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THE POTENTIAL OF WASTE STABILIZATION PONDS EFFLUENT AS A LIQUID FERTILIZER

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Abstract

This research investigation was aimed at demonstrating the technical and economic feasibility of waste stabilization ponds (WSP) under the climatic conditions of a subtropical region. A pilot plant was designed and constructed at the Karachi University Campus (KUC) for the treatment of domestic wastewater. An intensive analytical programme was followed for 24 months to evaluate the performance of ponding system. The algal-bacterial symbiotic system performed satisfactorily and achieved total BOD_5 removal upto 80 - 82%, COD 69-74%, NH_3-N 9-52%, Total Kjeldahl nitrogen (TKN) 38-47% and PO_4-P ranging between 34 to 38 % in the secondary pond (P-4) at very high organic loadings of 500 and 1168 kg/ha.d. The maximum efficiency for the removal of coliforms was 99%. The study demonstrated that high BOD_5 loadings at 500 and 1168 kg/ha.d were possible without deteriorating the performance of WSP. The research investigation practically demonstrated that WSP treatment technology is economically viable, as the effluent has been shown to be useful as a liquid fertilizer being rich in plant nutrients (N, K, P). An economic analysis of the treatment of 1000,000 gallons of wastewater indicated a net profit of Rs 7673 in addition to social and environmental benefits. At the same time this approach could conserve equivalent quantity of potable water, which is always, in short supply in mega cities like Karachi.

Introduction

Over the years, the severe shortage of water, primarily in arid and semi-arid regions has promoted the search of extra sources currently not intensively exploited especially in developing countries. Treated wastewater of domestic origin is now being considered and used in many countries throughout the world as an additional renewable and reliable source of water which can be used for irrigation purpose (Angelakis *et al.,* 2003; Oron, 2003). Treated wastewater reuse makes a contribution to water conservation and expansion of irrigated agriculture, taking on an economic dimension. It also solves disposal problems aimed at protecting the environment and public health and prevent surface water pollution (Papadopoulos & Savvides, 2003). The benefits and the potential health and environmental risks resulting from wastewater use for irrigation and the management measures aimed at using wastewater within acceptable levels of risk to the public health and environment are well documented (Asano & Levine 1996; Marcos do Monte *et al.,* 1996). Therefore, wastewater reuse requires effective treatment and measures to protect public health and the environment at a feasible cost (Sipala, *et al.,* 2003; Anderson, *et al.,* 2001).

WSP technology is one of the most appropriate extensive wastewater treatment methods especially in developing tropical and subtropical countries, which cannot afford the high cost of conventional treatment plants. Low operation and maintenance costs coupled with effective pathogens removal have made WSP technology widely employed all over the world (Mara & Pearson 1998; Alcalde *et al.,* 2003; Khan & Ahmed 1992).

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In the selection of a WSP system attention is paid to the climatic factors such as temperature, aeration, solar radiation that favour microbial growth because wastewater consists of organic matter whose degradation largely depends upon microbial activity. Mara & Pearson (1998) suggested that hot climate is ideal for pond operation. However, techno-economic affordability should be considered as an important selection criterion.

Research and development activities on WSP are mostly based on loading rate, retention time, pond depth, solar radiation, total sunshine hours, wind velocity and rain fall. Different workers have proposed different models for design and operation of WSP including loading rate, retention time, solar radiation, sunshine hours, rain fall and pond depth (Mara, 1987; Curtis *et al*., 1992; Curtis & Mara, 1994; Curtis *et al*., 1994; Ellis & Rodrigues 1995a, 1995b). However, the data on economic potential of WSP effluent is scanty. There is still a risk of contamination of crops and soil irrigated with the effluent of WSP (Alcalde *et al.*, 2003).

The requirement for municipal water supply to Karachi is ever increasing and now over 600 mgd are supplied with nearly 450 mgd end up in wastewater. A significant proportion of this is also taken away for agriculture and industrial uses. Thus a greater amount of municipal water supply is unavailable for drinking purpose. Most of the wastewater is discharged into the sea through Lyari and Malir river without significant treatment. This practice has multiple environmental health and economic impacts in that it causes marine pollution, marine food contamination with microorganisms of health significance and the loss of precious water.

The present paper is a part of multiple and integrated research interest and deals with the use of WSP effluent as a resource for agriculture production.

Materials and Methods

Technical details of ponds: The technical details and general layout of the four WSP at the KUC are shown in Table 1 and Fig.1. These ponds are trapezoidal in shape, of equal dimension and are lined with thin layer of concrete and cement at the bottom as well as on the sides in order to avoid seepage problem and mosquito breeding. Two ponds in one set are in series interlinked and outlet provided in such a way that they could be operated in series at a depth of 0.9, 1.20 and 1.50m. They are designated as P-1 and P-2. In another set two ponds are likewise interlinked and can be operated at a depth of 1.0, 1.3 and 1.5 m. They are designated as P-3 and P-4. P-1 and P-2 are equipped with baffles. These ponds are connected with influent distribution channel that is connected with the service tank. The service tank in turn receives water from the influent sump. The raw domestic wastewater is received in the influent sump through a network of under ground sewerage line laid down for the purpose. Only the data pertaining to P-3 and P-4 is presented and discussed.

Design criteria:

Summer flow = 150,000 gallons/day
Population served = 5000 population units

The design criteria for the development of ponds are that the surface BOD load on the ponds surface area should not be more than 500 kg/ha.d. The monthly average BOD_5 load of raw wastewater of Karachi University Campus was 200 mg/L.

Table 1. Technical data of waste stabilization pond system at the Karachi University Campus.

S. No	Parameters	1998	1999
1.	Pond area (bottom)	98 m^2	98 m^2
2.	Pond area (WSP)	184 m^2	184 m^2
3.	Pond area (average)	130 m^2	130 m^2
4.	Outlet for effluent	1.0, 1.3, 1.5 m	1.0, 1.3, 1.5 m
5.	Influent sump capacity	13630 L	13630 L
6.	Effluent sump capacity	5455 L	5455 L
7.	Service tank capacity	3068 L	3068 L
8.	Pond volume at 1.5m depth	198,625 L	198,625 L
9.	Average retention time in P-3	7.5 days	2.9 days
10.	Average retention time in P-4	7.5 days	2.9 days
11.	Average total retention time	15 days	5.8 days
12.	Total average hydraulic load	27000L	69000L
13.	Total average BOD_5 load	500 Kg/ha.d	1168 Kg/ha.d

(Based on average BOD_5 load of 225-250 mg/L)

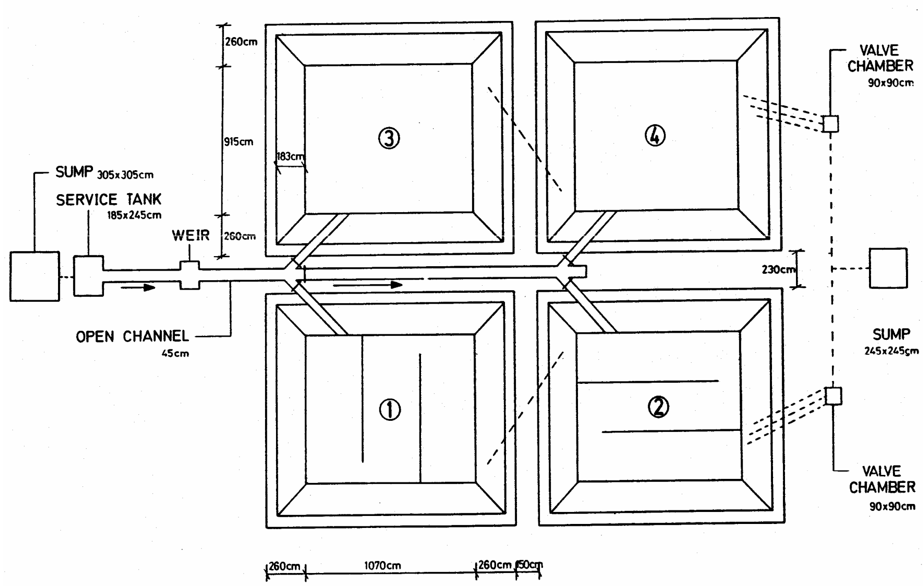

Fig. 1. General layout of waste stabilization ponds at the Karachi University campus.

Surface area: According to present experience two ponds constructed in series will give better performance and treatment. That is 0.4 ha of land will be required for the construction of ponds.

Depth: The convenient depth for the operation of ponds is worked out to be 1.5 m. At this depth no odour problem was experienced.

Ponds feeding schedule: The ponds were operated on a plug flow system. The raw wastewater was lifted with an electric pump and through the service tank it was fed into P-3. The feeding was intermittent and as soon as the daily hydraulic load of 27000 L

(BOD_5 load = approx. 500 Kg/ha.d) was achieved the feeding was stopped. Primary pond (P-3) took nearly 12 hours from 8.0 A.M. in the morning till 8.0 P.M. in the evening to receive the required hydraulic load. This would mean that the total retention time of 15.0 days in P-3 (primary pond) and P-4 (secondary pond) were kept constant through out the study period (January to December 1998). There was no undesirable odour indicating the presence of enough oxygen to maintain aerobic conditions. Periodic removal of scum helped in maintaining good performance of the ponds throughout the study.

In the second year of study (January to December 1999) the ponds performance efficiency was evaluated at a very high BOD loading rate (1168 Kg/ha.d). The required daily hydraulic load was approximately 69,000 L (15,000 gallons approx.) with a total retention time of 5.8 days (2.9 days in each pond).

Sample collection: Samples of influent were collected at the time of pumping of wastewater from the influent sump into the service tank. Samples from the individual ponds were collected from approximately 12 mm depth at the outlet of each pond in plastic containers. For biological parameter samples were collected in wide mouth sterile glass bottles. Sampling was performed twice a week and the collected samples were immediately transported to the laboratory for processing.

Processing of samples: After collection, the samples were analyzed for the following parameters.

i. Biochemical oxygen demand (BOD_5): BOD_5 was determined according to the Standard Methods for the Examination of Water and Wastewater (Anon., 1998) using azide modification method.

ii. Chemical oxygen demand (COD): COD was determined according to the Standard Methods for the Examination of Water and Wastewater (Anon., 1998) using potassium dichromate reflux method.

iii. Nutrients: Ammonia nitrogen (NH_3-N), Total Kjeldahl Nitrogen (TKN) and Phosphate phosphorus (PO_4-P) were determined as per methods described in the Standard Methods for the Examination of Water and Wastewater (Anon., 1998)

iv. Total coliforms count (TCC) was determined according to the methods described in the Standard Methods for the Examination of Water and Wastewater (Anon., 1998) using 3 tube fermentation technique and reported as MPN/100 ml.

Results and Discussion

Data taken during 24 months of this study were averaged (%) on monthly basis and are presented and discussed. Because of space reason, only the data pertaining to the performance of P-3 and P-4 connected in series have been presented. The parameters used to evaluate the performance of WSP were BOD_5, COD, NH_3-N, TKN, PO_4-P and TCC.

Biochemical performance: Data on the biochemical performance of P-3 and P-4 for 24 months are summarized in Tables 2 and 3.

Table 2. Ponds performance efficiency (%) in relation to temperature, wind velocity and total sunshine hours (1998).

Months (1998)	Temp. °C (water)		TSH	W.V Knot/hr	Performance of ponds (P-3 and P-4) mg/l											
	Min.	Max			BOD		COD		NH_3-N		PO_4-P		TKN		TCC (log values)	
					P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4
					204	204	486	486	16.0	16.0	4.5	4.5	43.8	43.8	3.38	3.38
Jan.	9.0	26.5	8.7	2.18	64	34	321	156	15.2	13.2	2.49	2.11	38.4	34.6	1.86	1.84
					(69)	(83)	(34)	(68)	(2)	(17)	(45)	(53)	(12)	(21)	(97)	(97)
					212	212	576	576	16.7	16.7	4.4	4.4	39.9	39.9	3.04	3.04
Feb.	14.5	27.8	8.6	2.66	68	50	215	164	16	15.5	3.42	2.24	35.8	30.9	2.45	1.97
					(68)	(76)	(63)	(71)	(4)	(7)	(22)	(49)	(10)	(23)	(74)	(91)
					203	203	314	314	39.6	39.6	7.6	7.6	55.2	55.2	2.93	2.93
Mar.	18.2	31	8.5	2.37	73	50	225	78	34.1	28.9	7.11	6.7	43.5	40.1	2.05	1.96
					(64)	(75)	(28)	(75)	(14)	(27)	(7)	(12)	(21)	(27)	(89)	(89)
					237	237	572	572	29.1	29.1	7.63	7.63	58.1	58.1	2.79	2.79
Apr.	18.5	31.5	9.7	4.2	53	34	153	133	27.9	24.9	6.2	6.3	49.9	47.8	1.96	1.91
					(78)	(86)	(73)	(77)	(4)	(14)	(18)	(18)	(14)	(17)	85	87
					233	233	720	720	23.5	23.5	5.4	5.4	49.7	49.7	2.46	2.46
May.	24.3	36.2	9.9	5.4	39	39	85	59	14.6	5.7	4.6	3.04	27.1	17.6	0.86	0.94
					(83)	(83)	(88)	(92)	(38)	(76)	(16)	(44)	(45)	(64)	(74)	(97)
					214	214	499	499	24.9	24.9	4.2	4.2	42.8	42.8	2.61	2.61
Jun.	27.4	35.3	8.4	8.2	26	26	127	108	11.7	9.16	3.87	3.8	31.4	22.1	1.81	1.61
					(88)	(88)	(65)	(78)	(53)	(63)	(9)	(11)	(26)	(48)	(84)	(90)
					248	248	341	341	17.7	17.7	4.6	4.6	37.9	37.9	2.95	2.95
Jul.	28.2	35.2	4.6	7.3	29	32	170	124	2.11	0.23	2.5	1.4	8.2	5.3	1.93	1.23
					(88)	(87)	(50)	(64)	(88)	(98)	(45)	(69)	(78)	(86)	(90)	(98)

Table 2. (Cont'd.).

Months (1998)	Temp. °C (water)		TSH	W.V Knot/hr	Performance of ponds (P-3 and P-4) mg/l											
	Min.	Max			BOD		COD		NH_3-N		PO_4-P		TKN		TCC (log values)	
					P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4
					282	282	372	372	39.8	39.8	3.35	3.35	39.8	39.8	2.98	2.98
Aug.	28.2	33.4	5.3	9.4	39	40	91	72	16.6	9.2	2.7	1.67	16.6	9.2	1.92	1.77
					(86)	(86)	(75)	(80)	(58)	(77)	(19)	(50)	(58)	(77)	(91)	(99)
					266	266	592	592	24.6	24.6	5.2	5.2	43.7	43.7	2.25	2.25
Sept.	27	32.3	7.0	8.8	43	40	176	156	12.2	7.4	4.3	4.1	26.1	15.2	1.89	1.94
					(84)	(85)	(70)	(74)	(50)	(70)	(17)	(20)	(40)	(65)	(96)	99
					254	254	454	454	26.4	26.4	5.31	5.31	46.6	46.6	2.23	2.23
Oct.	25.2	32.4	8.3	4.8	50	49	176	197	15.8	6.29	4.21	3.84	34.0	22.6	1.83	1.20
					(80)	(81)	(61)	(57)	(40)	(76)	(21)	(28)	(27)	(51)	(96)	(99)
					272	272	638	638	27.9	27.9	5.44	5.44	46.5	46.5	3.23	3.23
Nov.	22.4	34.5	9.1	3.0	62	76	128	113	21.9	11	4.24	3.63	34.1	20.3	2.30	1.10
					(77)	(72)	(80)	(82)	(21)	(61)	(22)	(33)	(27)	(56)	(88)	(99)
					264	264	603	603	28.6	28.6	5.19	5.19	47.7	47.7	2.26	2.26
Dec.	12.3	27.2	8.9	3.0	59	66	224	190	25.9	16.8	4.53	4.12	41.6	30.6	1.77	1.75
					(75)	(78)	(63)	(68)	(9)	(41)	(13)	(21)	(13)	(36)	(68)	(97)
Min-Max (%)	9.0-28.2	26.5-36	4.6-9.9	2.18-9.4	64-88	72-88	28-88	57-92	2-58	7-88	7-45	11-69	10-78	17-86	74-99	87-99
Mean (%)	21.2	31.94	8.08	5.10	78	82	62	74	33	52	21	34	31	47	86	95
Std.Dev.	6.64	3.29	1.64	2.66	8.06	5.26	17.7	9.14	25.4	27.6	12.1	18.7	9.97	20.8	9.96	4.52

Vertically first figure is influent value, second is effluent and figures in parentheses are percent performance efficiency
TSH = Total sunshine hours, W.V = wind velocity, TKN = Total Kjeldahl nitrogen, TCC= total coliform
Based on the analysis of minimum 8 samples per month

Table 3. Ponds performance efficiency (%) in relation to temperature, wind velocity and total sunshine hours (1999).

Months (1998)	Temp. °C (water)		TSH	W.V Knot/hr	Performance of ponds (P-3 and P-4) mg/l											
	Min.	Max			BOD		COD		NH_3-N		PO_4-P		TKN		TCC (log values)	
					P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4
					249	249	576	576	17.6	17.6	4.58	4.58	43.8	43.8	3.31	3.31
Jan.	9.0	25.6	8.70	2.18	84	70	215	164	16.2	16	3.64	2.81	38.4	34.6	2.45	1.97
					(66)	(72)	(63)	(71)	(8)	(9)	(20)	(39)	(12)	(21)	(86)	(95)
					212	212	535	535	17.4	17.4	4.91	4.91	46.5	46.5	8.31	8.31
Feb.	12.90	27.6	8.60	2.66	68	50	200	135	16.5	15.5	3.42	2.24	36	30.2	2.32	1.90
					(68)	(76)	(63)	(75)	(5)	(11)	(30)	(54)	(23)	(35)	(90)	(96)
					230	230	444	444	16.0	16.0	4.40	4.40	39.9	39.9	2.89	2.89
Mar.	14.30	2.9.6	9.40	2.66	102	32	240	90	16.9	15.8	3.11	1.84	35.8	30.9	2.10	1.75
					(55)	(86)	(46)	(80)	(0)	(1)	(29)	(58)	(10)	(23)	(84)	(93)
					200	200	439	439	16.0	16.0	4.20	4.20	46.6	46.6	3.24	3.24
Apr.	23.50	31.5	9.70	4.20	102	37	245	94	16	15.7	3.76	2.37	40.0	33.1	1.86	1.84
					(49)	(81)	(45)	(79)	(2)	(4)	(10)	(43)	(14)	(29)	(96)	(96)
					237	237	424	424	16.7	16.7	4.64	4.64	48.6	48.6	3.38	3.38
May.	26.40	36.5	8.60	5.46	61	29	147	77	16	15.5	3.75	2.21	31.0	25.2	2.63	2.83
					(74)	(88)	(65)	(82)	(4)	(7)	(19)	(52)	(39)	(48)	(82)	(71)
					225	225	234	234	15.9	15.9	6.80	6.80	46.4	46.4	3.38	3.38
Jun.	28.10	35.6	4.80	7.70	49	24	79	80	15.5	15.3	6.38	5.86	37.5	31.9	1.77	1.35
					(78)	(89)	(66)	(66)	(15)	(4)	(6)	(14)	(19)	(31)	(97)	(99)
					250	250	234	234	16.9	16.9	7.2	7.2	48.2	48.2	3.04	3.04
Jul.	27.70	35.0	5.10	6.30	39	19	111	50	16	14.4	4.62	4.06	24.4	20.7	1.95	1.26
					(83)	(92)	(52)	(79)	(5)	(14)	(36)	(43)	(49)	(57)	(92)	(98)

Table 3. (Cont'd.).

Months (1998)	Temp. °C (water)		TSH	W.V Knot/hr	Performance of ponds (P-3 and P-4) mg/l											
	Min.	Max			BOD		COD		NH_3-N		PO_4-P		TKN		TCC (log values)	
					P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4	P-3	P-4
					219	219	448	448	16.3	16.3	3.20	3.20	39.4	39.4	3.33	3.33
Aug.	26.30	34.3	6.80	7.90	45	34	322	202	16.1	16	2.27	2.23	37.8	18.6	1.59	1.13
					(79)	(85)	(28)	(55)	(1)	(2)	(29)	(31)	(4)	(53)	(96)	(99)
					211	211	384	384	16.9	16.9	3.87	3.87	41.7	41.7	3.29	3.29
Sept.	25.00	32.5	8.20	6.36	54	32	280	204	16.2	15.8	2.79	2.40	33.7	21.2	2.52	2.17
					(74)	(85)	(27)	(47)	(4)	(6)	(28)	(38)	(19)	(49)	(83)	(92)
					201	201	288	288	16.3	16.3	3.53	3.53	40.5	40.5	2.11	2.11
Oct.	20.30	32.5	8.60	5.40	57	34	263	127	15.0	13.2	3.07	2.35	27.8	23.5	2.77	1.80
					(72)	(83)	(09)	(60)	(8)	(19)	(5)	(27)	(31)	(42)	(55)	(95)
					200	200	308	308	15.1	15.1	3.48	3.48	38.0	38.0	2.74	2.74
Nov.	16.70	35.4	8.40	5.70	97	73	187	96	13.4	12.7	3.07	2.44	35.7	25.2	2.01	1.26
					(60)	(63)	(39)	(69)	(11)	(16)	(12)	(30)	(6)	(34)	(81)	(97)
					200	200	486	486	16.0	16.0	2.61	2.61	29.7	29.7	2.70	2.70
Dec.	12.60	30.3	8.20	3.70	47	27	321	156	13.7	13.2	2.15	1.72	25.7	19.5	1.95	1.38
					(76)	(66)	(34)	(68)	(14)	(18)	(18)	(34)	(13)	(34)	(82)	(95)
Min-Max (%)	9.0-27.70	25.6-36.5	4.80-9.70	2.18-7.90	49-83	63-92	9-66	47-82	1-15	1-19	5-36	14-58	4-49	21-57	55-97	71-99
Mean (%)	20.23	32.4	7.92	5.01	69	80	45	69	6.0	9.0	20	38	20	38	85	93
Std.Dev.	6.82	3.47	1.93	1.55	10.0	6.07	14.8	10.8	3.85	6.13	10.2	12.5	13.0	11.7	11.2	7.50

Vertically first figure is influent value, second is effluent and figures in parentheses are percent performance efficiency
TSH= Total sunshine hours, W.V= wind velocity, TKN= Total Kjeldahl nitrogen, TCC= total coliform (MPNx100ml x 10^6)
Based on the analysis of minimum 8 samples per month

Biochemical oxygen demand: From Table 3 it appears that 70% BOD_5 was removed in P-3 during most of the study period. However, in general no further significant reduction in BOD_5 in P-4 was noted. Infact mean BOD_5 removal for 12 months in P-3 and P-4 was 69 and 80%, respectively at the organic loading of 1168/kg.ha.d.

It is important to note that even at a very high organic loading of 500 and 1168 kg/ha.d the ponds worked satisfactorily as the BOD_5 of the WSP treated effluent from P-4 was less than the limits of 80 mg/L allowed by the EPA of Pakistan. Khan & Ahmed (1992) reported a similar work where they showed that the ponding system was effective at a high organic loading rate (507 kg/ha.d) in a subtropical country. However, Mara (1987) reported that maximum design permissible loading at 25°C is 350 kg/ha.d. It is seen from the Tables 2 and 3 that even with a short retention time the WSP worked well although the theoretical retention time of WSP is reported to be 40 days (Alcalde *et al.*, 2003).

Chemical oxygen demand: The trend of COD removal in P-3 and P-4 is similar to that of BOD_5. The average maximum COD removal in P-3 and P-4 was 62 and 74% respectively. However, with high organic loading (1168 kg/ha.d) it was reduced to 45 and 69% respectively. Even at such a high organic loading the COD removal efficiency was ≥ 60% in most of the months except August and September 1999 (55 and 47% respectively). Polprasert *et al*., (1992) reported 52-72% removal efficiency of COD in pilot scale WSP at the organic loading of 200 kg COD/ha.d which is much low as compared with the present study. From the BOD_5 and COD data in Table 2 and 3 it appears that maximum reduction in BOD_5 and COD took place in the primary pond (P-3). This observation is consistent with many previous reports (Uhlman, 1978; Middlebrooks, 1987; Khan & Ahmad, 1992).

Nutrients: Both NH_3-N and TKN removal efficiencies were not high and fluctuated between 33 to 52 and 31 to 47 % (1998) respectively. At high organic loading of 1168 kg/ha.d the removal of NH_3-N and TKN ranged from 6.0 to 9.0 and 20 to 38 % respectively. Khan & Ahmed (1992) particularly observed less nitrogen removal in wastewater treatment facilities operating with short retention time and high BOD_5 loading rate. The rate of production of ammonia by the fast growing heterotrophs through deamination process is faster than its conversion into nitrate by the slow growing autotroph in the ponds ecosystem. In fact ammonia nitrogen removal is difficult and slow in wastewater treatment systems dependent on biological activity except when a long retention time is given allowing autotrophs to grow on inorganic nitrogen.

The monthly average removal efficiency of PO_4-P in P-3 and P-4 ranged between 7.0 to 45% and 11 to 69% (1998) respectively. The PO_4-P removal in 1999 fluctuated between 5-36 and 14-58% in P-3 and P-4. The efficiency of PO_4-P removal is within the range as reported by the earlier workers in spite of a short retention time and a very high loading rate. The high removal rate of PO_4-P in P-4 could be correlated with the development of algal blooms and high dissolved oxygen concentration.

Bacteriological performance: The die off of coliforms in WSP depends upon several factors: high temperature, the penetration of U.V. light through the water column (Curtis & Mara 1994; Curtis *et al.,* 1994), high pH values (Pearson *et al.*, 1987) and aggregation and sedimentation. Through such systems it is possible to eliminate up to 99.99% of microorganisms of public health importance (Fernandez *et al*., 1992).

As shown in Tables 2 and 3 coliforms removal in both P-3 and P-4 ponds fluctuated between 74 to 99 % and 87 to 99 % respectively. In 1999, the values were 55 to 97 and 71 to 99% respectively. From Tables 2 and 3 it appears that most of the coliforms were removed in P-3 while no further significant reduction was observed in P-4. The minimum removal of TCC was in April 1998 (87%) and maximum in August 1999 (99%). The higher removal rates during summer months can be explained by the detrimental effects of high ambient temperature, intense solar radiation and high pH (Saqqar & Pescod, 1992; Davies-Colley *et al.,* 1999; Alcalde *et al.,* 2003). The climatological data and the ponds performance efficiency for 24 months are shown in Tables 2 and 3. From the Tables it is evident that maximum performance efficiency of the ponds was during the months of July and August when total sunshine hours were minimum and wind velocity was maximum. Although the mean minimum and maximum temperature was also high for other months, the ponds performance efficiency was not as high as in July and August. It seems that wind velocity has some significant effect on the efficiency of ponds in addition to temperature. It may be due to the fact that wind currents prevent stratification therefore, the ponds remain aerobic even upto deeper layers.

Economics of waste stabilization ponds technology: Waste Stabilization Ponds are far less expensive than other wastewater treatment options especially when compared with biomechanical systems such as trickling filter and activated sludge treatment systems. In Waste Stabilization Ponds there is no need for high cost, electromechanical equipment that requires regular skilled maintenance. It also does not require high annual consumption of electrical energy. This point is well illustrated in the following data from the USA for a flow of 10 million US gallons per day (37,800 m3/d) (Middlebrooks *et al*., 1982).

Treatment Process	**Energy consumption (KWH/yr)**
Activated sludge	10,000,000
Aerated Lagoons	8,000,000
Water Stabilization Ponds	Nil

Due to this reason and also the fact that plenty of land is available at a low cost the WSP technology has proved to be extremely beneficial for developing economies including Pakistan. Even affluent countries like USA is developing more biological systems of wastewater treatment where one third of all wastewater treatment plants are WSP systems and the tendency is to develop more and more.

The following data is based purely on preliminary economic analysis of the operational cost of the WSP, Karachi University model vis-à-vis financial benefits. This is done in order to practically demonstrate that WSP system is the best for developing countries.

Total operating cost per month

A. Man Power

Skilled and unskilled manpower

1. Assistant Forman (BPS-11) One	Rs. 12,500	
2. Lab Technician (BPS-11) One	Rs. 12,500	
3. Sanitary worker (BPS-01) One	Rs. 5000	
4. Watchman (BPS-01) Two	Rs. 10,000	
(As according to BPS 2005 scale)		**Rs. 40,000**
B. Power Consumption		Rs. 10,000
(1375 units @ Rs.7.27/unit current commercial rate)		
C. Cost of disinfectant (Chlorine)		Rs. 02000
D. Lab expenditure		Rs. 04000
E. Miscellaneous/Contingency expenditure		Rs. 02000
	Total Rs.	**58, 000**

The Karachi University model of WSP is designed to treat 150,000 gallons per day. During the entire month it would treat 4.5 million gallons at the total operational cost of Rs.58, 000 or Rs.12, 889 for 1 million gallons.

Economic potential of 1 million gallons wastewater

As irrigation water (@ Rs.9000 gallons)	Rs. 09000
*As liquid fertilizer	Rs. 11,562
Total Rs.	**20, 562**

Experiments conducted for determining the growth and irrigation of WSP treated effluent (Liquid fertilizer) potential for maize and sunflower crops have established it to be better than inorganic fertilizer (Urea nitrogen, Potassium and Phosphorus) (Sajda, 1983).

According to standard practice 1 million gallons of water is good enough for irrigating 20 acres of land for sunflower cultivation. Since liquid fertilizer has plant nutrients it can replace artificial addition of inorganic fertilizer.

Cost-benefit analysis (using 1 million gallons wastewater)

Total operational cost	Rs. 12, 889
Economic value	Rs. 20, 562
Net financial benefit	Rs. 7673

Conclusion

The facultative waste stabilization ponding system proved effective in that at a very high organic loading rates (BOD_5 500 and 1168 Kg/ha.d) the effluent quality met the National Environmental Quality Discharge Standards (NEQS) was acceptable for landscape irrigation and for growing plants of ornamental and economic value (sunflower, maize) for commercial use. The ponds were operated without being an aesthetic nuisance. The results indicated that the liquid fertilizer (WSP effluent) could be used for agricultural irrigation for high crop yield without additional nitrogen fertilizers. The plant nutrients load in the WSP effluent can be an important factor in saving costs of fertilizers, which would result in reducing the cost of production of crop. This kind of approach can be an important factor to the agricultural economy of developing countries where the fertilizer cost is a major constraint to improve production.

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