Investigation of municipal wastewater treatment by agricultural waste materials in locally designed trickling filter for peri-urban agriculture

Rana Muhammad Asif Kanwar, Zahid Mahmood Khan and Hafiz Umar Farid

ABSTRACT

A pilot scale trickling filter system was designed, developed, and operated using a constant recirculation method for treatment of municipal wastewater. Maize cob (TF1) and date palm fibre (TF2) were used as biofilm support media in a trickling filter system. Both the TF1 and TF2 were compared based on the removal efficiency of pollution indicators such as biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity (EC), total nitrogen (TN), total phosphorus (TP) and sulphates. The hydraulic flow rate and loading were set as 0.432 m^3/h and 0.0064 m^3/m^2.minute, respectively at temperature range of 15–42 °C for 15 operational weeks. Both the TF1 and TF2 showed acceptable removal efficiency (61% to 76.3%) for pathogen indicators such as total count, fecal coliforms and *Escherichia coli*. However, 8–15% higher removal efficiency was observed for TF1 for all the pollution indicators compared to TF2. The results suggest that both the biofilm support media in trickling filter have potential to treat municipal wastewater in peri-urban small communities to produce environmentally friendly effluent.

Key words | date palm fibre, maize cob, peri-urban agriculture, trickling filter, wastewater treatment

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HIGHLIGHTS

- Agricultural waste-based biofilm support media.
- Removal of carbonaceous and nitrogenous contaminants.
- Log reduction of pathogen indicators.
- Maize cob media is more efficient than date palm fiber.

INTRODUCTION

Rapid urbanization, industrialization and extensive agricultural activities are exerting colossal pressure on the water quality status of Pakistan due to increased wastewater disposal and reuse (Noreen *et al.* 2017; Wu *et al.* 2018). The existence of combined sewers for domestic and industrial effluents is also increasing the multifarious water pollution. It is estimated that 7.5708×10^6 m^3 of wastewater is being disposed of to receiving water bodies every day in Pakistan (Ali *et al.* 2017; Khan *et al.* 2019). This has increased the pollution in the water environment and impacted ecological health including humans, aquatic biota, animals, and agriculture. So, it becomes essential for planners to treat wastewater before disposal or reuse. Wastewater treatment (WWT) refers to removal of contaminants from the wastewater for

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production of environmentally friendly effluent for safe disposal and agricultural reuse (Licciardello *et al.*; 2018). It is estimated that about 10–20% of all the wastewater generated in the developing world receives treatment and the rest is discharged to the receiving water environment without treatment (Rasool *et al.* 2018). Similarly, in Pakistan, the status of WWT (6–8%) is poor, assuming all existing treatment systems operate at their full designed capability (Shah & Hashmi 2012; Ali *et al.* 2017; Haider *et al.* 2017).

The major constraints for WWT in the developing world are related to the cost and energy requirements of conventional WWT systems. The treatment systems' compatibility and combined sewers systems for both domestic and industrial effluents are also major limitations for development of a WWT system (Sato *et al.* 2013; Miller-Robbie *et al.* 2017; Udaiyappan *et al.* 2017). The optimal selection of suitable and practicable technology according to the local settings is important because of the monetary precincts and concerns of choice for effective adoption of WWT systems (Massoud *et al.* 2009; Zhang *et al.* 2015; Droste & Gehr 2018). The outcomes of various research studies recommended the practicality of attached growth treatments like rotating biological contactors, membrane reactors, fluidized bed biofilm reactors and trickling filter systems (Velázquez & Nacheva 2017; Antonie 2018). Among them, the trickling filter system is a prominent treatment technology because it is less mechanically complicated. It has better treatment stability, less energy demand and good sludge thickening physiognomies (Naz *et al.* 2015; Gikas 2016; Ali *et al.* 2017). Its working principle is based on biological attached growth treatment on support media using various microorganisms. This process degrades colloidal and dissolved organics into protoplasm and various gases. The settling of protoplasm is accomplished in a secondary clarifier (Eding *et al.* 2006; Zhu & Rothermel 2014).

The research trend of the trickling filter system can be related to its hybridization, such as of vertical or horizontal flow, low cost biofilm support media and treatment process optimization (Pang 2014; Aslam *et al.* 2017). Various media have been evaluated for WWT in trickling filters such as calcitic gravel, rocks/plastic, nylon pan scrubbers, geotextiles, commercial and pall rings, coal, tire rubber, plastic sheet (corrugated), ceramsite and zeolite, oyster shell, cylindrical luffa (Lekang & Kleppe 2000; Odd & Helge 2000; Liu *et al.* 2010; Alimahmoodi *et al.* 2012; Vianna *et al.* 2012; Zhao *et al.* 2013; Kim *et al.* 2014; Khan *et al.* 2015; Naz *et al.* 2015; Zhang *et al.* 2015; Li *et al.* 2016; Wu *et al.* 2016; Zhang *et al.* 2016). However, to further reduce the cost of the trickling filter system, self-sustainable support media having less economic value should be used (Ali *et al.* 2017). Therefore, the present research study aimed to develop a simple and efficient trickling filter WWT system with biofilm support media such as maize cob (TF1) and date palm fiber (TF2). The evaluation of biofilm support media was also accomplished to overcome the impacts of the pollution indicators and to produce good quality effluent that can safely be used for peri-urban agriculture.

MATERIALS AND METHODS

Experimental setup

A pilot-scale WWT system including two stage trickling filters was designed and developed at the farming area of BZU Multan, Pakistan (Figure 1). This WWT system utilises a trickling filter as the dominant form of biological treatment. This research mainly focused on the trickling filter part of the WWT system. The dimensions of the primary clarifier were 3.1 m length, 3.1 m width, and 1.5 m depth. The two-stage trickling filter was designed and installed for secondary biological treatment of wastewater. Both the trickling filters have a diameter of 1.0 m. Maize cobs (TF1) and date palm fibre (TF2) were applied as a biofilm support media for the first and second trickling filter, respectively (Figure 3). The biofilm support media depth was maintained as 1.95 m for comparison of TF1 and TF2. The dimensions (2.7 m length, 2.13 m width, and 1.52 m depth) of the secondary clarifier were the same for both the developed TF1 and TF2. The secondary clarifier also serves the purpose of a recirculation tank. The trickling filter distribution system installed at the uppermost part of filter was in the form of a rotating arm with perforations for uniform distribution. An electric submersible pump (1HP) was coupled to the distribution system by a polyvinyl chloride piping system. Polyethylene pipe with a diameter of 5.0 cm was connected to the outlet of a submersible pump to transfer the wastewater to the distribution system. Control valves were provided to adjust the

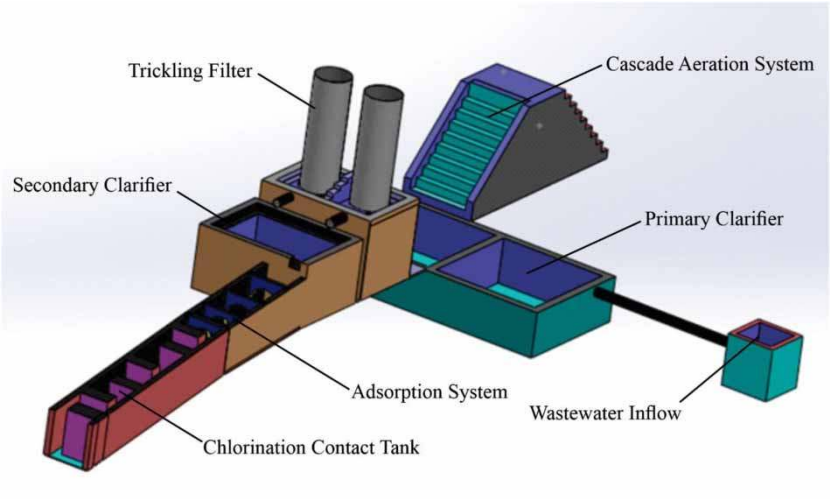

Figure 1 | WWT system including trickling filter (Kanwar *et al.* 2019).

flow rate. The bypass valves were used to control the rate of inflow. A drainage layer of 0.5 m (20 inches) depth was installed at the bottom of the TF1 and TF2 reactors for oxygenation. The other cause of ventilation was the production of convection currents due to the temperature difference between atmospheric air and wastewater. An underdrain system was installed below the trickling filter reactor to facilitate the flow of effluent and sludge to the secondary clarifier.

The TF1 and TF2 were operated for treatment of approximately 2.5 m^3 (2500 L = 660 gallons) of wastewater per day for about 15 weeks. The influent from the distribution system over the maize cob and date palm fibre bed was maintained at a hydraulic flow rate of 7.2 L/min (Q = 0.432 m^3/h, 0.0064 m^3/m^2. minute). The mixture of raw sludge and wastewater (7:3) was pumped into TF1 and TF2 for 12 days to develop active biofilm before the optimum operation of the system. The minimum, maximum and average ambient temperatures were found as 15, 42 and 29 °C respectively during the research.

Experimental operation

Wastewater from the domain of the Agricultural Engineering department was disposed of into the main sewage line. Wastewater taken from the septic tank of the main sewage line of the Department of Agricultural Engineering was used to assess the removal performance of the developed TF systems. A 1 HP submersible pump was installed in the septic tank of the sewage line to transfer wastewater from the septic tank to the primary clarifier of the WWT system. The retention time of 45 minutes was given to the primary clarifier for removal of suspended solids and particulate BOD. The primary treated wastewater was supplied to the trickling filter for organic matter stabilization using attached biofilm. This process produced protoplasm (biological floc) and various gases. The settling of protoplasm was accomplished in the secondary clarifier with retention time of 60 minutes. Thus, the secondary clarified effluent was obtained at the outflow of the secondary clarifier. The illustration of wastewater flow during WWT is shown in Figure 2.

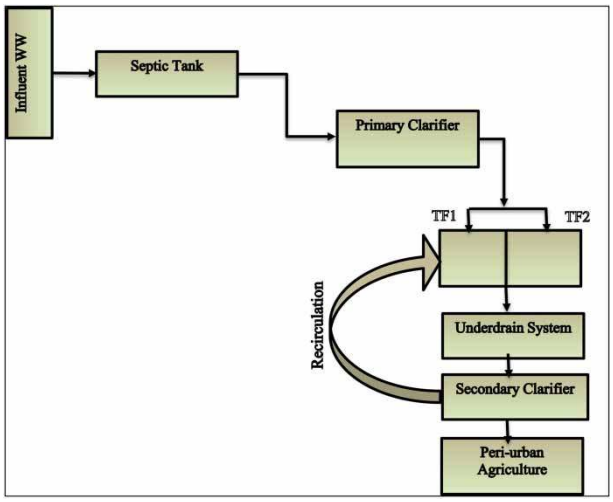

Figure 2 | WW flow scheme to the developed trickling filter system.

Physico-chemical and microbial characterization

The wastewater samples were analyzed for pH, chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), sulphate, total count, fecal coliform and *Escherichia coli* according to *Standard Methods for the Examination of Water and Wastewater* (APHA 2012; Khan *et al.* 2019).

RESULTS AND DISCUSSION

The TF1 (maize cob) and TF2 (date palm fiber) were compared for removal of COD, BOD, TSS, TDS, EC, TN, TP, sulphate, total count, fecal coliforms and fecal coliforms. These quality parameters are used to indicate the contamination strength of wastewater (Gatto *et al.* 2015; Seow *et al.* 2016). The other objective of this study is to remove the aesthetic unpleasantness of wastewater in terms of color and odour. The odour in wastewater is produced by the sulfuric aromatic compounds (mercaptans), excessive nutrients and decomposition of ketones and aldehydes (Abegglen *et al.* 2008). It was observed that several recirculations of wastewater over attached biofilm helps in the decomposition of organic compounds and odour removal. The increased contact of contaminants with biofilm facilitates the removal of odorous and other compounds. The mean values of the influent wastewater characteristics of TF1 and TF2 are given in Table 1.

BOD is considered as an important parameter used to determine the biodegradation rates of organic contamination load in wastewater (Shah *et al.* 2015). The BOD removal rates of TF1 and TF2 are presented in Figure 3. The mean value of BOD was 151.42 mg/L in the wastewater as an influent and decreased to an average value of 13.68 mg/L 17.4 mg/L and 30.9 mg/L in the effluent of TF1 and TF2, respectively. It presented an average removal rate of the BOD as 87.6% for TF1 and 78.7% for TF2 during the whole 15-week operational period. The results show that BOD removal efficiency increased with operational time from the 1st to 15th week and ranged from 77.4% to 97.5% for TF1 and 67% to 87.1% for TF2 at a flow rate of 7.2 L/min. The highest removal efficiency was recorded as 97.9% in the 10th week for TF1 and 87% in the 13th week for TF2. However, the TF1 was found to be more efficient

Table 1 | Influent wastewater characteristics

Operational weeks	Wastewater quality parameters									
	BOD [mg/L]	COD [mg/L]	DO [mg/L]	pH	TDS [mg/L]	TSS [mg/L]	TN [mg/L]	TP [mg/L]	EC [μS/m]	Sulphate [mg/L]
1	107	132	2.6	6.5	530	159	22.55	17.31	1250	202
2	119	148	2.8	7.1	535	214	16.69	15.38	1290	276
3	143	175	3.1	5.7	543	223	13.11	15.38	1230	187
4	138	171	2.3	5.9	538	168	20.22	15.38	1270	155
5	131	164	2.4	6.9	545	219	25.2	15.38	1960	140
6	133	168	2.6	7.5	525	283	17.99	30.77	1150	176
7	152	192	2.5	6.1	496	285	20.13	15.38	1070	181
8	201	247	2.7	7.2	380	291	22.77	15.31	1030	319
9	196	298	1.9	6.7	586	258	42	15.38	1200	127
10	179	226	1.7	7.1	540	263	53	15.3	1040	348
11	129	161	2.9	7.3	566	169	18.93	15.3	1100	383
12	187	242	2.5	7.9	496	231	37.34	15.3	1500	221
13	179	225	2.6	7.8	427	177	15.89	15.38	1798	173
14	158	195	2.9	7.8	425	105	32	15.77	1715	156
15	118	159	2.3	7.6	439	184	17.34	15.38	1780	169

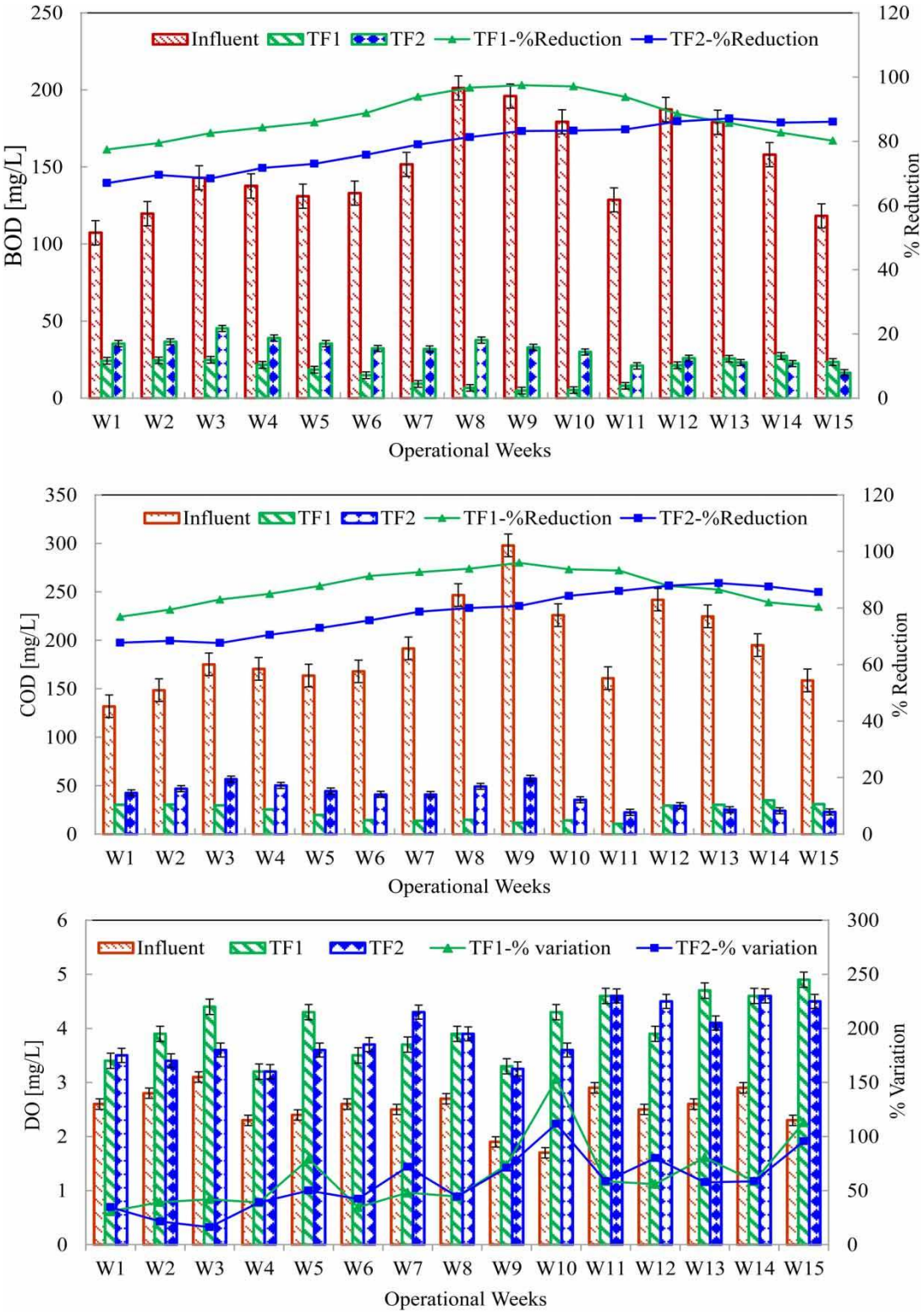

Figure 3 | Variations in BOD, COD and DO concentrations of effluent from TF1 and TF2 during 15 operational weeks.

in BOD removal than TF2, comparatively. Likewise, the mean COD of the influent and effluent was observed to be 189.3 mg/L and 22.8 mg/L for TF1 and 189.3 mg/L and 38.5 mg/L for TF2, respectively. However, the highest COD decline was recorded for the 9th operational week (96%) for TF1 (COD removal from 298 mg/L to 12 mg/L) and the 11th operational week (86%) for TF2 (COD removal from 161 mg/L to 22.5 mg/L) (Figure 3). It was also observed that effluent BOD and COD values were found to be much less than the BOD (80 mg/L) and COD (150 mg/L) values described by the National Environmental Quality Standards (NEQS) (Metcalf & Eddy 2013; Khan et al. 2019).

The constant increase in removal of COD and BOD can be credited to the provision of organic and inorganic nutrients by recirculation and increase in temperature difference between ambient air and wastewater. This temperature difference causes natural downward ventilation and development of metabolically competent biofilm (Kornaros & Lyberatos 2006; Monayeri et al. 2007; Takeyuki et al. 2008; Zieliński et al. 2013). The higher removal efficiency of TF1 than TF2 was obtained due to the filamentous structure of maize cob, which caused rapid microbial attachment (Ali et al. 2016). The constant increase in the decline in removal efficiency of BOD and COD for the first nine operational weeks of TF1 and the first 11 operational weeks of TF2 might be due to the maintenance of an aerobic zone in the exterior portion of the biofilm and destruction of the anaerobic zone by proper flushing (Wijeyekoon et al. 2004; Alimahmoodi et al. 2012). The COD and BOD removal efficiencies of TF1 and TF2 were observed to be higher than the trickling filter with polystyrene media (86.7% COD and 90.7% BOD), rubber media (81.9% COD and 86.7% BOD), plastic media (94.7% COD and 94.3% BOD), cotton stick media (80% COD and 78% BOD) and stone media (85.6% COD and 85.6% BOD) (Naz et al. 2015; Aslam et al. 2017; Rasool et al. 2018). The influent DO value was found to be very low (2.25 mg/L) but after treatment the DO enhancement was observed as 30–152% for TF1 and 16–111% for TF2. This DO enhancement with BOD and COD removal indicates active metabolism of organic pollutants by microbes in the developed biofilm of TF1 and TF2 (Sa & Boaventura 2001; Calheiros et al. 2015). The other reason for DO enhancement was the regular arrangement of media (maize cob and date palm fiber) with high porosity that causes effective passive aeration during recirculation of wastewater (Gullicks et al. 2011). Thus, this sufficient aeration produced by the natural draft increased the DO level and decreased organic pollutants (BOD and COD) in the effluent. Similar results of DO enhancement with BOD removal were observed by Khan et al. (2015).

The pH of untreated wastewater was observed as 7 ± 0.7 (Figure 4). The pH variation was obtained as 7.4 ± 0.7 for TF1 and 7.3 ± 0.6 for TF2 during 15 operational weeks at a temperature range of 18–42 °C. This pH variation may be due to the buffering capacity of the media and also the redox and nitrification-denitrification reactions converting nitrates to molecular nitrogen (Blum et al. 2018; Silva et al. 2017; Cavazana et al. 2018; Ugurlu & Ozturkcu 2018). pH is used to define the quality of biological WWT, macrophyte performance and the existence of biological life (Bai et al. 2011; Tarpani & Azapagic 2018). The obtained pH range indicated the feasibility of good biological treatment, effective nitrification and optimum operation of the trickling filter (Shah et al. 2015; Kanwar et al. 2019; Khan et al. 2019). The pH range of 6–9 was considered suitable for optimum performance of the trickling filter (Chen et al. 2017; Priya & Selvan 2017). The results of the present study for pH variation was also revealed in the same range that indicates the application potential of developed trickling filter systems for domestic WWT. Similar results were obtained for biofilm support media of oyster shell, maize cob and cotton sticks (Liu et al. 2010; Ali et al. 2016; Aslam et al. 2017).

The parameter EC is used to indicate the salinity potential of water by measuring the current carrying capacity due to the presence of free ionised constituents (Norton-Brandao et al. 2013; Khan et al. 2019). The permissible limit of EC by FAO is 7,000 μS/m (FAO 1992). The EC value of untreated wastewater was observed as 1,359 ± 310 μS/m. In the present study, about 15.5% and 14.9% reduction in EC value was found during treatment by TF1 and TF2, respectively (Figure 4). The EC value of effluent was found as 1,144 ± 247 μS/m for TF1and 1,152 ± 251 μS/m for TF2. The EC value of effluent was found to be much less than the permissible limit (FAO 1992). The major reason for EC removal was due to reduction in free metal ions by conversion of nitrates, nitrites and ammonium into molecular nitrogen. Pitchard et al. (2007) also reported that the reductions in the TSS

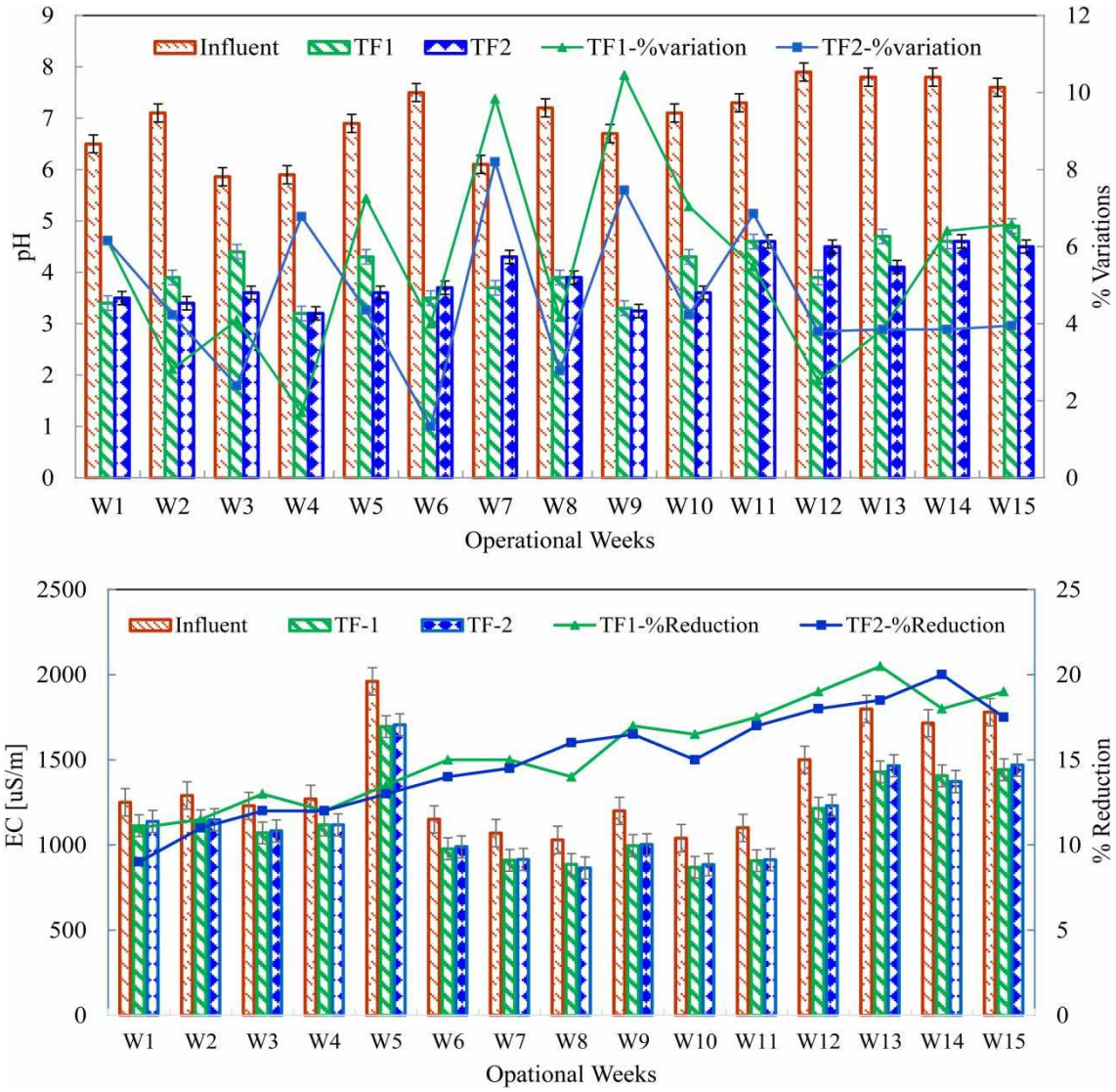

Figure 4 | Variations in pH and EC values of effluent from TF1 and TF2 during 15 operational weeks.

play a key role in the decline of EC values. Muthukumaran & Ambujam (2003) investigated that primary clarification reduces the EC concentration. A fixed biofilm reactor integrated with a sand column filter was also found to be effective in reduction of the EC value (29.4%) (Khan *et al.* 2015).

The important wastewater quality parameters are TDS and TSS because they act as rise in soil osmotic pressure, specific ion toxicity and carriers of pathogens. The TDS and TSS of untreated wastewater was observed as 505 ± 59.8 mg/L and 215 ± 54.6 mg/L, respectively (Table 1). The high TSS values were due to the existence of colloidal and non-settleable solids including large sand particles, clay and fine silt. The TDS concentrations were found to be higher than those of BOD and COD due to different inorganic contaminants (calcium, potassium, sodium, magnesium, fluorides, chlorides, phosphates, bicarbonates, and sulphates) along with dissolved organic constituents. In the present study, about 47.8% and 42.3% reduction in TDS value was found during treatment by TF1 and TF2, respectively (Figure 5). The TDS value of the effluent was found as 263 ± 45.5 mg/L for TF1 and 287 ± 44.9 mg/L for TF2. However, after treatment through the pilot-scale TF1 and TF2 systems, the concentrations of TSS were reduced to 16.4 ± 14 mg/L and 31.6 ± 13.8 mg/L, respectively (Figure 5). The treated

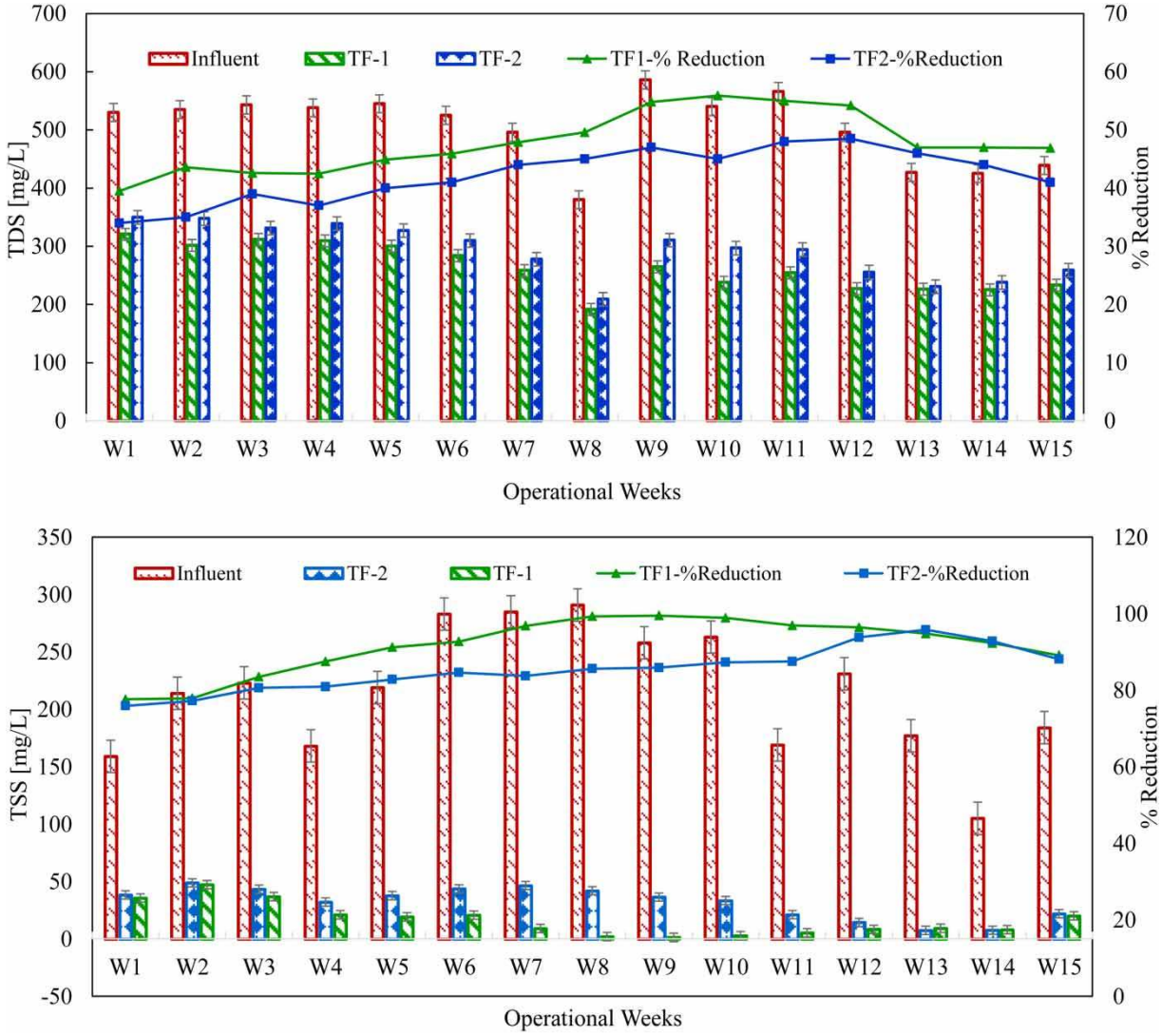

Figure 5 | Variation in TDS and TSS concentrations of effluent from TF1 and TF2 during 15 operational weeks.

wastewater was found to be feasible for agriculture and safe disposal based on the recommended TDS (<1000 mg/L) and TSS (25–80 mg/L) values (WHO 2006; US-EPA 2007). The reduction in TDS value was due to the continuous recirculation of wastewater over the media bed. This continuous recirculation enhances the contact time between microbial biofilm and dissolved contaminants and hence microorganisms performed metabolic activities to decompose these dissolved contaminants (Ali *et al.* 2017). Rasool *et al.* (2018) reported 62.8% reduction in TDS and 99.9% reduction in TSS while using the pilot-scale stone media trickling filter. Further reduction in TDS (66%) and TSS (100%) was also observed by integrating the stone media trickling filter with the sand column filter (Khan *et al.* 2015).

The total nitrogen (TN) of untreated wastewater was observed 25 ± 11 mg/L. In the present study, about 32% and 22.7 reductions in TN value was found during treatment by TF1 and TF2, respectively (Figure 5). The TN value of effluent was found as 16 ± 5.1 mg/L for TF1 and 18.7 ± 6.8 mg/L for TF2 (Figure 6). These effluent values were found to be within the permissible limit (30 mg/L), which indicated effective simultaneous nitrification and denitrification by the trickling filter (WHO 2006; US-EPA 2007). The basis to attain a better removal efficiency of TN

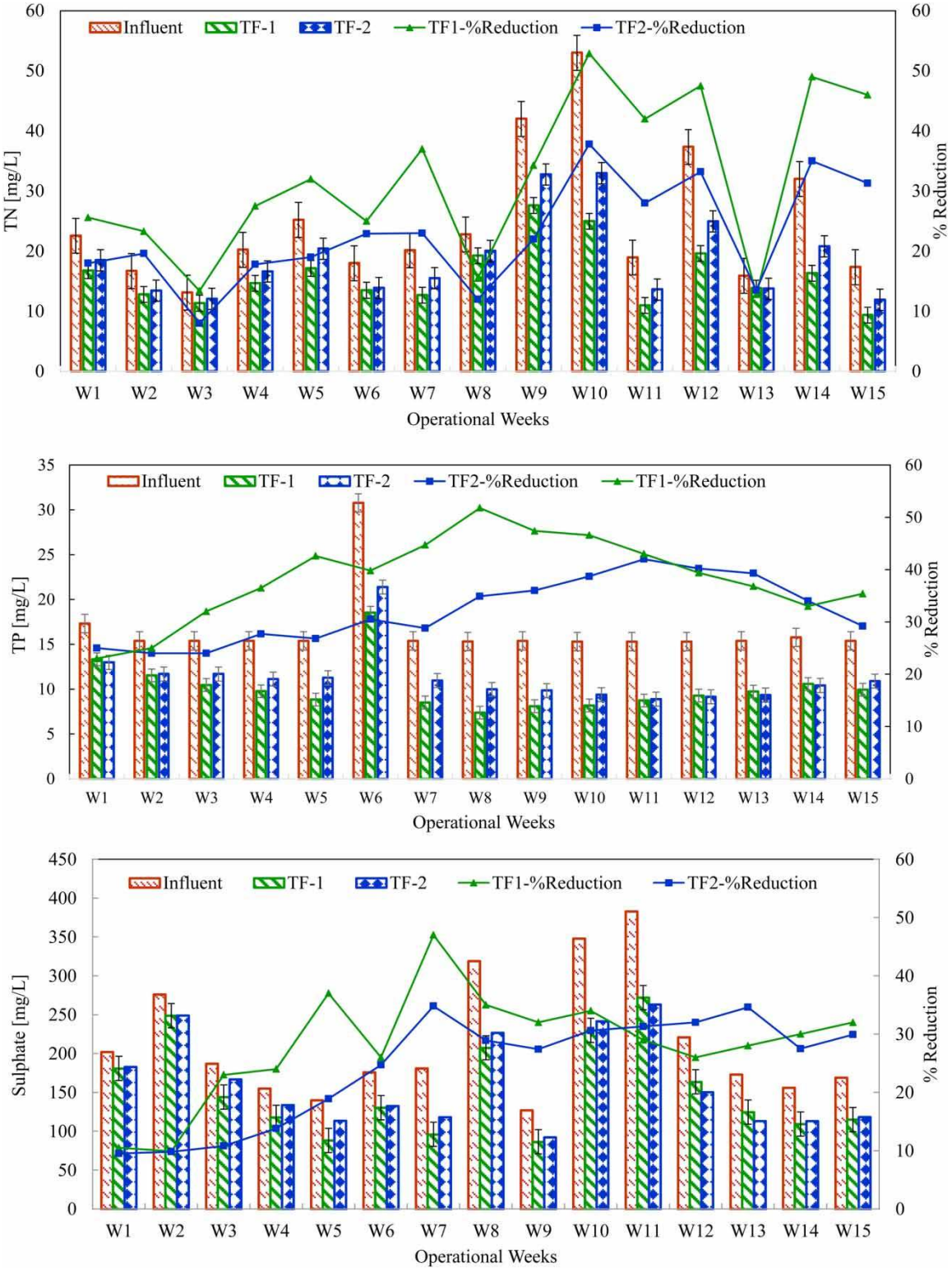

Figure 6 | Reduction in TN, TP and sulphate concentrations by TF1 and TF2 treatment.

was the favourable temperature, DO enhancement, good BOD/TN ratio and internal recirculation of wastewater (Diaz-Elsayed *et al.* 2017; Jiang *et al.* 2017). The observed temperature range of 18–42 °C was found to be feasible to enhance the population of nitrifiers (He *et al.* 2007; Ge & Champagne 2016). Moreover, the decline in inorganic/organic contaminants has a positive effect on the growth of nitrifiers, resulting in good nitrification/denitrification. Therefore, presently the removal efficiency of the TN can be correlated with the COD/BOD removal and enhancement of DO due to the continuous recirculation of wastewater over the media bed (Figures 3 and 6). The high DO level of treated wastewater indicated favourable BOD/TP and BOD/TN ratios that improved biological nutrient removal without external carbon addition (Morgan 1999). This supplemental DO is used primarily by the decomposing bacteria and later by the nitrifying bacteria to succeed in their own metabolic activities. The average carbon (BOD) to nitrogen (TN) ratio during the operational time of 15 weeks was observed to be in the range of 4:1–14:1. However, a maximum removal of TN of 52.9% was observed for a BOD/TN ratio of 3:1 during the 10th week of TF1 operation, while minimum removal (12.8%) of TN was obtained in the 13th week of TF1 operation at a BOD/TN ratio of 14:1. For TF2, the maximum and minimum reduction in TN was recorded as 37.8 and 8% under the condition of BOD/TN ratio of 4:1 and 13:1, respectively. The inadequate nitrification under high BOD/TN ratio may be due to the leading growth of heterotrophic bacteria and the repressing growth of autotrophic (Fdz-Polanco *et al.* 2000). This competition can produce spatial distribution of microbes inside the biofilm matrix that affects nitrification performance due to the impact of the mass transfer processes. Okabe *et al.* (1996) investigated whether nitrifiers and heterotrophs concurred in the outmost biofilm at $C/N = 0$. Michaud *et al.* (2014) reported a significantly lower removal rate of total ammonium nitrogen at $C/N \geq 0.5$ than at $C/N = 0$. Siebritz *et al.* (1983) observed that the process of nitrification was strongly inhibited if COD/TKN (BOD/TKN) was more than 20 (10). To reduce this inhibitory impact on nitrification, the particulate and soluble organic carbon should be reduced. The reduction in treatment efficiency of TN for higher COD/N ratio may be due to the excessive development of microorganisms.

TP is a macro-nutrient present in WW in small amounts. The high TP in WW causes eutrophication in water bodies. In the present research, phosphorus removal from TF1 and TF2 was recorded as 38.5% and 32.1% respectively (Figure 6). The effluent TP was found to be close to the permissible limit (8.6 mg/L) (WHO 2006; US-EPA 2007). So, this wastewater can be effectively used for agriculture based on the TP concentration. Phosphorus removal from TF1 and TF2 may be due to settling of non-soluble phosphorus in primary clarifier and incorporation of soluble phosphorus into the biofilm on the support media of TF (Richardsen 2017). This removal may also be due to the presence of phosphate-accumulating bacteria and high oxidation of iron (Fe^{2+}) into ferric ion (Fe^{3+}), which assists in the fixing of phosphorus by forming a chemical precipitate in an aerobic environment. The TP removal rate for a trickling filter was reported as in the range from 5–16% to 21–30% in the Thames Water region of UK while assimilation of TP into the biofilm was found from 0.9 to 1.2% through the TF and secondary clarifier (Pearce 1998). Naz *et al.* (2015b) reported the presence of *Dechloromonas* in the biofilm of stone media. Zhang *et al.* (2015) found the removal efficiency of COD, TN, and TP (94.1%, 92.8%, and 92.0% respectively) using a vertical flow trickling filter and horizontal flow multi-soil-layering bioreactor. Norton-Brandao *et al.* (2013) also suggested the WWT technology of media filtration for TP removal. The measurement of sulphate is of prime importance in wastewater samples due to the production of the sulphuric aromatic compounds (mercaptans). A higher sulphate removal rate was observed for TF1 than TF2 (Figure 6). The removal efficiency for sulphate was found to be 28.2% for TF1 and 24.3% for TF2. This reduction may be due to the accumulation of sulphate reducing bacteria and enhancement of DO that was used to oxidize reduced forms of sulphuric compounds (Särner (1990); Wik (2003)). Khan *et al.* (2015) recorded 63.15% sulphate removal by plastic media trickling filter through 48 hours of treatment.

The removal of pathogens was assessed using pathogen indicators such as total count, fecal coliform and *E. coli*. The concentrations of total count, fecal coliform and *E. coli* in the trickling filter system are mentioned in Table 2. The average removal of total count, fecal coliform and *E. coli* from combined TF1 and TF2 treatment were observed to be 76.3% (49–96%), 61% (33–91%) and 62% (31–85%)

Table 2 | Removal efficiency of pathogen indicators of developed TF

	Total count [cfu/100 mL]			Fecal coliform [MPN/100 mL]			*E. coli* [cfu/100 mL]		
Weeks	Untreated	Treated	Removal efficiency	Untreated	Treated	Removal efficiency	Untreated	Treated	Removal efficiency
1	397928	49989	87	3981	2681	33	72900	50400	31
2	251009	79303	68	32623	21589	34	78800	53700	32
3	158310	39681	74	6405	4011	37	37000	24600	33
4	316048	49989	84	7545	4689	38	79800	44400	44
5	398539	50350	87	1995	1100	45	85000	46600	45
6	158921	5243	96	15648	8497	46	83300	40000	52
7	100432	4213	95	19852	8488	57	95100	35200	63
8	20952	4592	78	8041	3456	57	91800	26100	71
9	51118	11430	77	1598	687	57	45000	11300	74
10	19953623	5013302	74	133852	51890	61	93600	20200	78
11	9998015	2510868	74	63095	5921	90	69900	16000	77
12	6307588	1994244	68	15948	1399	91	76300	17100	77
13	39808732	19951605	49	530987	44987	91	78500	14500	81
14	998889	251077.6	74	19952	1764	91	98200	15200	84
15	25117753	9999889	60	241799	24114	90	86900	13000	85

respectively. However, the further removal of total count, fecal coliforms and *E. coli* is essential in order to meet their permissible limits for safe agricultural reuse (WHO 2006; US-EPA 2007; Khan *et al.* 2019). The highest removal of total count was obtained for the 5th and 6th operational weeks. The removal of fecal coliforms and *E. coli* was observed to increase constantly from the 1st to 15th operational weeks. The removal of total count, fecal coliform and *E. coli* may be due to the adsorption of pathogenic bacteria in metabolically active biofilm by greater contact time in the reactor (Stefanakis *et al.* 2015, 2019). This removal is also directly associated with the removal of carbonaceous pollutants (BOD and COD) by settling of protoplasm in secondary clarifier (Curtis 2003). Abbadi *et al.* (2012) rejected the 1 log (90% reduction) through an activated sludge WWT system. Log reduction is the 10-fold reduction of microbial organisms present in the sample. Rasool *et al.* (2018) obtained 54–92% removal of total cfu/100 mL during treatment by pilot scale stone media trickling filter and reduction of 0–54% of fecal coliform for the first nine weeks and then 80–90% reduction after nine weeks due to the development of biofilm. The reduction of the geometric mean of fecal coliforms was observed as 4.3, 4.0, 5.8 and 5.4 $\log_{10}$ for media of polystyrene, plastic, rubber, and stones, respectively. Kaveh *et al.* (2019) also mentioned the 98 and 99% removal of total coliforms and fecal coliforms by sand cum four seed powder filter. Multi soil layering cum sand filter rejected 4.46, 4.47 and 4.13 log units for total coliforms, fecal coliforms and fecal streptococci, respectively (Latrach *et al.* 2016).

CONCLUSIONS

The developed pilot scale trickling filter system was evaluated for removal of BOD, COD, TDS, TSS, EC, TN, TP, sulphates and pathogen indicators using maize cob (TF1) and date palm fiber (TF2) biofilm support media for an operational time of 15 weeks. The treatment efficiency of TF1 was obtained as 88%, 87%, 48%, 91.6%, 32%, 38.4%, 16% and 28.2% for BOD, COD, TDS, TSS, TN, TP, EC, and sulphate, respectively. Similarly, the TF2 removed 79% BOD, 79% COD, 42% TDS, 85.5% TSS, 23% TN, 32.1% TP, 15% EC and 24.3% sulphate. Overall, the removal efficiency of TF1 was observed to be 8–15% higher than that of TF2 for removing the studied pollution indicators. Thus,

the present research can potentially play an important role in managing not only the regional wastewater pollution but also help relatively safe re-use of the wastewater for peri-urban agriculture and protect our receiving environment. This is particularly significant in the current water resource shortage scenario in the country and may also help to safe re-use of wastewater for peri-urban food agriculture in the Multan region of Pakistan as well as in the developing world.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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