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Performance of Centralized Wastewater Treatment System in Thimphu, Bhutan

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Abstract

The main objective of this research was to provide an evaluation of the performance of the Sequential Batch Reactor (SBR) employed in the centralized wastewater treatment system of Babesa, Thimphu, the capital city of Bhutan. The performance was analyzed based on the respective plant's flow capacity, pH of effluent, and removal of Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Fecal Coliform (FC), using Standard Method of Examination of Wastewater, APHA, as well as the capital cost and sustainability of the treatment system. Removal efficiencies of the SBR for TSS, COD, and BOD ranged from 93-97±1.131, 67-84±4.791, and 65-89±6.662, respectively. In addition, the SBR effluent samples analyzed from April 2022 to August 2022 revealed a consistent and successful removal of TSS, BOD, COD, and FC with the effluent meeting the industrial effluent discharge standards set by the National Environment Commission (NEC). Not only was SBR found to be feasible economically and capacity-wise, but the success of the technology was a function of its compatibility with Thimphu's specific characteristics. The conclusion of this study hopes to encourage a more rigorous consideration of treatment options to invest in Bhutan's growing urban cities in the future, as well as a redefinition in how we evaluate the success of wastewater treatment systems.

Keywords : Babesa Thimphu; sequential batch reactor; sustainability

Introduction

Bhutan is a small, landlocked, Himalayan nation in South Asia with a population of 771,612 characterized with a diverse topology ranging from elevation of 200 meters of the southern foothills to more than 7,000 meters in the north. Thimphu, the capital city, is spread out longitudinally in a north-south direction on the west bank of Wang Chu, at Latitude 27°30' and Longitude 89°30' and the altitudinal elevation ranges between 2,248 meters and 2,648 meters. The valley is thinly forested and spread out to the north and west. Thimphu experiences the monsoon season from May to September, while the remaining is dry. The temperature ranges from 15 °C to 26 °C in summer/monsoon season and from -4 °C to 16 °C during winter. The summer monsoon rain originates from the Bay of Bengal and the annual rainfall ranges from 500 mm to 1,000 mm mostly occurring between June and September [1].

Proper sanitation management and treatment of wastewater remains an important and focal point within the discussion of urbanization as the uncontrolled discharge of sewage and untreated wastewater into water sources is responsible for contamination of the environment which can also act as carriers for disease. UNFPA has predicted that the majority of the projected population in urban settlements by 2030 will unfold in Asia and Africa, which calls for more efficient wastewater treatment systems as most wastewater treatment plants in developing countries fail to function properly Waste stabilization ponds are an extremely popular choice of treatment in developing countries due to the associated low-cost (usually least-cost), low maintenance, high efficiency, and entirely natural and highly sustainable operation [2]. It was under these justifications that Danish International Development Assistance (DANIDA) funded the construction and commissioning of a waste stabilization pond in the town of Thimphu in 1997 with the overall developmental objective of contributing to a reduction in the overall incidence of diseases related to water and hygiene [2].

The wastewater treatment plant in Thimphu was constructed in 1996 as a waste stabilization pond with a design capacity of 1.75 MLD. It was located about 10 km downstream of Thimphu city in Babesa, on the left bank of the Wang Chu river where the effluent would be released. In the year 2016, the plant accepted flows in excess of 1.6 MLD with a 325 mg/l BOD removal covering up to 13 acres of land [1]. It was also reported that 70% of Thimphu's houses were connected to septic tanks, and 30% were connected to the sewer network. Due to a lack of funding, Thimphu afforded only four minor extensions of the plant. Under the UIDP 2258BHU project, sewer pipelines were laid in the 4 southern areas of Lungtenphu, Simtokha, Babesa, and Changbangdu. However, these sewerage system developments in Southern Thimphu were not permitted to connect to the main treatment system due to the pond's limited capacity. Hence, this allowed the pond to treat only 18% of the city's incoming wastewater. The growing strain of pressure on the performance of the treatment plant began to increasingly mount as Thimphu rapidly urbanized [3]. Assuming that all housing in new developmental areas in Southern Thimphu would be connected by 2020 to the main plant with an infiltration rate of 5%, water production was estimated to be 25 MLD with wastewater production of 13 MLD. Despite the connection to 60% of the core area, only 30% reached the treatment plant as most houses relied on individual septic tanks or excess wastewater was diverted to the drainage system due to a lack of plant capacity [3].

While the pond treatment system boasted many advantages for a developing country such as low operation and maintenance costs, the performance was unsustainable due to the rapid urbanization, not to mention the impracticability of obtaining an additional 90 acres of land in a city located in a valley. Taking into consideration these factors, Thimphu transitioned towards the acquisition of a new wastewater treatment plant. Comparisons between various treatment options yielded the best choice of Sequencing Batch Reactor due to the minimum land requirement, less expensive capital and operation and maintenance (O&M) cost and activities, less power requirement, easier disposal of sludge, and better quality of treated effluent within the same budget against contemporary treatment options. The headworks of the wastewater treatment plant (WWTP) were designed for 2027 requirements while the process units i.e. tanks, reactors, dewatering, chlorination) were designed for 2020 flow requirements with a connection to about 13,000 residential units. The plant's automated trial period started in October 2021 [4]. The main objective of this study was to assess the performance of the sequential batch reactor plant and the waste stabilization pond in Babesa, Thimphu. The goals were to conclude the performance of SBR in terms of technical overview, effluent quality, working capacity, capital costs, and sustainability; and to assess the limitations and failure of the WSP technology within the context of Thimphu, Bhutan.

Methodology

The primary data which includes the biological parameters of the incoming and treated wastewater and the physical parameter of incoming flow to the new treatment system (SBR) were collected from the data maintained by the Thimphu Municipality of the SBR treatment plant. These data include TSS, COD, BOD, FC, pH, and flow rate. The sampling points, data collection period, and water quality analyses are displayed in Table 1.

Table 1 Measurement, sampling, and water quality analyses

Parameter	Sampling point	Data collection period	Standard Method
TSS	Influent and effluent	The 3rd wk. of April 2022-the 1st wk. of August 2022	Standard method 2540 [5]
COD	Influent and effluent	The 3rd wk. of April 2022-the 1st wk. of August 2022	Standard method 5220 [5]
BOD	Influent and effluent	The 3rd wk. of April 2022-the 1st wk. of August 2022	Standard method 5210 [5]
FC	Influent and effluent	The 3rd wk. of April 2022-the 1st wk. of August 2022	Standard method 9221 [5]
pH	Influent and effluent	October 2021-July 2022	Standard method 4500 [5]
Flow rate	Influent	October 2021-July 2022	Electromagnetic current meter

The secondary data, including climate and population analysis of the city, capital costs, and the biological and physical parameters of the treated wastewater from the old treatment system (WSP), were retrieved from relevant published literature and reports from the archive [1]. The WSP data was collected during 2006-2007.

Results and Discussions

The flow data of the SBR obtained shows an average monthly inflow of 7,700 m^3/d throughout November 2021-July 2022 as shown in Figure 1. While back then from January 2006 to May 2007, the average daily of the WSP was observed between 1,266 m^3 and 1,741 m^3 daily [1]. This jump in value can be explained due to the connection of the SBR plant to the new sewerage network as well as the urban growth in the area within the last decade. The minimum flow to the SBR plant occurred in May 2022 with 6,915 m^3/d while the average monthly flow peaked in June 2022 with 8,912 m^3/d.

The monthly pH of the influent ranged from 7.18 to 7.9 with an annual average of 7.57 while the effluent pH was recorded between 6.25 and 7.6 with an annual average of 6.92 (Figure 2). This is in contrast to the average effluent pH of 7.6 from WSP [1] which is low compared to higher values expected from maturation ponds. However, the SBR value is within the standard effluent range of 6.5-8.5 [6].

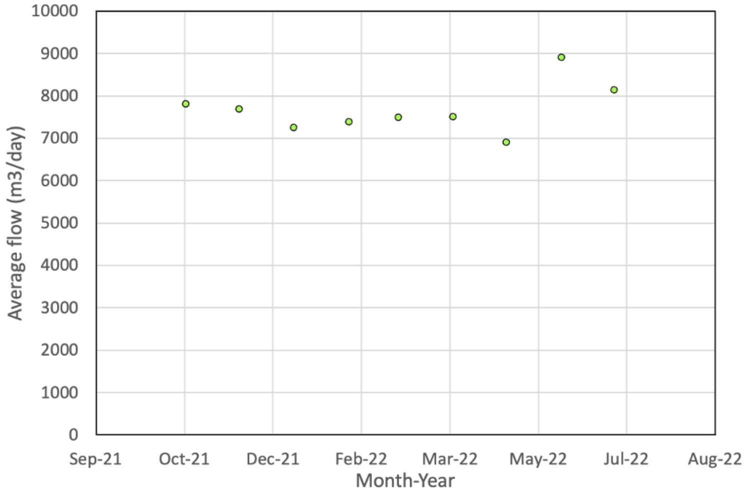

Figure 1 Average monthly flow to the plant

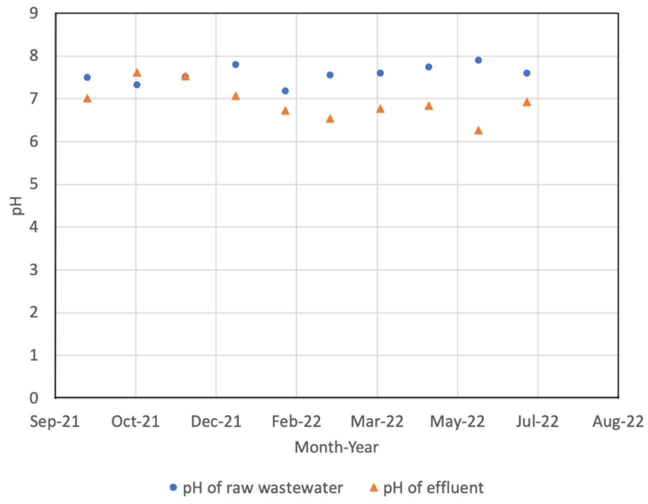

Figure 2 pH of influent to and effluent from SBR

The TSS of the influent samples collected for the duration of the third week of April 2022 to the first week of August 2022 was observed between 200 and 450 mg/L with an average of 323 mg/L (Figure 3). TSS removal by SBR was found to be consistent with an average of 95.11% with the effluent values between 12.5 and 17.5 mg/L meeting the National Environmental Commission (NEC) industrial effluent discharge standards of 80 mg/L [6].

Figure 4 shows the weekly variations of COD values from April to August 2022 varying from 194 to 297 mg/L for incoming wastewater with an average of 228.81 mg/L while treated effluent was observed to be within the ranges of 33.6-72 mg/L with an average of 50.78 mg/L meeting the NEC industrial effluent discharge standards of 150 mg/L [6].

The influent BOD values ranged from 52-156 mg/L with an average of 111.68 mg/L (Figure 5). The effluent BOD values ranged from 16-20 mg/L during the whole period meeting the NEC industrial effluent discharge standards of 30 mg/L [6]. The resulting average BOD removal rate was found to be 82.25%.

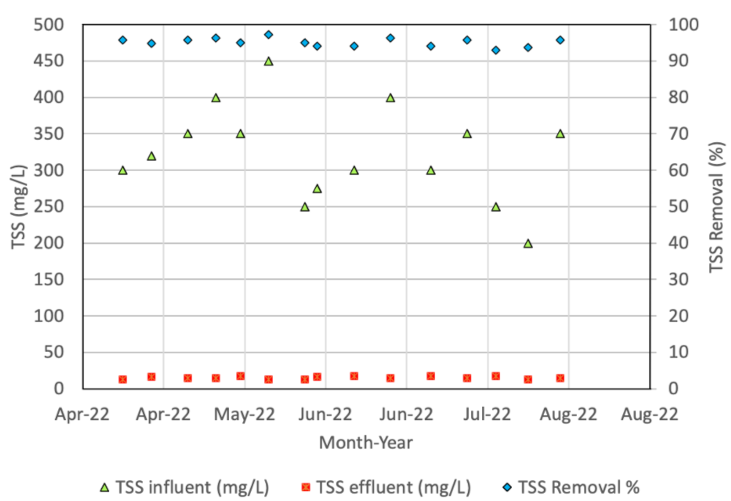

Figure 3 TSS content in influent, effluent, and removal in SBR

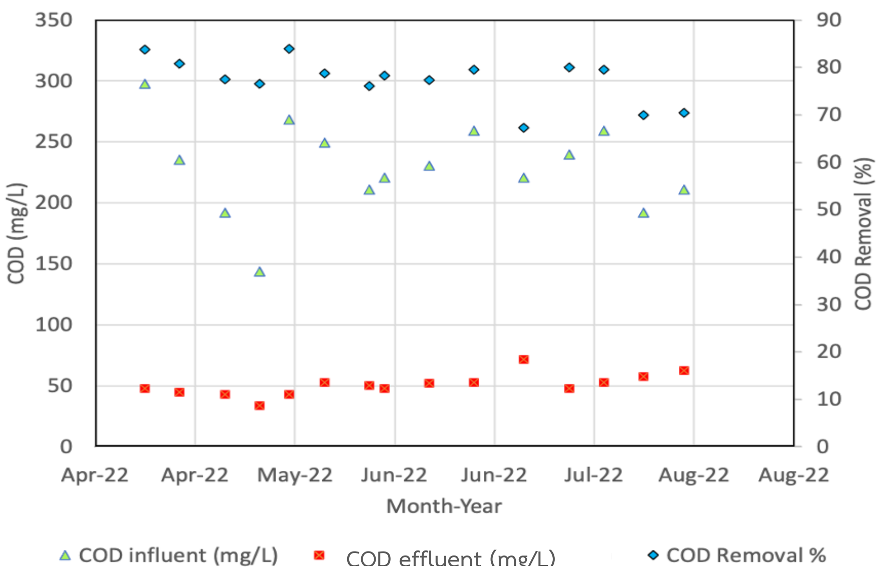

Figure 4 COD content in influent, effluent, and removal in SBR

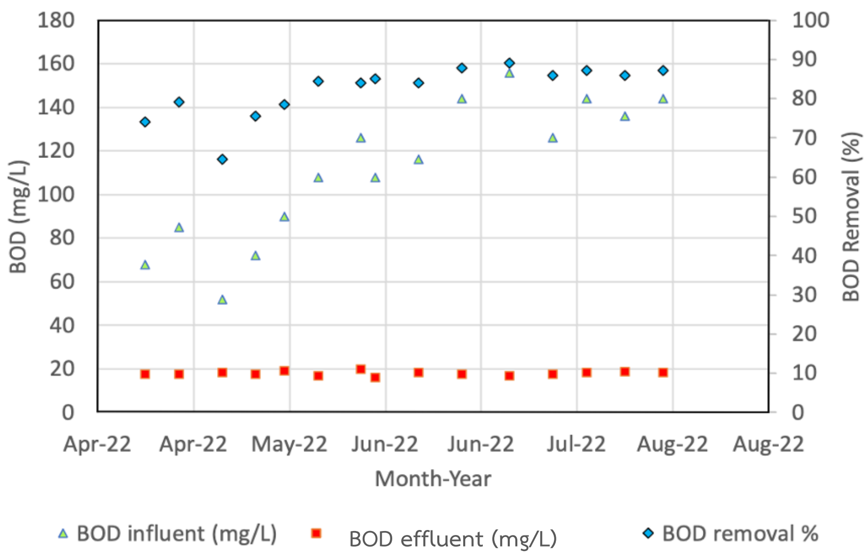

Figure 5 BOD content in influent, effluent, and removal in SBR

Table 2 describes the removal efficiency of TSS, COD, and BOD of the wastewater using the SBR and WSP technologies. Removal efficiencies of the SBR for TSS, COD, and BOD ranged from 93-97±1.131, 67-84±4.791, and 65-89±6.662, respectively. While the TSS, COD, and BOD of the WSP were in the range of 30-80%, 83-95%, and 78-90%, respectively [1].

Table 2 Removal efficiency of two WTTPs

Parameter	SBR	WSP
TSS Removal Efficiency (%)	93-97±1.131	30-80
COD Removal Efficiency (%)	67-84±4.791	83-95
BOD Removal Efficiency. (%)	65-89±6.662	78-90

However, a closer look at the actual parameter values reveals good quality of effluent from SBR, in which all parameters meet the industrial effluent discharge standards set by the NEC (Table 3). Whereas, WSP effluent of poor quality that does not meet industrial effluent discharge standards was observed. The TSS of effluent from SBR ranged from 12.5-17.5 mg/L. The SBR achieved effluent with a COD and BOD content of 33.6-72 mg/L and 16-20 mg/L, respectively.

Kochanek, A. et al. [7] evaluated the wastewater treatment efficiency of the WWTP using the SBR technology in the mountain area (Poland) and found that the removal efficiencies of TSS, BOD, and COD were 95.25%, 97.72%, and 95.58%, respectively. Hydraulic load of wastewater ranged from 2,644 m^3/d to 4,001 m^3/d. The TSS removal efficiency received from this research was comparable with the one from Kochanek A. et al. [7]. While the BOD and COD removal efficiencies of our work were slightly lower than the ones from their work. Wilk, B. K. and Cimochowicz-Rybicka, M. [8] determined the efficiency of the Biovac® wastewater treatment plants operating in the mountain areas of the Polish national parks (NP): Tatrzanski NP and Babiogórski NP as well as in the West Spitsbergen NP. The wastewater treatment plant was evaluated during the off-peak tourist season. The research revealed that the Biovac® treatment plants (SBR technology) objected to treating sewage discharged from mountain hostels yielded a high level of removal of pollutants. The average values of BOD and COD removal efficiencies ranged from 94% to 99% and 92% to 97%, respectively. In addition to the comparison of the same wastewater treatment technology (SBR), the findings of this work are also compared with the WWTP using different technologies. Bachi, O. E. et al. [9] studied the performance of aerated lagoons (AL), activated sludge (AS), and constructed wetlands (CW) under an arid Algerian climate. The minimum and maximum temperatures were observed to be about 12 ^oC and 36 ^oC for winter and summer time. The BOD removal efficiencies for the studied processes were 61.2–82.7%, 89.0–94.2%, and 87.9–91.2% for AL, AS, and CW, respectively. These values are in good agreement with our findings. The efficiencies of 65.5–69.1% (AL), 84.0–89.9% (AS), and 85.0–90.2% (CW) were obtained for the removal of COD. While the SS removal efficiencies of 39.2–67%, 93.4-96.9%, and 87.7–95.2% were received for AL, AS, and CW, respectively. The results suggested that the performance of SBR for Thimphu city is effective regarding the removal efficiency of pollution.

Table 3 Physical and biological parameters of effluent from two WWTPs against NEC standards [6]

Parameter	SBR	WSP	NEC standards
TSS Range (mg/L)	12.5-17.5	90	<80
COD Range (mg/L)	33.6-72	<80	<150
BOD Range (mg/L)	16-20	30-48	<30
FC (MPN/100 mL)	11-70	6.0×10^4-2.0×10^5	<1000

The justifications for these adverse differences in initial BOD and COD values can be that the sample origin is not of the same population nor within the same period. The WSP data was collected between 2006-2007 while the SBR data was collected in the year 2022. It is also important to note that one of the primary reasons for replacing the WSP was its insufficient capacity to handle the loadings of the new sewerage network of recent urban developments in the area, which was promptly connected to the new SBR STP after completion.

The estimated construction cost of the waste stabilization pond system and associated river training works funded by DANIDA in 1997 was approximately DKK 38.5 million (USD 7 million). Adjusting for inflation, this value is equal to USD 10.5 million in 2016. Approximately USD 2 million was expended for technical assistance and the training component with an additional USD 2 million also expended for upgrading of the water supply system and associated technical assistance, including a computerized billing system [2]. The estimated capitalized cost of the SBR plant with mechanical dewatering offered by the project consultant was RS 452.2 million (USD 5.48 million). The total contract bill was summarized as USD 10.5 million. Given that these figures are similar, the advantages offered by the SBR make the technology a more viable and economic option compared to the WSP. The figures for operational costs were not available for retrieval and hence were not included in the discussion.

One of the three principal reasons put forward by Parr and Horan [10] for the failure of WWTP in developing nations is the failure to consider all relevant local factors at the pre-design stage, leading to the selection of inappropriate treatment options. The WSP capacity of 1.75 MLD was already exceeded by the 30% of the city connected to the core sewer network, which allowed the treatment of only 18% of the total incoming sewage. While USD 2.28 million was allocated through an ADB loan agreement for the expansion of the WSP, the agency consultant concluded in 2007 that the expansion would be inadequate as the pond technology is a function of depth and deepening the ponds would be impossible, and installation of aerators was not expected to improve the pond performance. This intermediate solution, if pursued, was also projected to last only a few years and a new treatment plant was deemed necessary, as spatial expansion would require an additional 90 acres of land to treat the total incoming sewage. As Thimphu is located on a narrow strip of land at the base of a valley, this land requirement is unfeasible and so, treatment options that are spatially concentrated such as the SBR technology that congregates much of the unit operations into one tank, is a more suitable option.

Furthermore, the temperate climate of Thimphu where temperatures can plunge into negatives is not compatible with the waste stabilization pond technology where the performance is a direct function of microbial activity which is inhibited by cold temperatures. This incomplete degradation of organic matter would cause foul odor to be emitted especially during the winter which became a common source of complaint from the settlements nearby. Thus, investment in the SBR technology is not only a more economical but also a sustainable and compatible option.

Conclusion

Despite the selection of waste stabilization pond technology in 1997 due to its economic and operational feasibility, overloading of the plant's capacity due to rapid expansion in the urban area of Thimphu within the last decade and failure of effluent to meet discharge standards caused the municipality to seek options for replacement. The SBR plant replaced the pond technology with the automated trial period starting in October 2021. Not only is SBR technology a more compact treatment system compatible with Thimphu's limited availability of land, but the technology is also independent of Thimphu's temperate climates and high altitude, and capital cost figures are similar to that associated with the pond technology. Data of SBR samples collected from April 2022 to August 2022 were compared against the values of WSP data collected in 2006-2007 as well as July 2011. Despite the COD and BOD removal rates of SBR being lower than that of the WSP, it is not a reliable parameter to determine the success of wastewater treatment as unusually high and low initial values of COD and BOD affect the removal rate. High COD and BOD values, possibly due to analytical errors, were recorded for WSP influent while wastewater incoming to SBR had lower values, which explains the discrepancy in removal rates. However, despite the high removal rates of the WSP, the effluent failed to meet the discharge standards set by NEC and WHO. Meanwhile, SBR samples analyzed from April 2022 to August 2022 revealed a consistent and successful removal of TSS, BOD, COD, and FC with the effluent meeting discharge standards set by both the NEC and the contract. The incoming flow was also within the plant's operating capacity and is expected to handle future projected loadings, making the project a successful and sustainable form of wastewater treatment in urban Thimphu. While the waste stabilization pond technology is still an economically feasible option for developing nations with a lack of access to resources, it is recommended that the sites and settlements be studied more thoroughly to gauge the compatibility of the treatment option as evaluated in this study before investment, especially within Bhutan's growing urban cities in need of more centralized sewage treatment systems. This study also calls for a redefinition of how we evaluate the success of wastewater treatment systems, as removal efficiency is an unreliable parameter that does not accurately indicate effluent of high quality. Rather, the final parameter values of the effluent are a much better indicator of wastewater treatment success.

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