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Performance of Waste Stabilization Ponds: Experience from Cold Climatic Conditions of Bhutan

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ABSTRACT

Like any other developing countries, Bhutan too is facing the challenges of rapid urbanisation and the need to improve wastewater treatment and management. Waste stabilization pond (WSP) of capacity 1,750 m^3 per day capacity with 12,500 population equivalent was constructed at Thimphu in 1996 to treat the domestic wastewater. This paper reports the study conducted in 2010 based on the available data of the wastewater effluent quality between 2006 and 2007. After 11 years of commissioning, the performance of the Thimphu SWP was observed to be very promising. The effluent quality meets the National Environment Commission (NEC) industrial effluent standards, and the performance of anaerobic pond in removing BOD of up to 70% was also particularly significant. The flow record indicates that the sewage treatment plant (STP) is yet to be loaded to its full designed capacity, although the flow measuring techniques need to be improved preferably by automatic flow recording device. The study of various influent and effluent qualities have concluded that the WSP is an efficient and suitable technology for removing organic and microbiological pollutants from wastewater in Bhutan with climatic conditions similar to that of Thimphu.

Keywords: Bhutan; waste stabilisation pond; wastewater treatment; developing country

1. INTRODUCTION

1.1 Background

According to the World Health Organization, about 2.6 billion people, i.e. 42% of the world population, lacked access to basic sanitation in 2002 (WHO, 2000). Poor sanitary conditions are generally found in the developing countries where the governments are not able to provide adequate public sanitation or help improve private onsite sanitation system. Lack of sanitation facilities results in open defecation directly affecting the sanitary conditions of the land and water which in turn could affect the health and hygiene of the population living in the area. The mortality rate as a result of water and sanitation associated diarrhoeas and other water/sanitation-associated diseases has been estimated at to be more than 57 million people in 2002 of which large proportion of those effected are children under five (UNESCO, 2003). Hence, the United Nations declared 2008 as the International Year of Sanitation (IYS) mainly to address this preventable morbidity by raising awareness on the issue of the global sanitation crisis which is considered as one of the major obstacles to human development in many developing countries. Besides, proper management of both liquid waste and solid waste is one of the basic

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requirements of ecologically sustainable development in any parts of the world (Munda, 1997).

The basic sanitation coverage in Bhutan is impressive with only about 4% of the urban households and about 13% of the rural households lacking toilet facility of any kind (OCC, 2005). High percentages of access to flush toilet facilities are reported especially in the urban areas. This means that the wastewater from the toilets containing black water should be treated and disposed well which otherwise could pose a significant sanitation problem within the surrounding areas receiving the wastewater discharge. The Royal Government of Bhutan under the financial aid from DANIDA completed two major sewage management projects at the capital city of Thimphu and the other major city Phuntsholing in 1996. After eleven years of the operation, the Thimphu sewage treatment plant (STP) has covered about 20% of city's 80,000 populations.

There are contrasting opinions regarding the feasibility of waste stabilisation ponds (WSP): some emphasize their advantages while others are concerned with their high land area requirements (Varon, 2002). Nevertheless, WSP have been proven to be generally low-cost and sustainable particularly suited to the socioeconomic and climatic conditions prevailing in many developing countries (Havelaar et al., 2001). Other advantages include its robustness, low O & M cost and low energy treatment system. Furthermore, it does not require specialized manpower and is not sensitive to shock loading as it can accommodate large fluctuations in the flow (Spellman and Drinan, 2014). Because of many advantages this natural treatment system has been used not only in the developing countries but also in many developed countries (Mara and Pearson, 1998). More than 9,200 WSP in the United States (US EPA, 2000), 2500 in France, 1100 in Germany, 39 in UK and many are reported in Canada, Australia, New Zealand, etc. (Phuntsho, 2006). But proper planning and design is essential for keeping the cost of construction, operation and maintenance to a minimum (Hosetti and Frost, 1998).

The aim of this paper is to study and review the performance of WSP at Thimphu. The results and observations could be a valuable source of information for future planners and urban authorities in preparing strategies for wastewater management. Since only two towns in Bhutan have centralized wastewater treatment system till now the prospects of research on wastewater treatment and management is quite high. Although many literatures have been published on WSP, there is no single literature available so far on the performance of WSP in Bhutan and therefore this paper is expected to provide some insight on the experiences in Bhutan. The performance of the plant is assessed mainly for organic and microbiological removal. The evaluation of nutrient removal is not included in this study since the small lab attached to the plant was not fully equipped to analyse all the plant performance parameters and the authors could not have any nutrient removal data.

1.2 Thimphu, the capital city of Bhutan

Bhutan is a small landlocked country located in the eastern Himalaya between Tibet-China (in the North) and India (in the east, south and west). Fig. 1 shows the location map. Its total population in 2005 was 672,425 (OCC, 2005) and it has a total area of 38,394 km^2 (MoA, 2004). The Royal Government of Bhutan's (RGOB) development strategies are guided by the unique philosophy of Gross National Happiness (GNH). The development policies place high emphasis on the environment and therefore "Conservation of Environment" is one of the four pillars of development strategies. Like any other developing countries, Bhutan too is facing the challenges of rapid urbanisation with more than 30% of the country's population living in the urban areas which is expected to increase in the next few decades. Although the national annual population growth rate in Bhutan is 1.28% (MoWHS, 2007; OCC, 2005), its average urban population growth rate has been reported to be 7.3% annually with the western region including Thimphu experiencing maximum growth rate of about 11% (MoWHS, 2007). The topography of the country is generally associated with rugged mountainous terrain with altitude ranging from 200 m (above sea level) in the southern Himalayan foothills to as high as 7500 m in the northern part. The country's extreme altitudinal variation has created a corresponding range of climatic conditions varying from hot and humid tropical/subtropical conditions in the southern foothills to cold and dry tundric conditions in the northern mountains. This is further modified by latitude, precipitation, slope gradient, and exposure to sunlight and wind, giving each valley and often opposite-facing slopes a unique set of climatic conditions (Phuntsho, 2006).

Thimphu is the capital city of Bhutan with a total population of 79,185 (OCC, 2005) in 2005 which is more than 40% of the entire urban population in Bhutan. It is located at Latitude 27˚30' and Longitude 89˚30' at an altitude ranging from 2248 m to 2648 m above sea level with warm temperate climate in summer and cold dry climate in winter. The temperature ranges from 15˚C to 26˚C in summer/monsoon season (June-August) and from -4˚C to 16˚C during winter (Dec-Feb). The summer monsoon rain originates from the Bay of Bengal and the annual rainfall ranges from 500 mm to 1000 mm mostly occurring between June and September. Thimphu city has grown from about 9.0 km^2 in 1999 to 26.23 km^2 today (DUDES, 2004). The municipal boundary was extended in 2002 following the approval of Thimphu Structure Plan, a city's long term plan till 2027.

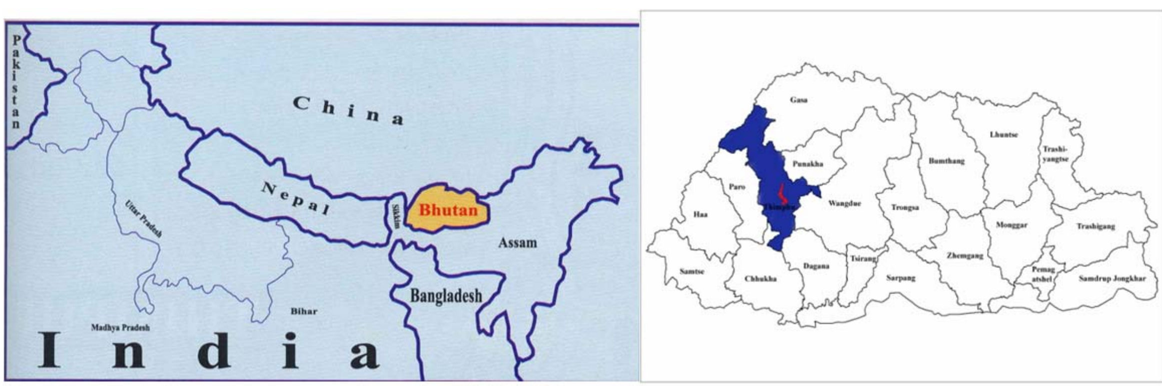

Figure 1 Map showing location of Bhutan and Thimphu city

1.3 Wastewater Management for Thimphu city

The Danish International Development Assistance (DANIDA) funded the construction of the sewerage system for Thimphu city under the Urban Centres Water Supply and Sanitation Project which was completed in 1996. The main objective of the sewerage project was to reduce the incidence of diseases related to water and hygiene through improved sanitation (Charlton, 1997). The choice of wastewater treatment process in Thimphu was determined keeping in mind the numerous constraints such as capital cost, operation and maintenance cost and availability of technical skills (Charlton, 1997). The concern now is to determine whether the plant is performing to its objective of keeping the environmental impact to a minimum from its effluent discharge. The STP currently serves mainly Thimphu core area and Changjiji government housing complex. Both black water and grey water from the buildings flow to the sewerage system. The designed treatment capacity for 12,500 P.E is far too small for Thimphu's total population and hence the total sewerage coverage has remained below 20% of the total municipal area. Moreover, with lack of fund, Thimphu city could have only about four minor sewerage extension works since the plant's inception in 1996.

Although the wastewater treatment and management in Bhutan still has a long way to go, a notable example of WSP application in the developing countries is exhibited by the WSP constructed at Thimphu. The rest of the city not connected to the plant have individual on-site sanitation system in the form of septic tanks and soak pits. The septic tank de-sludging service is provided by Thimphu Municipality at certain fee but with the treatment efficiency estimated to be poor and desludging frequency irregular and not up to acceptable standard, the septage often overflows to the open storm water drains (Kampsax, 2000).

Because of many reasons, wastewater management has remained poor in most towns in Bhutan. Currently only Thimphu and Phuntsholing cities have piped water borne sewerage systems with centralized wastewater treatment system. One more sewerage project with WSP treatment system is coming up at Gelephu, Bhutan's third largest town. Although on-site sanitation system is common in many smaller towns, its performance has remained poor because of many factors such as poor design and construction, poor operation and maintenance, lack of awareness on the part of the people on the health and environmental impacts and also the small plot sizes have made the onsite sanitation system at more risk to failures. The results are usually chocked soak pits with septage overflowing to the open surface drains, gutters or in the open land creating public health hazards ultimately undermining the qualities of waters in the stream and rivers.

Therefore, conventional sewerage system with centralized wastewater treatment such as WSP will continue to substitute the more expensive centralized treatment system in Bhutan for some time to come. The 2005 Population and Housing Census of Bhutan (PHCB) survey reported that of 15,728 toilets in Thimphu, 72% of them are flush toilets which indicate the urgent necessity to connect these toilets to the public sewer system. But the issue of land availability for upgrading the STP and the choice of low cost treatment system such as WSP will still remain controversial until Bhutan is ready to afford more expensive and compact treatment technologies. Compact treatment systems are much more expensive both in terms of capital cost and O&M costs than the WSP system and moreover the absence of technological know-how in Bhutan is another major setback. Despite all the above constraints WSP will still remain popular for some years especially for those towns with adequate land. The urban development documents for most of the towns also emphasize on the piped collection sewerage system with centralized treatment.

2. STUDY METHODOLOGY

The case study is based purely on the wastewater effluent and influent parameter data maintained by the plant manager cum lab technician, a staff of the Thimphu Municipality which was made available upon request from the authors. During the time of this study in 2008, the authors did not have facilities to verify the water quality data at the site and hence the conclusions arrived in this paper must be viewed from these limitations.

2.1 Thimphu WSP site description

The WSP is located about 10 km downstream of Thimphu city and on the left bank of Thimchu River. The nearest settlements are located more than 200 m away from the STP. The plant is operated and maintained by Thimphu Municipality. Currently the plant occupies a total of 13 Acres of land. One small lab and the living quarter for the plant operator are also located within this plant. The whole plant area is fenced with adequate storm water drainage facilities. The spaces around the ponds are covered with well-maintained grass. Throughout the treatment plant boundary, river training works are provided which was one of the major capital cost component of the plant. Fig. 2 shows the pictures of the treatment plant.

2.2 Design process and treatment system

Raw sewage flowing with natural gravity reaches the plant via a single 800 mm main trunk line and enters the open channel with manual screening bars (20 mm) and then to the venturi flume. The flow is then directed to anaerobic ponds using flow divider with V-notch weir which then enters the facultative ponds and then to maturation ponds before finally discharging to the Thimchu River which has a perennial lean flow of about 3.0 to 5.0 cumecs. Dimensions of the ponds are shown in Table 1. The treatment plant has two series of ponds in parallel. Series I consists of two anaerobic ponds (A1 & A2) in parallel, one facultative pond (F1) and one maturation (M1) pond while Series II consists of one anaerobic (A3), one facultative (F2) and one maturation (M2) ponds. Fig. 3 shows the layout of the WSP system. Anaerobic ponds were designed based on volumetric BOD (all referred for BOD_5 in this paper) loading considering the coldest month of Thimphu to be below 8˚C while facultative ponds were designed based on surface BOD loading assuming that 40% of BOD is removed by anaerobic ponds. For the design of maturation ponds it was assumed that 75% BOD removal is achieved by anaerobic and facultative ponds together and that the surface BOD loading does not exceed that of facultative ponds (Charlton, 1997). Baffle wall also has been provided for the facultative pond in order to increase the length to width ratio of the pond.

Figure 2 View of Thimphu sewage treatment plant (WSP) located at Babesa

Table 1 Design parameters of Thimphu sewage treatment plant (Charlton, 1997; Kampsax, 2000)

Parameters	Unit	Design values
Population equivalent served	EP	12,500
Flow rate, influent	m^3/d	1,750
BOD, load per EP	g/L·EP·d	45
BOD, influent concentration	mg/L	325
BOD, daily design load	kg/d	569
Faecal coliform, influent	FC/100 ml	5E+07
Temperature, design	˚C	8
Flow rate, river	m^3/s	5
River dilution	-	250
Anaerobic pond		
Volumetric load, for T<=10˚C	g BOD/m^3/d	100
Volume	m^3	5,688
Depth	m	3.0
Area	m^2	1,896
Retention time	d	3.3
Secondary facultative pond		
BOD reduction in prior steps	-	0.4
Surface load for T>10˚C	Kg BOD/ha/d	80
Surface load for T<=10˚C	Kg BOD/ha/d	100
Area	m^2	34,125
Depth	m	2.0
Retention time	d	39
Maturation Ponds		
BOD reduction in prior steps	-	0.75
Area	m^2	14,219
Depth	m	1.5
Retention time	d	12.2
Designed performance		
BOD	<20-50 mg/L (80% attributable to algae)	
SS	<60-120 mg/L (80% attributable to algae)	
Retention time	54 days	
Helminth eggs	<0 eggs/l	
FC	<370,000/100 ml	
Influent flow rate	1,750 m^3/d = 20l/s	
River dilution	>250	

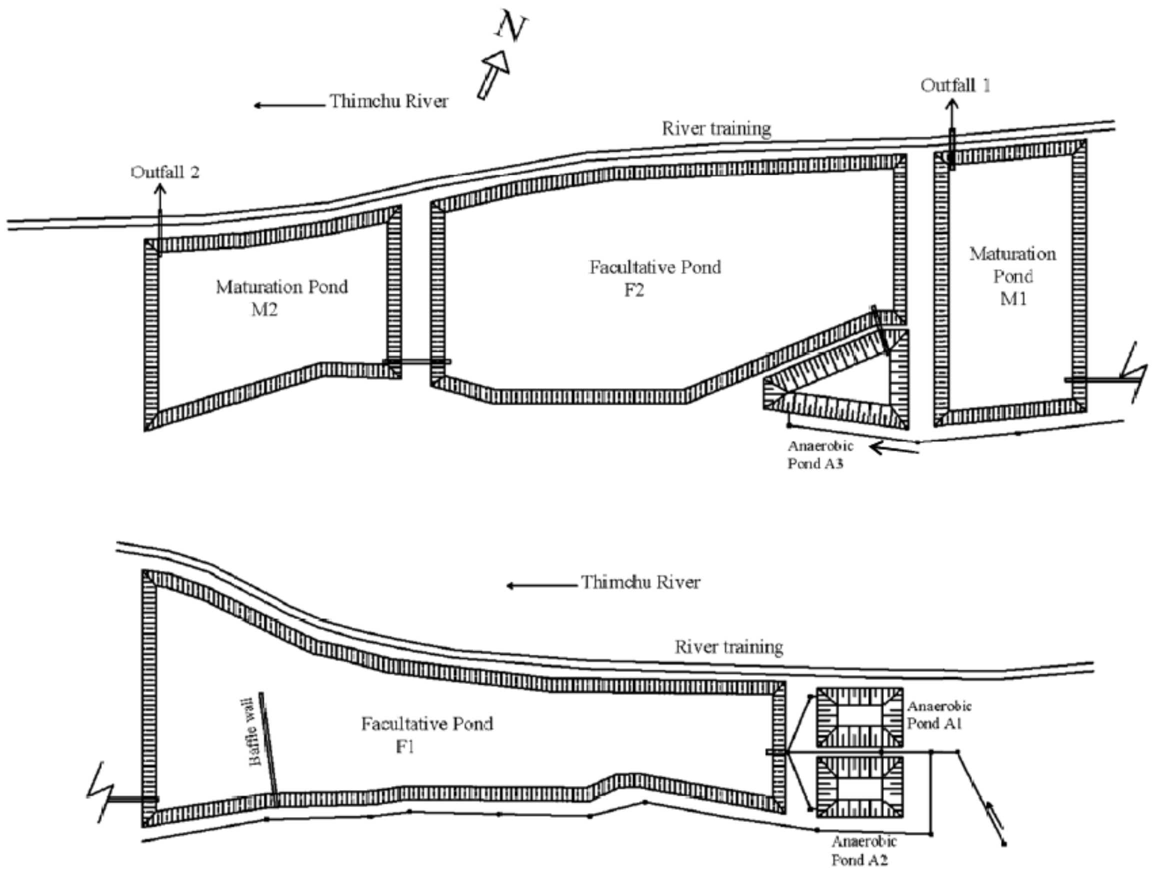

Figure 3 Schematic lay out plan of Thimphu waste stabilization ponds

Series I: (A1+A2) →F1→M1→Outfall 1. Series II: A3→F2→M2→Outfall 2

2.3 WSP monitoring system

The quality and quantity of the wastewater is being monitored at the small laboratory built within the plant. The flow recording, sampling and analysis of physio-chemical and microbiological parameters are conducted regularly. Initially, sampling was performed fortnightly but due to high chemical and reagent costs (as most of the reagents have to be imported from India or elsewhere) the frequency of sampling has been now reduced to once every month while the flow measurement is done once every day.

2.3.1 Flow measurement

At the entry to the pond and following the bar screen is a venturi flume and a diversion chamber with two V-notch weirs. The flow is recorded by measuring the water level at the 90˚ V-notch weir. The following equation has been used for converting the water height to flow:

$$Q = C_d \times (8/15)\,(2g)^{0.5} \times H^{2.5} \tan(\theta/2) \quad (1)$$

Where Q is the flow rate in m^3/s, H is the water level above the crest in m, $C_d = 0.6$ for 90˚ V-notch is the effective discharge coefficient, θ is the V angle and $g = 9.81\ m/s^2$.

Although automatic flow recorder has been installed in January 2003 its use has been discontinued since the operator was not familiar with its use and calibration.

2.3.2 Wastewater sampling

The routine sampling procedures practised at the plant include grab samples from influent raw sewage and anaerobic ponds and column samples from facultative and maturation ponds. The quality of the raw sewage varies considerably throughout the day and therefore composite samples are usually recommended for the raw sewage which was not actually practised in this case. The results for the raw sewage included here are actually from grab samples.

2.3.3 Sample analysis

The monthly data for the physical and biological parameters are maintained at the plant's laboratory for routine monitoring. Physico-chemical and micro-biological tests are performed alternatively for each pond series in a month. For example, for a particular month if the physico-chemical tests are performed for pond series I microbiological tests are performed for pond series II and vice versa. The analyses of the wastewater samples are performed as per the *Standard Methods for the Examination of Water and Wastewater* (18^{th} edition, 1992; published by the American Public Health Association, Washington D.C) except for faecal coliform and Helminth eggs. The enumeration of faecal coliform is performed by 5-tube MPN procedure with A-1 broth following multiple dilutions using 0.85% NaCl and incubating at 44.5˚C for 18-24 hours. As the dilution factor was erroneously excluded due to ignorance of the plant operator, the faecal coliform data data were excluded from this study. However, separate and independent sampling and analysis were performed exclusively to study the pond performance on faecal coliform (FC) removal. The test method consisted of membrane filtration using M-FC Gelman and M-FC Iso-grid membranes. Helminth egg count was performed using the modified Bailenger technique. Meteorological data was obtained from the Metrology Unit, Hydomet Services Division under the Department of Energy.

3. RESULTS AND DISCUSSION

3.1 Wastewater flow to the plant versus the plant capacity

Correct estimation of the sewage inflow to the treatment plant is critical for assessing the hydraulic and the organic loading on the pond system so that the performance of the plant could be compared to the original design assumptions. Fig. 4 shows the average daily sewage inflow to the plant. The flow is observed once every day at 9:00 AM in the morning while, the hourly flow variation is recorded once a month and the results are shown in Fig. 5. It was observed that the peak flow at the plant occurs between morning 9:00 AM and 10:00 AM. Assuming that the water takes about 2 to 3 hours to reach the plant the maximum usage of water occurs between 5:00 AM and 8:00 AM in the morning which is the usual time for washing and cooking before going to the offices or the day's work. The hourly flow recorded once a month has been used to calculate the average daily flow of that particular month in the absence of more accurate daily flow data. The average daily flow for the period of January 2006 to May 2007 was observed between 1266 m^3 and 1741 m^3 which indicate that the hydraulic loading is yet to reach its full plant capacity. The exact figure of the population connected to the sewerage system is not maintained but the city authorities reported that about 80 to 90% of the Thimphu core area and Changjiji Housing complex has been connected but this represents only about 20% of the whole Thimphu municipal area. The flow to the plant is expected to increase since more people are being shifted to the recently developed additional apartments at Chanjiji government housing colony. No increase in the average daily flow was observed during the summer monsoon season as reported earlier which was cited as possible rainwater intrusion to the sewer system (Kampsax, 2003).

Higher average flow recorded during March and April 2006 could be attributed to measurement errors without any unexpected interventions. The result in Fig. 4 shows generally lower average peak flow during the winter months. One possible reason could be that less water is used during the usual morning hours because schools are closed in winter and no students go to school. The population figures of PHCB 2005 indicate that the students constitute about 27% of Thimphu city's total population. Moreover the temperature of water is freezing cold in the early morning of the winter because of which water usage is less. Not all residents have inbuilt water geysers at their homes.

The accuracy of flow depth measured at the V-notch was seen to have significant effect on the flow rate. An error of 1 cm in measuring the flow depth was observed to have about 30% variation in the flow rate (Kampsax, 2003), which is quite significant. In order to provide a more accurate and reliable flow measurement, it is important that the operator is trained and becomes more conversant with the automatic flow recorder since probabilities of making errors while taking the readings of the water height at the V-notch weir are high.

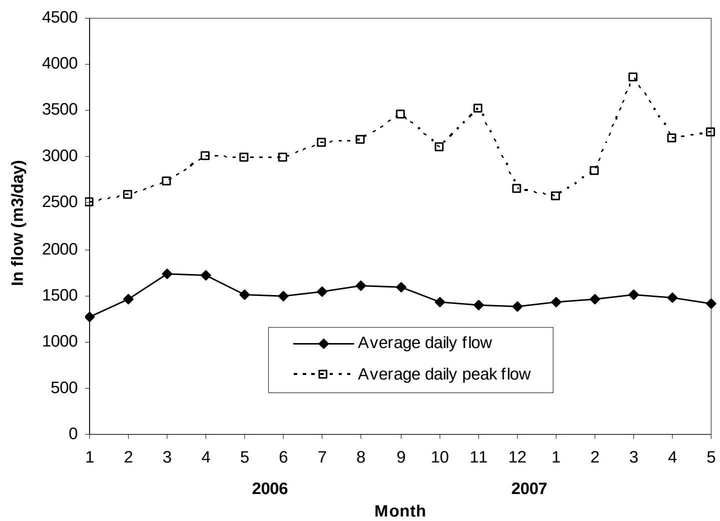

Figure 4 Variation of daily sewage inflow to the plant

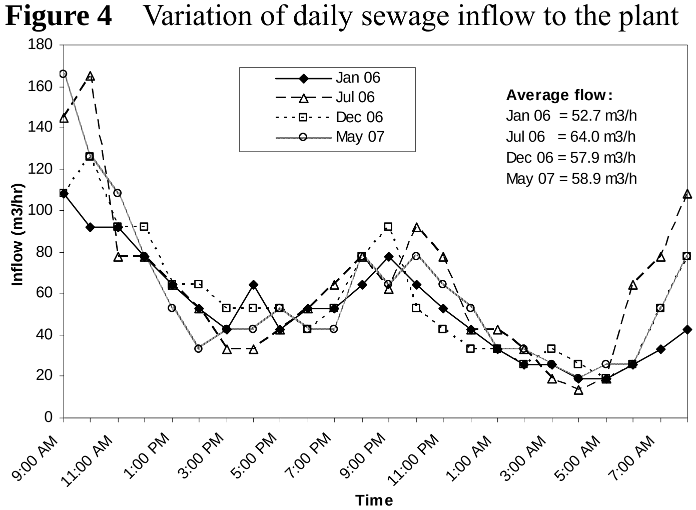

Figure 5 Hourly variation of sewage inflow for 4 selected months

3.2 Temperature and pH

Figs. 6 and 7 show the variation of wastewater temperature and pH respectively during the last 17 months. Inflow average temperature was recorded from 8.1˚C in winter to 18.5˚C during the summer with annual average temperature of 15.4˚C. The average temperature of the effluent wastewater was recorded between 8.1 and 17.8˚C with an annual average of 15˚C. Fig. 6 shows the variation of monthly average temperature of the influent and the effluent wastewater.

The monthly pH of the influent ranged from 7.1 to 8.2 with an annual average of 8.0 while the effluent pH was recorded between 7.0 and 8.0 with an annual average of 7.6. This is in contrast to higher pH usually expected in the maturation ponds.

3.3 Suspended solids (SS) removal

The SS of the influent was observed between 150 and 350 mg/L with an annual average of 230 mg/L (Fig. 8). An unusually high SS concentration was observed in the month of April 2007 possibly due to analytical errors. The annual average SS of the final effluent was 90 mg/L and did not cross the maximum allowable value of 120 mg/L by NEC during any month. Unlike BOD and COD removal efficiencies, the efficiency of SS removal was observed to be irregular ranging from 30% to 80%.

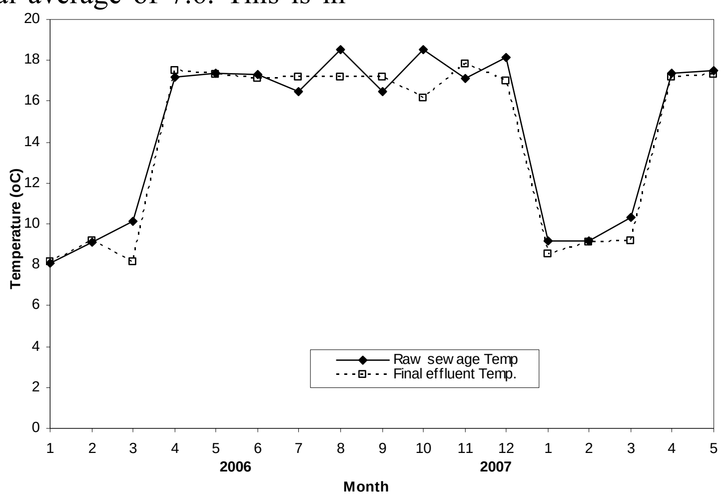

Figure 6 Variation of monthly average temperature of the influent and effluent

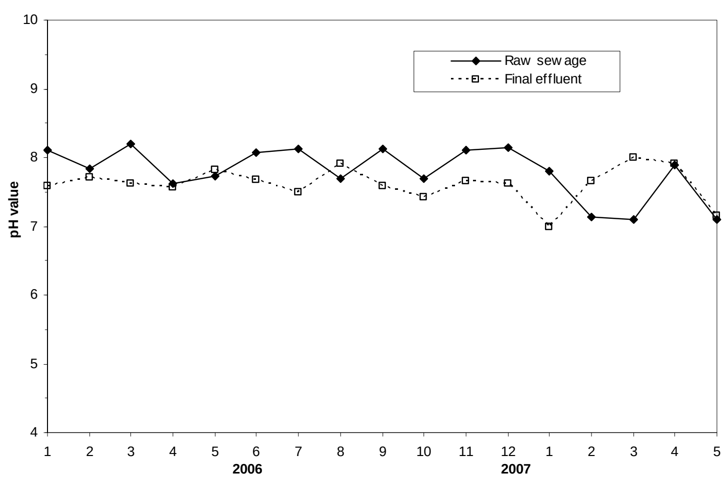

Figure 7 Variation of monthly pH of the influent and effluent

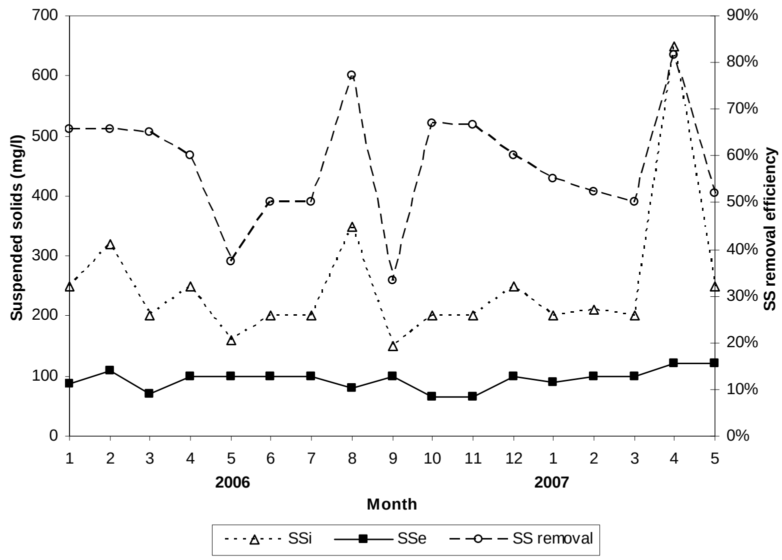

Figure 8 SS variation of the raw sewage and the effluent & the SS removal efficiency of STP

3.4 BOD and COD removal

Fig. 9 shows the monthly variation of influent and effluent BOD from January 2006 till May 2007. The BOD of the influent varied from 200 to 310 mg/L against the design assumption of 325 mg/L. The BOD (unfiltered) of the final effluent was observed between 30 to 48 mg/L during 17 months observation period with removal efficiency between 78% and 90%. No decrease in BOD removal efficiency was observed during the cold winter seasons (December-February) although winter sewage temperatures were observed to be about 8 to 9˚C lower than the summer (June-August) temperatures (Refer Fig. 6). Although, the temperature of the anaerobic ponds at different depth is not available, it is possible that the temperature of the anaerobic pond at the lower depths might be higher than the pond surface temperature or the raw influent. This is because the anaerobic process itself is an exothermic process and the heat retention must be further aided by long sludge retention time thereby likely favouring BOD/COD removal even though the surface temperature of the pond water is low during the cold winter period. The expected BOD (unfiltered) of the final effluent is less than 50 mg/L and hence the effluent meets NEC's industrial effluent discharge standards.

The monthly variation of influent and effluent COD is shown in Fig. 10. Influent COD was observed between 330 mg/L and 630 mg/L although an unusually high COD recorded for the month of April 2007 is possibly due to analytical errors. The COD of the final effluent was observed to be less than 80 mg/L during all the months with removal rate from 83% to 95%.

This clearly shows that the plant has achieved much higher BOD and COD removal than it was expected during the design. Algae usually contributes to about 70-90% of the BOD, COD & SS (Mara, 1997) and the fact that the above effluent results are obtained with unfiltered samples, the performance of the plant in organic removal is still higher. Although the data on the algae is not available for this pond however it is highly likely that the wastewater effluents from the facultative and maturation ponds could contain algal BOD, COD and SS. This is because the presence of nutrients in the facultative and maturation pond water aided by sunlight and slight atmospheric mixing at the pond surface could provide conditions for the growth of certain amount of algae. The visual appearance of algal growth in the facultative and maturation pond especially during the warm summer months was confirmed by the plant in-charge although the ponds did not experience major algal bloom. Because of high algal contents in WSP effluent, most European WSP can contain as high as 150 mg/L of SS although the actual non-algal SS is limited to less than 35 mg/L (Mara, 1997). These results therefore indicate that WSP can perform quite well in the cold climates of Bhutan and therefore is very suitable technology for domestic wastewater treatment.

Fig. 11 shows the BOD removal by anaerobic and facultative ponds. As shown the anaerobic pond alone removed more than 70% of BOD which is much higher than expected of up to 40% (Table 1). Therefore, anaerobic ponds are very effective in Bhutan for BOD removal although its efficiency decreases slightly during the cold winter. The anaerobic ponds and facultative ponds together removed more than 80% of the BOD against the expected removal of 75%. This also confirms the earlier report by Kampsax (2003) that the removal efficiency of constantly higher than 60% was observed which were not accounted for in the design. The high values of BOD/COD ratio (0.3 to 0.8) indicate the biologically degradable nature of the raw sewage which is one reason for high removal of BOD by anaerobic ponds. Moreover, the desludging period of the anaerobic pond was 7 years since commissioning of the plant against the expected period of 5 years which indicates the high biodegradability of the raw sewage.

The BOD removal efficiencies of facultative pond in the winter months of December and January were observed to be comparatively higher which likely compensated the lower efficiency of the anaerobic ponds during the lower temperature. The removal efficiency of facultative ponds was observed to be rather irregular which may be due to sampling and analytical errors. The effluent BOD during the summer monsoon season should be less because of the dilution from the rain water but the result does not show significant lowering of effluent BOD, COD or SS concentrations of the effluent.

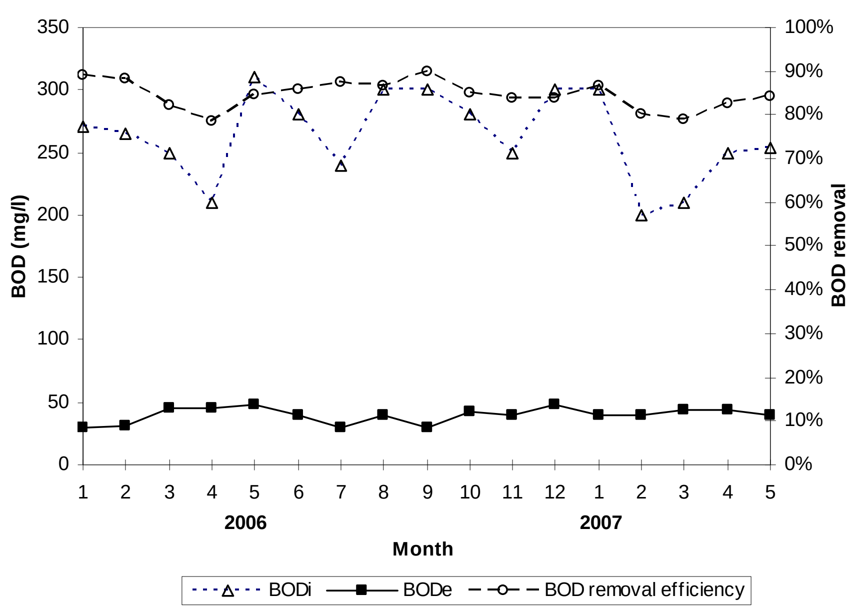

Figure 9 BOD variation of the influent and the effluent & the BOD removal efficiency of STP

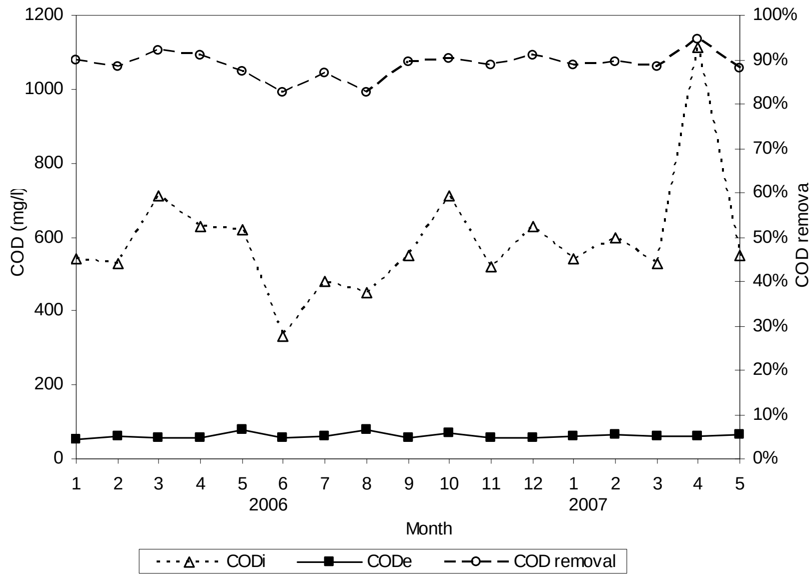

Figure 10 Variation of influent and effluent COD and removal efficiency

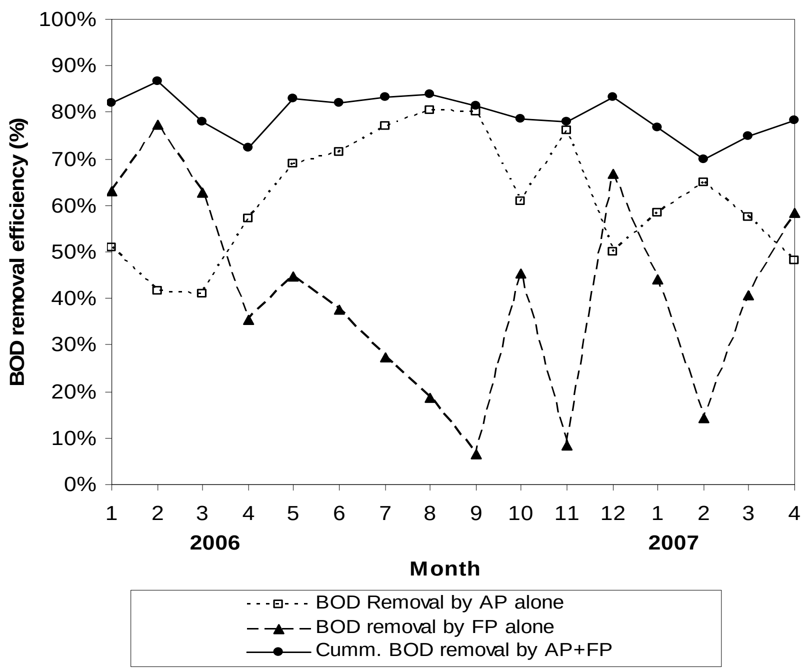

Figure 11 Performance of Anaerobic & Facultative ponds for the removal of BOD

3.5 Faecal Coliform or FC removal

Biological data is one of the most important parameter for evaluating the performance of the plant especially if the final effluent is for reuse. Stabilization ponds are very efficient process for the removal of all kinds of pathogens (Jimenez, 2007). Although the final effluent for this particular treatment plant is not intended for any reuse its discharge to the river is a concern especially if the river down stream is used for human consumption. But there are no reports of human consumption down stream of the river. The river flows during the lean period vary from 4.0 to 5.0 m^3/s and therefore high dilution factor is usually achieved after discharge of the effluent. The river samples from 100 m up stream and 100 m downstream of the out falls are collected and its quality is monitored together with the regular influent and effluent samples. The result does not indicate any significant changes in the quality of the river water downstream because of the discharge of the effluent from the STP.

The FC of the influent varied from 9.2×10^6 to 5.1×10^7 Nos. per 100 ml (not shown here). The FC count in the final effluent was observed between 6.0×10^4 and 2.0×10^5 Nos. per 100 ml against the expected performance to less than 3.7×10^5 Nos. per 100 ml. This indicates that the WSP meets the effluent discharge standards set by NEC but it does not meet the WHO standard of <1000 per 100 ml for restricted irrigation. In order to achieve higher FC removal efficiency, the pond retention time should be increased which of course demands for increased area of the maturation ponds.

3.6 Helminth Eggs removal

Helminth Eggs are pointed out as one of the major concerns in wastewater effluent especially if water is for reuse not only in agriculture but also in aquaculture, particularly in developing countries (Jimenez, 2007). No helminth eggs were observed in the final wastewater effluent indicating that the WSP practically removed all the eggs.

4. DATA LIMITATIONS

These results were obtained through the monthly routine test performed and the data maintained at the plant laboratory. These data has not undergone any quality check as evident from the faecal coliform data maintained so far and therefore the degree of accuracy of these results and interpretation are dependent on the reliability of the data provided by the plant officials. Because of lack of fully equipped research laboratories anywhere in Bhutan, only the minimum essential evaluation parameters have been used for assessing the plant's performance.

CONCLUSIONS AND RECOMMENDATIONS

The wastewater flow records maintained by the plant indicate that the hydraulic and organic loading is yet to reach its full design capacity. Before drawing correct conclusions more accurate daily flow data are necessary. This could be done by increasing the frequency of hourly flow readings. Without using automatic flow recorder, hourly flow measurement every day could be too tedious and unnecessary but hourly flow once a week instead of once a month could provide a more accurate average daily flow data. The city authorities should encourage the use of automatic flow measuring device. The comparison of the influent and the effluent parameters for the last 17 months indicates that the plant effluent meets the NEC industrial discharge standards for organic, SS and microbiological removal but the results also demonstrate that it is necessary to have a good amount of quality data over a long period to provide full information on the performance of the WSP treatment system. The anaerobic ponds were found very effective in BOD removal of up to 70% against the designed expectation of 40% and therefore anaerobic pond is a promising method for primary treatment of wastewater. For more accurate and reliable results, composite samples are recommended instead of single grab sample for raw sewage. Some of the analytical equipment needs to be upgraded so that the analytical results are more reliable. Further research is necessary with more accurate analytical equipment to study the suitability of such treatment systems in other parts of Bhutan. Finally we conclude that WSP is a very effective system for wastewater treatment in Bhutan. The perennial river with high flow velocity and turbulence has greater probabilities of further removing the residual pollutants from the discharged pond effluent.

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