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Quantification of the River Ravi pollution load and oxidation pond treatment to improve the drain water quality

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ABSTRACT

The study was based on the wastewater quality of the four drains (Outfall, Gulshan-e-Ravi, Hudiara and Babu Sabu) entering into river Ravi in Lahore, Pakistan. Pollution parameters were analyzed including pH, dissolved oxygen, biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity, electrical conductivity (EC), total suspended solids, nitrates, phosphates, sulfates and fecal coliform. All parameters of drains exceeded the permissible level of wastewater standards. Hudiara drain showed the highest pollution load in terms of COD: 429.86 t/d while in Babu Sabu drain, highest pollution load was calculated in terms of BOD: 162.82 t/d. Lab-scale treatment (oxidation ponds) was designed to treat the wastewater of the Babu Sabu drain, through combination of different algae species, namely *Chaetomorpha sutoria, Sirogonium sticticum* and *Zygnema* sp. Two different size ponds (horizontal and vertical), and three different concentration of algal samples (25, 50 and 75 g/3 L) were selected for 6 d retention time. Percentage removal efficiencies of parameters in vertical and horizontal ponds, that is, turbidity: 62.12%, 69.79%; EC: 79.3%, 83%; BOD: 86.6%, 88.5%; COD: 79.72%, 83.01%; FC: 100%, 100%; nitrates: 89.6%, 89.8%; sulfates: 96.9%, 97%; phosphates: 85.3%, 86.3% and TOC: 75.6%, 79% were observed, respectively. Maximum reduction was observed after day 6 in the 50 g/3 L algae setup in horizontal pond due to large surface area. Results concluded that algae-based treatment is the most energy efficient and cost-effective in improving water quality in drains.

Keywords: Oxidation pond; Ravi pollution; Wastewater treatment; Algal treatment

1. Introduction

Water is a basic necessity for all life and survival. It is also important for the economic development of any country. Pakistan features on the global list of water-scarce countries due to limited water resources. Although there is not any reuse technology, approximately 4.43 billion m^3 wastewater is produced annually in Pakistan and only a fraction of wastewater is processed by treatment plants prior to discharge into natural water sources [1]. Pakistan lacks appropriate water storage facilities as found in other countries such as the United States of America and Australia (having storage capacity of 5,000 m^3), and China (storage capacity of 2,200 m^3). Pakistan can only store 1,500 m^3 per capita water. In Pakistan the per capita annual water resources are 1,305 m^3. Typical sources of water include rivers, streams, rain water, lakes, ponds and underground water [2]. With increasing pollution in many tropical countries, there is limited awareness about the weaknesses and strengths of

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different institutional frameworks to deal with pollution, ecosystems and their effects on biota [3]. Normally in developing countries, wastewater is disposed of in waterbodies without any treatment. High energy consumption, process intricacy, high capital and functioning costs have made the traditional treatment procedures difficult to implement in these countries. This situation is exasperated by a lack of trained and skilled workers [4].

In arid regions such as Pakistan, where the conditions are more favorable with respect to sunlight and temperature, oxidation ponds are the most appropriate approach for sewage treatment. Algae growth with most favorable photosynthetic activity in diverse climates has been extensively studied for decades [5]. Wastewater can be treated naturally without the use of chemicals in oxidation ponds. The ponds which can be established with varying depths can contain bacteria and algae to naturally treat wastewater. The chief purpose of these oxidation ponds is to increase the production of algae and oxygen, to get the aerobic conditions over the depth of the pond. Algae play an incredible part in municipal wastewater treatment [6]. The eradication of fecal bacteria in the wastewater treatment ponds as well as wetlands through algae is very well documented in the literature. Algal handling ponds emerge to be more successful in the elimination of fecal bacteria than ponds having macrophyte [7]. Ahmad et al. [8] studied algae farming in wastewater. The organisms take up nutrients from manure in a more effective and economical manner than numerous other biological processes. Algae increase the elimination of heavy metals, nutrients and pathogens. Furthermore they release O_2 to heterotrophic aerobic microorganisms in order to mineralize organic pollutants, using in turn the CO_2 liberated from bacterial respiration [9]. Algae-based treatment of wastewater in ponds is a cost-efficient method of treatment as this process is cheaper, and biomass can be used for other purposes such as biofuel production [10]. Wastewater treatment is assumed very expensive through conventional methods in numerous countries. Algae-based treatment in oxidation ponds was compared with conventional treatment methods with respect to energy loads and yields of water. The exercise found that algae treatment is more effective with reference to energy use in removing the pollutants in aquatic environments [11].

Lahore city is situated at the bank of River Ravi, which is receiving untreated industrial and domestic wastewater on a daily basis from various domestic and industrial drains. This water invades aquifers threatening the health of local residents [12]. Lahore is the second biggest city in Pakistan, where approximately 4,847,040 m^3/d (1,981 cusec) of wastewater is being discharged into Ravi [13]. Key issues in treating this wastewater are the capital cost, inherent process complication and energy extensiveness of conventional wastewater treatment technologies [14].

The objectives of the study were to quantify the pollution load entering into river Ravi from (Gulshan-e-Ravi, Outfall, Babu Sabu and Hudiara drains), its impacts on water quality and to optimize the oxidation pond treatment for the surface area requirement, retention time and biomass concentration.

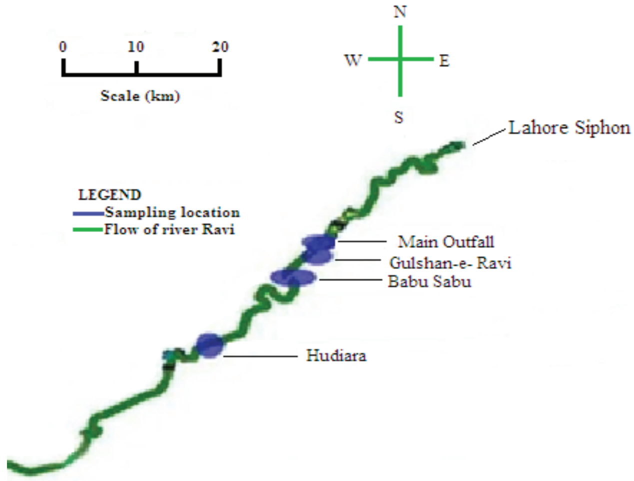

Fig. 1. Map showing the sampling location from the four drains.

2. Methodology

Samples of wastewater were collected from four drains (Fig. 1). Physical, chemical and biological analyses were performed to quantify the pollution level at different location. The wastewater of Babu Sabu was collected for the oxidation pond treatment at lab scale.

2.1. Sampling and storage

2.1.1. Wastewater sampling and storage

Sampling from drains was carried out in the month of March, from four sites. Samples were taken from Outfall, Gulshan-e-Ravi, Hudiara and Babu Sabu drains in plastic cans and bottles, and were sealed tightly to prevent any leakage and brought to laboratory for further analysis and experimentation. Physical tests were performed immediately after collecting the samples. Further chemical and biological tests were performed in laboratory.

2.1.2. Algae collection and identification

Algal sampling was performed at Government College University Botanic Garden (Pakistan). These samples were cultured in the ponds containing sewage water for treatment. The algae sample was identified. The algae species were *Chaetomorpha sutoria, Sirogonium sticticum* and *Zygnema* sp.

2.1.3. Analytical techniques

The analytical techniques were used to check the water quality parameters including dissolved oxygen (DO meter, DO 6+, EUTECH, Singapore), pH (pH meter, pH 100, YSI Company, USA), electrical conductivity (EC) (EC meter, EC 300, YSI Company, USA), turbidity (turbidity meter, HANNA HI 93703), nitrates (4500-NO_3^{-1} spectrophotometric method), phosphates (4500-P ascorbic acid method), sulfates (4500-SO_4^{-2} turbidimetric method), biological oxygen demand (5210b-5d BOD test), chemical oxygen demand in COD reactor (Lovibond, ET108), TOC by TOC Analyzer (Method 5310), total suspended solids (TSS) (filtration method) and fecal coliform (most probable number method) by adopting the standard method of APHA [15].

2.2. Experimental setup

Wastewater treatment through oxidation ponds setup was made depending on the variation in pond depth and quantity of algae. A wastewater sample was taken in two different ponds (horizontal and vertical) to verify the impacts of surface area to depth ratio on treatment. Measurement of square pond: depth 0.5 ft × height 1 ft × width 1 ft while the measurement of vertical pond: depth 1 ft × height 0.5 ft × width 0.5 ft. Three square and three vertical ponds were setup having 25, 50 and 75 g of algae and 3 L of wastewater sample each. Retention time for the all the ponds was 6 d. Treated water samples were taken every 2 d for analysis.

Percentage removal efficiencies were calculated using following formula:

Percentage removal efficiency = output – input / output × 100.

3. Results and discussion

3.1. Wastewater analysis of drains

The physical, chemical and biological parameters of the four drains in Lahore, that is, Outfall, Gulshan-e-Ravi, Hudiara and Babu Sabu were analyzed. Among the four, Hudiara receives largest amount of wastewater from almost 100 industries. Hudiara takes domestic and industrial effluent from both the Indian terrain and from Lahore. The physiochemical and biological parameters are shown in Table 1.

Hudiara takes wastewater from the township industrial estate and goes eventually into river Ravi with an average discharge of 430.56 cusec. Babu Sabu on the other hand receives most of its wastewater from communities and residential areas. Its average discharge is 165.7 cusec. BOD was high (401 mg/L) at Babu Sabu drain and DO was 0.12 mg/L while COD was higher (1,288 mg/L) in Outfall drain with DO 0.2 mg/L indicating the water is highly polluted. These readings were above the permissible limits.

3.2. Pollution load

Pollution load was calculated with reference to different pollutants, that is, BOD, COD and TSS. Table 2 showed that the pollution load with reference to BOD is highest in the Babu Sabu drain due to the large amounts of untreated sewage water discharged into it. It contained three times more pollution load than Gulshan-e-Ravi drain and Hudiara. Load with reference to COD and TSS was highest in Hudiara due to untreated chemical effluent discharge from industrial sources. Results showed high amounts of pollutants in the drain water and also in the river water which pose serious health hazards as well as deteriorating effects to the natural environment. Large-scale treatment plants are therefore critical for these sites. According to Punjab

Table 1
Physiochemical and biological parameters of wastewater of four drains

Parameters	Outfall drain	Gulshan-e-Ravi	Hudiara	Babu Sabu	PEQS[a]
pH	7 ± 0.1	6.5 ± 0.1	7.12 ± 0.02	6.82 ± 0.02	6–9
DO (mg/L)	0.2 ± 0.01	0.29 ± 0.02	0.1 ± 0.01	0.12 ± 0.04	–
EC (µs/cm)	866 ± 33	747 ± 1	1,696 ± 3	1,105 ± 2	–
Turbidity (mg/L)	94 ± 2	142 ± 2	42.98 ± 1.5	34.56 ± 2	–
BOD (mg/L)	388.07 ± 8	107 ± 2	134 ± 2	401.27 ± 0.8	80 mg/L
COD (mg/L)	1,288.07 ± 8	304 ± 2	408 ± 8	917 ± 4.36	150 mg/L
TOC (mg/L)	758 ± 8	256 ± 2	276 ± 2	468 ± 8	–
Fecal coliform	≥1,600 ± 0	≥1,600 ± 0	≥1,600 ± 0	≥1,600 ± 0	–
Nitrates (mg/L)	11.85 ± 1.51	7.93 ± 0.04	12.11 ± 0.01	12.57 ± 0.16	–
Phosphates (mg/L)	15.22 ± 1	1.80 ± 0.2	16.57 ± 0.16	14.6 ± 0.2	–
Sulfates (mg/L)	115 ± 2	84 ± 2	260.1 ± 1.15	140 ± 2	600 mg/L

[a]Punjab Environmental Quality Standards (2016).

Table 2
Pollution load of drains, with reference to BOD, COD and TSS

Sr. No.	Site description	Average discharge (cusec)	Pollution load (t/d)[a]		
			BOD	COD	TSS
1	Gulshan-e-Ravi drain	176.66	46.25	131.41	8.64
2	Babu Sabu drain	165.76	162.82	371.94	18.32
3	Hudiara drain	430.56	141.15	429.86	105.14
4	Outfall drain	127.56	121.1	402.03	29.34

[a]Multiply average discharge (cusec) with concentration (mg/L) and multiply with factor 0.002447.

EPA [16], all drains enter into Ravi River which has been severely hit by the disposal of untreated municipal and industrial effluents. Having extremely low flows during winter season, the river just acts as a sludge drain due to excessive sewage discharge.

3.3. Oxidation ponds treatment

After 6 d of treatment, the value of pH decreased with increase in retention time due to photosynthetic reaction [17].

The graphical representation showed the reduction efficiencies of pollutants with different algae setups and different types of ponds (Figs. 2 and 3) also represented in Table 3.

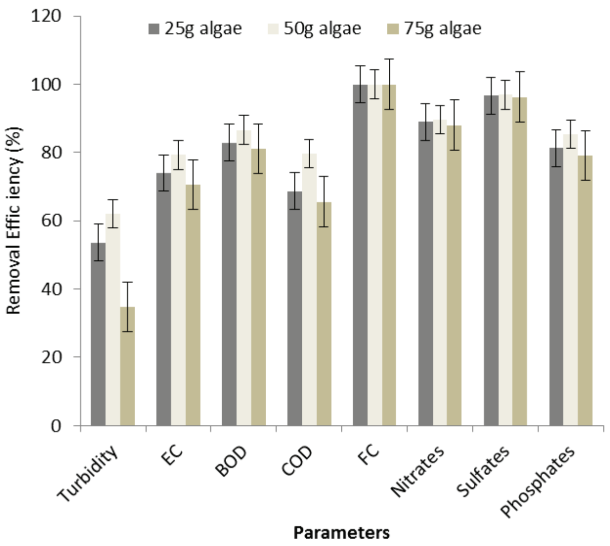

Fig. 2. Percentage removal efficiency of pollutants in vertical ponds after 6 d of retention time.

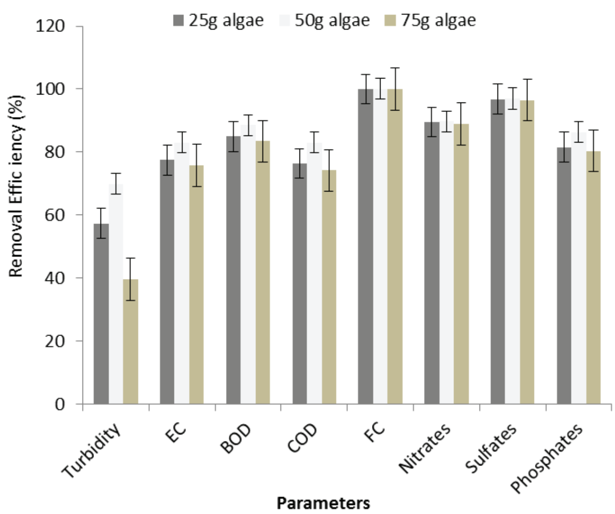

Fig. 3. Percentage removal efficiency of pollutants in horizontal ponds after 6 d of retention time.

3.3.1. Effect of pond depth on pollution reduction

The results showed that the turbidity in all sample setup decreased after treatment. For the vertical ponds, the percentage reduction of turbidity in 25, 50 and 75 g setup was 53.67%, 62.12% and 34.89% while in horizontal ponds the percentage decrease of turbidity in 25, 50 and 75 g setup was 57.31%, 69.79% and 39.63%. The percentage reduction values of EC in vertical ponds in 25, 50 and 75 g setup were 74%, 79.3% and 70.69%. In horizontal ponds, the reduction in 25, 50 and 75 g setup was 77.5%, 83% and 75.87%. The trend of BOD in all ponds was decreasing. The reduction efficiency in 25, 50 and 75 g was 82.9%, 86.6% and 81.10% in vertical ponds while in the horizontal ponds, in 25, 50 and 75 g algae reduction was 84.9%, 88.5% and 83.56%. The percentage reduction value of COD in 25, 50 and 75 g was 68.73%, 79.72% and 65.67% in the vertical ponds and in horizontal ponds in 25, 50 and 75 g was 76.4%, 83.01% and 74.25%. Fecal coliforms decreased with increase of algae concentration after day 6 of treatment. The trend in vertical ponds in 25, 50 and 75 g algae concentration was same, that is, 100% and same in the horizontal ponds as well after completion of treatment. It reflects that removal of fecal coliforms were irrespective of pond size or shape or depth. The nitrates decreased after the algae treatment. In the vertical ponds, the results showed that in 25, 50 and 75 g setup the reduction was 89%, 89.6% and 88% while in horizontal ponds, the percentage reduction in 25, 50 and 75 g setup was 89.5%, 89.8% and 88.94%. In vertical ponds, sulfate reduction efficiency in 25, 50 and 75 g setup was 96.7%, 96.9% and 96.6%. In horizontal ponds, the reduction in 25, 50 and 75 g setup was 96.8%, 97% and 96.8%. The trends in phosphates in all ponds were decreasing. In 25, 50 and 75 g setup, the reduction was 81.3%, 85.3% and 79.14% in vertical ponds. In the horizontal ponds, in 25, 50 and 75 g algae the reduction was 81.5%, 86.3% and 80.45%. The maximum reduction was shown in 50 g algae setup. TOC removal was more in 50 g algae setup in horizontal pond, that is, 79%. Horizontal ponds have the more reduction in parameters as compared with vertical ponds due to large surface area.

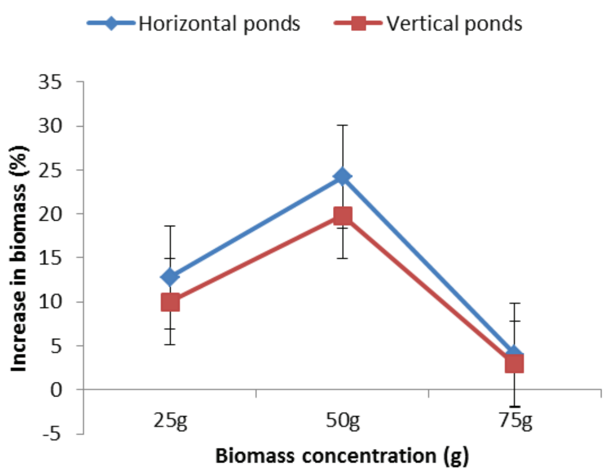

Fig. 4. Percentage increase of biomass in vertical and horizontal ponds.

Table 3
Percentage reduction in pollutants after treatment

Sample setup	Percentage reduction in Parameters								
	Turbidity (NTU)	EC (μs/cm)	BOD (mg/L)	COD (mg/L)	FC (0/100 mL)	Nitrates (mg/L)	Sulfates (mg/L)	Phosphate (mg/L)	TOC (mg/L)
25 g/3 L (V)	53.67	74	82.9	68.73	100	89	96.7	81.3	63.1
25 g/3 L (H)	57.31	77.5	84.9	76.4	100	89.5	96.8	81.5	68.2
50 g/3 L (V)	62.12	79.3	86.6	79.72	100	89.6	96.9	85.3	75.6
50 g/3 L (H)	69.79	83	88.5	83.01	100	89.8	97	86.3	79
75 g/3 L (V)	34.84	70.69	81.10	65.67	100	88	96.3	79.14	67.9
75 g/3 L (H)	39.63	75.87	83.56	74.25	100	88.94	96.5	80.45	73.5

The results showed decreased trend of pollution parameters in all the types of ponds. The percentage reduction increased with algae concentration, for example, from 25 to 50 g algae weight, decreasing at the 75 g concentration. Ahmad et al. [18] studied ponds of diverse sizes and shapes to find out the connection of uncovered surface to pollution decline. Microalgae remained suspended in the wastewater while macroalgae move toward the surface frequently; therefore, the wastewater at the bottom was not in contact with the algae which can be the cause of small reduction. In order to get maximum reduction in pollution load, a pond should be designed in such a way that it should have wide surface area exposed to light and shallow water for proper light penetration.

3.3.2. Effect of biomass on pollution reduction

Three different algae biomass (25, 50 and 75 g/3 L) were used in the experimental setup. The results showed that more pollutants were removed in denser algae weight ponds (in this case, the highest being 50 g/3 L), maximum reduction was achieved on day 1. The reduction in pollutant increased with increase in algae concentration from 25 to 50 g and then it decreased at the 75 g setup because at longer timeframes, the algae changes its color due to deficiency of nutrients. Ruiz-Marin et al. [19] determined that on that last day of treatment, the algae became brown due to decreased chlorophyll contents, microalgae illustrated high growth rates in early days but growth and chlorophyll contents were reduced after four rounds of culture representing disintegration of the culture as a result of nutrient deficit.

In both types of ponds (vertical and horizontal), the algae biomass increased. The biomass in both setup increased after day 6 of treatment. Fig. 4 illustrated the values of increased in biomass. The g/L/d concentration of algae was also drawn to interpret the best and suitable setup for treatment in Table 4.

The best setup for the treatment is 50 g algae with 3 L of wastewater in the horizontal pond because it has shown maximum increase in g/L/d. Similar results were illustrated by Ahmad et al. [8] that increase in biomass of algae with time was determined by taking into account its fresh weight. Increase in biomass was examined from day 2 to 8 in all three types of algae. Highest growth rate (0.75 g/L/d) was examined.

Table 4
Increase in biomass (g/L/d) of algae

Sr. no.	Sample setup	Final weight (g)	Increase in biomass (g/L/d)[a]
1	25 g (H)	28.2	0.17
2	50 g (H)	62.1	0.67
3	75 g (H)	78	0.16
4	25 g (V)	27.5	0.13
5	50 g (V)	59.9	0.55
6	75 g (V)	77.2	0.12

[a]6th day increase in biomass is divided by 3 (L^{-1}) then by 6 (day^{-1}).

4. Conclusion

Quality of wastewater of all four drains (Outfall, Gulshan-e-Ravi, Hudiara and Babu Sabu) did not meet the standards of wastewater discharged. The pollution load with reference to BOD was highest in Babu Sabu drain due to large amounts of untreated sewage water discharged into it. The pollution load with reference to COD and TSS was highest in Hudiara due to untreated chemical effluent discharged from different industries. The 50 g algae weight gave more efficient results than 25 and 75 g after 6 d retention time. Algal treatment reduced the pollutants level up to 98% and 100% removal in fecal coliforms. Horizontal pond with large surface area reduced the pollutant level more efficiently than a vertical pond setup; decreasing the depth of the pond had positive effects on pollution reduction.

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