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Supplemental information

A nature-based closed-loop wastewater treatment system at vehicle-washing facilities: From linear to circular economy

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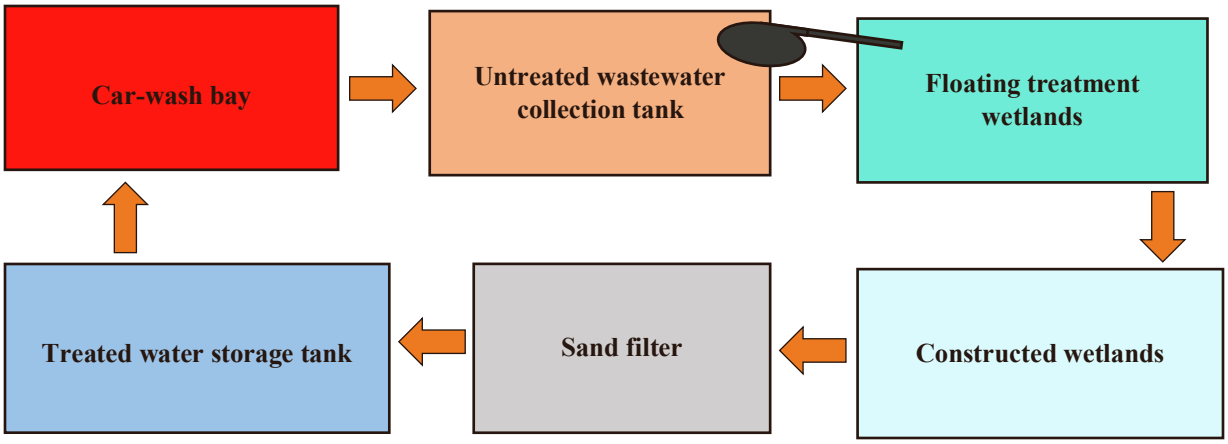

Figure S1. Flow diagram illustrating Toyota Lyallpur Motors Faisalabad's car-wash wastewater treatment and reuse system, processing 4000 liters daily over six days, with components including a single 14.6 m³ collection tank, five 0.9 m³ floating wetlands, a 0.3 m³ constructed wetland, a 0.3 m³ sand filter, and a 10 m³ treated water storage tank, related to STAR Methods.

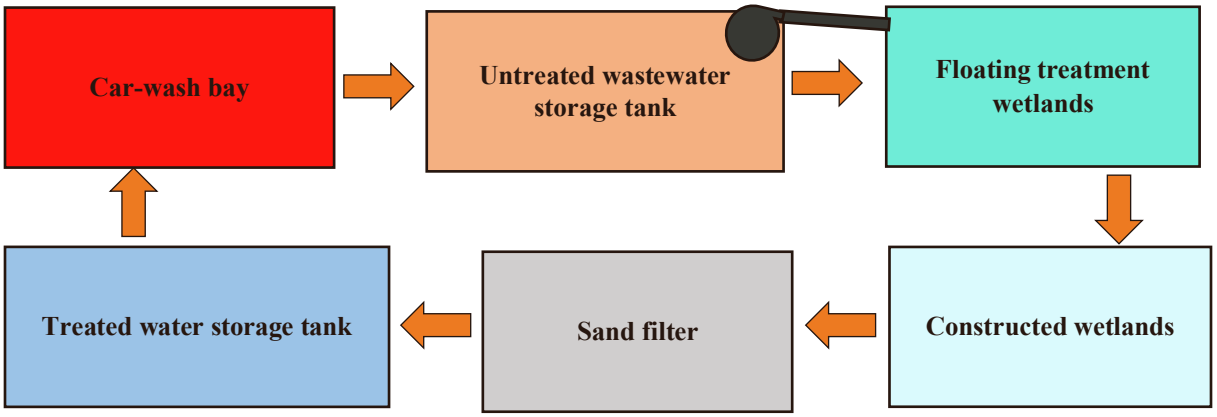

Figure S2: Diagram of Toyota Chenab Motors Faisalabad's wastewater treatment for car washes, handling 8,000 liters daily over six days, featuring a 12.5 m^3 collection tank, two 6.33 m^3 floating wetlands, ten 2.113 m^3 constructed wetlands, a 1.118 m^3 sand filter, and two 10 m^3 storage tanks, related to STAR Methods.

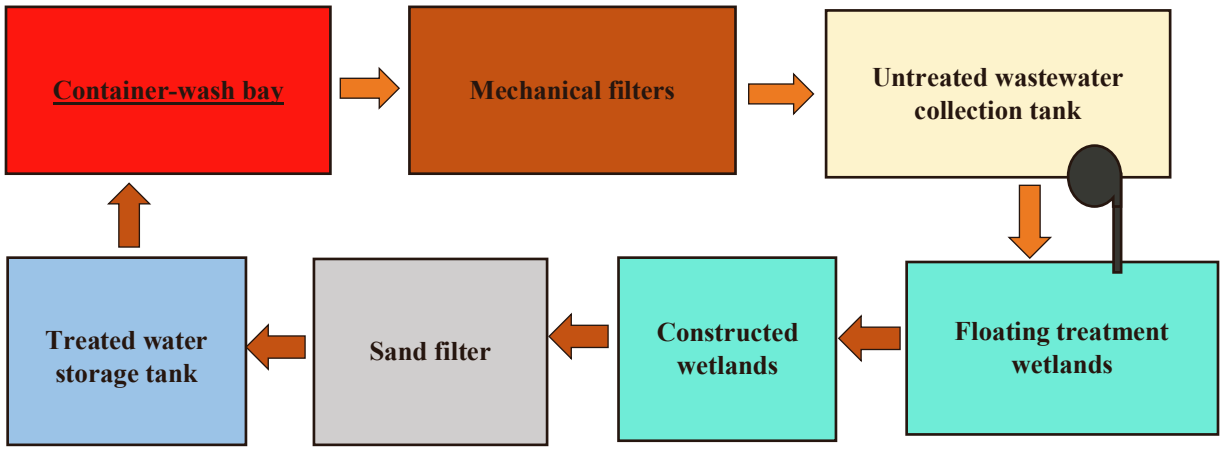

Figure S3: Toyota Momentum Logistics Khanewal's wastewater system diagram for container washes processes 9,000 liters daily with a six-day retention, including a 19.01 m³ tank, three 5.101 m³ floating wetlands, eighteen constructed wetlands of varying volumes, a 0.91 m³ sand filter, and an 18.72 m³ storage tank, related to STAR Methods.

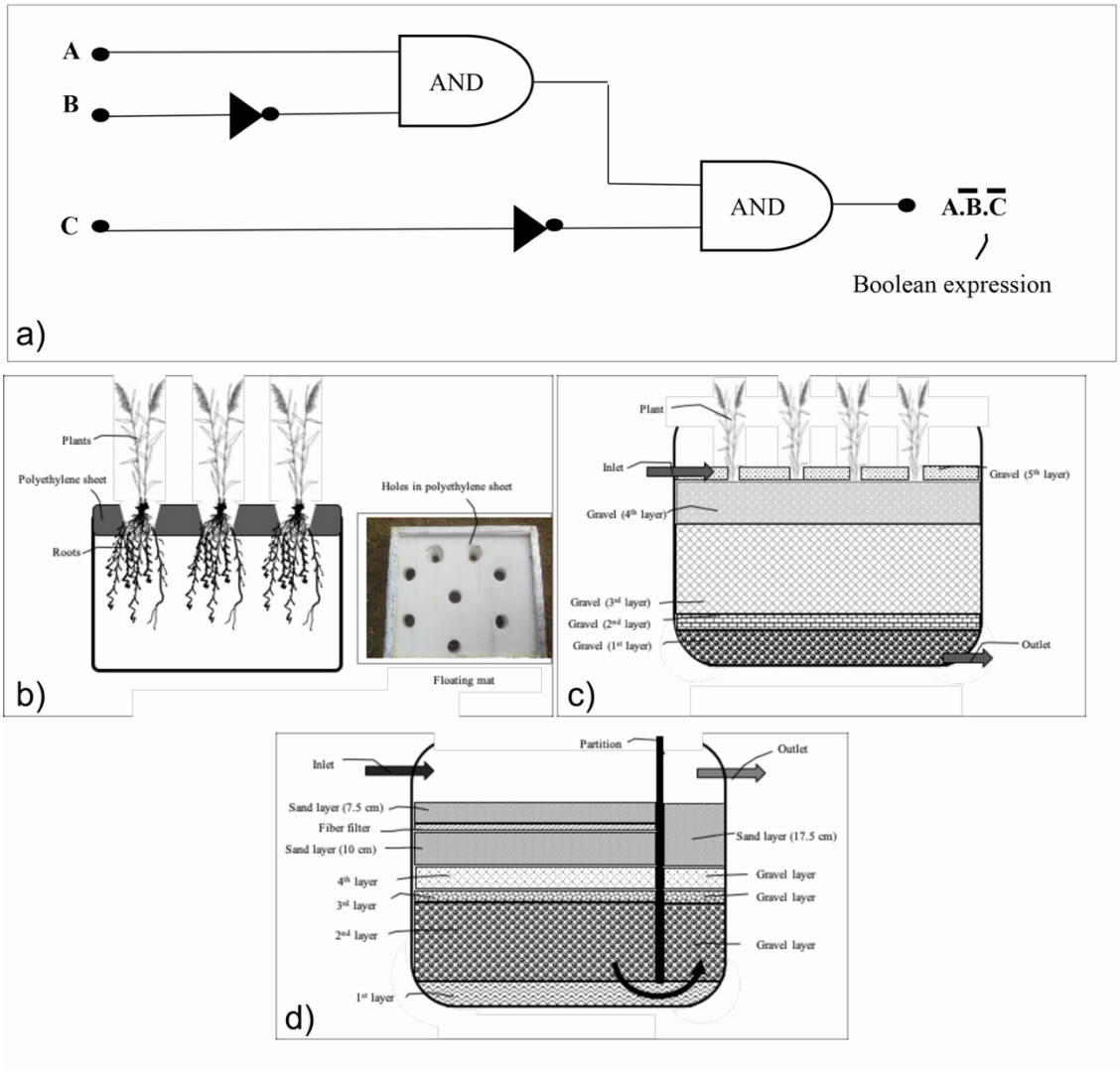

Fig. S4: Schematic representation of wastewater management components, related to STAR Methods. A.) Logic diagram for pump. B.) Design of floating treatment wetland. C.) Design of the constructed wetland. D.) Design of the sand filter system.

(d).

Fig. S5. Development of integrated system for the treatment and reuse of vehicle-wash wastewater at Toyota Lyallpur Motors Faisalabad, related to STAR Methods. Gravel at the bottom of the tank (a), second layer of the gravel (b), third layer of the gravel (c), and fourth layer of the gravel (d), washing of the gravel (e), twenty tanks in the series (f), seedlings of the plants (g), and vegetation of seedlings in the gravel (h). Installation of automatic integrated system at Toyota Lyallpur Motors, Faisalabad (i-m) for the treatment and reuse of car-wash wastewater, the water in the reagent bottles (n) shows the water collected at inlet and outlet. Development of integrated system of floating treatment wetlands, constructed wetlands and sand filtration at Interloop Logistics Momentum Khanewal (o) for the treatment and reuse of containers-wash station. The bottles shown in (p) contain water collected at the inlet and outlet.

Table S1: Quantitative analysis of hydrocarbon-degrading bacteria, *alkB* gene in outlet water from FTWs, CWs, SF, and plant rhizospheres in the final units at TLM, TCM, and ILM sites, related to Figure 3.

	Water (10^4)			Rhizoplane (10^6)		
	TLM	TCM	ILM	TLM	TCM	ILM
	FTWs					
Hydrocarbon degrading bacteria (CFU/ml)	9.43 (0.32)	8.85 (0.18)	9.03 (0.28)	5.15 (0.34)	4.35 (0.12)	6.52 (0.27)
Gene abundance (*alkB* copy/g)	3.51 (0.21)	3.80 (0.54)	5.14 (0.54)	3.26 (0.24)	2.08 (0.18)	3.82 (0.35)
Gene expression (*alkB* copy/g)	0.82 (0.11)	1.24 (0.27)	1.08 (0.30)	2.50 (0.12)	1.52 (024)	1.88 (0.20)
	CWs					
Hydrocarbon degrading bacteria (CFU/ml)	30 (22)	25 (12)	23 (6.25)	9.72 (0.48)	10 (3.05)	8.75 (2.72)
Gene abundance (*alkB* copy/g)	28 (13)	17 (4.70)	12 (2.85)	0.98 (0.35)	11 (2.82)	4.04 (0.75)
Gene expression (*alkB* copy/g)	6.07 (4.52)	3.72 (2.80)	1.03 (0.52)	0.68 (0.14)	1.08 (0.41)	3.17 (1.26)
	SF					
Hydrocarbon degrading bacteria (CFU/ml)	0	0	0	ND	ND	ND
Gene abundance (*alkB* copy/g)	0	0	0	ND	ND	ND
Gene expression (*alkB* copy/g)	0	0	0	ND	ND	ND

ND = Not determined as there is no vegetation in SF.

Table S2. Truth table (logic table for water pump), related to STAR Methods

Makeup wastewater tank (low level)	Makeup wastewater tank (high level)	Wastewater storage tank (low level)	Water pump
A	B	C	Out put
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

Table S3. Karnaugh map, related to STAR Methods

C \ AB	00	01	11	10
0	0	0	0	1
1	0	0	0	0

Data S1: Financial Analysis of Groundwater Extraction and Recycling for Toyota Lyallpur Motors (TLM), related to Table 3.

Cost to extract groundwater annually without recycling = 6,935 m^3 × 0.8 kWh/m^3 × \$0.4/kWh = \$4,468

Annual expenses with recycling:

Total cost for the first year:

= \$5,341 (interventions) + \$225 (maintenance)

= \$5,566

Annual expenses for subsequent years: \$225

Reduction in total expenses per year:

Savings from not extracting groundwater = \$4,468

Net saving:

= \$4,468 (savings from not extracting groundwater) - \$225 (maintenance for subsequent years)

= \$4,243

Cost per unit meter cube before and after recycling:

Before recycling:

= \$4,468/6,935 m^3}

= \$0.644/m^3

After recycling for subsequent years:

= \$225/6,935 m^3}

= \$0.0324/m^3

1. **Payback Period:**

$$\frac{\text{Initial Investment}}{\text{Net Annual Savings}}$$

$$= \frac{5,341}{5,323}$$

$$= 1.00 \text{ years}$$

2. **ROI:**

$$\left(\frac{\text{Net Annual Savings}}{\text{Initial Investment}}\right) \times 100$$

$$= \left(\frac{5,323}{5,341}\right) \times 100$$

$$= 99.7\%$$

3. **BCR:**

$$\frac{\text{Net Savings}}{\text{Total Costs}}$$

$$= \frac{5,323}{5,341+225}$$

$$= 1.0$$

4. **EVI:**

$$\frac{\text{Annual Groundwater Volume}}{\text{Total Annual Cost}}$$

$$= \frac{6,935}{5,566}$$

$$= 1.24 \text{ m}^3/\$$$

Data S2: Financial Analysis of Groundwater Extraction and Recycling for Toyota Chenab Motors (TCM), related to Table 3.

Cost savings from groundwater extraction and treatment:
Cost to extract and treat groundwater annually without recycling:
= 11,096 m^3 × 0.8 kWh/m^3 × \$0.4/kWh
= \$8,876.8
Annual expenses with recycling:
Total cost for the first year:
= \$12,283 (interventions) + \$300 (maintenance)
= \$12,583
Annual expenses for subsequent years: \$300
Reduction in total expenses per year:
Savings from not extracting groundwater = \$8,876.8
Net saving:
= \$8,876.8 (savings from not extracting groundwater) - \$300 (maintenance for subsequent years)
= \$8,576.8
Cost per unit meter cube before and after recycling:
Before recycling:
= \$8,876.8/11,096 m^3}
= \$0.8/m^3
After recycling for subsequent years:
= \$300/11,096 m^3}
= \$0.027/m^3

1. **Payback Period:**

$$\frac{\text{Initial Investment}}{\text{Net Annual Savings}}$$
$$= \frac{12,283}{8,576.8}$$
$$= 1.43 \text{ years}$$

2. **ROI:**

$$\left(\frac{\text{Net Annual Savings}}{\text{Initial Investment}}\right) \times 100$$
$$= \left(\frac{8,576.8}{12,283}\right) \times 100$$
$$= 69.8\%$$

3. **BCR:**

$$\frac{\text{Net Savings}}{\text{Total Costs}}$$
$$= \frac{8,576.8}{12,283+300}$$
$$= 0.7$$

4. **EVI:**

$$\frac{\text{Annual Groundwater Volume}}{\text{Total Annual Cost}}$$
$$= \frac{11,096}{12,583}$$
$$= 0.88 \text{ m}^3/\$$$

Data S3: Financial Analysis of Groundwater Extraction and Recycling for Interloop Logistics Momentum (ILM), related to Table 3.

Cost savings from groundwater extraction and treatment:
Cost to extract and treat groundwater annually without recycling = 13,870 m^3 × 0.8 kWh/m^3 × \$0.4/kWh = \$8,870.4
Annual expenses with recycling:
Total cost for the first year:
= \$15,373 (interventions) + \$400 (maintenance)
= \$15,773
Annual expenses for subsequent years: \$400
Reduction in total expenses per year:
Savings from not extracting groundwater = \$8,870.4
Net saving:
= \$8,870.4 (savings from not extracting groundwater) - \$400 (maintenance for subsequent years)
= \$8,470.4
Cost per unit meter cube before and after recycling:
Before recycling:
= \$8,870.4/13,870 m^3}
= \$0.639/m^3
After recycling for subsequent years:
=\$400/13,870 m^3
= \$0.0288/m^3

1. **Payback Period:**

$$\frac{\text{Initial Investment}}{\text{Net Annual Savings}} = \frac{15,373}{10,696} = 1.44 \text{ years}$$

2. **ROI:**

$$\left(\frac{\text{Net Annual Savings}}{\text{Initial Investment}}\right) \times 100 = \left(\frac{10,696}{15,373}\right) \times 100 = 69.6\%$$

3. **BCR:**

$$\frac{\text{Net Savings}}{\text{Total Costs}} = \frac{10,696}{15,373+400} = 0.7$$

4. **EVI:**

$$\frac{\text{Annual Groundwater Volume}}{\text{Total Annual Cost}} = \frac{13,870}{15,773} = 0.88 \text{ m}^3/\$$$