Multi-method efficiency analysis of Rainwater Harvesting Systems in Corredor Seco region, Central America

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WATER AND THE 3 DIMENSIONS OF SUSTAINABLE DEVELOPMENT

- Healthy and educated people
- Social and political stability
- Employment and poverty reduction
- Finances for public services

- Sustainable water use and pollution control
- Education and legislation

- Water resources and other ecosystem services

- Water resources and other ecosystem services
- Sustainable water use and pollution control
- Finances for the environment
Efficiency of Rooftop Water Harvesting systems (RWHS) was calculated by Probability Analysis (PA) and Water Balance (WB).

Results evidence that RWHS for rural community in Guatemala are designed for high demand ratios.

Efficiency may be maximized just modulating the demand ratio, thus preserving water harvested for food production.

Efficiency analysis may be used to achieve sustainable development goals.
To fully realize the vision, **increased capacities and competencies** are needed, through sharing success stories from other cities, **learning to work differently with new tools**, pooling resources, and opening to other sectors’ approaches and methods.

(IWA)
Rainwater harvesting systems for low demanding applications

Luís F. Sanches Fernandes, Daniela P.S. Terêncio, Fernando A.L. Pacheco
Mani Tese project n. 2339 SOBERANOS – Right to Food for farmers of the Corredor Seco in Guatemala related to "Agroecology, nutritional education, creation of seed reserves, construction of water collection systems rainwater and water systems to irrigate vegetable gardens"
Agricultural System

- Rainfed cropping from **April to November – December**
- Dry period from **January to March**
- Need of additional water supply for **dry season cropping**

Data source

- 2017 – 2019 rainfall season (with 2018-2019 extreme dry year)
- **Daily** data from project rainfall stations
- Water use and tank data from in-field survey

Objective

- Check **Rooftop water harvesting efficiency in extreme drought conditions** and improve the project approach
Study area

- Communities of **Rodeo, Despoblados, Lantinquin, Peñablanca, Dosquebradas** and **Tontoles**
- Municipalities of **Camotán** and **Jocotán, Chiquimula Department, Guatemala**
- **Central American Dry Corridor (CADC)**
- 25 RWHS surveyed and analysed
Study area

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- 25 RWHS surveyed and analysed

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (standard deviation) rainfall 2017-2019 (mm)</td>
<td>1374 (421)</td>
<td>1620 (457)</td>
</tr>
<tr>
<td>Rainfall dry season 2017 (mm)</td>
<td>104</td>
<td>133</td>
</tr>
<tr>
<td>Rainfall dry season 2018 (mm)</td>
<td>97</td>
<td>161</td>
</tr>
<tr>
<td>Rainfall dry season 2019 (mm)</td>
<td>47</td>
<td>78</td>
</tr>
<tr>
<td>Average (standard deviation) rainfall dry season 2017-2019 (mm)</td>
<td>83 (26)</td>
<td>124 (35)</td>
</tr>
</tbody>
</table>

Food security issues in rural households
Analysis period
PROBABILITY ANALYSIS

Data were used for estimating:
• Daily average rainfall depth $\frac{1}{\zeta}$
• Average length $\frac{1}{\lambda}$ of the time $\tau$ between two rain events

Probability distribution of rainfall depth and inter-arrival time:

\[
f_h = \zeta e^{-\zeta h}
\]
\[
f_t = \lambda e^{-\lambda t}
\]
PROBABILITY ANALYSIS

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$$f_h = \zeta e^{-\zeta h}$$
$$f_t = \lambda e^{-\lambda t}$$

Statistical maximum and minimum efficiencies ($E_{max}$ & $E_{min}$):

$$E_{max} = 1 - e^{-b}$$
$$E_{min} = \frac{b}{a + b} \left[ 1 + e^{-(a+b)} \right]$$

$$a = \frac{\zeta V_s}{\phi S} \quad b = \frac{\lambda V_s}{Q_0}$$

$V_s = storage distance$
$\phi = runoff coefficient$
$S = catchment surface$
$Q_0 = water demand$
PROBABILITY ANALYSIS

Data were used for estimating:
- Daily average rainfall depth $\frac{1}{\zeta}$
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Probability distribution of rainfall depth and inter-arrival time:

$f_h = \zeta \ e^{-\zeta h}$

$f_t = \lambda \ e^{-\lambda t}$

Statistical maximum and minimum Demand Ratio ($\text{DR}_{\text{max}}$ & $\text{DR}_{\text{min}}$):

$$\text{DR}_{\text{max}} = \frac{a+b}{ab} \frac{1}{1-e^{-(a+b)}}$$

$$\text{DR}_{\text{min}} = \frac{a}{b} \frac{1}{1-e^{-a}}$$

$$a = \frac{\zeta V_s}{\phi S} \quad b = \frac{\lambda V_s}{Q_0}$$

$V_s = \text{storage capacity}$

$\phi = \text{runoff coefficient}$

$S = \text{catchment surface}$

$Q_0 = \text{water demand}$
MASS BALANCE (Daily)

\[ \frac{\Delta V}{\Delta t} = \begin{cases} 
I - Q & \text{if } h > 0 \text{ and } V \geq Q\Delta t \\
-Q & \text{if } h = 0 \text{ and } V \geq Q\Delta t \\
I & \text{if } V \leq Q\Delta t 
\end{cases} \]

\[ I = h S \varphi \]

- \( h \) is daily rainfall
- \( S \) is the area of the rooftop
- \( \varphi \) is a runoff coefficient less than 1

\[ E = \frac{M}{T} = \frac{1 - \sum_{i=1}^{T} \delta_V(t) \Delta t}{T} \]

- \( \delta_V(t) = 1 \) if \( V \geq Q\Delta t \),
- \( \delta_V(t) = 0 \) otherwise

\[ DR = \frac{\sum_{i=1}^{T} \Delta V(t)}{QT} \]
RESULTS

Water Demand (Baseline Scenario)

- domestic water demand: 25 l/d/cap
- livestock water demand: 50 l/family
- cropped area,: 40 m2 [average size of a family vegetable garden (FAO, 1995; FAO-TCP, 2006).]
- ET, FAO CLIMWAT
### RESULTS (DEMAND MANAGEMENT AND DESIGN OPTIMISATION)

<table>
<thead>
<tr>
<th>Cropped area (m²)</th>
<th>Tank Volume</th>
<th>Water Demand</th>
<th>Average Efficiency (Water balance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>From survey</td>
<td>From survey</td>
<td>0.11</td>
</tr>
<tr>
<td>20</td>
<td>From survey</td>
<td>From survey</td>
<td>0.2</td>
</tr>
<tr>
<td>20</td>
<td>5 m³</td>
<td>From survey</td>
<td>0.42</td>
</tr>
<tr>
<td>40</td>
<td>5 m³</td>
<td>From survey</td>
<td>0.26</td>
</tr>
<tr>
<td>40</td>
<td>From survey</td>
<td>Irrigation</td>
<td>0.12</td>
</tr>
<tr>
<td>20</td>
<td>From survey</td>
<td>Irrigation</td>
<td>0.28</td>
</tr>
<tr>
<td>20</td>
<td>5 m³</td>
<td>Irrigation</td>
<td>0.54</td>
</tr>
<tr>
<td><strong>20</strong></td>
<td><strong>6 m³</strong></td>
<td><strong>Irrigation</strong></td>
<td><strong>0.63</strong></td>
</tr>
<tr>
<td>15</td>
<td>From survey</td>
<td>Irrigation</td>
<td>0.39</td>
</tr>
<tr>
<td>12</td>
<td>From survey</td>
<td>Irrigation</td>
<td>0.5</td>
</tr>
<tr>
<td>40</td>
<td>6 m³</td>
<td>Irrigation</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Extreme dry years (2017-2018-2019):** Sufficient water for dropping vegetables in a reduced area.
CONCLUSIONS

- On a **baseline scenario**, the tanks lay in the **high DR range**, with **E** less than the maximum achievable and depending on **DR**.

- The **less conservative hypothesis for PA** overestimates **E**, provides an estimate of the maximum achievable **E** but cannot be used for the redefinition of a more suitable consumption schedule.

- Instead, the **most conservative hypothesis for PA**, underestimates **E** but identifies the trend of **E(DR)** in good agreement with the outcome of **WB** for a large number of **RWHS**.

- With reference to the case study considered here, **sensitivity analysis** evidences how the allocation of resources may help to preserve water stored for the most dry days, preserving water for food and increasing the tank **E**, in agreement with a more sustainable development policy.
Thanks from the full research group including also: Elia Degli Innocenti, Beatrice Laurita, Tomas Etcheverry, Marlon Salazar, Alonzo Torres, Jose Angel Urzua

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