Remediation of sewage and industrial effluent using bacterially assisted floating treatment wetlands vegetated with *Typha domingensis*

Amna Ijaz, Zafar Iqbal and Muhammad Afzal

**ABSTRACT**

This investigation reports the quantitative assessment of endophyte-assisted floating treatment wetlands (FTWs) for the remediation of sewage and industrial wastewater. *Typha domingensis* was used to vegetate FTWs that were subsequently inoculated with a consortium of pollutant-degrading and plant growth-promoting endophytic bacteria. *T. domingensis*, being an aquatic species, holds excellent potential to remediate polluted water. Nonetheless, investigation conducted on Madhuana drain carrying industrial and sewage water from Faisalabad City revealed the percentage reduction in chemical oxygen demand (COD) and biochemical oxygen demand (BOD5) to be 87% and 87.5%, respectively, within 96 h on coupling the plant species with a consortium of bacterial endophytes. With the endophytes surviving in plant tissue, maximal reduction was obtained in not only the aforementioned pollution parameters but for other major environmental quality parameters including nutrients (N and P), ions (Na⁺ and K⁺), Cl⁻, and SO₂⁴⁻ as well, which showed percentage reductions up to 90%, 39%, 77%, 91.8%, 40%, and 60%, respectively. This significant improvement in polluted wastewater quality treated with the proposed method render it safe to be discharged freely in larger water bodies as per the National Environmental Quality Standards (NEQS) of Pakistan or to be reused safely for irrigation purposes; thus, FTWs provide a sustainable and affordable approach for in situ remediation of sewage and industrial wastewater.

**Key words** | floating treatment wetlands, industrial effluent, plant-bacteria partnership

**INTRODUCTION**

Anthropogenic activities based on industrial, domestic, and agricultural demands have consumed nearly one-third of the available freshwater reservoirs of Earth while contaminating them simultaneously through uncontrolled disposal of polluted wastewater (Schwarzenbach et al. 2006). A major source of this pollution are municipal waste discharge routes, such as drains, that bring sewage and industrial effluent from cities to be released into surface water resources. This wastewater contains numerous organic and inorganic pollutants as well as biological contaminants which deteriorate natural water bodies receiving such water and put all life-forms associated with them in jeopardy (Nergis et al. 2012; Jilani & Khan 2013).

Conventional technologies for wastewater treatment demand high cost, environmental invasion, engineering skills, labor administration, and operational management (Liu et al. 2009). On the contrary, methods based on natural processes for optimization of water quality offer little of the aforementioned hurdles. One such modern product of environmental engineering is floating treatment wetlands (FTWs), which is a soil-less planting technology recently introduced to treat different types of wastewater to an extent that it can be discharged into the Earth’s hydrological cycle and also be reused for purposes like fisheries and irrigation without compromising life and environment (Ahn et al. 2004; Faulwetter et al. 2011; Zhu et al. 2011). FTWs are made up with an extremely simple structure: a synthetic buoyant mat supporting phytoremediating plants with their roots hanging freely into the water column. With the help of associated pollutant-degrading microbes, these plants
assist in pollution-control by removing pathogenic microorganisms, reducing pollutants by absorbing nutrients, removing heavy metals, and degrading phytotoxic compounds (Kadlec & Wallace 2008; Billeore & Sharma 2003; De Stefani et al. 2011; Vázquez-Burney et al. 2015).

In this investigation, an aquatic species, Typha domingensis, that is commonly known as cattail, has been selected to vegetate artificial floating wetlands because of its tendency to not only survive in highly polluted water (Abdel-Ghani et al. 2009) but also for high nutrient and contaminant uptake without harming itself (Newman et al. 1998). Keeping in mind the fact that the effect of endophytic bacteria in FTWs has been rarely evaluated for remediation of wastewater, three endophytic bacterial strains reported to degrade pollutants were inoculated to the vegetation. A combination of vegetation and endophytic bacterial strains (T. domingensis and endophytes: Klebsiella sp. strain LCRI87, Pseudomonas sp. strain BRRI54, and Acinetobacter sp. strain CYRH21) engineered within a system of microcosmic FTWs has been evaluated within a time period of 4 days to propose an affordable in-situ means of sewage and industrial wastewater remediation.

### MATERIALS AND METHODS

#### Collection and characterization of effluent

Effluent samples were collected from September to October 2014 from Madhuana drain of Faisalabad City, Pakistan, and were subjected to physicochemical analysis for water quality parameters (Table 1). The drain contains both domestic (70%) and industrial (30%) effluent. pH and electrical conductivity (EC) were estimated using bench top apparatus. Dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD₅), total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), oil and grease, sulphate content (SO₄²⁻), and chloride content (Cl⁻) were estimated as described by Eaton et al. (2005). Nutrients including total N and PO₄³⁻ were determined using commercial test-kits as demonstrated by Ijaz et al. (2015). Na⁺ and K⁺ were measured using flame photometry (FP 20, SEAC, Italy) while heavy metals including Cd, Co, Cr, Cu, Fe, Mn, Ni, and Pb were estimated through atomic absorption spectroscopy (AAS), (Hitachi Model Z-8000 Polarized Zeeman AAS, Hitachi Ltd, Tokyo, Japan) as described earlier (Afzal et al. 2014a).

According to manufacturer’s instructions, standard optimum analytical conditions were maintained and periodically checked on the flame photometer and AAS system for each metal. Blank and sample solutions were prepared in the same way in all determinations. A regular check on the accuracy of the results and the precision of the instrument and other analytical methods was executed by using standard reference material (SR-96, OL). Normally, the sets of results matched within ±1.0 to ±1.5%. The parameters of flame photometer used for the analysis of water were: automatic calibration with memorization of reference values, constant flame energy control, incorporated sample dilution system, ranges (Na 0–250 meq/L, and K 0–10 meq/L), wavelength for K 766 nm and for Na 589 nm, response time less of 10 s, sample volume 10 μL, precision within 1%. The parameters of AAS used for the analysis of water were shown in Table 2.

#### Endophytic bacterial strains

Three endophytic bacterial strains, namely Klebsiella sp. strain LCRI87, Pseudomonas sp. strain BRRI54, and Acinetobacter sp. CYRH21, were employed in this study (Fatima et al. 2015). After cultivating in 500 mL lysogeny broth (LB) and incubating at 35 °C for 24 h, cells were harvested through

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>NEQS</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.4 (0.85)</td>
<td>6–10</td>
</tr>
<tr>
<td>COD mg l⁻¹</td>
<td>538 (83)</td>
<td>150</td>
</tr>
<tr>
<td>BOD mg l⁻¹</td>
<td>228 (65)</td>
<td>80</td>
</tr>
<tr>
<td>DO mg l⁻¹</td>
<td>0.5 (0.04)</td>
<td>NG</td>
</tr>
<tr>
<td>TDS mg l⁻¹</td>
<td>4,230 (450)</td>
<td>3,500</td>
</tr>
<tr>
<td>TSS mg l⁻¹</td>
<td>190 (24)</td>
<td>150</td>
</tr>
<tr>
<td>SO₄²⁻ mg l⁻¹</td>
<td>518 (78)</td>
<td>600</td>
</tr>
<tr>
<td>Total N mg l⁻¹</td>
<td>32.8 (3.6)</td>
<td>NG</td>
</tr>
<tr>
<td>PO₄³⁻ mg l⁻¹</td>
<td>14.5 (2.4)</td>
<td>NG</td>
</tr>
<tr>
<td>Cd mg l⁻¹</td>
<td>0.82 (0.08)</td>
<td>0.1</td>
</tr>
<tr>
<td>Co mg l⁻¹</td>
<td>0.84 (0.09)</td>
<td>NG</td>
</tr>
<tr>
<td>Cr mg l⁻¹</td>
<td>9.4 (1.33)</td>
<td>1</td>
</tr>
<tr>
<td>Cu mg l⁻¹</td>
<td>0.60 (0.12)</td>
<td>NG</td>
</tr>
<tr>
<td>Fe mg l⁻¹</td>
<td>13.7 (1.60)</td>
<td>2</td>
</tr>
<tr>
<td>Ni mg l⁻¹</td>
<td>6.5 (0.62)</td>
<td>1</td>
</tr>
<tr>
<td>Pb mg l⁻¹</td>
<td>0.62 (0.08)</td>
<td>NG</td>
</tr>
<tr>
<td>Oil and grease mg l⁻¹</td>
<td>17.4 (2.7)</td>
<td>10</td>
</tr>
</tbody>
</table>

Each value is a mean of three replicates, standard deviations are presented in parentheses, NG — Not given in NEQS list, NEQS — National Environmental Quality Standards for wastewater discharge, set by Government of Pakistan.
centrifugation at 10,000 g at 4 °C for 10 min. Cells were vortexed mildly to form mixed-bacterial culture suspension in 0.9% (w/v) sterile NaCl solution. Optical density was adjusted to 0.7 at 600 nm. 50 mL of the bacterial culture suspension was used as inoculum in each microcosm.

**Experimental setup**

Experiment for improvement in quality of sewage and industrial effluent was conducted in microcosms established in polyethylene tanks of 30 L capacity (Figures 1 and 2). Artificial wetlands were prepared by cutting 60 × 40 × 10 cm mats out of Diamond Jumbolon Role (Diamond Foam Company, Pvt. Ltd, Pakistan) as recommended previously (Ijaz et al. 2015). Five holes were drilled in each mat at equal distances with one of them resting in the center. One *T. domingensis* seedling was inserted in each hole of the mat; every mat – vegetated and unvegetated – was allowed to float on 25 L tap water to form a microcosm. In this manner, 12 microcosms were developed and the seedlings were allowed to develop roots for 30 days in the presence of ambient conditions of temperature and light for optimal growth. Tap water was changed weekly. Hoagland solution was applied twice during this initial month to augment the process of root establishment.

Tap water was replaced with undiluted wastewater without sludge from Madhuana drain after 30 days. Microcosms were divided in four categories on the basis of the treatment being applied. The treatments were categorized as given below in order to observe the potential of *T. domingensis* to enhance the quality of sewage and industrial effluent with and without the help of endophytic bacterial strains.

![Figure 1](https://iwaponline.com/wst/article-pdf/74/9/2192/457839/wst074092192.pdf)

**Figure 1** Plant-endophyte partnerships in FTWs for the remediation of wastewater.

**Table 2** Operational parameters of atomic absorption spectrophotometer Hitachi Model Z-8000 Polarized Zeeman AAS used for the analysis of wastewater

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cd</th>
<th>Co</th>
<th>Cr</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Ni</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp current (mA)</td>
<td>7.5</td>
<td>10</td>
<td>7.5</td>
<td>7.5</td>
<td>10</td>
<td>7.5</td>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>Wavelength (nm)</td>
<td>228.8</td>
<td>240.7</td>
<td>357.9</td>
<td>324.8</td>
<td>248.3</td>
<td>279.6</td>
<td>252.0</td>
<td>283.3</td>
</tr>
<tr>
<td>Slit (nm)</td>
<td>1.3</td>
<td>0.2</td>
<td>1.3</td>
<td>1.3</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Oxidant (air) (kg/cm²)</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Fuel (C₂H₂) (kg/cm³)</td>
<td>0.25</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Burner height (mm)</td>
<td>7.5</td>
<td>10</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>10</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Integration time: 1 sec for all. Atomizer: Air-C₂H₂ head. ZEEMAN background correction was used for background correction.

Integration time: 1 sec for all. Atomizer: Air-C₂H₂ head. ZEEMAN background correction was used for background correction.
A fourth treatment was set up to ensure that improvement in performance of *T. domingensis* was due to the endophytes’ capability to reduce contaminating factors from the effluent.

**Control:** Effluent without *T. domingensis* or endophytic inoculation

**Treatment II (T-1):** Effluent with *T. domingensis* but no endophytic inoculation

**Treatment III (T-2):** Effluent with both *T. domingensis* and endophytic inoculation

**Treatment IV (T-3):** Effluent with endophytic inoculation but no *T. domingensis*.

**Physical and chemical analyses**

Treated effluent was collected after every 24 h. Collected samples at 0, 24, 48, 72, and 96 h were subjected to physical and chemical analyses as described earlier (Eaton *et al.* 2005).

**Enumeration of inoculated endophytes**

To confirm the persistence of inoculated endophytes, roots and shoots of vegetation as well as treated wastewater were collected from inoculated treatments, i.e. T-2 and T-3. Surface sterilization was performed on roots and shoots of T-2 followed by homogenization and plating on LB agar as demonstrated by Ijaz *et al.* (2015). Furthermore, treated wastewater from both treatments was also plated on LB agar and incubated at 37°C. The inoculated strains were identified among the isolates by subjecting all colonies to restriction fragment length polymorphism analysis (Afzal *et al.* 2012).

**Toxicity assay**

After 15 days of treatment, treated effluent from each treatment was subjected to toxicity analysis as described earlier (Eaton *et al.* 2005; Afzal *et al.* 2008). Ten healthy fish, *Labeo rohita*, of uniform weight and size were exposed to each treated sample and their survival rate was observed by counting the number of fish that expired after every 24 h for four consecutive days.

**Statistical analysis**

Numerical data from both experiments were analyzed with SPSS software package (SPSS Inc. Chicago, IL). The data from triplicates of each experiment were subjected to one-way analysis of variance (ANOVA) and the standard deviation from mean values was carried out using the Duncan’s multiple range test.

**RESULTS AND DISCUSSION**

The city of Faisalabad is called the ‘Manchester of Asia’ due to its high industrial and metropolitan activities (Afzal *et al.* 2008). With a population of more than three million, the sewage and industrial effluent generated here is estimated to be 435 million gallons per day. A large portion of this wastewater is discharged into the river Ravi via Madhuana...
drain, thus reducing it to a gutter for the city and its neighboring areas (Kahlown et al. 2005; Ijaz et al. 2015). Effluent received by river Ravi through Madhana drain is not only sewage waste from the city’s domestic areas but also industrial waste from about 2,000 small and large-scale industries. Thus, wastewater received and discharged through this drain has a dire need of treatment before its release into rivers or reuse in irrigation.

Quality of effluent from Madhuana drain

Madhuana drain exhibited high pollution levels (Table 1). Physicochemical tests revealed COD, BOD$_5$, TSS, and heavy metal contents to be much higher than the threshold allowed by the National Environmental Quality Standards (NEQS) of Pakistan (Khan 1998).

Improvement in quality of effluent

FTWs carrying T. domingensis alone improved the quality of sewage and industrial wastewater from Madhuana drain by lowering organic and inorganic wastewater pollutants. However, significant improvement in the capability of the plant to reduce pollution levels, i.e. COD, BOD$_5$, excess nutrients (N and PO$_4^{3-}$), as well as SO$_4^{2-}$ and Cl$^-$ content, was observed after combining it with the chosen endophytes. For instance, a percentage reduction in COD up to 87% in the effluent was observed in T-2 in comparison to 62% reduction in control (Figure 3(a)). Similarly, from an initial value of 320 mg/L, minimum BOD of 45 mg/L was reached by combined application of plants and endophytes. Figures 3–5 exhibit the better reduction of pollutant concentrations in T-2 in comparison to not only the control but to T-1 and T-3 as well.

A similar trend was observed for physicochemical parameters, such as pH, EC, and DO, that also exhibited promising changes as shown in Table 3. The pH was observed to move towards alkalinity that is attributable to the use of organic acids by the plants. EC, on the other hand, decreased from 4.7 to 2.4 mS/cm. EC is an important environmental quality parameter for water meant to be reused for irrigation, as happens in the case of Madhuana drain. According to the Natural Resources Conservation Service (NRCS), water with EC 2 mS/cm is safe to be used for irrigating crops (NRCS 1999). With an initial EC of 4.7 mS/cm, effluent from Madhuana drain was generally harmful for reuse in crops. In corroboration with previous findings of Lynch et al. (2015) and Van de Moortel (2008), reduction in EC was obtained with a simultaneous reduction in Na$^+$ and K$^+$ content. Thus, treatment with FTWs, rendered the water safe for reuse in irrigation (Table 3).

FTWs either vegetated with T. domingensis only or inoculated with endophytes alone exhibited lowered capability to reduce pollutant concentrations in wastewater as compared to their combined application in T-2. Previously, the same trend has been reported, whereby the application of endophytes with plants was observed to be a far more successful approach as compared to use of either entity alone (Shehzadi et al. 2014; Ijaz et al. 2015; Fatima et al. 2016). In the microenvironment developed around floating roots of vegetation in FTWs, inoculated endophytes and microbes thrive for optimal functioning to enhance the quality of wastewater being treated.

Moving on, higher reduction in COD and BOD$_5$ was observed in T-2 in comparison to other treatments (Figure 3). Here, a primary factor in the reduction of these pollution parameters is the increase in DO, which was observed to increase from 0.5 mg/L to 6.6 mg/L in T-2 in comparison to highest concentration of 2.3 mg/L in the control. Presence of T. domingensis increased oxygen concentration,
Thus increasing the degradation of organic pollutants that takes place through oxidation reactions. Inoculated bacteria enhanced this removal capability due to their ability to transform and decompose organic matter (Vymazal 2010).

In a very similar experiment, Sun et al. (2013) used bacterially assisted FTWs carrying Canna indica for enhanced removal of organic pollutants from water. Similarly, successful removal of 3-methylbenzoate has been reported using Zea mays in combination with Pseudomonas putida (Ronchel & Ramos 2001). Hence, the use of plants in combination with endophytes is indeed a promising approach for COD and BOD5 reduction.

Apart from transformation and breakdown of organic compounds, bacterial endophytes can also carry out ammonium oxidation, nitrification, and denitrification for the removal or conversion of NO3 and NH4 in the effluent (Tao & Wang 2009). Plants, on the other hand, use NO3 and NH4 as nutrients (Vymazal 2010). Phosphorus is an essential nutrient in both bacteria and plants and is taken up readily after solubilization to P from different forms, such as PO43- (Brix 1994). An excess of these nutrients in wastewater poses the threat of eutrophication which promotes explosive algal growth followed by death and oxygen-dependent decomposition by microbes – eventually causing hypoxia in eutrophicated water bodies. Better removal of nutrients, N and P (Figure 5), by combined action of plants and endophytes is, thus, easily attributable to the abovementioned metabolic processes of the two partners.

The aforesaid positive results obtained for reduction in pollution parameters by use of vegetation and associated bacteria are corroborated by recent reports as well. Ijaz et al. (2015) used Brachiaria mutica and endophytes (Actinobacter sp. strain BRSI56, Bacillus cereus strain BRSI57, and Bacillus licheniformis strain BRSI58) on sewage effluent to obtain reduction as high as 80% and 91% in COD and BOD, respectively, within 72 h. Similarly, Shehzadi et al. (2014) investigated treatment of wastewater containing textile effluent using FTWs vegetated with Typha domingensis.
domingensis and inoculated with plant growth-promoting endophytes to report a reduction of 79%, 77%, 59%, and 27% in COD, BOD, TDS, and TSS, respectively. Nitrogen removal up to 72% and COD removal up to 94% was reported in 5 days by Canna indica in combination with supporting bacteria in FTWs (Sun et al. 2009). In 2013, Chen and colleagues reported 80–90% reduction in COD of synthetic wastewater using perennial rye grass in a biofilm reactor (Chen et al. 2013). Collectively, all these results corroborate the findings in this paper and indicate a promising approach for wastewater remediation that is economically feasible and implementable in a wide range of settings.

Heavy metal reduction

Endophytic inoculation improved the efficiency of T. domingensis to remove heavy metals from the effluent resulting in the treated effluent becoming safe for disposal and reuse (Table 4). Cr, which is one of the major pollutants of groundwater, was removed up to 91% in wastewater by the combined use of T. domingensis and endophytes. Significant reduction in the amount of Fe and Ni was similarly observed. While T. domingensis removed heavy metals on its own, the effectiveness of its removal was enhanced by inoculation of endophytic bacteria. The improvement in elimination of heavy metals is attributable to the capacity of bacterial cells to sorb metallic ions on their cell-walls (Mullen et al. 2011). They also enhance the bioavailability and, thus, the uptake of heavy metals by plants (Jilani & Khan 2013). Continuous harvest of leaves and stems helps the plant to lose the burden of heavy metals acquired during remediation (Raskin et al. 1997).

Detoxification

An overall reduction in toxicity of wastewater after treatment with both T. domingensis and endophytes was witnessed which was due to the better quality of water resulting from an improvement in content of DO, Na⁺/K⁺, COD, BOD₅, nutrients, and heavy metals. Toxicity analysis on treated effluent indicated that T. domingensis alone in T-1 was not able to restore the quality of sewage and industrial effluent completely: death of three fish in wastewater, from a total of 10, after 4 days indicated only partial detoxification (data not shown). In comparison, less than five fish survived in control. However, no fish were observed dead in T-2 indicating the possibility of complete detoxification when T. domingensis was coupled with endophytic bacteria.
Persistence of inoculated endophytes

In order to confirm that the improvement in performance of *T. domingensis* was because of inoculated endophytes, it was necessary that their persistence was first confirmed within the plant tissue and wastewater. As shown in Table 5, the inoculated endophytes showed high occurrence within plant tissue, especially the roots, in T-2 as well as survival in wastewater in T-3.

The enhancement in the performance of *T. domingensis* can be attributed to the symbiotic relationship that it develops with the inoculated endophytes. However, to ensure that optimal results were obtained by the combination of vegetation and endophytes, T-1 was designed with vegetation only while T-3 carried endophytes only. Compromised performance in both as compared to T-2 indicated the beneficial effect of co-employing *T. domingensis* and endophytes in the FTWs. The inoculated endophytes were chosen on the basis of their tendency to degrade contaminating hydrocarbons in polluted soil and water as reported by Fatima et al. (2018). Moreover, these strains exhibited plant-growth promoting activities including production of ACC-deaminase and siderophores as well as phosphate solubilization. Apart from this, endophytes are generally known to be helpful in enhancing the uptake of pollutants by the plant and in reducing phytotoxicity in their host by degrading recalcitrant compounds that are not degradable in planta (Arslan et al. 2017). While inoculated endophytes augment plant growth in harsh conditions of the polluted water, research has revealed plants to in turn help pollutant-degrading microbes to thrive in their rhizosphere and tissue (Van de Moortel 2013; Khan et al. 2016; Afzal et al. 2017b).

CONCLUSIONS

The investigation undertaken here reports the promising role that endophytes play in enhancing the capability of

| Table 4 | Remediation of wastewater using floating treatment wetlands |

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>T-1</th>
<th>T-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>0.82 (0.02)</td>
<td>0.60 (0.03)</td>
<td>0.35 (0.02)</td>
</tr>
<tr>
<td>Co</td>
<td>0.84 (0.04)</td>
<td>0.62 (0.04)</td>
<td>0.33 (0.03)</td>
</tr>
<tr>
<td>Cr</td>
<td>9.40 (0.42)</td>
<td>6.32 (0.23)</td>
<td>3.52 (0.42)</td>
</tr>
<tr>
<td>Cu</td>
<td>0.60 (0.03)</td>
<td>0.40 (0.05)</td>
<td>0.28 (0.05)</td>
</tr>
<tr>
<td>Fe</td>
<td>13.7 (0.27)</td>
<td>9.50 (0.31)</td>
<td>3.44 (0.26)</td>
</tr>
<tr>
<td>Ni</td>
<td>6.5 (0.45)</td>
<td>4.03 (0.28)</td>
<td>2.69 (0.13)</td>
</tr>
<tr>
<td>Pb</td>
<td>0.62 (0.01)</td>
<td>0.40 (0.03)</td>
<td>0.32 (0.06)</td>
</tr>
</tbody>
</table>

Units: mg L⁻¹. Each value is a mean of three replicates; standard deviations are presented in parentheses.

| Table 5 | Survival and colonization of the inoculated endophytes in the wastewater, root, and shoot of *Typha domingensis* |

<table>
<thead>
<tr>
<th></th>
<th>CFU ml⁻¹ water × 10³</th>
<th>CFU g⁻¹ root × 10³</th>
<th>CFU g⁻¹ shoot × 10³</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-2</td>
<td>11.5 (0.48)</td>
<td>34.3 (2.6)</td>
<td>12.5 (0.62)</td>
</tr>
<tr>
<td>T-3</td>
<td>3.5 (0.18)</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

T-2: the wastewater with vegetation and endophytes inoculation. T-3: the wastewater with endophytes inoculation only. Each value is a mean of three replicates; standard deviations are presented in parentheses.

While inoculated endophytes augment plant growth in harsh conditions of the polluted water, research has revealed plants to in turn help pollutant-degrading microbes to thrive in their rhizosphere and tissue (Van de Moortel 2013; Khan et al. 2016; Afzal et al. 2017b).
plants to restore the quality of industrial and sewage wastewater by reducing polluting factors. Maximum reduction in COD and BOD$_3$ was 87% and 87.5%, respectively. Despite being performed at laboratory scale and for a short time period of 4 days, the investigation reinforces the usefulness of *Typha domingensis* as a means of restoring quality of wastewater through the innovative mode of biocidentally enhanced FTWs. The hyperaccumulator, *Typha domingensis*, proves to be an excellent choice for water remediation due to its survival in harsh conditions while being able to interact with microbial life and optimize its performance in decontaminating water. Furthermore, the report reveals the potential that FTWs have for application in pilot-scale studies to effectively provide a platform for plant-microbe interaction for removal of organic and inorganic pollutants, ions, excess nutrients, heavy metals, and toxicity. While *Typha domingensis* is suitable for the regional climate in Faisalabad, Pakistan, appropriate choice of pollutant-tolerant vegetation promises an ecological technology that can be retrofitted and custom-designed for in-situ treatment of contaminated water virtually anywhere that plants can grow.

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