Characterization of water renewal in Cartagena Bay, Colombia: A hydrodynamic modelling approach

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Cartagena, Colombia

- #1 Touristic Destination

- UNESCO World Heritage Site

- Tourism & Ecosystems

- Fishing Communities

Legend

- Urban Area
Cartagena, Colombia

- Pollution “Hot-Spot”

- Urban Wastewater

- Industrial Zone

- Watershed Runoff
Basin Sea Interactions with Communities

“BASIC Cartagena”

2014 - 2017
Basin Sea Interactions with Communities

“BASIC Cartagena”

Coastal Component

1. Assess water and sediment quality
   • 2-year monthly monitoring program

2. Identify potential sources of pollution
   • Assessment of land-based discharges

3. Apply hydrodynamic and water quality models
Study Zone: Cartagena Bay

Area: 84 km²
Depth $\text{avg}$: 16 m
Depth $\text{max}$: 32 m
Mixed, mainly diurnal micro-tides: 20-50 cm

$Q_{\text{avg}}$: 150 m³/s
Study Zone: Cartagena Bay

Area: 84 km²
Depth \( \text{avg} \): 16 m
Depth \( \text{max} \): 32 m
Mixed, mainly diurnal micro-tides: 20-50 cm

Oct-Dec: Jan-Sept:
10-32‰  20-32‰
Pollution Issues

- Turbid Plumes

SEPTEMBER

Legend
- Sample sites

Turbidity (NTU)
- < 1.5
- 1.5 - 10
- 10 - 20
- > 20

Turbidity Surface Waters

Station (Zone)
- Bahia
- Baru
- Playa

Pollution Issues

- Turbid Plumes
**Pollution Issues**

- Occasionally inadequate recreational waters
- Metals in sediments and fish

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**Fecal Coliforms Surface Waters**

- **Station (Zone)**: B1, B2, B3, B4, B5, B6, B7, B8, ZP1, ZP2, ZP3, PL1, PL2, PL3
- **Bahia Barú Playa**

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**Metals in Sediments**

- Average Concentrations Normalized to TEL Limits
- **Barú Point**

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- **Pollution Issues**
  - Occasionally inadequate recreational waters
  - Metals in sediments and fish

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**MinSalud, 1984**

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**F.Cholerae**
Pollution Issues

- Hypoxic Conditions
Cartagena Bay revived by El Niño

Less sediments and nutrients from the Magdalena River allow Bay to breath..... All goes back to normal.
Is reduced runoff responsible for the temporary improvement in water quality?

Can future upstream canal mitigation result in continuous improved water quality?

Research Question: How do factors such as wind, tides and freshwater discharge affect water renewal?
MOHID water modelling system

• 3-Dimensional model
• Based on the finite volume approach
• Baroclinic hydrodynamic free surface model
• Eulerian and lagrangian transport models
• Integrates coupled modules that describe:
  • hydrodynamics
  • geometry
  • advection-diffusion processes
  • atmosphere
  • water properties
  • GOTM
  • …amongst others
• Open-source code
Model Setup

- **Horizontal Cartesian Grid**
  - Horizontal Resolution (m) | Length N-S (km) | Length E-W (km) | Area (km^2)
  - 75 | 18.9 | 12.3 | 235.7

- **Vertical Sigma Discretization**
  - 10 equal layers
  - Stratification based on CTD profiles

- **Semi-implicit time-step**
- **Tides**: FES Global Tide Model
Hydrodynamic Simulations

- to characterize controlling factors
Lagrangian Approach:

• to estimate renewal time scales
  • passive particle tracing
  • residence time: 95% particles
  • Braunschweig et al., 2003

• Scenarios:
  • wind (northerly)
    • min.: 0 m/s
    • avg.: 3 m/s
    • max.: 8 m/s
  • freshwater discharge:
    • min.: 50 m$^3$/s
    • avg.: 150 m$^3$/s
    • max.: 250 m$^3$/s
  • tide: yes / no
Surface water hydrodynamics

- Controlling factors:
  - wind stress
  - freshwater discharge

Tides only
- Max Velocity ($V_{\text{max}}$) = 6 cm/s

Wind only
- High Wind: $V_{\text{max}}$ = 41 cm/s

Wind & Discharge (Q)
- High Wind & High Q: $V_{\text{max}}$ = 37 cm/s

Wind, Q & Tide
- High Wind & High Q: $V_{\text{max}}$ = 36 cm/s
Bottom water hydrodynamics

- weaker dynamics

Tides only
- Max Velocity ($V_{\text{max}}$) = 10 cm/s

Wind only
- High Wind: $V_{\text{max}}$ = 21 cm/s

Wind & Discharge ($Q$)
- High Wind & High $Q$: $V_{\text{max}}$ = 18 cm/s

Wind, $Q$ & Tide
- High Wind & High $Q$: $V_{\text{max}}$ = 18 cm/s
Scenarios of water renewal

- High winds ➔ water renewal in 1-2 months
- Low discharge without high wind ➔ 3-9 months
- Other scenarios ➔ water renewal in 5-11 months

Approximation - order of magnitude

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Conclusions

Is reduced runoff responsible for the temporary improvement in water quality? **Partly, along with seasonal strong winds.**

Can future upstream canal mitigation result in continuous improved water quality? **Not alone. Local sources of pollution will also need to be reduced, because outside of the windy season the water renewal time scales are too long to assimilate high pollution inputs.**
Pollutants associated with surface waters (turbidity, coliforms) depend on winds and discharge for flushing

- However, realistically higher discharges also bring more pollutants into the system

Pollutants associated with bottom waters (metals, organic matter causing hypoxia) are flushed much less frequently due to weaker bottom hydrodynamics

- Highlights the importance of land-based pollution control
Next Steps

Model calibration & validation
- CTD profiles
- ADCP data

Water quality modeling
- Suspended sediments
- Coliforms
- Eutrophication
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Thank you
Спасибо

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