Evaluation of Technical Performance of Beit-Lahia Wastewater Treatment Plant in the Northern Gaza Strip- Palestine

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1. BACKGROUND

The Gaza strip has suffered years of occupation, neglect and infrastructure destruction. The quality of the groundwater is a major problem in the Gaza strip. Access to sewerage facilities, at present, varies from area to area. On average, it is estimated that about 60% of the population is connected to a sewerage network **(UNEP, 2003; World Bank, 2004)**. Cesspits and boreholes are the other wastewater disposal systems in the area. There are three wastewater disposal and treatment facilities in Gaza strip, Beit Lahia, Gaza City and Rafah, but none are functioning effectively **(MOPIC, 1998)**. The effluent from the Gaza and Rafah treatment plants is mostly discharged into the Mediterranean Sea. In the case of the Beit Lahia wastewater treatment plant (BLWWTP), a substantial quantity of wastewater infiltrates into the ground, contaminating soil and groundwater in the area. High level of nitrate have recently been detected from the aquifer, and it is most likely that the excess effluent is responsible for the deterioration of the water quality of the aquifer **(Abu-Jalalah, 1999)**.

The actual BLWWTP (Waste Stabilization and Aerated Lagoon Hybrid System) serves Jablia refugee camp, villages of Beit Lahia, Nazla, Aum El-Naser and Beit Hanoun and the system doesn't operate in accordance with its original design. In fact, the actual plant differs from the original design in the number of ponds as well as the function of the pond. The plant is over loaded: it was designed to serve a population of 50 thousand inhabitants while it is currently serving around 265 thousand inhabitants. Today, the ponds are operating in series with the following order: 2 anaerobic lagoons, 2 actively aerated lagoons, 2 facultative lagoons and 1 maturation lagoon (figure 1).

This study aims to evaluate and identify the performance and removal efficiency of each treatment unit of BLWWTP through a comprehensive field and laboratory analysis program of wastewater collected samples from different locations of the treatment plant and reviewing the historical and existing monitoring data in the last five years. From this data, the options available to improve the performance of the plant and mitigate health and environmental problems are examined and recommendations presented.

2. METHODOLOGY

A sampling program was conducted at Beit Lahia Wastewater Treatment Plant (BLWWTP). The treatment system was monitored for three and half months, starting from 15/2/2005 to 26/5/2005. Figure (1) presents the sampling locations and table (1) illustrates the purpose of selection of each location. Effluent from each treatment unit was analyzed for temperature, dissolved oxygen, pH, Electrical Conductivity (EC), 5 Days Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), NH_4, Fecal Coliform (FC), solids, salmonella and nematodes. Chlorophyll-a was analyzed for location 4 and 5 in the laboratories of Environment and Earth sciences

Department- Islamic University of Gaza according to standard methods for the examination of water and wastewater **(APHA, 1995)**.

The sampling of the wastewater was conducted 30 cm below the lagoons surface. Wastewater was pumped to the sample bottles manually by using a pump with a polyethylene pipe that immerged beneath the water surface. Precautions and proper procedures of sampling processes and preservation were taken into account and done according to standard methods for the examination of water and wastewater **(APHA, 1995)**.

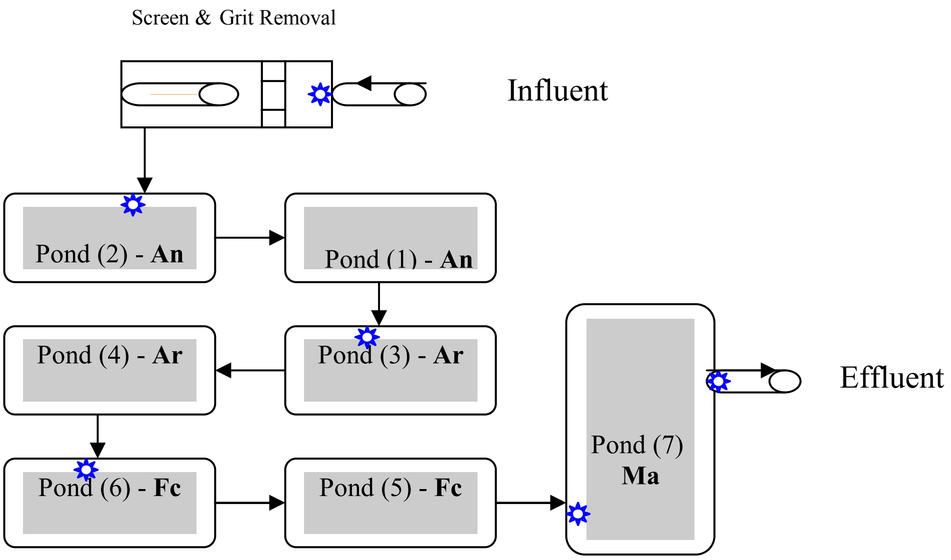

Figure 1: Flow diagram of treatment system and sampling points.
An = anaerobic pond, Ar = aerated pond,
Fc = facultative pond, Ma = maturation pond,
☼ *= Sampling points.*

Table1: Purposes of sampling sites selection**.**

Location	Purpose of selection
1	Determine the characteristics of raw wastewater.
2	Evaluate performance of pre-treatment (screen and grit removal).
3	Identify removal efficiency primary treatment unit (anaerobic lagoons-ponds 1+2)
4	Determine removal efficiency of aerated lagoons (ponds 3+4)
5	Identify removal efficiency of facultative ponds (ponds 5+6).
6	Determine the removal efficiency of maturation lagoon (pond 7).

3. Results and Discussion

The results include the main physical, chemical and biological parameters of different locations of the treatment system. Table (2) summarized the average values of different parameters at different sampling locations of the wastewater treatment plant.

3.1 Dissolved Oxygen (DO)

Measurements taken from aerated, facultative and maturation ponds showed that average DO concentrations are 3.07mg/L, 2.52mg/l, and 2.57 mg/L respectively. Solubility of gases

Table 2: Average monitoring values of the different parameters of the sampling locations of the treatment system.

Parameters	Unit	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	% Total Removal
Water Temp.	C°	21.50	21.80	21.00	20.00	21.00	21.30	-
DO	mg/L	2.300	2.100	2.100	4.400	2.800	2.800	-
Settleable S	1hr - ml/L	9.400	2.100	0.700	1.600	0.300	0.100	98.93
Settleable S	2hr - ml/L	9.600	2.400	0.800	1.700	0.310	0.120	98.75
TS	mg/L	1382.5	1235	1165	1082.5	1090	1065	22.96
DS	mg/L	954.6	914.7	920.7	891.0	903.9	912.3	4.43
SS	mg/L	308.8	206.3	129.6	80.60	73.80	39.40	87.24
FS	mg/L	792.5	880.0	885.0	868.1	845.0	845.0	-
VS	mg/L	590.0	355.0	280.0	214.4	245.0	220.0	62.71
pH	-	7.4	6.9	7.4	7.8	7.5	7.6	-
BOD_5	mg/L	425.0	290.6	210.0	124.4	178.1	178.8	57.93
COD	mg/L	885.0	590.1	470.4	393.3	377.6	349.8	60.47
Chlorophyll a	mg/L	-	-	-	55.40	145.3	-	-
TKN		106.1	81.70	86.00	82.80	84.70	84.30	20.54
NH_4	mg/L	84.10	72.20	71.60	72.60	73.9.0	72.9.0	13.31
F.Coliform	MPN/100ml	3.86 E+06	2.59 E+06	9.40 E+05	1.00 E+06	3.50 E+05	2.04 E+05	94.70
Salmonella		-ve	-ve	-ve	-ve	-ve	-ve	-
Nematodes		+ve	+ve	-ve	-ve	-ve	-ve	-

generally declines with an increase in temperature. As the temperature increased from February to May, the average dissolved oxygen concentration decreased as shown in figure 2 of location 4 as an example.

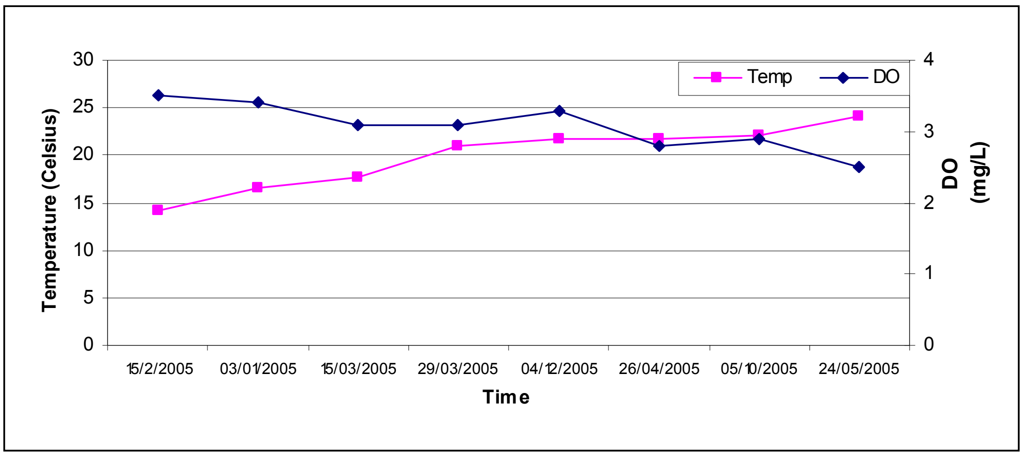

Figure 2: Average dissolved oxygen and temperature values over the time in location 4.

Dissolved oxygen levels are maintained by surface aeration, which is stimulated by wind, rain and algal photosynthetic activity **(Reed et al., 1995)**. Oxygenation from photosynthesis is directly proportional to algal activity levels, which are controlled by the presence of light, temperature, availability of nutrients and other growth factors **(Reed et al., 1995)**. The availability of dissolved oxygen (DO), which regulates processes such as microbial oxidation of carbonaceous and nitrogenous compounds, is strongly temperature dependent. The solubility of oxygen is greatest in cold wet seasons and lowest in dry warm periods, which would suggest that BOD reduction would be enhanced in winter **(Reed et al., 1995; Kadlec and Knight, 1996)**. Concentration of dissolved oxygen in BLWWTP is eligible to be dropped in summertime as long as water temperature increases and as a result of this, BOD_5 removal is expected to decline.

3.2 Solids

The results showed that the system is achieving remarkable reductions of total solids (TS), total volatile solids (TVS), and total suspended solids (TSS) concentrations while total fixed solids (TFS) and total dissolved solids (TDS) reveal fluctuation in concentration without significant reduction. Influent to the system contained an average of 1382, 308 and 590 mg/L of total solids (TS), suspended solids (TSS) and volatile solids (TVS) respectively. The average percentage reductions for TS, TSS and TVS concentrations through different treatment stages of the system were 23%, 87% and 63%, respectively. With comparison to previous monitoring programs **(Word Bank, 2004)** with the results from this study in 2005, the average pond effluent TSS removal for 1999, 2000, 2001, and 2005 are 98.2%, 94%, 90.5%, and 87.2% respectively, indicating deterioration of the treatment plant performance with respect to this parameter **(Word Bank, 2004)**.

Cumulative removal of TSS along sampling points is presented in figure (3). Samples collected as part of this study showed that the average TSS concentration was reduced from 308.75 mg/L to 129.625 mg/L with an average removal of 58%. The average TSS through the aerated lagoons (pond 3, 4) was reduced from 129.625 mg/L to 80.625 mg/L with a removal of 37.8%. Reductions of TSS solids that took place in facultative lagoons (pond 6, 5) were 8.5% while it reaches 46.6% in maturation lagoon (pond 7). Over all removal of TSS in the whole treatment plant was 87.24% with an average of 39.37 mg/L. Anaerobic lagoons and to a lesser extent maturation ponds showed the highest TSS removal while facultative ponds had a limited contribution to TSS removal due to algal growth.

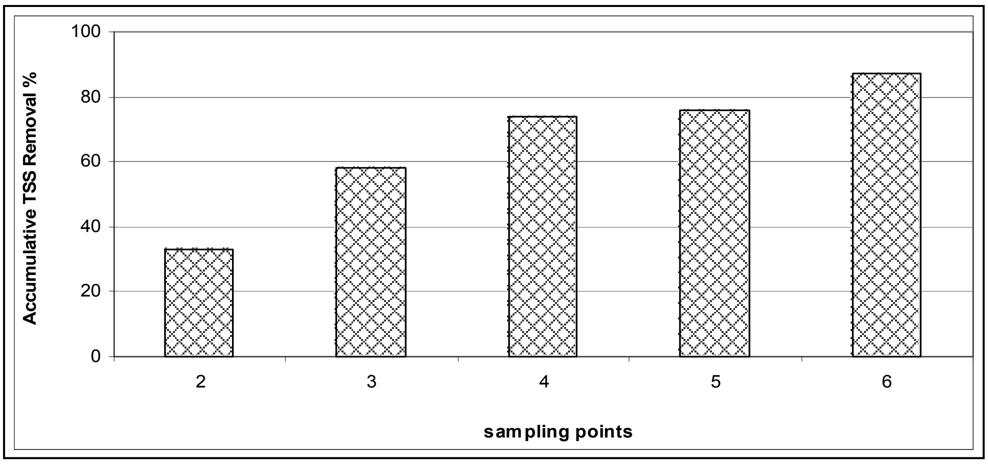

Figure 3: Cumulative removal of TSS along sampling points.

The system is achieving remarkable reductions of total solids (TS) concentrations. Most reductions of TS were apparent as suspended and volatile solids. However, reductions of the more conservative dissolved and fixed solids revealed fluctuation in concentration without significant reduction. The production of suspended solids in aerated lagoons may be due to the disturbance and re-suspension of settled organic matter caused by aerators. TSS reductions in facultative and maturation ponds were hindered by contributions of suspended material from algal growth. Average reduction of suspended solids in the treatment plant (87%) was less effective than observed in previous years. **Reed (1995)** reports that short-circuiting resulted in decreased suspended solids removal. Over the years, BLWWTP received increased amounts and higher flux of flow which exceeded the design capacity of the WWTP resulting in a short detention time.

Removal of suspended solids is facilitated by the physical settling of particles and subsequent biological decomposition and mineralization of compounds. **Crites and Tchobanoglous, (1998)** stated that the influent suspended solids in BLWWTP are mainly removed by sedimentation in lagoon systems. Some reduction in suspended solids is due to the breakdown and oxidation of suspended particulates. Algal solids that developed during treatment dominated the effluent suspended solids which ranged as high as 140 mg/L for aerobic lagoon to 60 mg/L for aerated lagoons. Because the most algal solids are difficult to remove from water and effluent, standards often cannot be met and additional processes may be needed to remove the solids. **(Reed et al., 1995)** reported that the effluents from Waste Stabilization Ponds (WSP) systems are characterized by a high concentration of suspended solids, which in some occasions can exceed 100 mg/L due to algae in the effluent. The BLWWTP treatment system is performing relatively well with regard to TSS removal. It is believed that about 37% of effluent suspended solids refer to contribution of algae.

Settleable solids were measured in the laboratory using Imhoff Cone for one and two hours. Minimal variation had been reported between the two readings which reflect high settleability of organic material removed by gravity especially in the primary treatment unit. The average settleable solids concentration after one hour settling time was reduced from 9.4 ml /L to 0.1 ml /L with an average removal of 98.80% (Figure 4) in the all stages of the treatment system. The main reduction of settleable solids concentration taken place in grit removal and the anaerobic pond with an average removal of 92.8%. Settleable solids increased from 0.675 ml /L to 1.55 ml/L in the aerated lagoon. This increase was due to the mechanical agitation of aerators and mixers which caused excitation for settled particles.

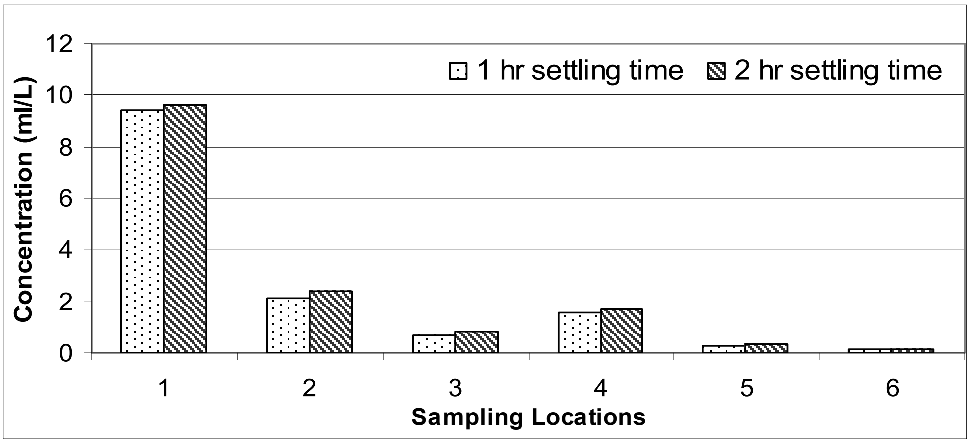

Figure 4: Average settleable solids after one and two hour concentration at different sampling points.

3.3 Carbonaceous Organic Matter

The carbonaceous organic mater removal was measured through biochemical and chemical oxygen demand (BOD_5 and COD). Figure 5 presents the average BOD_5 concentration at different sampling points of the treatment system. The average BOD_5 concentration was reduced from 425 mg/L to 210 mg/L in the anaerobic ponds with a removal of 50.6% and reduced from 210 mg/L to 124.375 mg/L in the aerated lagoons with an average removal of 40.8%. Through passage of wastewater in the facultative lagoons (pond 6, 5), the average BOD_5 was increased from 124.375 mg/L to 178.1429 mg/L with an average of 30.18%. No considerable change in BOD_5 has been measured in maturation lagoon removal. Over all BOD_5 removal in the whole treatment plant system was 57.94% with 178.75 mg/L effluent concentrations.

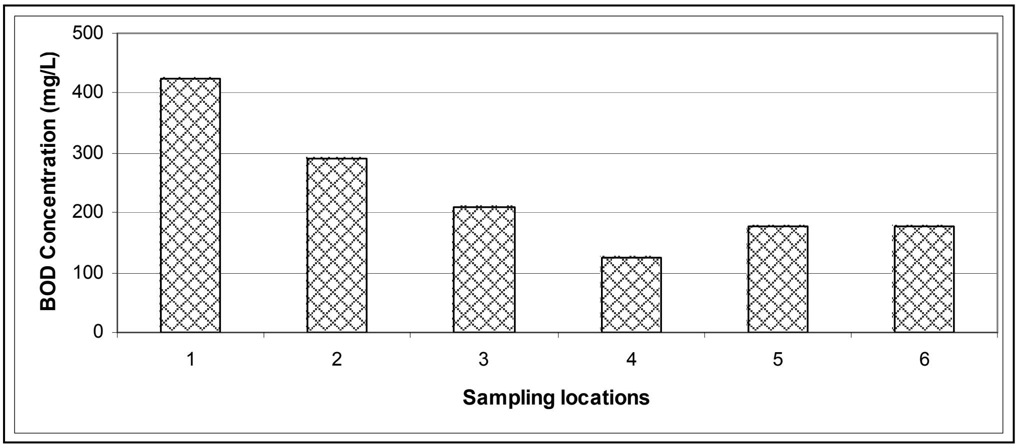

Figure 5: Average BOD_5 concentration at different sampling points.

To set aside the effects of algae growth on effluent BOD_5, analysis were also performed on selected samples for BOD_5 before and after filtration. The average BOD_5 value for filtered samples was 115 mg/L. The contribution of algae to effluent BOD_5 concentration is around 36%. That means that the total removal efficiency of the system is around 72%, taking in account only the average BOD_5 value of the effluent.

Effluent BOD_5 has been seriously increased since 1999 and the average BOD_5 removal percentage was decreased in the same period (figure 6). The BLWWTP removal efficiency is continually decreased over time. This phenomenon may enhance the claim that BLWWTP is seriously hydraulically and organically overloaded.

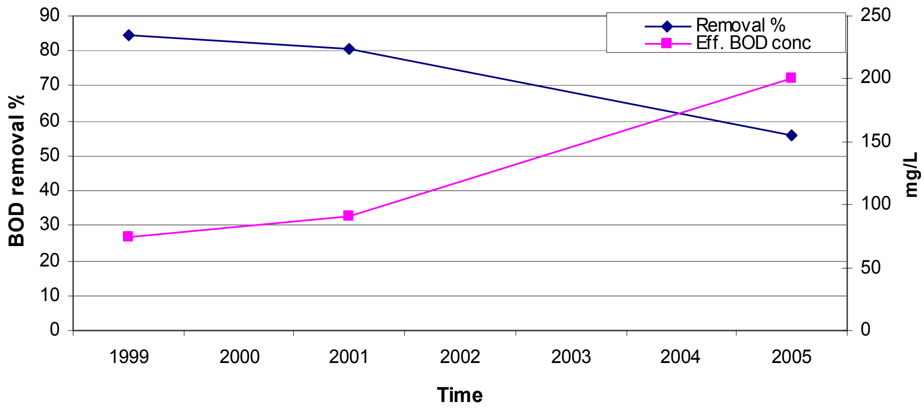

Figure 6: Percentage removal and effluent concentration of BOD_5.

Lowering of BOD_5 is both a physical process by way of settling of organic particles and a biochemical process through decomposition and mineralization of organic and inorganic compounds **(Reed, 1995)**. A well-designed anaerobic pond has been reported to achieve up to 60% reduction in BOD depending upon the temperature and retention time **(Horan, 1990)**. Although the anaerobic pond achieved more than 50% of the influent BOD_5 removal through a good settleableaty of SS, the residence time is suspected to be sufficient to remove that accumulated organic mater by anaerobic decomposition. Consequently, anaerobic ponds could not be operating for a long time without desludging.

In a good designed system, aerated lagoons can reliably produce an effluent with both biological oxygen demands (BOD_5) and TSS < 30 mg/L if provisions for settling are included at the end of the system **(EPA, 2002)**. Effluent of this quality from aerated lagoons is not produced along the monitoring program in BLWWTP due to incorrect operation and high surface organic loading. The high organic load that is applied to facultative ponds creates conditions that prevented a normal concentration of algae which reflected on BOD_5 removal efficiency in these lagoons. During study monitoring programs, final effluent were measured for filtered BOD_5 on four occasions and the result showed that maximum contribution of algae to effluent BOD_5 was 38.7%. This is incorporated with low concentration of chlorophyll-a due to the overloading of facultative.

The results showed that the average influent COD concentration was 885 mg/L over the monitoring period. Figure (7) presents the average percentage removal efficiency and cumulative removal effects of different ponds types. The total removal efficiency of the system reached an average of 60.6%. The greater portion of reduction was achieved in the anaerobic ponds (46.9%), while the aerated, facultative, and maturation lagoons caused a reduction of 16.4%, 4.1%, and 7.4% respectively.

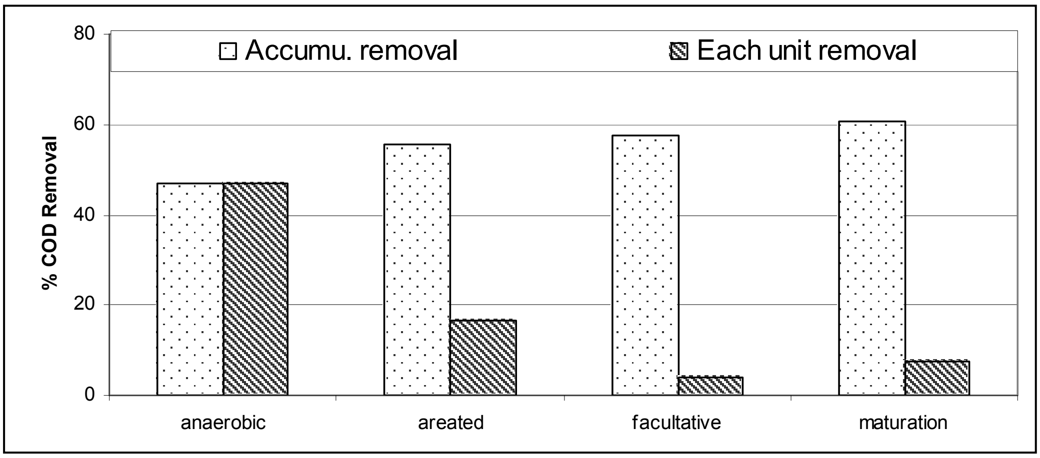

Figure 7: COD average percentage removal efficiency and accumulative removal effects of different ponds types.

The study results showed that effluent COD concentrations for the existing condition were notably higher than COD concentration in years 1999 and 2001 by two and half folds (349 mg/L) **(PWA 1999a; Word Bank 2004)** and; in spite of that the average influent COD concentration at the present time is lower than it was in the year 1999 **(PWA 1999a)**. Average COD reduction efficiency in 2000, 2001 was 87.6% and 84.9% (**Word Bank 2004)**.

The reduction percentage of COD are higher slightly than BOD_5. Figure (8) showed that displayed average COD: BOD_5 ratio at different sampling points indicated a slight increase of this ratio in anaerobic lagoons. The increase could be related to the fair decomposition of readily biodegradable material. The sharp increase of COD: BOD_5 ratio in the aerated lagoon did not indicate a reasonable level of digestion activity of readily biodegradable material but may refer to the action of aerators that re-suspended a well stabilized settled organic matter and as a result elevated COD concentration in the sample collected from these lagoons. Easily evacuation of re-suspended well stabilized organic matter, by resettling and decrease of algae concentration in facultative and maturation ponds that absorb BOD_5, may be responsible for reduction of this ratio.

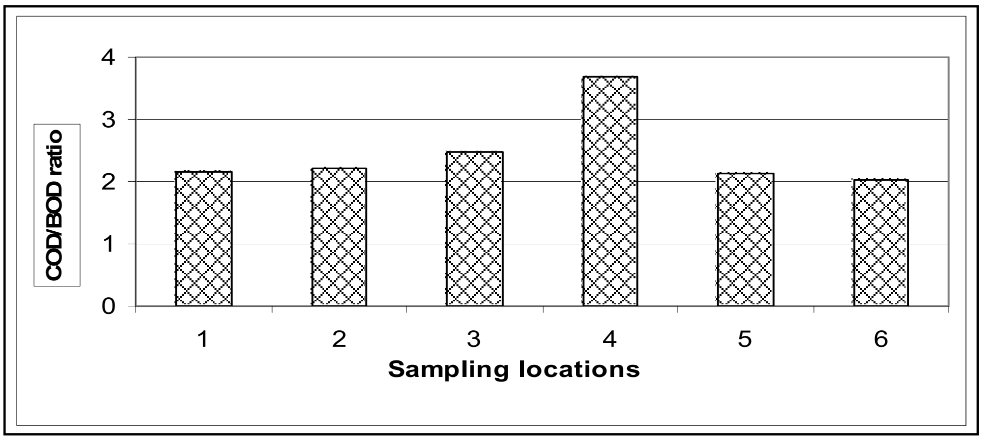

Figure 8: Average COD: BOD_5 ratio at different sampling points.

3.4 Chlorophyll-a

Unlike other parameters, chlorophyll-a was measured only in influent and effluent of the facultative ponds (locations 4 and 5) to determine the concentration of algae biomass. Table (3) shows Chlorophyll-a concentrations at the effluent of both locations in the period from February to May 2005.

Table 3: Chlorophyll-a concentration at the effluent of facultative lagoons.

Sampling Date	Location 4 (µg/ L)	Location 5 (µg/ L)
15/02/2005	34.1	34.1
15/03/2005	38.4	68.1
29/03/2005	45.4	79.5
12/04/2005	56.8	272.5
24/05/2005	102.2	272.5
Average	**55.4**	**145.3**

The results indicated a good increase of chlorophyll-a in facultative pond effluents from winter season to spring and the values varied between about 34 and 102 µg/ L with an average of about 55 µg/L in location 4, compared with an average of 145 µg/L in location 5.

The concentration of algae in an optimally performing facultative pond depends on organic load and temperature, but is usually in the range of 500 to 2000 µg chlorophyll-a per liter **(Cinara, 2004)**. **(Curtis et al., 1992)** stated that the concentration of algae in a well-functioning facultative pond depends on loading and temperature. It is usually in the range of 500−1000 µg chlorophyll-a per liter (algal concentrations are best expressed in terms of the concentration of their principal photosynthetic pigment).

3.5 Nitrogen

Sewage of domestic origin contains nitrogen either organically bound as protein and nucleic acids, as urea or as the ammonium ion (NH_4^+). Nitrates and nitrites are rarely present. The total nitrogen content referred to as Total Kjeldah1 Nitrogen (TKN) represents the organic nitrogen and the free ammonium. Figure (9) presents average values of TKN and NH_4 of different sampling location during the monitoring period. The results showed relatively high TKN content of the influent and limited reductions of both parameters through the treatment system. The average percentage of ammonia fraction from TKN was more than 75%. The results showed that the main reduction step was in anaerobic pond location 2.

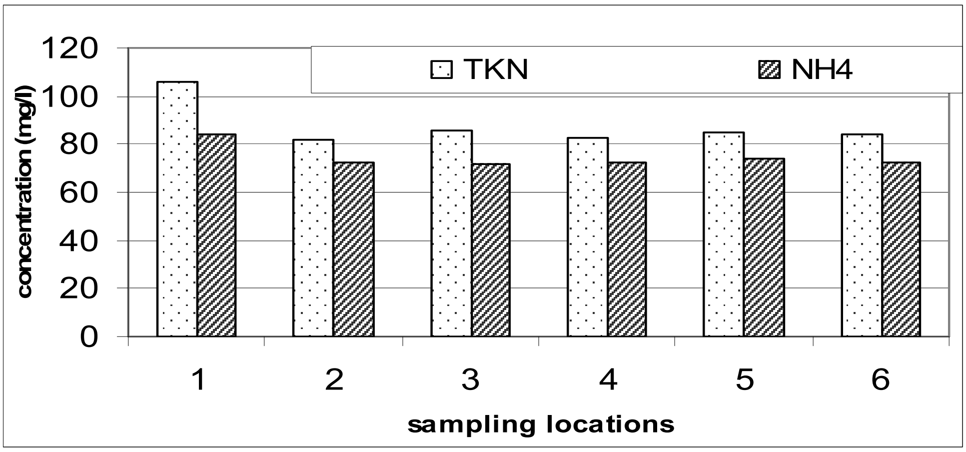

Figure 9: Average TKN and NH_4 concentrations along sampling points.

The ammonia was the mean percentage fraction of the influent TKN with more than 75%, which mean rapid mineralization of organic nitrogen that converted to ionized ammonia inside sewerage networks which characterized as a highly anaerobic environment. The three mechanisms for ammonia removal in ponds are volatilization, assimilation into algal biomass and biological nitrification coupled to denitrification **(Middlebrooks et al., 1982)**. **Mara et al. (1992)** reported a total nitrogen removal of 80% in all waste stabilization pond systems, which in this figure corresponds to 95% ammonia removal. It should be emphasized that most ammonia and nitrogen could be removed in maturation ponds, but the monitoring results, as seen in figure (9), showed that limited removal of TKN and NH4 parameters along sampling points. Removal of around 20% of TKN and ammonia took place in the inlet and the anaerobic ponds while other lagoons did not reveal significant contributions in the removal. Strong flux of wastewater flow from closed sewerage systems to open screening and grit removal unit makes agitation which allows ammonium volatilization especially if we take into account relatively high water temperature. So, 50% of total removed TKN can be attributed to ammonia volatilization while the rest is settled as organic nitrogen in anaerobic ponds **(Horan, 1990)**. Treatment after anaerobic ponds was maintained steady concentration of TKN and ionized ammonia. Nitrification-denitrification process which eligible to accomplished in aerated and facultative ponds is not expected to be realized due to high organic load and limited oxygen supply. Low concentration of algae can be interpreted as the limited assimilation of ionized ammonia into algal biomass.

3.6 Biological Parameters

Fecal coliform (FC), Salmonella and Nematodes were used as indicator parameters for the biological contamination level of collected samples. Figure (10) presented the average FC couint of the different sampling locations of the treatment plant. The average removal of FC through the whole treatment train was 94.7% with an average effluent concentration of 5.00 log units/100 ml. The FC count in the final effluent of the treatment system maintained the value of 4.00 log units/100 ml along study period. With comparison to monitoring programs that carried out in 1999 **(PWA, 1999a; PWA 1999b),** the average removal of FC is 99.52% with an average effluent concentration of 4.00 log units/100 ml.

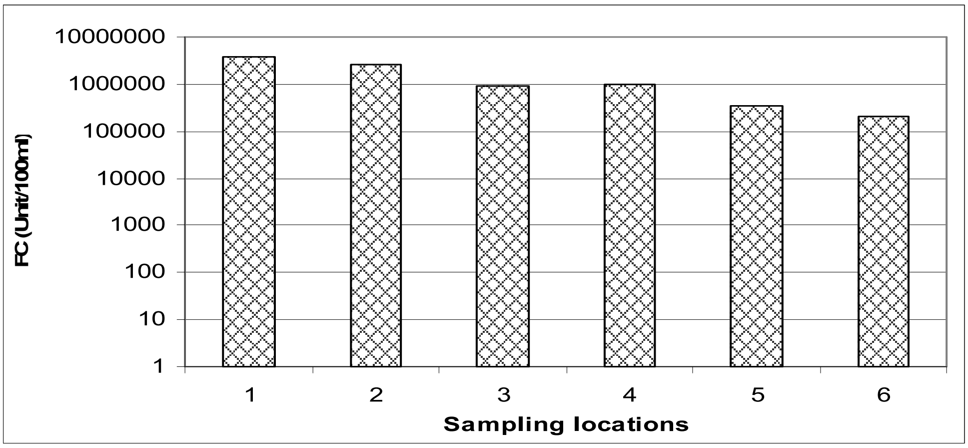

Figure 10: Average FC count of the different sampling locations of the treatment plant.

The final effluent of BLWWTP has not complied with the WHO guidelines for unrestricted irrigation regarding the FC (≤1,000 CFU/100 ml). Consequently the effluent can not be used for unrestricted irrigation of several crops without any additional disinfection treatment. Normally, faecal bacteria are usually removed in facultative and maturation ponds. However, the results showed that the highest removal efficiency was achieved at anaerobic and facultative ponds. The increased organic loading that lowering pH value and the concomitant shortening of the retention time as well as the inadequate design of the maturation pond (regarding its depth) can be viewed as the main reason of underperformance of the maturation pond. In the last 5 years the capability of the treatment system to remove FC is reduced continually, taking into account increased volume of wastewater inflow, high organic loading, and improper design criteria particularly in maturation pond. **(Pearson et al., 1987)** assured that fecal bacteria (with the notable exception of *Vibrio cholerae*) die very quickly at pH > 9. **Pearson et al., 1995,** in their study around the influence of pond geometry and configuration on facultative and maturation WSP performance, indicated that baffled maturation ponds are more efficient at Faecal coliform removal than un-baffled ponds.

Salmonella and nematodes are waterborne organism. As with most waterborne pathogens, Salmonella is difficult to detect and enumerate with accuracy in wastewaters due to methodological limitations. Qualitative analysis for nematodes and salmonella has been conducted 7 times from the different sampling collection sites of the treatment system. Table (4) presented the number of isolation incidences of studied samplings. Salmonella was not isolated from any of the collected samples during the whole monitoring program. Nevertheless, the presence of pathogenic enteric microorganisms in water represents a potential threat to human health.

Nematodes were analyzed qualitatively on the base of presence or absence. Helminth eggs were not counted during the monitoring program. The study results showed that nematodes nematode was isolated 3 times from location 1 (raw sewage) and 5 times from location 2 (effluent of anaerobic ponds). No nematode was isolated from other locations. **Pearson et al., (1996)** found that a combination of anaerobic pond plus a secondary facultative pond with an overall retention time of 2 days eliminated helminthes eggs**. (Mara and Silva, 1986)** concluded that effluents with < 1 egg per liter can be produced by a 1 day anaerobic pond followed by a 5 days secondary facultative and 5 day maturation pond. In comparison with BLWWTP, the wastewater has a retention time that matches or exceeds the retention time suggested by Mara and Silva. So, Egg-free effluent was expected to be produced by BLWWTP.

4. CONCLUSIONS

The BLWWTP is experiencing significant underperformance due to the overloading and hydrodynamic inefficiencies that refer to some design mistakes. The removal efficiency of organic matter, nutrient, and fecal bacteria has continually declined due to a reduction in the mean detention time of the treatment plant. The results showed that BLWWTP are produced an effluent with BOD, ammonia-nitrogen, total nitrogen and TSS content of 178.8 mg/L, 72.85 mg/L, 84.3 mg/L and 39.4 mg/L respectively. The average removal of FC is 99.52% with an average effluent concentration of 4.00 log units/100 ml. On the other hand, no nematodes were detected in the effluents of BLWWTP during the study period.

The system needs to be improved or totally replaced. The following suggestions can be recommended as short and simple solutions that may lead to overcome and improve partially the inefficiencies and poor treatment plant performance; Inlet-outlet rearrangement to be located in diagonally opposite corners of the pond is a simple intervention to improve system performance; The provision of two baffles in the anaerobic pond placed at 1/3L and 2/3L increases the pond retention time and BOD_5 removal efficiency. The baffling of the maturation pond can be increasing its disinfection power. Disinfection facilities should be installed at the final effluent overflow point to secure harmful microbiological effects on the ambient area of the effluent lake. Periodical cleaning and desludging of partially-mixed aerated lagoons is needed and installation of an instrument to measure the hydraulic load for both influent and effluent. A monitoring and control system should be incorporated to give warning of any breakdown in treatment and effluent quality. The effluent lake should be transferred as an urgent short-term solution to prevent immediate threat of flooding posed to the communities adjacent to the BLWWTP.

Further studies using tracers are required to describe the hydraulic regime and predict treatment efficiency. Such studies are needed also to evaluate fully the effect of inlet-outlet arrangement and baffling on pond hydrodynamics efficiency.

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