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PROPOSED MODEL FOR WASTEWATER TREATMENT IN LAHORE USING CONSTRUCTED WETLANDS

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Abstract

In developing countries, large quantities of wastewater are disposed into water bodies without any treatment. Process complexity, high energy consumption, lack of highly skilled operators, and high capital and operational costs have made the conventional treatment methods difficult to adopt in these countries. Constructed wetlands (CW) are engineered systems that are designed and constructed to utilize the natural processes, involving wetland vegetation, soils and the associated microbial assemblages to assist in treating wastewaters. It is a low cost and energy efficient option for a developing countries like Pakistan. In this study, the application of CW for the treatment of wastewater of Lahore city has been investigated in this study. A local plant, Reed (*Phragmites*) was evaluated (using a lab scale wetland model) for its potential use in constructed wetland. Removal efficiency of the system was evaluated at different detention times ranging from 1 to -5 days. The results demonstrated 90% removal for TSS, 75% removal for BOD and 80% removal for COD at 5 days detention time. The mean effluent concentration of 10 mg/L, 40 mg/L and 68 mg/L for TSS, BOD, and COD, respectively was obtained at 5-days detention period, thus complying with effluent standards of Pakistan. The results of the study support the suitability of CW for Lahore, and also motivate for detailed pilot plant studies.

Key words: Constructed Wetland; Free Water Surface Wetlands; Wastewater Management; Phragmites Removal Efficiency; Wastewater Treatment; Low Cost Treatment

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1 INTRODUCTION

Annual per capita water availability in Pakistan has decreased from 5,000 in 1951 to 1038 cubic meter in 2010. This is slightly above the internationally recognized scarcity level of 1000 cubic meter [1]. The projection for 2015 is 900 cubic meter per annum [2, 3]. In addition, discharge of untreated wastewater into fresh water bodies is polluting this already squeezing resource [4]. The Ravi River is the most polluted river in Pakistan. It receives untreated domestic and industrial wastewaters through five outfalls and two natural surface drains located between a stretch of 98 km between Ravi Siphon and Balloki Headworks (Haider & Ali 2010). Estimates show that about 4, 847,040 m^3/day (1981 cusec) of wastewater is being discharged into Ravi [5]. Major hindrance in treating this wastewater is the huge capital and operational cost, inherent process complexity and energy extensiveness of conventional wastewater treatment technologies [6, 7, 8]. Therefore, there is a need to investigate the option for a low cost treatment method for the city of Lahore.

According to Kadlec and Knight [9], the use of wetlands for wastewater treatment dates back to 1912. Constructed Wetlands(CW) are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils and the associated microbial assemblages to assist in treating wastewaters. They are low cost and energy efficient way of treating diverse types of wastewaters originating from various sources i.e. agriculture, domestic, municipal, mine drainage, storm water runoff and airport runoff [9, 10, 11, 12]. CW offer multiple benefits which include integration into parks and recreational facilities, wildlife habitat, aesthetic value and providing superior treated effluent that can be used for landscape irrigation [13]. In the above scenario a low cost treatment method such as constructed wetlands (CW) should be examined for Lahore [14]. It is especially desired in the wake of severe power shortage in the country, as CW does not require energy for its operation.

There are two types of CW: (1) Free surface and (2) Sub surface, flow type wetlands [15, 16]. They use multiple mechanisms for pollutant removal like microbial breakdown of pollutants, plant uptake, retention, settling and adsorption. Pollutants removed include solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrates, nitrites, phosphorous, microbes etc. [17, 18, 19]. Plants used in constructed wetland play a vital role in the removal and retention of nutrients thereby preventing the eutrophication of wetlands. A range of plants has shown their ability to assist in the breakdown of wastewater, including the plants that remain outside wastewater and known as emergent plants like bulrushes (*Scirpus*), spikerush (*Efeocharis*), *Cyperus*, rushes (*Juncus*), common reed (*Phragrnites*) and cattails (*Typha*) [20, 21]. Some species remain submerged in wastewater, such as coon tail or hornwort (*Ceratophyllumdemersum*), redhead grass (*Potamogetonperfoliatus*), pondweeds (*Potamogeton spp.*), widegeon grass (*Ruppiamaritima*), wild celery (*Vallisneria Americana*), and water milfoil (*Myriophyllumheterophyllum*), which can be applied in open deep-water zones for nitrogen removal [22].

Owing to their low cost and process simplicity, many lab, pilot and full scale studies have been conducted to determine the effectiveness of the CW for treating wastewaters of diverse types. Different projects have shown different pollutant removal rates depending upon the local environmental conditions, i.e., type of wetland, type of plants used and mode of wastewater application on the wetlands [17, 23, 24, 25]. The reported range of percentage removal of TSS and BOD are 50-90 %, and 60-85% respectively [26, 27]. Haider and Ali [5] evaluated various water quality control planning alternatives for the River Ravi by using a calibrated and verified water quality management model. The water quality simulation results revealed that CW is a suitable option to improve water quality of the River Ravi. However, the simulations were based on the literature values of the removal of BOD and other water quality parameters. Moreover, little research has been carried out to evaluate a practical model of CW for its application to wastewater treatment for the city of Lahore. Hence the present study is carried out with the following objectives; (1) evaluate the suitability of a local plant species named Reed (*Phragmites*), using a free surface, batch type lab scale CW model; (2) determine a suitable detention time in CW to achieve desirable removal efficiencies to meet National Environmental Quality Standards (NEQS); and (3) present a planning model based on CW for the treatment of Lahore wastewater before its disposal in River Ravi.

2 MATERIALS AND METHODS

2.1 Development of laboratory scale CW

An earthen pot (length=1m; width=0.3 m; depth=0.3 m) was used as lab scale model of CW and was operated in a batch mode. Seventy five millimeter layer of locally available gravel was laid at the bed of pot [28]. It was overlain by 150 mm layer of canal soil for vegetation growth; leaving 75 mm freeboard. In the past, various researchers have used batch CW models for wastewater treatment [23, 24, 25].

A local plant named "reed" (*Phragmites*) was used as vegetation to evaluate its effectiveness in removing pollutants. The plant was obtained from botanical garden of Government College University, Lahore and sown at about 20 mm distance in the lab scale CW. It took about 6 weeks to grow the reed fully. Different stages of reed growth shown in Figure 1 reveal that significant growth was observed in 6 weeks (Figure 1ab).

(a): Initial stage: less reed density

(b) After 6 weeks; comparatively denser reed growth

Fig. 1: Different Stages of lab scale batch CW with reed

2.2 Wastewater sampling and testing

The wastewater for lab scale CW was collected from the main sewer of the University of Engineering and Technology (UET) Lahore. Primary settling is recommended as pre-treatment for CW; therefore, the collected wastewater was settled for one hour, and the supernatant was then fed to CW. At one time, 40 L of wastewater was added to the lab scale CW.

First sample was drawn from the lab scale CW immediately after feeding settled wastewater. Settled wastewater characteristics were determined from this sample. Subsequent sampling was done after first, second, third, fourth, and fifth day to evaluate the performance of CW at different detention times. TSS, BOD and COD tests were performed on all the wastewater samples collected. All the tests were performed as per procedures laid down in standard methods for the examination of water and wastewater [29].

3 RESULTS AND DISCUSSION

3.1 Removals of pollutants in lab scale CW

Table 1 presents the influent and effluent concentration of tested parameters at various detention times. TSS, BOD and COD concentrations at zero day were found to be 103, 146 and 321 mg/L, respectively. These concentrations are relatively less than the average reported values for raw wastewater of Lahore. For example, the average reported BOD concentration for raw wastewater of Lahore is 246 mg/L [30]. This shows that pre-settling significantly reduced the BOD value. It can be seen in Table 1 that values of wastewater parameters reduced with an increase in detention time. At a detention time of 4 days the BOD and COD reduced to 62 and 119 mg/L, respectively and meet the effluent water quality standards in Pakistan (i.e., BOD=80 mg/L; COD=150 mg/L). Thus, a detention time of 4 days is sufficient to meet the NEQS if the wastewater is pre-settled.

Table 1: Pollutant concentration at various detention times from reed planted CW

Sampling Day	TSS (mg/L)	BOD (mg/L)	COD (mg/L)
0	103	146	321
1	78	120	254
2	53	102	185
3	31	88	156
4	18	62	119
5	10	40	68

Using the zero day values of pollutants as datum line, percentage removals of each pollutant were evaluated for the bench scale CW. The results shown in Figure 2 depict the percentage reduction of TSS. On Day-1, the observed reduction was 24%, and on Day-5 it increased to 90%, with a residual concentration of 10 mg/L. These results show a significant TSS removal potential of CW for Lahore wastewater. For the BOD, the percentage removal at Day-1 was 18% which improved to 73% at Day-5 with a residual concentration of 40 mg/L. Similarly, the percentage removal of COD at Day-1 was 21% which improved to 79% at Day-5 with a residual concentration of 68 mg/L.

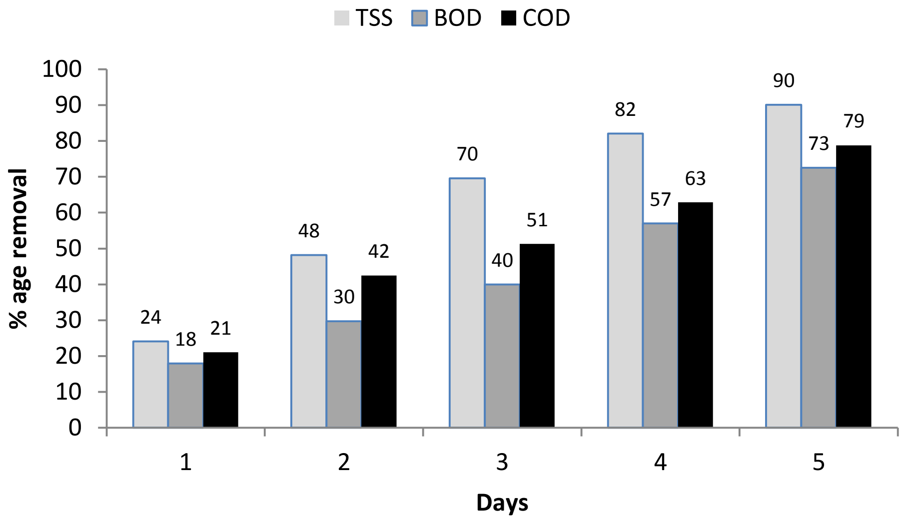

Fig. 2: Percentage removal at various detention times

3.2 Water quality management of the Ravi River with constructed wetlands

The 98 Km reach of River Ravi, from Siphon to Balloki Headworks, especially under low flow conditions, is completely devoid of dissolved oxygen (DO). This reach of the river receives untreated domestic and industrial wastewater from five wastewater outfalls and two surface drains (Figure 3). All of these five outfalls carry the wastewater from the city of Lahore; however, the surface drains receive discharge from wider watershed including storm water during monsoon period in addition to municipal wastewater. For example, Hudiara drain originates from Batala in Gurdaspur district, India, and enters Pakistan near Village Lalloo. Deg drain collects both surface runoff and wastewater from different industries, villages and towns including the city of Sheikhupura [31]. Ground water recharge with this highly polluted water seriously undermines the ground water quality along the river. It adversely affects public health, when water is drawn from the shallow bore holes from the affected aquifer.

As mentioned earlier, Haider and Ali [5] evaluated the option of wetlands for the river Ravi as a planning alternative using BOD removal values reported in the literature. The proposed site of wetlands is shown in Figure 4 along with an average river cross-section between Hudiara and Deg drains. In the planning alternative, the transportation of wastewater from five wastewater discharge points including the Hudiara drain, using a collector channel, along the left bank to the proposed site was evaluated. The wastewater after transporting to the CW site was proposed to be pre-treated (i.e., primary sedimentation). Afterwards, further treatment can be achieved with the help of CW. For the two points along the left bank, waste stabilization ponds were proposed. Details of the wetland alternative for dissolved oxygen (DO) management can be seen in Haider and Ali [5].

It can be seen in Figure 4, that the river flood plain can be utilized for CW by securing it with earthen berms. In that planning study, 66% reduction of BOD of the settled wastewater was assumed based on literature values. Present study showed a BOD removal of 73% at a detention time of 5 days (Figure 2). Therefore, there is a need for re-evaluating the DO profile for the CW option for the city of Lahore.

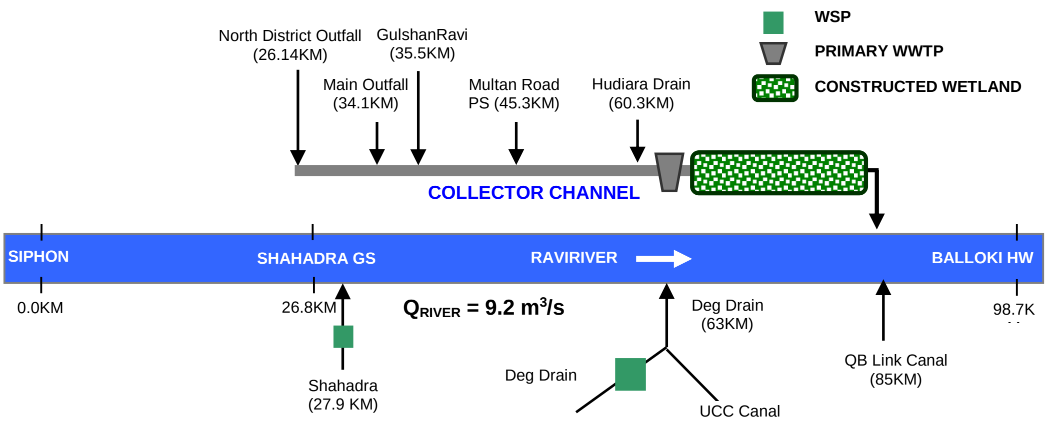

Figure 3: Proposed wastewater treatment strategy for Lahore wastewater using CW for the year 2032 Source: [5]

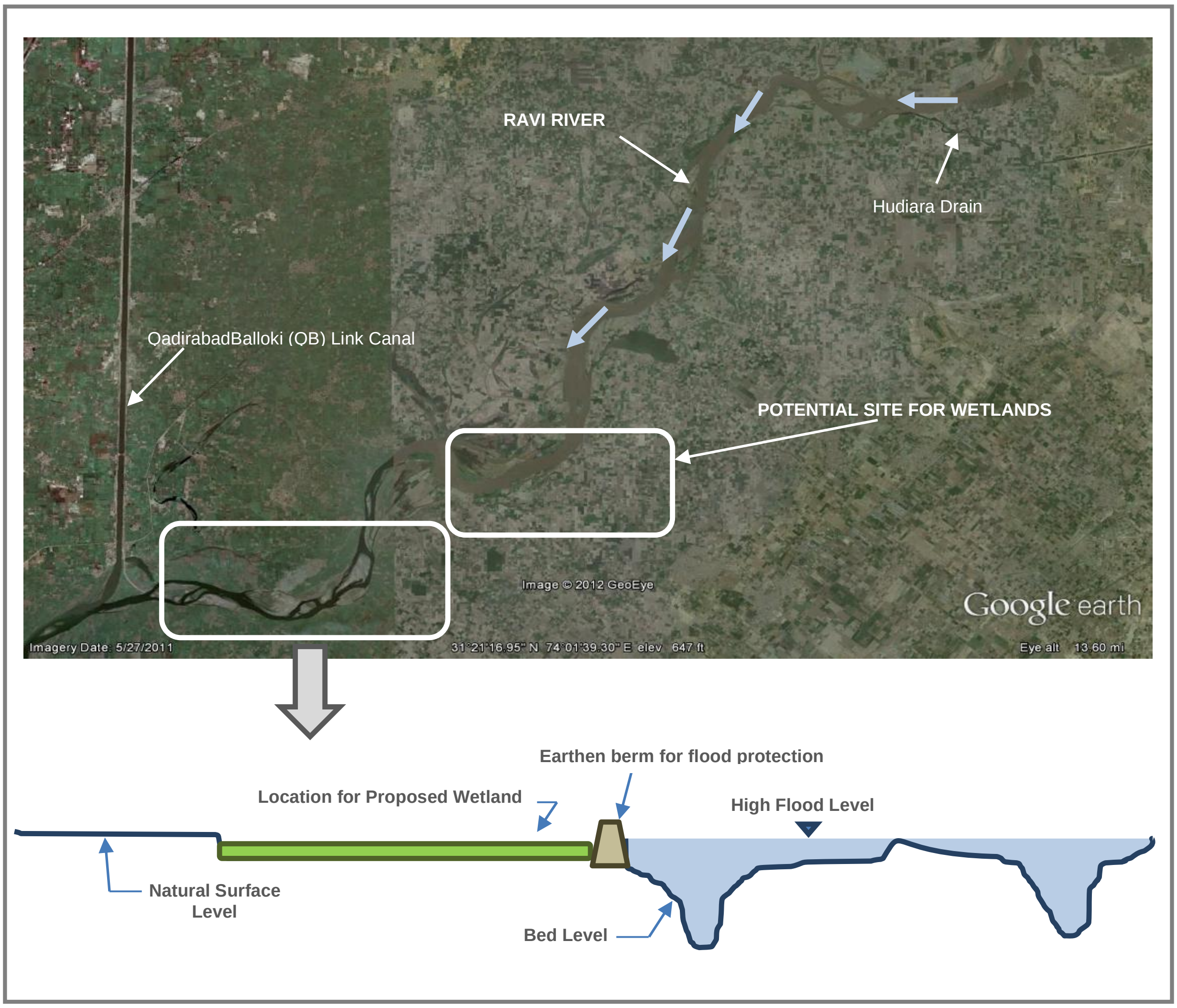

Figure 4: Satellite image (Source: Google Earth) of the proposed site for CW for Lahore wastewater treatment

Taking a planning horizon of 20 years, the wastewater flows in the River Ravi in year 2034 are presented in Table 2. Measured BOD values are also given in the same table [5]. The weighted BOD comes out to be 245 mg/L (Table 2). If 40% reduction in BOD is assumed in primary treatment then effluent after primary treatment would have a BOD value of 147 mg/L. It is quite close to the BOD of settled wastewater used in batch CW in the present study (146 mg/L in Table 1). The wastewater flows given in Table 2 were used to find out the DO levels in the River Ravi. The DO model developed, calibrated and verified by Haider and Ali [32, 33] is used to evaluate the possibility of wetlands as a potential wastewater treatment method for the River Ravi. Details of the model development are out of scope of this paper. For more details, interested readers are referred to Haider and Ali [32, 33]. However, new BOD removal rate obtained during this study are used in the verified model. The simulations were carried out at minimum average seven consecutive days flow (MA7CD) of 9.2 m^3/s for the river.

Table 2: Wastewater discharges in river Ravi in year 2034

No.	Wastewater Outfalls/ Surface Drains	BOD (mg/L)	Flow (m^3/s)	BOD Weighted average (mg/L)
LEFT BANK				
1.	NE District Outfall	240	13.3	**245**
2.	Main Outfall	198	7.8	
3.	Gulshan Ravi Outfall	246	6.4	
4.	Multan Road Outfall	234	4.1	
5.	Hudiara Drain	270	18.8	
	Total		**50.4**	
RIGHT BANK				
6.	Shahadra Outfall	465	2.7	
7.	Deg Drain	379	9.3	
	Total		**62.4**	

Source: [5]

A 73% removal efficiency of BOD obtained during the present study is used for the model simulations, and the results are shown in Figure 5. It shows that the DO levels reach a desirable range of 4 mg/L given the above treatment on left and right bank outfalls. There is only a small length of the river between 63 Km to 67 Km where DO levels fall just below 4 mg/L (i.e., 3.6-3.9mg/L), which is acceptable. Moreover, corresponding to this BOD removal

60% Nitrogenous Biochemical Oxygen Demand (NBOD) is expected to be removed as well [5]. In addition to oxygen demanding pollutants, the other water quality parameters have been evaluated by Haider and Ali [30] for Lahore wastewater. They reported average values of TDS, sulphates, and chlorides as 514mg/L, 151mg/L, and 96mg/L respectively. These values meet the irrigation water quality standards and do not need tertiary level treatment. It was also found in their study that sufficient alkalinity (i.e., 300mg/L) is available in Lahore wastewater for effective growth of nitrifiers in secondary treatment [35]. The pH variation was observed between 6.5 and 7.5, which again qualifies the irrigation water quality standards (i.e., 6.5 – 8.4) [36]. These results show that secondary treated effluent from CW, as proposed in this study, will meet both the river and irrigation water quality standards.

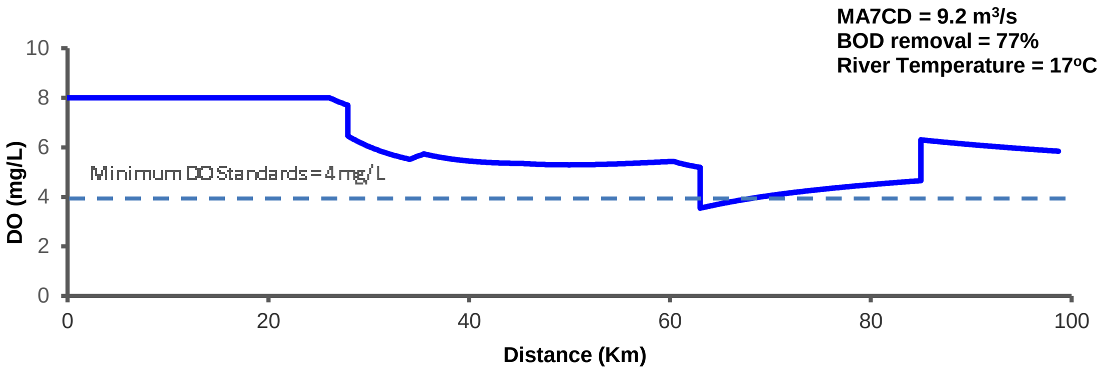

Figure 5: Simulation results of DO levels after treatment with CW

3.3 Design of Constructed Wetlands

The area of the CW was calculated using the Reed's Method [34]. The design equation used is given and defined below.

$$\mathbf{A_w} = Q \times \frac{(lnC_o - lnC_e)}{K \times d_w \times \rho} \qquad (1)$$

where; A_w is the area of CW, m^2; Q is the flow rate, m^3/day; C_o is the influent BOD; C_e is the effluent BOD required; K is the BOD removal rate; d_w is the depth of wastewater in the CW and ρ is porosity of soil used in CW.

Using the above equation (1) for the estimated Q of 50.4 m^3/sec (4,354,560 m^3/day) for year 2034, C_o of 146 mg/L after primary treatment, C_e of 62 mg/L, K value of 0.678 day^{-1}, d_w of 0.7m, and ρ as 0.75, the land area required for the proposed CW was found to be 1305 hectares. This estimated area also includes 20 % of additional area required for berms, access roads etc. The recommended detention time 4 days with a BOD loading of 170 Kg BOD/ha-day.

4 CONCLUSIONS AND RECOMMENDATIONS

Following conclusions can be drawn from the present study:

1. The locally available plant reed (*Phragmites*) is suitable for use in CW, and has appreciable removal efficiency for major pollutants.
2. Based on the removal efficiency of lab scale CW, a detention time of 4 days is recommended, for pre-settled wastewater, to meet the NEQS for TSS, BOD and

COD. The effluent concentration at this detention time was 18, 62 and 119 mg/L for TSS, BOD and COD, respectively for batch scale model.

3. A treatment system based on collector channel, primary sedimentation tank and CW is proposed for Lahore. This system will cater for all the wastewater disposal points situated on left bank of the River Ravi with a total discharge of 50.4 m^3/sec (4,354,560 m^3/day). After implementation, this will help to meet the desired DO level of 4 mg/L in 98 Km long reach of river Ravi starting from Siphon to Balloki Headworks. Presently, anaerobic conditions prevail in about 60% of this reach with no aquatic life, especially under low flow conditions.
4. The area requirement of CW for the wastewater from left bank is 1305 hectare based on a detention time of 4 days in CW. However, this area calculation needs to be re-evaluated after conducting pilot plant studies followed by detailed site specific investigations.
5. A detailed pilot plant study is recommended with extensive and repeating experiments supported by detailed design of experiments (DOE) and statistical analysis for final design of CW as a sustainable wastewater treatment alternative for the city of Lahore.
6.

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