Greywater reuse: Benefits, Challenges, and means for Safe Reuse

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Why greywater (GW)?

- Greywater is all domestic water excluding toilet effluents (black water)
- Reuse of greywater can potentially reduce water use by up to 50%

![Pie chart showing water usage percentages:]
- Bathing: 25%
- Laundry: 20%
- Kitchen sink: 8%
- Other: 7%
- Toilet: 40% (crossed out)
Major usages of water

Toilet flushing

Irrigation

https://vimeo.com/51587224
Composition of domestic wastewater: quantity and quality

Most domestic effluent is greywater (GW), rather than blackwater (urine and feces)

50-200 L/person/day

30-50 L/person/day
Composition of domestic wastewater: quantity and quality

<table>
<thead>
<tr>
<th>Approximate loads (kg/person/year)</th>
<th>% in each source</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GW</td>
<td>Urine</td>
<td>Feces</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>3</td>
<td>87</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>10</td>
<td>50</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>34</td>
<td>54</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>TOC</td>
<td>40</td>
<td>10</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>
Composition of domestic wastewater: quantity and quality

1. GW is less polluted. Thus, it can be treated by simple means and be safely reused.

2. If reused for irrigation, GW can replace or lower the need for fertilization.
What are the challenges?

Reusing greywater

- Two major difficulties
  - Environmental effects: i.e. elevated levels of surfactants & dissolved ions
  - Health risks: spread of pathogenic organisms
Pollutants in raw (untreated) greywater quality varies from negligible to significantly high concentrations.
Pollutants in raw (untreated) greywater quality varies from negligible to significantly high concentrations.
Unhealthy plants following irrigation with raw GW
Fecal coliform

• Indicator for potential presence of pathogens
• Its concentration in raw GW varies and can be similar to full domestic wastewater
Potential hazards of GW – Public Health

Pathogenic Bacterial Gene Copies in Treated Greywater - Not Disinfected

All means between $\sim 10^2$-$10^3$ bacteria per 100 mL GW
Maximum concentration for safe reuse based on QMRA
Insights so far

1. GW has great potential as an alternative water source that can alleviate water and food scarcity (if used for on-site farming).

2. There are still challenges that must be resolved for reliable and safe use of greywater.

Greywater must be treated before it can be reused.
Technological challenges of treating GW

1. Treatment must consider changing quality and quantity

2. Low tech, low cost systems are required??

3. Simplicity in operation and maintenance

4. High reliability
# Reliability and failure definitions

<table>
<thead>
<tr>
<th></th>
<th>General definition</th>
<th>In GW biological treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reliability</strong></td>
<td>The probability that no operational interruptions will occur during a stated time interval</td>
<td>The probability that the system will produce treated GW effluent of satisfactory quality during a stated time interval</td>
</tr>
<tr>
<td><strong>Failure</strong></td>
<td>An event where the system stops performing as required</td>
<td>When the quality of the treated GW effluent is not satisfactory</td>
</tr>
</tbody>
</table>

**Assumption**

- Failures are considered as repairable
- After repair of a certain failure the system is “as good as new”
Reliability function $R(t)$

Failure is a random variable and can be described with statistical tools:

$R(t)$: Reliability function, is a survival function

$F(t)$: The probability that an item will operate for a certain amount of time without a failure

\[ F(t) = 1 - R(t) \]

\[ F(t) = \int_0^t f(t) \, dt \]

(Lazzaroni 2011)
Mean Time Between Failures (MTBF)

- Mean Time Between Failures (MTBF) can be calculated by integrating the reliability function $R(t)$

$$MTBF = \int_0^\infty R(t) \, dt = \int_0^\infty [1 - F(t)] \, dt$$

- In order to calculate the MTBF, $R(t)$ needs to be measured or assumed

- $R(t)$ can be described by distribution models such as:
  - Normal
  - Exponential
  - Log-normal
  - **Weibull**
Reliability and MTBF

- 45% of the systems no failure occurred during that whole period
- Most failures resulted from a small number of defective systems

<table>
<thead>
<tr>
<th>Region</th>
<th>North &amp; central</th>
<th>Negev</th>
<th>Jordan rift</th>
<th>All 20 systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of systems</td>
<td>9</td>
<td>8</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>MTBF (d/failure)</td>
<td>208</td>
<td>336</td>
<td>128</td>
<td>305</td>
</tr>
<tr>
<td>Standard Error</td>
<td>13</td>
<td>60</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Time from last failure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of systems that failed (at least once)</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Number of systems that did not fail at all</td>
<td>4 (44%)</td>
<td>5 (63%)</td>
<td>0 (0%)</td>
<td>9 (45%)</td>
</tr>
</tbody>
</table>
Design considerations

a) Wastewater flows directly into the plant root zone/filter

b) Water trickles down through the filter and into the reservoir

c) The bed: planted organic soil, high surface media, limestone gravel
Design considerations

d) From the reservoir the water is recycled back to the bed several times

e) Recirculation pump keeps the wetland constantly wet and aerated

f) Treatment process: Mechanical filtration, microbial degradation, nitrification, and buffering by limestone gravel
Design considerations

**g)** The treated water is released for drip irrigation via a disinfection unit (e.g. UV)

**h)** The system is modular, enabling the attachment of additional units

Recirculating Vertical Flow Constructed Wetlands (RVFCW)
It is possible to meet strict guidelines for unlimited irrigation even with simple biological treatment units.
Disinfection

Low cost and pressure, UV device

Simple Chlorinator, using chlorine tablets
Disinfection

![Graph showing disinfection levels over time]

- **FC (log CFU 100 ml⁻¹)**
- **Date**: Dec, Jan, Feb, Mar
- **Lines**:
  - **Chlorine** (solid line)
  - **Not disinfected** (dotted line)
  - **UV** (dashed line)
Membrane bioreactor (MBR) - Combines biological treatment and physical separation

Membrane pore size: MF 0.4-0.1μm UF 0.1-0.01 μm
MBR: Major Pros and Considerations

- **Independent** control (decoupling) on hydraulic retention time (HRT) and sludge retention time (SRT)

- Very high effluent quality: no SS; low COD; pathogens free; rich in nutrients

- Membrane fouling is a significant factor

- In AnMBR (mainly) - High SRT – Fairly low sludge production

- AnMBR – biogas production
Operational energy balance

Modified from: Pretel et al., 2016 (JEMA)
Smith et al. 2014 (ES&T)
Capital and operational costs

After Pretel et al., 2016 (JEMA)
Summary

• Greywater reuse can save significant amounts of water but must be treated prior to reuse.

• Treatment and reuse can recover nutrients, energy, support plant growth (food) which can also sequester CO₂ and produce O₂.

• Regardless to the treatment of choice, it must be robust, reliable, and able to endure large variations in water quality and quantity.

• Irrigation effluents can be recycled through the system and water exchange should be determined to prevent salinization.
Thanks for your attention

The Greywater team

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RCF
Model for off-grid near zero water discharge aquaponics – which can be used with treated GW
Summary: off-grid system.

- Theoretic full energy recovery:
  - ~1 ton fish stock
  - 2% daily feeding rate:
    - 20kg, 45% protein feed per day
Summary: off-grid system.

- Nutrient recovery by anaerobic digestion:
  - **4-5 times bigger vegetable area**
    - 3500 m² tomato beds Vs 750 m²
    - 250 kg tomato per day Vs 60 kg
  - Full (99.5%) water recovery (recirculation) except for evapotranspiration
Pilot study demonstrating the model
Required and Available Energy for Wastewater Treatment, Exclusive of Heat Energy

- Energy required for secondary wastewater treatment
  
  1,200 to 2,400 MJ/1000 m³

Energy available in wastewater for treatment (assume COD = 5.0 g/m³)

Q = [500 kg COD/1000 m³] (1000 m³) (13 MJ/kg COD)

6,000 MJ/1000 m³

- Energy available in wastewater is 2 to 4 times the amount required for treatment

Based on G. Tchobanoglous