Visualizing resource dependencies of the urban system at multiple scales: a hydrological case study

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INTRODUCTION

Freshwater is one key component of the resource dependency of urban areas, linking concentrated population centers to geophysical and ecosystem processes operating at regional and global scales.

Resources like water, food, biofuels, fibers or energy that sustain cities directly depend on the productive or assimilative capacities of the freshwater system, operating at multiple nested scales (from catchment to river basins)—areas orders of magnitude greater than the extent of the built-up urban areas. (Grimm et al., 2008)

Although the freshwater system–urban population relationship has a broad regional and sectorial scope, the quantification of the extent of regional and global impacts of cities' resource demands, and more importantly, their integration into decision-support frameworks, continues to be overlooked in water-management and urban planning practice.

A key limitation to understanding the scope of impacts of urban systems is the distributed and non-linear nature of the regional relationship between water and cities, wherein a given region can simultaneously supply resources to—or be affected by—multiple urban areas (and vice-versa), and the heterogeneity of physical and biotic processes of freshwater systems.

Here we introduce a novel approach to assess and visualize the interactions between urban resource demands and the freshwater system.

We propose a set of indicators that make use of freshwater drainage structure to incorporate the cumulative effects and concurrent resource dependency of urban areas across multiple nested scales, using the Global river hydrography and network routing dataset (Lehner et al., 2013).

The cumulative character of the proposed indexes aims to replace the fixed control boundary (i.e. basin, sub-basin, etc.—the current practice in water resources appraisals), with the (topological) integral of the process across multiple nested scales.

- Water balance magnitudes
- Water balance change related to resource supply
- Topological change metrics
- Change in temporal patterns of water availability
- Pressure indexes

N	COMPONENT	INDICATOR	DESCRIPTION
1	Renewable freshwater supply	Runoff $\overline{Q_0}$	Mean long-term annual runoff. (Shiklomanov et al., 2000)
2		Runoff Q_{95}	Monthly runoff at basin level at observed P95 conditions (corresponds to January 2010 in the MRB).
3		$\overline{ETa_0}$	Total long-term yearly actual evapotranspiration (No Irrigation condition).
4	Appropriation of renewable freshwater supply	Total ETa appropriation	Mean annual total evapotranspiration of areas with productive land cover/use. (Postel et al., 1996)
5		$Green\ \overline{ETa}$	Mean annual evapotranspiration of areas with productive land cover/use. (No Irrigation condition). (Hoekstra et al., 2011)
6		Blue ETa and Blue ETa_{95}	Fraction of Q_0 and Q_{95} withdrawn and not returned (i.e. consumed as increased ET from irrigation). (Hoekstra et al., 2011)
7	Instream or non-consumptive uses	Connectivity: Changes in free river length	The difference between the total length of the river network, between two consecutive barriers.
8		Degree of regulation (weighted)	The ratio between the volume of upstream storage and the yearly average runoff at a given river, weighted by the fraction of the total runoff at a river reach that is controlled by artificial storage. This indicator relates to potential changes in the streamflow regime associated with storage infrastructure operations.
9	Pressure indexes	E_{ETa}: ETa scarcity index	Compares the cumulative ETa urban demands at a given point of the basin, with the ETa appropriation in the upstream basin, providing an estimate on the amount of ETa sourced outside the catchment to supply local demands.
10		E_{energy}: Energy stress index	Compares the cumulative electricity demands at a given point of the basin with the electricity generation in the upstream basin, providing an estimate of the electricity source. Values less than or equal to 1 indicate the upstream sub-catchment fully meets local demand, while greater than 1 indicates a source outside the catchment supplies local demands.

This approach allows:

(i) visualizing how factors like patterns of size, spatial distribution and interconnection of urban resource demands or the nested and hierarchical character of freshwater systems influence the cumulative pressure exerted on an urban system on the freshwater system,

(ii) mapping the spatial patterns of resource import and export across different scales and regions of a freshwater system, and

(iii) quantifying the scales of the process required to sustain the resource supply of multiple cities sharing the same provisioning freshwater system

The presented advances contribute to an informational framework for integrated water management and urban planning.

A CASE STUDY

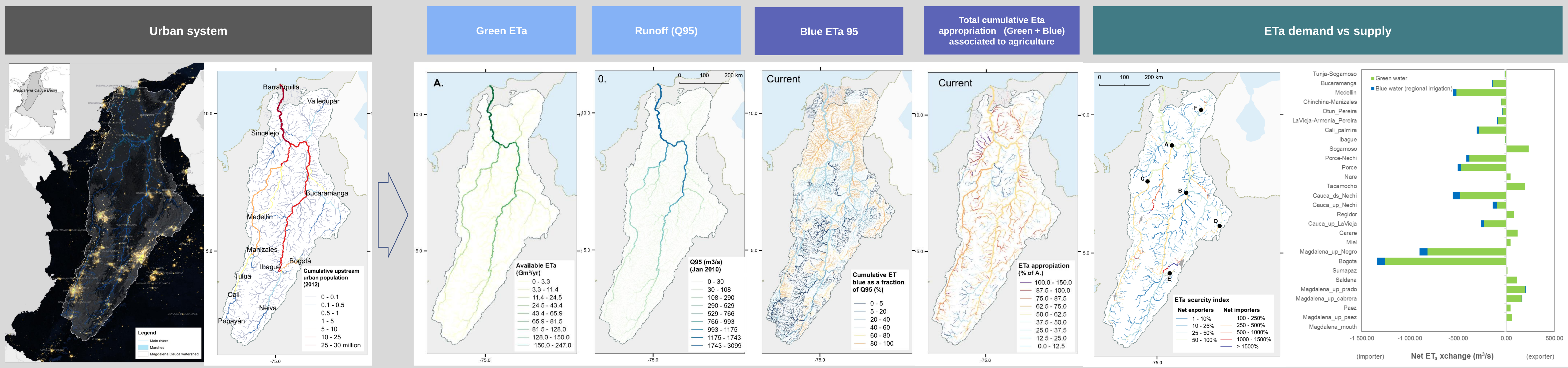
Magdalena River Basin (MRB)

Total population (2012): 35.96 million (DANE, 2015).

29.11 million (81.0%) reside in main urban settlements (DANE, 2015).

Urban agglomerations in the MRB cover six orders of magnitude of population, from ~10^2 to 10^7 inhabitants.

Examples of indicators in table above for biomass supply to the Urban System of the MRB



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