Investigation of municipal wastewater treatment by agricultural waste materials in locally designed trickling filter for peri-urban agriculture
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ABSTRACT
A pilot scale trickling filter system was designed, developed, and operated using a constant recirculation method for treatment of municipal wastewater. The 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 m³/h and 0.0064 m³/m².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 coliform and E-Coli. However, 8–15% higher removal efficiency was observed for TF1 for all the pollution indicators as 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

HIGHLIGHTS
• Agricultural Waste Based Biofilm Support media.
• Removal of Carbonaceous and Nitrogenous Contaminants.
• Log Reduction of Pathogens Indicators.
• More efficient Maize cob media than Date Palm Fiber

INTRODUCTION
Rapid urbanization, industrialization and extensive agricultural activities are exerting colossal pressure on 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 water pollution multifarious. It is estimated that $7.5708 \times 10^6$ m³ of wastewater is being disposed to receiving water bodies for every day in Pakistan (Ali et al. 2017; Khan et al. 2019). This increased the pollution in water environment and impacted ecological health including humans, aquatic biota, animals, and agriculture. So, it becomes essential for planers to treat wastewater before disposal or reuse. Wastewater treatment (WWT) refers to removal of contaminants from the wastewater for
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 developing world receives treatment and the rest being discharged to receiving water environment without treatment (Rasool et al. 2017). Similarly, in Pakistan, the status of WWT (6–8%) is poor assuming all existing treatment systems operation at their full designed capability (Shah & Hashmi 2012; Ali et al. 2017; Haider et al. 2017).

The major constraints for WWT in developing world are related to 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 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, trickling filter system is found 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). It’s working principle is based on the 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 secondary clarifier (Eding et al. 2006; Zhu & Rothermel 2014).

The research trend of trickling filter system can be related to its hybridization like 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 filter such as calcitic gravel, rocks/plastic, nylon pan scrubber, geotextile, commercial and pall rings, coal, tire rubber, plastic sheet (corrugated), ceramsite and zeolite, oyster shell, cylindrical luffa (Lekang & Kleppe 2000; Odd & Helge 2000; Liu 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 trickling filter system, the self-sustainable support media having less economic values should be used (Ali et al. 2017). Therefore, the present research study is 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 which can safely be used for peri-urban agriculture.

MATERIALS AND METHODS

Experimental setup

A pilot scale WWT system including two stage trickling filters were designed and developed at the farming area of BZU Multan, Pakistan (Figure 1). This WWT system utilises trickling filter as dominant form of biological treatment. This research mainly focused the trickling filter part of WWT system. The dimensions of primary clarifier were 3.1 m in length, 3.1 m in width, and 1.5 m in depth. The two-stage trickling filter was designed and installed for secondary biological treatment of wastewater. The both the trickling filter have diameter of 1.0 m. Maize cobs (TF1) and date palm fibre (TF2) were applied as a biofilm support media for 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 in length, 2.15 m in width, and 1.52 m in depth) of secondary clarifier were same for both the developed TF1 and TF2. The secondary clarifier also serves as the purpose of recirculation tank. The trickling filter distribution system installed at the uppermost part of filter in the form of rotating arm with pores for uniform distribution. Electric submersible pump (1HP) was coupled to the distribution system by piping system of polyvinyl chloride. Polyethylene pipe having diameter of 5.0 cm was connected to outlet of submersible pump in order to transfer the wastewater to distribution system. Control valves were provided to adjust the
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 TF1 and TF2 reactors for oxygenation. The other cause of ventilation was due to production of convection currents due to temperature difference between atmospheric air and wastewater. An underdrain system was installed below trickling filter reactor to facilitate the flow of effluent and sludge to 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 frequency of 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 system. The minimum, maximum and average ambient temperature were found as 15, 42 and 29 °C respectively during the research.

**Experimental operation**

Wastewater from the domain of Agricultural Engineering department was disposed into the main sewage line. Wastewater taken from the septic tank of main sewage line of Department of Agricultural Engineering was used to assess the removal performance of developed TF systems. 1 HP submersible pump was installed in the septic tank of the sewage line to transfer wastewater from septic tank to the primary clarifier of 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 flock) 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 1](image1.png)  
**Figure 1** | WWT system including trickling filter (Kanwar et al. 2019).

![Figure 2](image2.png)  
**Figure 2** | WW Flow Scheme to 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 E-Coli according to standard methods of wastewater examination (APHA 2012; Khan et al. 2019).

RESULTS AND DISCUSSIONS

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 coliform and fecal coliform. These quality parameters are used to indicate the contamination strength of wastewater (Topare et al. 2011; Gatto et al. 2015; Seow et al. 2016). The other objective of this study is to remove the aesthetically unpleasance 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 recirculation 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 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 weeks operational period. The results show that BOD removal efficiency increased with operational time from the 1st to 15th week and range 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% at 10th week for TF1 and 87% at 13th week for TF2. However, the TF1 was found more efficient in BOD

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     | 1920      | 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 | 459        | 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.
removal than TF2 comparatively. Likewise, the mean COD of influent and effluent observed as 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 recorded for 9th operational week (96%) for TF1 (the COD removal from 298 mg/L to 12 mg/L) and 11th operational week (86%) for TF2 (the 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 highly less than the BOD (80 mg/L) and COD (150 mg/L) values as described by the National Environmental Quality Standards (NEQS) (Metcalf & Eddy 2003; 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 downward natural ventilation and development of metabolically competent biofilm (Kornaros & Lyberatos 2006; Monayeri et al. 2007; Takeyuki et al. 2008; Marcin et al. 2013). The higher removal efficiency of TF1 than TF2 was obtained due to filamentous structure of maize cob that caused rapid microbial attachment (Ali et al. 2016). The constantly increase in the decline in removal efficiency of BOD and COD for first nine operational weeks of TF1 and first eleven operational weeks of TF2 might be due to the maintenance of aerobic zone in the exterior portion of biofilm and destruction of anaerobic zone by proper flushing (Wijeyekoon et al. 2004; Alimahmoodi et al. 2012). These COD and BOD removal efficiencies of TF1 and TF2 were observed higher than the trickling filter with poly styrene 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 sticks 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). (Naz et al. 2015; Rasool et al. 2017; Aslam et al. 2018). The influent DO value was found 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 indicate active metabolism of organic pollutants by microbes in developed biofilm of TF1 and TF2 (Sa & Boaventura 2001; Calheiros et al. 2015). The other reason of DO enhancement was due to 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 natural draft increased the DO level and decreased organic pollutants (BOD and COD) from effluent. Similar results of DO enhancement with BOD removal was observed by Khan et al. 2014.

The pH of untreated wastewater was observed 7 ± 0.7 (Figure 4). The pH variation was obtained 7.4 ± 0.7 for TF1 and 7.3 ± 0.6 for TF2 during 15 operational weeks at temperature range of 18–42 °C. This pH variation may be due to buffering capacity of 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 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 trickling filter (Shah et al. 2014; Kanwar et al. 2019; Khan et al. 2019). The pH range of 6–9 was considered as suitable for optimum performance of trickling filter (Chen et al. 2017; Priya & Selvan 2017). The results of present study for pH variation was also revealed the same range that indicate 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 current carrying capacity due to presence of free ionised constituents (Norton-Brandao et al. 2015; 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 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 1,144 ± 247 μS/m for TF1 and 1,152 ± 251 μS/m for TF2. The EC value of effluent was found highly less than the permissible limit (FAO 1992). The major reason of 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 the reductions in the TSS play a...
key role in the decline of EC values. Muthukumaran & Ambujam 2003 investigated that primary clarification reduces the EC concentration. Fixed biofilm reactor integrated with sand column filter was also found effective in reduction of EC value (29.4%) (Khan et al. 2014).

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 505 ± 59.8 mg/L and 215 ± 54.6 mg/L, respectively (Table 1). The high TSS values were due to existence of colloidal and non-settleable solids including large sand particles to clay and fine silt. The TDS concentrations were found higher than that 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 effluent was found 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 concentration of TSS were reduced to 16.4 ± 14 mg/L and 31.6 ± 13.8 mg/L, respectively (Figure 5). The treated
wastewater was found feasible for agriculture and safe disposal based on the recommended TDS (<1000 mg/L) and TSS (25–80 mg/L) value (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. 2017 reported 62.8% reduction in TDS and 99.9% reduction in TSS during using the pilot scale stone media trickling filter. Further reduction in TDS (66%) and TSS (100%) was also observed by integrating stone media trickling filter with sand column filter (Khan et al. 2014).

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 16 ± 5.1 mg/L for TF1 and 18.7 ± 6.8 mg/L for TF2 (Figure 6). These effluent values were found within the permissible limit (30 mg/L) which indicated the effective simultaneous nitrification and denitrification by 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 might be 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 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 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 media bed (Fifure 3 and 6). The high DO level of treated wastewater indicated the favourable BOD/TP and BOD/TN ratios that improve 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 their own metabolic activities. The average carbon (BOD) to nitrogen (TN) ratio during the operational time of 15 weeks was observed in the range of 4:1–14:1. But, a maximum removal of TN as 52.9% was observed for BOD/TN ratio of 3:1 during the 10th week of TF1 operation. While minimum removal (12.8%) of TN was obtained on 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 impact of mass transfer processes. Okabe et al. 1996 investigated that nitrifiers and heterotrophs concurred in the outmost biofilm at C/N = 0. Michaud et al. 2014 reported the significantly lower removal rate of total ammonium nitrogen at C/N > 0.5 than C/N = 0. Siebritz et al. 1983 observed that the process of nitrification is strongly inhibited if COD/TKN (BOD/TKN) was more than 20 (10). To reduce this inhibitory impact on nitrification, one should decrease the particulate and soluble organic carbon. 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 wastewater causes eutrophication in water bodies. In the present research, phosphorus removal from TF1 and TF2 was recorded 38.5% and 32.1% respectively (Figure 6). The effluent TP was found 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 (Fe²⁺) into ferric ion (Fe³⁺) which assists in the fixing of phosphorus by forming chemical precipitate in aerobic environment. The TP removal rates for trickling filter was reported in the range from 5–16% to 21–30% in 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. 2016 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 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 production of the sulphuric aromatic compounds (mercaptans). The higher sulphate removal rate was observed for TF1 than TF2 (Figure 6). The removal efficiency of sulphate was found 28.2% for TF1 and 24.5% for TF2. This reduction may be due to the accumulation of sulphate reducing bacteria’s and enhancement of DO that was used to oxidize reduced forms of sulphuric compounds (Särner 1990; Wik 2003). Khan et al. 2014 was recorded the 63.15% sulphate removal by plastic media trickling filter through 48 hours treatment.

The removal of pathogens was assessed using the pathogens 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 76.3% (49–96%), 61% (33–91%) and
62% (31–85%) respectively. However, the further removal of total count, fecal coliform 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 5th and 6th operational week. The removal of fecal coliform and E-coli was observed to increase constantly from 1st to 15th operational week. 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 was rejected the 1 log (90% reduction) through activated sludge WWT system. Log reduction is the 10-fold reduction of microbial organisms present in the sample. Rasool et al. 2017 was 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 first nine weeks and then 80–90% reduction after nine weeks due to development of biofilm. The reduction of geometric mean of fecal coliforms was observed 4.3, 4.0, 5.8 and 5.4 log_{10} for media of polystyrene, plastic, rubber, and stones, respectively. Kaveh et al. 2019 was also mentioned the 98 and 99% removal of total coliform and fecal coliform by sand cum four seed powder filter. Multi soil layering cum sand filter was rejected the 4.46, 4.47 and 4.13 Log unit 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 pathogens indicators using maize cob (TF1) and date palm fiber (TF2) biofilm support media for operational time of 15 weeks. The treatment efficiency of TF1 was obtained 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 the 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 8–15% higher than that of TF2 for removing studied pollution indicators. Thus, the
present research can potentially play an important role in managing not only the regional wastewater pollution but also help a 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 Multan region of Pakistan as well as in developing world.

**DATA AVAILABILITY STATEMENT**

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

**REFERENCES**

Abbadi, J., Saleh, R., Nusseibeh, S., Qurie, M., Khamis, M., Karaman, R., Scrano, L. & Bufo, S. A. 2012 Microbial removal from secondary treated wastewater using a hybrid system of ultrafiltration and reverse osmosis. Journal of Environmental Science and Engineering A1 (7A), 853.

Abegglen, C., Ospelt, M. & Siegrist, H. 2008 Biological nutrient removal in a small-scale MBR treating household wastewater. Water Research 42 (1–2), 338–346.

Ali, I., Khan, Z. M., Sultan, M., Mahmood, M. H., Farid, H. U., Ali, M. & Nasir, A. 2016 Experimental study on Maize Cob trickling filter-based wastewater treatment system: design, development, and performance evaluation. Polish Journal of Environmental Studies 25 (6), 2265.

Ali, I., Khan, Z. M., Peng, C., Naz, I., Sultan, M., Ali, M., Mahmood, M. H. & Niaz, Y. 2017 Identification and elucidation of the designing and operational issues of trickling filter systems for wastewater treatment. Polish Journal of Environmental Studies 26 (6).

Alimahmoodi, M., Yerushalmi, L. & Mulligan, C. N. 2012 Development of biofilm on geotextile in a new multi-zone wastewater treatment system for simultaneous removal of COD, nitrogen and phosphorus. Bioresource Technology 107 (78–86).

Antonie, R. L. 2018 Fixed Biological Surfaces-Wastewater Treatment: the Rotating Biological Contactor. CRC press.

APHA, AWWA 2012 Standard Methods for the Examination of Water and Wastewater. p. 22.

Aslam, M. M. A., Khan, Z. M., Sultan, M., Niaz, Y., Mahmood, M. H., Shoaib, M., Shakoor, A. & Ahmad, M. 2017 Performance evaluation of trickling filter-based wastewater treatment system utilizing cotton sticks as filter media. Polish Journal of Environmental Studies 26 (5).

Bai, J., Xiao, R., Cui, B., Zhang, K., Wang, Q., Liu, X., Gao, H. & Huang, L. 2013 Assessment of heavy metal pollution in wetland soils from the young and old reclaimed regions in the Pearl River Estuary, South China. Environmental Pollution 159 (3), 817–824.

Blum, J. M., Su, Q., Ma, Y., Valverde-Pérez, B., Domingo-Félez, C., Jensen, M. M. & Smets, B. F. 2018 The pH dependency of N-converting enzymatic processes, pathways and microbes: effect on net N₂O production. Environmental Microbiology 20 (5), 1623–1640.

Calheiros, C. S., Bessa, V. S., Mesquita, R. B., Brix, H., Rangel, A. O. & Castro, P. M. 2015 Constructed wetland with a polyculture of ornamental plants for wastewater treatment at a rural tourism facility. Ecological Engineering 79 (1–7).

Cavazana, T. P., Pessan, J. P., Hosida, T. Y., Monteiro, D. R. & Delbem, A. C. B. 2018 Ph changes of mixed biofilms of Streptococcus mutans and Candida albicans after exposure to sucrose solutions in vitro. Archives of Oral Biology 90 (9–12).

Chen, Y., Lan, S., Wang, L., Dong, S., Zhou, H., Tan, Z. & Li, X. 2017 A review: driving factors and regulation strategies of microbial community structure and dynamics in wastewater treatment systems. Chemosphere 174 (173–182).

Curtis, T. 2005 Bacterial Pathogen Removal in Wastewater Treatment Plants. The Handbook of Water and Wastewater Microbiology. pp. 477–490.

Diaz-Elsayed, N., Xu, X., Balaguer-Barbosa, M. & Zhang, Q. 2017 An evaluation of the sustainability of onsite wastewater treatment systems for nutrient management. Water Research 121 (186–196).

Drost, R. L. & Gehr, R. L. 2018 Theory and Practice of Water and Wastewater Treatment. John Wiley & Sons.

Eding, E. H., Kamstra, A., Verruth, J. A. J., Huisman, E. A. & Klapwijk, A. 2006 Design and operation of nitrifying trickling filters in recirculating aquaculture: a review. Aquacultural Engineering 34 (3), 234–260.

FAO 1992 Wastewater Treatment and use in Agriculture. Irrigation and Drainage Paper, p. 47.

Fdz-Polanco, F., Mendez, E., Uruena, M. A., Villaverde, S. & Garcia, P. A. 2000 Spatial distribution of heterotrophs and nitrifiers in a submerged biofilter for nitrification. Water Research 34 (16), 4081–4089.

Gatto, D., Andrea, M. L., Salas, B. A. G. J., Garcés, V., Rodriguez-Alvarez, M. S. & Iribarnegaray, M. A. 2015 The Use of (Treated) domestic wastewater for irrigation: current situation and future challenges. International Journal of Water and Wastewater Treatment 1 (1).

Ge, S. & Champagne, P. 2016 Nutrient removal, microalgal biomass growth, harvesting and lipid yield in response to centrate wastewater loadings. Water Research 88 (604–612).

Gullicks, H., Hasan, H., Das, D., Moretti, C. & Hung, Y. T. 2011 Biofilm fixed film systems. Water 3 (3), 843–868.

Haider, R., Yasar, A. & Tabinda, A. B. 2017 Urban emission patterns at a semi-arid site in Lahore, Pakistan. Polish Journal of Environmental Studies 26 (1), 5.
He, S. B., Xue, G. & Kong, H. N. 2007 The performance of BAF using natural zeolite as filter media under conditions of low temperature and ammonium shock load. *Journal of Hazardous Materials* **143** (1–2), 291–295.

Jiang, Y., Sun, Y., Pan, J., Qi, S., Chen, Q. & Tong, D. 2017 Nitrogen removal and N2O emission in subsurface wastewater infiltration systems with/without intermittent aeration under different organic loading rates. *Bioresource Technology* **244** (8–14).

Kanwar, R. M. A., Khan, Z. M. & Farid, H. U. 2019 Development and adoption of wastewater treatment system for peri-urban agriculture in Multan, Pakistan. *Water Science and Technology* **80** (8), 1524–1537.

Kaveh, O. A., Saeid, E., Vijay, P., Singh, N. R., Dalezios, M. G., Hossein, G., Shahide, D. & Majedeh, H. 2019 Decreasing the number of colliforms of wastewater treatment plants using sand filtration together with four-seed powder. *International Journal of Research Studies in Agricultural Sciences* **5** (2454–6224).

Khan, Z. U., Naz, I., Rehman, A., Rafiq, M., Ali, N. & Ahmed, S. 2015 Performance efficiency of an integrated stone media fixed biofilm reactor and sand filter for sewage treatment. *Desalination and Water Treatment* **54** (10), 2638–2647.

Khan, Z. M., Asif Kanwar, R. M., Farid, H. U., Sultan, M., Arsalan, M., Ahmad, M., Shakoor, A. & Ahson Aslam, M. M. 2019 Wastewater evaluation for Multan, Pakistan: characterization and agricultural reuse. *Polish Journal of Environmental Studies* **28** (4).

Kim, B., Gautier, M., Prost-Boucle, S., Molle, P., Michel, P. & Gourdon, R. 2014 Performance evaluation of partially saturated vertical-flow constructed wetland with trickling filter and chemical precipitation for domestic and winery wastewaters treatment. *Ecological Engineering* **71** (41–47).

Kornaros, M. & Lyberatos, G. 2006 Biological treatment of wastewaters from a dye manufacturing company using a trickling filter. *Journal of Hazardous Materials* **136** (95–102).

Lattrach, L., Ouazzani, N., Masunaga, T., Hejjaj, A., Bouhoum, K., Mahi, M. & Mandi, L. 2016 Domestic wastewater disinfection by combined treatment using multi-soil-layering system and sand filters (MSL–SF): a laboratory pilot study. *Ecological Engineering* **91** (294–301).

Lekang, O. I. & Kleppe, H. 2000 Efficiency of nitrification in trickling filters using different filter media. *Aquacultural Engineering* **21** (3), 181–199.

Li, W., Loyola-Licea, C., Crowley, D. E. & Ahmad, Z. 2016 Performance of a two-phase biotrickling filter packed with biochar chips for treatment of wastewater containing high nitrogen and phosphorus concentrations. *Process Safety and Environmental Protection* **102** (150–158).

Licciardello, F., Milani, M., Consoli, S., Pappalardo, N., Barbagallo, S. & Cirelli, G. 2018 Wastewater tertiary treatment options to match reuse standards in agriculture. *Agricultural Water Management* **210** (232–242).

Liu, Y. X., Yang, T. O., Yuan, D. X. & Wu, X. Y. 2010 Study of municipal wastewater treatment with oyster shell as biological aerated filter medium. *Desalination* **254** (1–3), 149–153.

Marcin, Z. et al. 2013 Application of microwave radiation to biofilm heating during wastewater treatment in trickling filters. *Bioresource Technology* **127** (223–230).

Massoud, M. A., Tarhini, A. & Nasr, J. A. 2009 Decentralized approaches to wastewater treatment and management: applicability in developing countries. *Journal of Environmental Management* **90** (1), 652–659.

Metcalfe & Eddy 2015 *Wastewater Engineering: Treatment, Disposal, and Reuse*. McGraw-Hill Science.

Michaud, L., Giudice, A. L., Interdonato, F., Triplet, S., Ying, L. & Blanchet, J. P. 2014 C/N ratio-induced structural shift of bacterial communities inside lab-scale aquaculture biofilters. *Aquacultural Engineering* **58** (77–87).

Miller-Robbie, L., Ramaswami, A. & Amerasinghe, P. 2017 Wastewater treatment and reuse in urban agriculture: exploring the food, energy, water, and health nexus in Hyderabad, India. *Environmental Research Letters* **12** (7), 075005.

Monayeri, S. E., Atta, N. N., Mokadem, S. E. I. & About, A. M. 2007 Effect of organic loading rate and temperature on the performance of horizontal biofilters. In *Eleventh International Water Technology Conference*. IWTC11 2007, Sharm El-Sheikh, Egypt, Vol 2007, pp. 671–682.

Morgan, S. J. 1999 *Upgrading A Trickling Filter Wastewater Treatment Plant to Biological Nutrient Removal Standard*. Doctoral dissertation, University of Tasmania.

Muthukumaran, N. & Ambujam, N. K. 2005 Wastewater treatment and management in urban areas – a case study of Tiruchirapalli City, Tamil Nadu, India. In: *Proceedings of the Third International Conference on Environment and Health*, Chennai, India, pp. 15–17.

Naz, I., Saroj, D. P., Mumtaz, S., Ali, N. & Ahmed, S. 2015 Assessment of biological trickling filter systems with various packing materials for improved wastewater treatment. *Environmental Technology* **36** (4), 424–434.

Noreen, M., Shahid, M., Iqbal, M. & Nisar, J. 2017 Measurement of cytotoxicity and heavy metal load in drains water receiving textile effluents and drinking water in vicinity of drains. *Measurement* **109** (88–99).

Norton-Brandão, D., Scherrenberg, S. M. & van Lier, J. B. 2015 Reclamation of used urban waters for irrigation purposes—a review of treatment technologies. *Journal of Environmental Management* **122**, (85–98).

Odd, I. L. & Helge, K. 2000 Efficiency of nitrification in trickling filters using different filter media. *Aquacultural Engineering* **21** (181–199).

Okabe, S., Hirata, K., Ozawa, Y. & Watanabe, Y. 1996 Spatial microbial distributions of nitrifiers and heterotrophs in mixed-population biofilms. *Biotechnology and Bioengineering* **50** (1), 24–35.

Pang, H. 2014 *Study of the Hydrodynamic Characteristics, COD Elimination and Nitrification in A new Multi-Section Bioreactor*. Doctoral dissertation.
Pearce, P. A. 1998 Options for phosphorus removal on trickling filter plants. In: Chemical Water and Wastewater Treatment V. Springer, Berlin, Heidelberg.

Pitchard, M., Mkandawire, T. & Neill, J. G. O. 2007 Biological, chemical and physical drinking water quality from shallow wells on Malawi: case study of Blantyre, Chiradzulu and Mulanje. Physics and Chemistry of the Earth Parts A/B/C 32, 1167–1177.

Priya, E. S. & Selvan, P. S. 2017 Water hyacinth (Eichhornia crassipes)—an efficient and economic adsorbent for textile effluent treatment—a review. Arabian Journal of Chemistry 10 (S3548-S3558).

Rasool, T., Rehman, A., Naz, I., Ullah, R. & Ahmed, S. 2018 Efficiency of a locally designed pilot-scale trickling biofilter (TBF) system in natural environment for the treatment of domestic wastewater. Environmental Technology 39 (10), 1295–1306.

Richardsen, K. L. 2017 Enhanced Biological Phosphorus Removal in Typical Norwegian Wastewater. Master’s thesis, NTNU.

Sa, C. S. A. & Boaventura, R. A. R. 2001 Biodegradation of phenol by Pseudomonas putida DSM 548 in a trickling bed reactor. Biochemical Engineering Journal 9 (3), 211–219.

Särner, E. 1990 Removal of sulphate and sulphite in an anaerobic trickling (ANTRIC) filter. Water Science and Technology 22 (1–2), 395–404.

Sato, T., Qadir, M., Yamamoto, S., Endo, T. & Zahoor, A. 2013 Global, regional, and country level need for data on wastewater generation, treatment, and use. Agricultural Water Management 130 (1–13).

Seow, T. W., Lim, C. K., Nor, M. H. M., Mubarak, M. F. M., Lam, C. Y., Yahya, A. & Ibrahim, Z. 2016 Review on wastewater treatment technologies. International Journal of Applied Environmental Sciences 11 (1), 111–126.

Shah, M. & Hashmi, H. N. 2012 Macrophyte waste stabilization ponds: an option for municipal wastewater treatment. International Journal of Physical Sciences 7 (30), 5162.

Shah, M., Hashmi, H. N., Ghumman, A. R. & Zeeshan, M. 2015 Performance assessment of aquatic macrophytes for treatment of municipal wastewater. Journal of the South African Institution of Civil Engineering 57 (3), 18–25.

Siebritz, I. P., Ekama, G. A. & Marais, G. V. R. 1985 A parametric model for biological excess phosphorus removal. Water Science and Technology 15 (3–4), 127–152.

Silva, T. F., Vieira, E., Lopes, A. R., Nunes, O. C., Fonseca, A., Saraiva, I., Boaventura, R. A. & Vilar, V. J. 2017 How the performance of a biological pre-oxidation step can affect a downstream photo-Fenton process on the remediation of mature landfill leachates: assessment of kinetic parameters and characterization of the bacterial communities. Separation and Purification Technology 175 (274–286).

Stefanakis, A., Bardiau, M., Trajano, D., Couceiro, F., Williams, J. B. & Taylor, H. 2015 Removal of Indicator Bacteria and Bacteriophages in A Full-Scale Trickling Filter-Aerated Constructed Wetland Wastewater Treatment Plant.

Stefanakis, A. I., Bardiau, M., Trajano, D., Couceiro, F., Williams, J. B. & Taylor, H. 2019 Presence of bacteria and bacteriophages in full-scale trickling filters and an aerated constructed wetland. Science of the Total Environment 659 (1135–1145).

Takeyuki, S., Siriwat, J., Toshihiro, H., Marc, A. & Deshusses 2008 Removal of ammonia from contaminated air in a biotrickling filter-Denitrifying bioreactor combination system. Water Research 42 (4507–4513).

Tarpani, R. R. Z. & Azapagic, A. 2018 Life cycle environmental impacts of advanced wastewater treatment techniques for removal of pharmaceuticals and personal care products (PPCPs). Journal of Environmental Management 215 (258–272).

Udaiyappan, A. F. M., Hasan, H. A., Takriff, M. S. & Abdullah, S. R. S. 2017 A review of the potentials, challenges and current status of microalgae biomass applications in industrial wastewater treatment. Journal of Water Process Engineering 20 (8–21).

Ugurlu, A. & Ozturkcu, S. D. 2018 Treatment of nitrocellulose industry wastewaters by upflow denitrification filter: effect of packing media and recirculation. Environmental Processes 5 (1), 81–94.

US-EPA 2007 Bureau of Water Supply and Wastewater Management: Department of Environmental Protection Agency, Wastewater Treatment Plant Operator Training (Module 20: Trickling Filters).

Velázquez, Y. F. & Nacheva, P. M. 2017 Removal of pharmaceuticals from municipal wastewater by aerated submerged attached growth reactors. Journal of Environmental Management 192, 243–253.

Vianna, M. R., de Melo, G. C. & Neto, M. R. V. 2012 Wastewater treatment in trickling filters using luffa cylindrica as biofilm supporting medium. Journal of Urban and Environmental 6 (2).

WHO 2006 Guidelines for the Safe use of Wastewater, Excreta and Greywater: Policy and Regulatory Aspects, Vol. I. World Health Organization, Geneva.

Wijeyekoon, S., Mino, T., Satoh, H. & Matsuo, T. 2004 Effects of substrate loading rate on biofilm structure. Water Research 38 (2479–2488).

Wilk, T. 2003 Trickling filters and biofilm reactor modelling. Reviews in Environmental Science and Biotechnology 2 (2–4), 193–212.

Wu, H., Yin, Z., Quan, Y., Fang, Y. & Yin, C. 2016 Removal of methyl acrylate by ceramic-packed biotrickling filter and their response to bacterial community. Bioresource Technology 209, 237–245.

Wu, Z., Wang, X., Chen, Y., Cai, Y. & Deng, J. 2018 Assessing river water quality using water quality index in Lake Taihu Basin, China. Science of the Total Environment 612 (914–922).

Zhang, Y., Cheng, Y., Yang, C., Luo, W., Zeng, G. & Lu, L. 2015 Performance of system consisting of vertical flow trickling filter and horizontal flow multi-soil-layering reactor for
treatment of rural wastewater. *Bioresource Technology* 193 (424–432).

Zhang, X., Li, J., Yu, Y., Xu, R. & Wu, Z. 2016 Biofilm characteristics in natural ventilation trickling filters (NVTFs) for municipal wastewater treatment: comparison of three kinds of biofilm carriers. *Biochemical Engineering Journal* 106, 87–96.

Zhao, Q., Zhong, H., Wang, K., Wei, L., Liu, J. & Liu, Y. 2015 Removal and transformation of organic matters in domestic wastewater during lab-scale chemically enhanced primary treatment and a trickling filter treatment. *Journal of Environmental Sciences* 25 (1), 59–68.

Zhu, J. & Rothermel, B. 2014 Everything you need to know about trickling filters. *Clear Waters* 44 (2), 16–19.

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