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Application of Stabilization Ponds in the Nile Delta of Egypt

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Abstract. In this study, domestic wastewater treatment via stabilization ponds, in the Nile Delta of Egypt, was investigated. The plant was implemented by the German Technical Co-operation (GTZ) project in water and wastewater sectors with the Egyptian consultant. The treatment system, of El-Moufty village, contains a series of stabilization ponds operated at a total hydraulic retention time (HRT) of 39.3 d. The anaerobic, facultative and maturation ponds were operated at an organic loading rate (OLR) of 29.4 g-BOD/m^3.d, 141.1 kg-BOD/ha.d and 41.9 kg-BOD/ha.d, respectively and achieved total BOD removal of 89.4%. Additionally, due to nitrification process in the facultative ponds ammonia levels decreased from 46.2 to 28.6 g/m^3 (i.e. 38.1% removal), corresponding to ammonia removal rates of 1,478 mg-N/m^2.d. Economic evaluation revealed that construction costs, including land, lining and excavation prices, was 35.6 €/P.E.y. Moreover, the land price accounts for more than 96% of the construction costs. Based on the environmental and economic findings, the proposed stabilization pond is a recommended treatment system in the Nile Delta.

Keywords: BOD Removal, Construction Cost, Egypt-German Co-Operation, Nile Delta, Stabilization Ponds.

1. Introduction

In Egypt, several sanitation projects have been conducted by the co-operation of Egyptian and German contractors. For example, the first phase of decentralized sanitation project in Kafr El-Sheikh city (in the Nile Delta) was achieved by the German technical co-operation (GTZ) in the period of April 2002 – March 2005. The second phase was carried out from April 2005 to March 2008. The projects aimed at designing, constructing and operating sanitation services (i.e. collection, pumping and treatment works) for ten villages. In this context, the Egyptian-German water supply and wastewater management programme (WWMP), with the GTZ partner, has an ongoing plan aimed at replacing and upgrading the recent sanitation services. In the strategic arrangement, stabilization ponds were highly recommended due to their efficient operation over a wide range of levels of flow and load, as well as minimum energy consumption. Additionally, this process is highly recommended for treating urban wastewater with small populations (>7 m^2/PE) [1]. Moreover, the prevailing climate and local environmental conditions, in Egypt, are ideal for treating domestic wastes using stabilization ponds [2]. This is mainly due to the domination of high temperature and sunlight that kill the pathogens, as well as reduce organic materials by oxidation [3].

Stabilization ponds can be a combination of one or three different ponds: anaerobic, facultative and/or maturation, depending on the design criteria and operating conditions of each type [3]. Choosing the optimum configuration varies significantly according to various parameters as; organic loading rate, available land area, and the required effluent characteristics. Anaerobic digestion is commonly used in the first pond due to its stability at higher volumetric organic loading (usually greater than 100 g-BOD/m^3.d) [4]. A properly designed and operated anaerobic pond will achieve about 40% removal of BOD at 10 ℃. Normally, those ponds are not containing dissolved oxygen or algae. The effluent from the primary stage, i.e.

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anaerobic digestion, is further treated through facultative ponds (FP). In the FP, complex wide range of microorganisms (algae, virus, protozoa, rotifers, insects, crustaceans and fungi) interacts to promote the biodegradation process [5]. The dissolved oxygen consumed by bacterial action is proportionate with that generated by photosynthesis using Algae i.e. the main pond oxygenators [6]. Consequently, aerobic, facultative and anaerobic zones, as well as different biochemical processes take place within the pond layers. The facultative ponds are designed for BOD removal based on their surface organic loading (i.e., kg-BOD/ha.d) [7]. In order to polish the wastes from fecal coliform and viruses, the effluent from FP are subsequently introduced to the last stage, i.e. maturation pond (MP). These ponds are shallow (i.e. optimum depth of 1.0 m), allowing for complete oxygenation and penetration of sunlight radiation throughout their depth. Consequently, MP provides tertiary treatment for pathogen reduction of wastes from the preceding facultative ponds [8].

Therefore this work highlights the proposed sanitation systems that were successfully applied in several villages in the Nile Delta, with focusing on their economic aspects.

2. Materials and Methods

2.1. Data Collection and Analysis

Samples were harvested from the final collecting wastewater sump of each village. Those villages are El-Moufty, Om Sen, Qoleaah, Om Shour, Handakokha, Kafr El-Gedid, Kouzman, El-Fayrouz, Om El-Koraa, and El-Kadesaya. Each village has an average population of 3,500 capita. The gathered samples were analyzed by Kafr El-Sheikh water and sewage company (KWSC) financed by the German federal ministry for economic cooperation and development. Analysis results were compared to the permissible limits proposed by the Egyptian law 48/1982 (Table 1) [9]. Taking an example of El-Moufty village, the collected domestic wastewater was further pumped through the force main line to the treatment system, i.e. stabilization ponds. The stabilization ponds are located at 31°06′42″N 30°56′45″E, in Kafr El-Sheikh (about 134 km north of Cairo), in the Nile Delta of Lower Egypt. The existing system contains ponds operated in series as follows: anaerobic pond + facultative pond + maturation ponds.

Table 1: Domestic wastewater characteristics of the ten villages compared to the permissible Egyptian law 48/1982

Village	Temp. ℃	pH	BOD g/m^3	COD g/m^3	TSS g/m^3	NH_4-N g/m^3	Phosphate g/m^3	Total coliform counts /100 mL
Law 48/1982	35	6.0-9.0	60	80	50	4.0	1.0	5,000
El-Moufty	24.52	8.09	346	755	569	44.4	6.5	35,000
Om Sen	28.87	8.49	327	670	570	39.9	5.5	50,000
Qoleaah	29.15	8.44	389	773	612	41.2	5.3	50,000
Om Shour	25.53	7.47	302	714	577	36.5	5.7	90,000
Handakokha	23.49	8.03	368	786	669	40.7	6.8	17,000
Kafr El-Gedid	23.58	7.85	315	693	522	33.9	6.6	16,000
Kouzman	26.13	8.46	399	759	612	44.6	6.5	26,000
El-Fayrouz	24.69	7.62	372	723	632	34.2	6.7	16,000
Om El-Koraa	27.52	7.12	341	819	682	38.3	5.6	55,000
El-Kadesaya	25.24	8.02	317	833	596	41.3	5.8	36,000

2.2. Design Criteria of the Stabilization Ponds

For the anaerobic ponds, the allowable OLR was calculated, based on the temperature, as Eq. 1 and Eq. 2 [10]

$$\text{At } T = 10 - 20;\ OLR = 20T - 100 \quad (1)$$

$$\text{At } T = 20 - 25;\ OLR = 10T + 100 \quad (2)$$

Additionally, for the facultative ponds, the designed organic loading rate was estimated from empirical equations (Eq. 3 and Eq. 4) [10]

$$OLR = 20T - 120 \quad (3)$$

$$OLR = 350\left[1.107 - 0.002\,T\right]^{(T-20)} \quad (4)$$

Where, OLR: organic loading rate (g-BOD/m^3.d and kg-BOD/ha.d for anaerobic and facultative ponds, respectively); T: temperature (℃); Q: flow rate (m^3/d); BOD: biochemical oxygen demand (g/m^3)

The required surface area, based on OLR [11], can be calculated from Eq. 5

$$A = \frac{Q \times BOD}{OLR} \quad (5)$$

3. Results and Discussion

3.1. Stabilization Ponds Performance

Due to the availability of sunlight and temperature, i.e. average of 18-25℃ in the year, stabilization ponds are considered a promising technology for sewage treatment in the Delta area. For El-Moufty village (Table 2), the first treatment step is two anaerobic ponds, i.e. each has a designed area of 625 m^2 and depth of 4.0 m. The ponds were operated at an OLR of 29.4 g-BOD/m^3.d (based on 42 g-BOD/c.d), and HRT of 11.9 d. The ponds achieved an average BOD removal efficiency of 52.0%. The ponds implied anaerobic degradation of organic matter, in addition to the sedimentation of suspended solids. Due to the high residence time in the ponds, the sludge was stabilized and consolidated, resulted in average values of fixed solids more than 50% [12]. The satisfactory BOD removal performance can be attributed to the higher HRT applied. Those results were supported by Catunda and van Haandel [13] who stated that there is a positive correlation between the BOD removal and the HRT. However, in cold winter days the ponds showed poor performance due to 1. the lower air temperature (i.e. reached to 11.6% BOD removal at 9℃), 2. misuse of the system and/or 3. rising groundwater table. In another study, Mara [14] found that anaerobic ponds, operated at OLR: 100 to 300 g-BOD/m^3.d and HRT: 1–6 d, would achieve about 70% of the BOD removal. Additionally, Del Nery et al. [15] attained BOD removal efficiency of 38±15% at an OLR of 550±200 g-BOD/m^3.d and HRT of 2.87±0.21 d.

In the second treatment process, four facultative ponds were used with a total designed area of 5,000 m^2 and depth of 1.5 m. The operated OLR and HRT were 141.1 kg-BOD/ha.d and 17.9 d, respectively. Using Eq. 3 and Eq. 4 that correlates the OLR with the average local air temperature, the allowable OLR should be 280 and 350 kg-BOD/ha.d, with an average value of 315 kg-BOD/ha.d (i.e. estimated at 20℃). Accordingly, the facultative ponds could handle higher BOD concentrations (i.e. more than 168 g/m^3). The two steps anaerobic and facultative ponds achieved total BOD removal of 88.6%. The facultative ponds were characterized by a dark green color. The water turbidity could result in unavailability of sufficient sunlight penetration in some parts of the ponds, causing lower BOD removal. Similarly, at an OLR of 470±250 kg-BOD/ha.d, Del Nery et al. [15] obtained BOD removal of 66±23% using facultative ponds (without aeration), which increased to 75±15% using 48 hp of aeration at an OLR of 507±74 kg-BOD/ha.d.

In the last stage, four maturation ponds were operated at an OLR of 41.9 kg-BOD/ha.d and achieved integrated BOD and ammonia removal of 89.4 and 42.6%, respectively. The maturation ponds size and number were mainly designed for pathogen removal, and they reduced parasites up to 98%. Conversely, Mara [16] stated that applying anaerobic and secondary facultative ponds with aerated rock filters, without maturation ponds, can produce high quality effluents.

Table 2: Operation conditions and BOD removal for the stabilization ponds of El-Moufty village

	First stage	Second stage	Third stage
Type and characteristics	Anaerobic pond (A=1,250 m^2 D=4.0 m)	Facultative pond (A=5,000 m^2 D=1.5 m)	Maturation pond (A=4,000 m^2 D=1.0 m)
OLR	29.4 g-BOD/m^3.d	141.1 kg-BOD/ha.d	41.9 kg-BOD/ha.d
HRT (d)	11.9	17.9	9.5
BOD removal efficiency (%)	52.0	88.6	89.4
Ammonia removal (%)	-	38.1	42.6

Additionally, results show that pH value decreased from neutrality in raw wastewater (i.e. pH: 7.36) to acidic values (i.e. pH: 6.26) in the anaerobic ponds indicating the generation of volatile fatty acids. However, the pH values were slightly adapted in the facultative ponds reflecting the good photosynthetic activity, where algae utilize dissolved carbon dioxide in the form of bicarbonate/carbonate ions.

3.2. Ammonia Removal Rates

The presence of nutrients, in terms of N and P, may be because of the fact that wastewater travels a long distance through agricultural areas, where mostly fertilizers are used. Nitrogen presents in forms of nitrate, ammonium and organic nitrogen, while phosphorus exists as phosphate and organic phosphorus. Because of the anaerobic action, ammonification and organic nitrogen mineralization occurred leading to excess levels of nitrogen in the anaerobic ponds. Additionally, ammonia accumulation in the anaerobic ponds may be due to protein degradation. Consequently no significant ammonia removal occurred in the first treatment stage. However, in the second treatment process, ammonia removal was achieved by nitrifying bacteria which obtain energy by the oxidation of ammonium to nitrite then to nitrate (Eq. 6). As a result nitrification reaction decreased ammonia levels from 46.2 to 28.6 g/m^3 (i.e. 38.1% removal), corresponding to ammonia removal rates of 1,478 mg-N/m^2.d. Those results are in agreement with Zimmo et al. [6] who found NH_4^+-N removal rates ranged 1,657 – 2,782 and 1,174 – 2,380 mg-N/m^2.d for algae and duckweed based stabilization ponds, respectively at HRT of 28 d. Conversely, Mburu et al. [17] found that only a slight decrease in ammonium concentration was observed in the secondary facultative pond due to 1. the mineralization of organic compounds within the aerobic layer (due to the supply of oxygen from algae) and 2. lack of attachment surfaces for the nitrifiers.

$$NH_4^+ + 2O_2 \rightarrow NO_3 + H_2O + 2H^+ \quad (6)$$

3.3. Economic Evaluation

An economic approach of the stabilization ponds, in terms of: land, lining and excavation costs, was estimated and expressed per population equivalent (PE). A design period of 20 years and 3,500 PE were used for cost evaluation. The average costs of lining sides were 80 and 50 LE/m^2 for deep and shallow ponds, respectively. The land price was estimated based on unit cost of 2,000 LE/m^2 and area requirement of 3.3 m^2/PE. The land cost was calculated as 23,190,000 LE, corresponding to more than 96% of the construction cost (Table 3). Therefore, costs will be less when land is cheap. Accordingly, the total construction cost was 24,087,680 L.E, equivalent to 35.6 €/PE.y (based on 1€ = 9.66 LE in April, 2014). The higher construction cost than that observed by Mburu et al. [17] (i.e. 13.2 €/PE.y) was mainly due to the higher land cost in the Delta zone. Additionally, the study of Mburu et al. [17] reported an area requirement of 8.3 m^2/PE of stabilization ponds operated at total HRT of 41 d, for serving 2,700 PE.

Table 3: Capital costs of waste stabilization ponds for 3,500 PE in El-Moufty village of Kafr El-Sheikh city (design lifetime of 20 years)

Work		Quantity
Land area (m^2)		11,595
Land equivalent (m^2/PE)		3.3
Lining area (m^2)		15,074
Excavation (m^3)		18,470
Land cost [a] (LE)		23,190,000 (96.3%)
Lining cost [b] (LE)		807,300 (3.4 %)
Excavation cost [c] (LE)		90,380 (0.4%)
Total cost	(LE)	24,087,680
	(€)	2,493,550
Total cost per P.E (€/PE.y)		35.6

[a] based on 2,000 LE/m^2; [b] based on 80 and 50 LE/m^2 for deep and shallow ponds, respectively; [c] based on 7 and 4 LE/m^3 for deep and shallow ponds, respectively

4. Conclusions

The benefits of treating sewage in the Nile Delta zone by stabilization ponds were highlighted. Those ponds were anaerobic, facultative and maturation ponds. Environmental benefits showed that the ponds achieved total BOD and ammonia removal rates of 89.4 and 42.6%, respectively. The unit land requirement per PE of El-Moufty village was 3.3 m^2. Economic evaluation estimated the construction cost as 35.6 €/PE.y (based on lifetime of 20 years). From the environmental and economic aspects of the implemented stabilization ponds in El-Moufty village, it's recommended to apply such system in the Nile Delta of Egypt.

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6. References

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