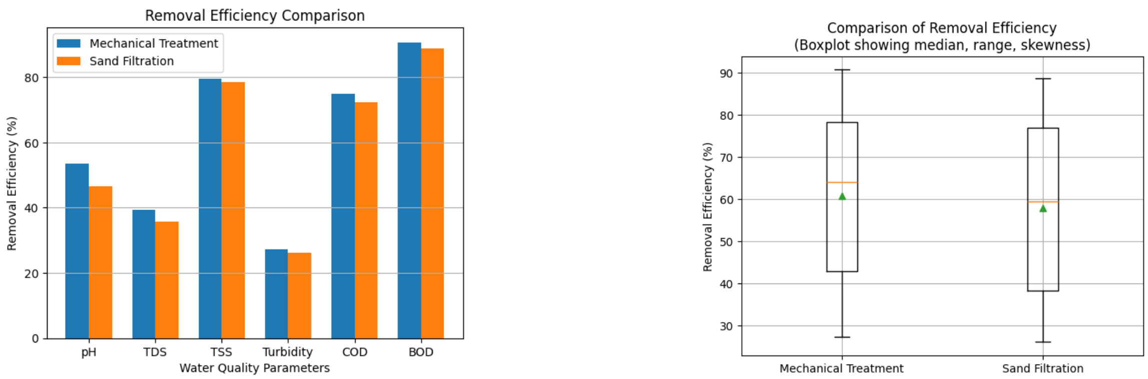


Fig. 10: BOD Value and Removal Efficiency

Overall, the Mechanical Treatment Plant demonstrated higher average efficiency (60.83%) compared to Sand Filtration (57.96%). Statistical tests confirmed this difference, where the Shapiro–Wilk test indicated normal data distribution ($p > 0.05$), and the paired t-test ($t = 3.151$, $p = 0.025$) and Wilcoxon signed-rank test ($p = 0.031$) showed a significant difference between the two treatment methods as shown in Fig. 11.



(a) (b)

Fig. 11: (a) Water Quality Parameter and Removal Efficiency, (b) Mechanical Treatment , Sand Filtration and Removal Efficiency

A comparison between historical data (2053 BS) and present data (2081 BS) indicates a decline in treatment efficiency. In 2053, removal efficiencies for TSS, turbidity, COD, and BOD were 80%, 25.45%, 75.23%, and 95.94%, respectively. In contrast, the present efficiencies decreased to 77.82%, 23.02%, 74.11%, and 91.02%. This represents a reduction of 2.66% for TSS, 9.34% for turbidity, 4.08% for COD, and 2.06% for BOD as shown in fig. 12.

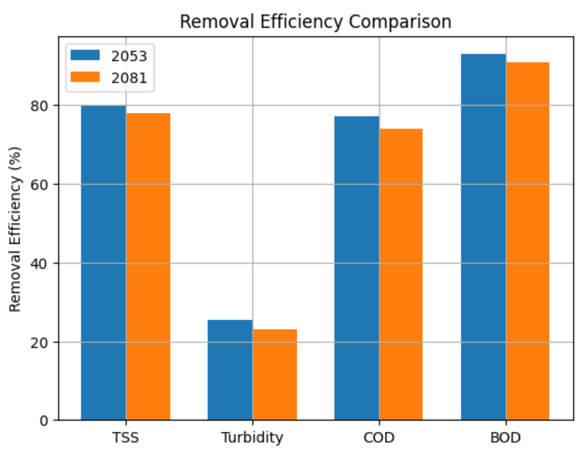
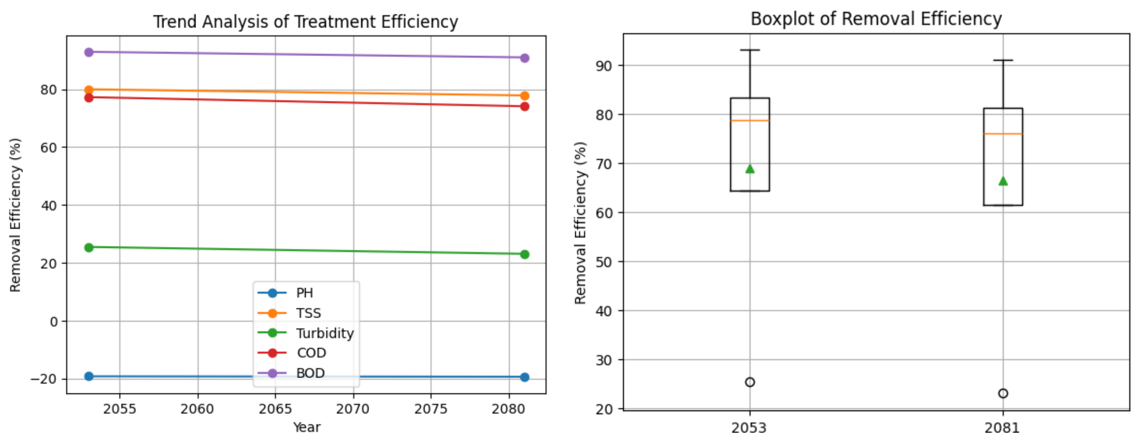


Fig. 12: Removal Efficiency of Parameter in 2053 and 2081 Years

The results suggest a gradual decline in treatment performance over time, likely due to aging infrastructure and operational limitations. Turbidity showed the most significant decrease, indicating weaker removal of suspended and colloidal particles. Overall, the trend confirms that the treatment plant performed more efficiently in 2053 than in the present operational period as shown in Fig. 13.



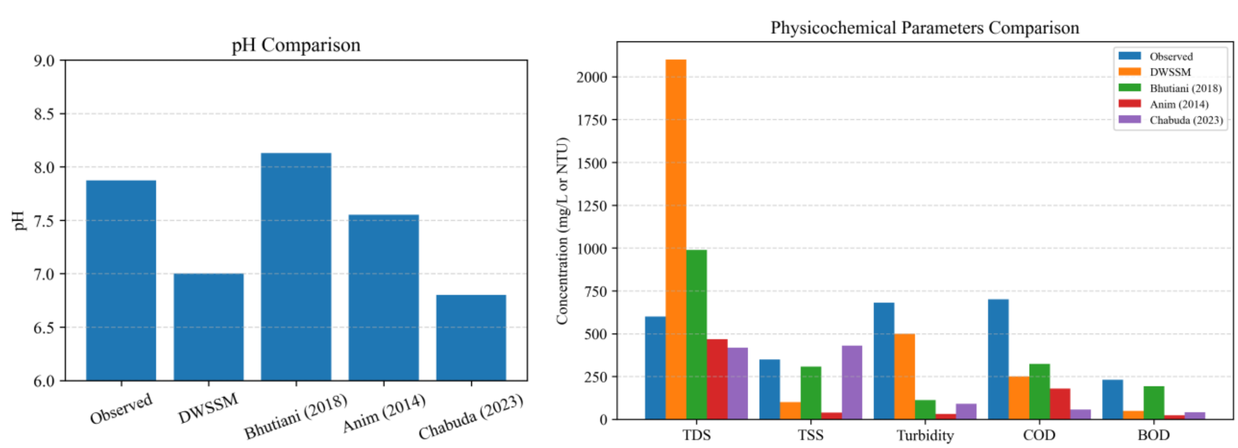
(a) (b)

Fig. 13 (a) Trend Analysis of Removal efficiency (b) Removal efficiency in 2053 and 2081 years.

Table 2 : Limits of effluents to be disposable to inland, water bodies

SN	Parameters	Concentration not to be Exceed
1	PH	6-9
2	TDS (mg/l)	<2100
3	TSS (mg/l)	100
4	Turbidity (NTU)	500
5	COD (mg/l)	250
6	BOD (mg/l)	50

Source: Norms and Specification, Source: Government of Nepal (Department of Water Supply and Sewerage Management)



(a) (b)

Fig. 14 (a) Comparision of PH (b) Comparision of Physicochemical Parameters with other paper

The results indicate as shown in Fig. 14 (a & b) that the observed pH (~7.9) remains within an acceptable range, reflecting stable and slightly alkaline conditions. TDS (~600 mg/L) is well below the

Department of Water Supply and Sewerage Management limit (DWSSM) (2100 mg/L) as shown in table 2, suggesting effective removal of dissolved solids. However, TSS (~350 mg/L) exceeds the permissible limit (100 mg/L), indicating insufficient removal of suspended particles, while turbidity (~680 NTU) also remains significantly higher than standard values, pointing to poor clarification efficiency. Similarly, COD (~700 mg/L) and BOD (~230 mg/L) are considerably above their respective limits (250 mg/L and 50 mg/L), revealing incomplete degradation of organic matter. Overall, although the system performs satisfactorily in terms of pH stabilization and TDS reduction, it shows limited efficiency in removing suspended solids and organic pollutants, highlighting the need for further optimization of treatment processes.

4. Conclusion

The present study demonstrates that the Mechanical Treatment Plant performs more effectively than the Traditional Sand Filtration system in improving wastewater quality. Higher removal efficiencies were consistently observed for key parameters, including TSS, TDS, turbidity, COD, and BOD, confirming the superior treatment capability of the mechanical system. The overall average treatment efficiency of the Mechanical Treatment Plant (60.83%) exceeded that of the sand filtration system (57.96%), indicating a comparatively better performance. The treated effluent exhibited a shift in pH from neutral or slightly acidic conditions at the inlet to mildly alkaline conditions at the outlet, with an average pH of approximately 7.9, which lies within acceptable limits. In terms of pollutant removal, TDS concentrations were reduced effectively and remained well below the Department of Water Supply and Sewerage Management (DWSSM) standard limit. However, TSS, turbidity, COD, and BOD values in the effluent exceeded permissible limits, indicating that the treatment processes were not fully effective in removing suspended solids and organic pollutants.

A comparison with historical data further revealed a gradual decline in treatment efficiency over time. Although the system performed efficiently in earlier years, the present results indicate reductions in removal efficiencies for TSS, turbidity, COD, and BOD. This decline suggests possible operational challenges, aging infrastructure, or inadequate maintenance.

Overall, while the Mechanical Treatment Plant shows better performance relative to sand filtration and maintains acceptable pH and TDS levels, its limited efficiency in removing key pollutants highlights the need for process optimization and system upgrades to meet regulatory standards and ensure sustainable wastewater management.

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