Integrated ecological modelling for water management in the urbanized area of the Cuenca River basin (Ecuador)

Urban Catchment Problems

Image: Integrated modelling and design of basin management plans - Nopens - 2016
Objectives

Which measures are more effective to improve the current water quality in the Cuenca Basin?
Study area

Cuenca Basin

Urban and suburban area

Basins
- Cuenca
- Machangara
- Tarqui
- Tomebamba
- Yanuncay

Ecuador

Quito

Guayaquil

Cuenca
Study area: Urban and suburban area of Cuenca Basin

Number of sites: 43
Data collection

In situ measurements

Lab analyses

Macroinvertebrates collection
Biological water quality (ABI)
Dry season
Biological water quality (ABI)

Rainy season
Integrated river management (IRM) model

Model simulation

Driving Forces
- Sewer system
- Wastewater Treatment plant
- Hydro-morphological modifications

Water Quality Assessment
- River water quality
- Hydro-morphological conditions
- Ecological models:
  - Habitat suitability models
  - Ecological assessment models
- Ecological water quality in a river
Ecological models development

Ecosystem

Training dataset

Validation dataset

Measurement set

Generalized Linear Model (GLM) to identify variable that influence the ABI

**Gaussian GLM:**

\[ E(Y_i) = \mu_i = \eta_i = \alpha + \beta_1 \times X_{1i} + \beta_2 \times X_{2i} + \cdots + \beta_n \times X_{ni} \]  

**Gamma GLM:**

\[ E(Y_i) = \mu_i = \frac{1}{\eta_i} = \frac{1}{\alpha + \beta_1 \times X_{1i} + \beta_2 \times X_{2i} + \cdots + \beta_n \times X_{ni}} \]  

**Inverse Gaussian GLM:**

\[ E(Y_i) = \mu_i = \frac{1}{\sqrt{\eta_i}} = \frac{1}{\sqrt{\alpha + \beta_1 \times X_{1i} + \beta_2 \times X_{2i} + \cdots + \beta_n \times X_{ni}}} \]

\( X_{ji} = \) explanatory variables  --> physicochemical and hydromorphological variables
Integrated river management (IRM) model

Model simulation

Driving Forces

Sewer system
Hydromorphological modifications
Wastewater Treatment plant

Water Quality Assessment

River water quality
Hydromorphological conditions

Restoration actions

Ecological models:
- Habitat suitability models
- Ecological assessment models

Integrated urban wastewater system (IUWS) model

Ecological water quality in a river
Integrated urban wastewater system (IUWS) model

Continuously Stirred Tank Reactor in Series (CSTRS)

Image: Integrated modelling and design of basin management plans - Nopens - 2016
**Scenarios to recover the ecological water quality in the Tomebamba and Cuenca Rivers**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Season</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc-1</td>
<td>Dry season</td>
<td>Implementation of the new G-WWTP (carbon removal).</td>
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<tr>
<td>Sc-2</td>
<td>Dry season</td>
<td>Implementation of the upgraded G-WWTP (carbon and nutrients removal).</td>
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<tr>
<td>Sc-4</td>
<td>Rainy season</td>
<td>Implementation of the upgraded G-WWTP (carbon and nutrients removal).</td>
</tr>
<tr>
<td>Sc-1 to Sc-4</td>
<td>Dry and rainy seasons</td>
<td>Connection of isolated sewage networks to the main network of the city:</td>
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<td></td>
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<td>- Reduction in the concentration of nutrients and organic pollutants in 80% of small streams.</td>
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<tr>
<td></td>
<td></td>
<td>- Reduction in the concentration of nutrients and organic pollutants in 50% of the main effluents.</td>
</tr>
<tr>
<td>Sc-3 &amp; Sc-4</td>
<td>Rainy season</td>
<td>Implementation of four retention tanks before CSO discharges.</td>
</tr>
</tbody>
</table>
Integrated urban wastewater system (IUWS) model

Scenario analysis – dry season
Calibrated and validated river water quality model

- Dissolved oxygen, nitrites, nitrates, COD and orthophosphates
Scenario analysis: dry season

- DO (mg/L) vs Distance (Km)
- BOD$_5$ (mg/L) vs Distance (Km)
- Ammonium-N (mg/L) vs Distance (Km)
- Orthophosphate-PO$_4$ (mg/L) vs Distance (Km)

Symbology:
- Current conditions: measured
- Current conditions: simulation
- Scenario 1 & 3: simulation
- Scenario 2 & 4: simulation
- Ecuadorian threshold to preserve the aquatic ecosystem
- Confluence with the Yanuncay River
- Confluence with the Machangara River
Integrated urban wastewater system (IUWS) model

Scenario analysis – rainy season
Scenario analysis: rainy season

- **DO (mg/L)**: DO concentration varies with distance, showing a decrease after 15 km.
- **BOD$_5$ (mg/L)**: BOD$_5$ concentration increases towards the end of the monitored distance.
- **Ammonium-N (mg/L)**: Ammonium-N concentration shows a peak at 15 km, decreasing afterwards.
- **Orthophosphate (mg/L)**: Orthophosphate concentration remains relatively stable with minor fluctuations.

**Symbology**
- **Current conditions: measured**: Represented by blue diamonds.
- **Current conditions: simulation**: Represented by black lines.
- **Scenario 1 & 3: simulation**: Represented by red lines.
- **Scenario 2 & 4: simulation**: Represented by blue lines.
- **Ecuadorian threshold to preserve the aquatic ecosystem**: Represented by red-dotted line.
- **Confluence with the Yanuncay River**: Represented by green line.
- **Confluence with the Machangara River**: Represented by blue line.
Scenario analysis

**Dry season**

- **Sc1**
- **Sc2**

**Rainy season**

- **Sc3**
- **Sc4**

**Symbology**
- Simulated ABI for different scenarios
- Measured ABI: current conditions
- Simulated ABI: current conditions
- Confluence with the Yanuncay River
- Confluence with the Machangara River
Final Conclusions

Which measures are more effective to improve the current water quality in the Cuenca River basin?

- The connection of isolated sewage systems to the urban sewage network.
- The construction of a new wastewater treatment plant with activated sludge technology (carbon and nitrogen removal).
- The inclusion of retention tanks before the discharges of the combined sewer overflows – rainy season.
Acknowledgement

- VLIR-UOS IUC Programme - Universidad de Cuenca
- VLIR Ecuador Biodiversity Network Project
- Ecuadorian Environmental Ministry
Thank you
for your attention
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Bibliography:


