IMPROVEMENT OF URBAN WATER METABOLISM AT THE DISTRICT LEVEL FOR A MEDITERRANEAN COMPACT CITY

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ABSTRACT

Cities are under constant and increasing pressure because of global changes, fast urbanization and growing resources demand. Those threats force urban systems to find development opportunities and solutions to minimize the demand and to shift from linear to circular economy, in which recycling and reusing are key activities [1]. Urban Metabolism (UM) analysis has become an important tool for the study of urban ecosystems. The problems of large metabolic throughput, low metabolic efficiency and disordered metabolic processes are a major cause of unhealthy urban systems. Nowadays, the most critical urban resource flow is water, followed by energy and materials: water is vital for our survival and the largest component in terms of sheer mass [2]. Furthermore, climate change increases geo-hydrological risks (landslides, floods and sinkholes), especially in Italy, causing damages and threats to the population, requiring a better management of the water cycle. However, due to the complexity of contemporary urban phenomena, it is difficult to understand what happens within those urban systems and to answer to these current pressures. Applying the UM at the city level presents some limitations due to the lack of data and the generalizations required at this scale. The traditional approach considers the city as a "black box", quantifying in-flows and out-flows. Indeed, resources availability depends strongly on local context characteristics that enable the reduction of input water flows, maximizing the reuse of wastewaters and closing water loops. Along with the new challenges of sustainable design, it is possible to define different scenarios and roadmaps for compact cities, developing decision support systems that follows the principles of urban metabolism at the local scale. This research presents a project to evaluate the local water potential in a portion of the compact city of Rome in order to improve the local metabolism through a more efficient use of the resource. The innovative methodology will enable sustainable actions through the identification and assessment of a set of green projects to suggest pathways that enhance the modification of water metabolic flows.

Keywords: urban water metabolism, water sensitive cities, sustainable development, city district, water cycle, resilience, circular economy

INTRODUCTION

Urban water systems play an important role in sustainable development and in urban metabolism flows, dealing with a fundamental human need: access to drinking water, sanitation, water quality and health. According to the European Environment Agency (2006), approximately 75 percent of the population in Europe lives in urban areas and forecasts show an increase between 80 to 90 percent by 2020. Cities exploit resources, producing wastes in a linear way; the high rate of resource consumption and massive disposal of waste stress the resources availability by depletion, causing pollution. Projections [3] for the near future show that scarcity of water will have more of a limiting effect on human activities than either energy or capital. Furthermore, as growing urban communities seek to minimize their impact on already stressed water resources, an emerging challenge is to design for resilience to reduce the impacts of climate change, ensuring secure water supplies and the protection of environments.

Despite considerable progress over the past ten years, the forecasting of natural water cycle variability and extreme weather events in the short and medium term still suffers from severe limitations. Improved understanding of the impacts of climate change on the hydrological cycle is necessary to better inform decision-makers and ensure sustainable water supply, management of water systems and quality of water bodies. This strong trend creates an enhanced need to understand water flows through and within the urban boundary, meeting the needs of water planners but without considering the hydrological performance of a system [4]. In the Mediterranean regions, the risk of water shortage is significant and the demand is growing despite limited renewable water resources, mainly irregular and of unequal quality as for the European Commission Mediterranean water scarcity and drought report in 2007. In the last 50 years, many cities faced increasing vulnerability to water stress, especially in Italy, where extreme weather events increased geo-hydrological risks (landslides, floods and sinkholes), causing damages to the population and requiring an accurate management of the water cycle to increase the resilience of cities. Those threats depend on climate changes, on the rapid growth in the urban population, on the pollution and the depletion of groundwater, increasing per capita water use, soil sealing and the aging of traditional drainage systems, having a discernible impact on the aquifers' level variation below urban systems and on the water cycle integrity [5].

The transition to water centric cities: closing water cycles at the district level

The study of the water metabolism is crucial for the future of sustainable cities and of high relevance to the water industry [6]. To solve current urban water problems it is necessary to solve their metabolic processes and to organize water flows in a sustainable way, reducing their metabolism and reusing the resource according to the quality of the demand. In this perspective, the reuse of remaining qualities should match with lower quality demanding purposes. Reducing flows through cities while improving human livability and overall ecosystem well-being represents both a clear sustainability pathway and a challenge [4, 6]. In a circular model, water is reused several times, retaining full value for a "circular economy". Optimal regulation of an urban metabolic system starts with research on the mechanisms that govern interactions among the components of the system's structure and the functioning of the system [7]. Without a change in the paradigm of water management, urban water demand will eventually keep increasing, water supplies will diminish and the population pressure will cause the decay of the infrastructures [8]. As an example, Agudelo-Vera and colleagues [9] illustrate an innovating water resilience strategy including demand, output minimization and multisourcing, the Urban Harvest Approach.

Over the past decade, the green/sustainable building industry attended significant progress in tracking energy and material flows at the building scale, but there is arguably a need to step to higher level. The incorporation of sustainability principles in neighborhood design is important because many of the problems encountered at the macro-city scale are cumulative consequences of poor planning at the micro-neighborhood level. This is particularly evident in the historical reliance on large-scale, centralized urban infrastructure projects. Neighborhood-scale analysis is necessary to evaluate and develop more sustainable local infrastructure, including buildings, transportation, urban vegetation and water systems [10]. Today, studies of resource flows at the city scale become an increasing practice but present some serious and recurring deficiencies like accounting problems, lack of available, reliable and updated data, lack of knowledge on the use of these data (if present), absence of a clear and well-funded methodology. However, the most important limitation of the majority of current UM studies is the black box approach, which means that all the different studies show only macroscopic inputs and outputs of an urban system. Neighborhoods and intermediate to large-scale mixed-use development projects offer interesting advantages and opportunities. Neighborhoods have a mix of uses, which makes it easier to balance loads and match the intermittent supply of resources, with larger flows to treat that can generate the critical mass to enable sustainable intervention. The urban landscape becomes an infrastructure that can play a role to temper the climate, absorb carbon, clean stormwater and sewer effluent. The challenge is to redesign the UM of cities, downscaling results from urban planning and upscaling household models to a relevant scale.

Cities need to make a transition towards a more Sustainable Urban Water Management (SUWM) with a strong need to compare and analyze their performances [11]. How can we achieve these objectives? Researchers emphasize the need for the integration and decentralization of water supply, wastewater, stormwater systems and their assessment of social and economic impacts while neighborhood design features, such as lot size and street layout, have a large impact on the performance of water systems. Only a systemic approach will result in a reduction of local water use, wastewater generation and stormwater runoff, in a socially and economically acceptable way [10]. A critical barrier to progress is the lack of decision support systems to develop of long-term policy for SUWM. While there has been significant progress in many cities, particularly related to the innovation of more sustainable technologies and shifts in community values around the environment and waterways, numerous commentators argue that current progress is still too slow [12]. More recently, some cities used a distributed "green infrastructure" strategy through the Water Sensitive Urban Design (WSUD) approach to urban planning and design [13]. This method integrates the management of the total water cycle into the urban development process, including:

- integrated management of groundwater, surface runoff (including stormwater), drinking water and wastewater to protect water related environmental, recreational and cultural values;
- storage, treatment and beneficial use of runoff;
- treatment and reuse of wastewater, using vegetation, water efficient landscaping and enhancing biodiversity;
- water saving measures within and outside domestic, commercial, industrial and institutional premises to minimize requirements for drinking and non-drinking water supplies.

The WSUD techniques are considered as "best practice level" which means that we still have little information on their technical effectiveness under different types of climate. It is also desirable to decentralize the water system by promoting multiple spatial scales. This could include rainwater harvesting and local water reuse/treatment that might increase the flexibility, transformation and resilience of the whole system in the face of external shocks, including those resulting from climate change [14].

METHOD

Today, the scientific literature shows that WSUD methodologies help to reach these objectives but the effects of the integration of water-sensitive design strategies for a specific urban morphology and for a particular climate are still unknown. This is what the SOS_Urbanlab (Engineering Laboratory for Construction and Environmental Sustainability, "Sapienza" University of Rome) is trying to explore, focusing on the Mediterranean climate and on the compact city of Rome. This network reshaping rests on one side on part of the principles of the Urban Harvesting Approach like estimation of the local demand-supply and wastewater's recovery potential. On the other side, the study follows the Urban Water Metabolism of the city of Brussels [15] for some city water indicators and for correlations with climate factors. The methodology of flow reshaping will act as follows:

- Calculating the local water demand: after the identification of a roman neighborhood and its different urban functions (residential, shopping+horeca, public services, sport facilities etc), the demand results as a weighted sum of the average requirements per function (demand inventory in m^3/ha – year for every function).
- Calculating in-flows (local water supply, rainwater and waterways): data of the supply inventory arise from the roman municipality, considering network leakages. In 2005, the supply of the case study's district is 499.736 m^3/year. For rainwaters, we consider data coming from the nearest weather stations. Waterways data comes from the average annual flow values for the Tevere and the Aniene rivers (Tevere: 240 m^3/s – year; Aniene: 31 m^3/s - year).
- Calculating internal flows (infiltration, runoff and stock): the infiltration and the runoff change the destination of the rainwater in-flows towards out-flows, depending on the sum of pervious and sealed surfaces within the urban tissue. The stock of water (surface water, groundwater and accumulation systems) is the amount of water remaining in the urban system, without generating a flow in output.
- Calculating out-flows (wastewaters, evapotranspiration, waterways): like the local water demand, wastewater data arise from the specific urban tissue, its inner functions and the average wastewater per function. Another part of wastewaters comes from the runoff, estimated by the sum of the sealed surfaces of the specific urban tissue. The evapotranspiration depends on the sum of green surfaces within the urban tissue. Like the in-flow waterways, out-flow waterways data arises from the average annual flow values for the Tevere and the Aniene rivers (similar in and out discharge).
- Coupling water demand and supply: deriving from the Mass Flow Analysis (MFA) and adapting to the water flows in figure 1, the general water mass balance WMB (water storage) at any specific instant in time (t) becomes:

$$WMB(t) = \sum Water\ inputs\ I(t) - \sum Water\ outputs\ O(t) - \sum Consumptions\ C(t)$$

$$I(t) = S(t) + W(t) + R(t) \quad \text{and} \quad O(t) = W_w(t) + W(t) + E(t)$$

S = Supply; W = Waterways; R = Rainwaters; W_w = Wastewaters; E = Evapotranspiration

Consumption is a fraction of the demand that cannot be reused or recycled (e.g. diminished by decay). The goal is trying to satisfy the demand with the water mass stored into the system and wastewaters in out-flow. The challenge is to manage these flows, using internal and out-flows to reduce the in-flow, which means reducing the resource's use through its reuse.

- Calculating wastewater's and rainwater's recovery potential: by studying the urban tissue, it is possible to calculate the potential resource to capture and transform into new sources to remain within the urban area. The urban tissue will display the spatial distribution of flows, hierarchy of activities and uses to improve water management and providing guidelines for urban planning. Wastewaters have different levels of quality: some wastewaters can become in-flows to fulfill some of the demand. The total sum of rainwaters and wastewaters is the maximum value of the reuse potential. The real reuse potential derives from the assessment of the level of quality of the maximum potential, on the distribution of the system functions and on the level of quality required by these functions.

- Select the WSUD to reshape flows: the next step is to reorganize and reshape those flows to achieve the faster closure of water cycles and a greater autonomy of the urban cells. The reorganization of water flows within the local context, with consequent benefits on the water balance at the larger scale, aims at matching the demand with the recovery potential with the help of WSUD techniques that enable this possibility. Once identified the resource's recovery potential, the implementation of WSUD allows transforming both stock and out-flows in lower quality in-flows, reshaping the actual linear water management in a circular water cycle.

The methodology can support stakeholders in decision-making, considering WSUD in terms of delta-flows based on the current and the future water-flow scenarios. The combination of the different categories of WSUD generates a set of possible interventions with a high level of flexibility to reach many different targets of sustainability, characteristics of the local urban system, to maximize its degree of independence.

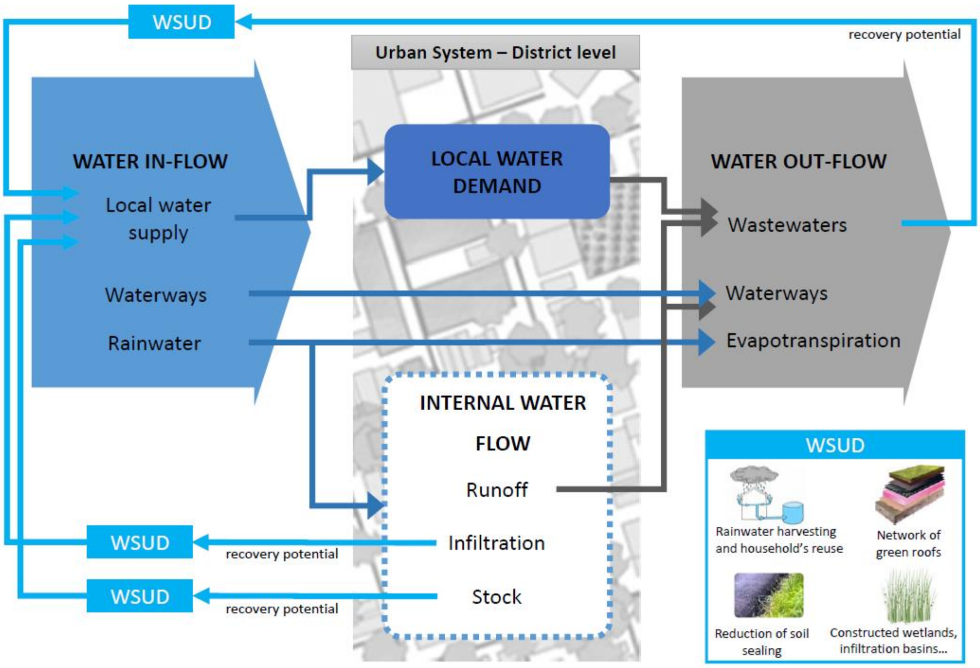

Figure 1: Urban water metabolism of a sustainable district

RESULTS

The research is an ongoing project that analyses three urban tissues within the third municipality of Rome, in the northeast area of the city, with an extension of 97.818 km^2. The total population amounts to 204.623 with a density of 2.103,1 inhabitants per km^2 (2013). The whole municipality shows many dissimilar built regions related to different historical construction periods, ranging from the beginning of the 20^{th} century to the "eco-monsters" public housing, characteristics of the 60's and the 70's. Given the heterogeneity of the whole district, the study will consider different types of areas with different density (calculated through the FAR index - Floor Area Ratio), with particular attention to more compact regions. Considering the difficulties in finding data at the local scale for the city of Rome, a bottom-up approach is necessary to avoid the lack of information and macro approximations. The study sets three regions (approximatively 1 ha each) within the municipality and identified the amount of the urban functions (residential, commercial and industrial) to evaluate the local water demand. After this step, the study will calculate the water in-flows, out-flows and internal flows to determine the water mass balance and the recovery potential of wastewaters and rainwaters to evaluate the possibility of water reuse. The choice of the typologies of

WSUD will depend on the local characteristics of the built environment and the local flows structure. For example, the rainwater collected by roofs can partly fulfill the water demand. The standard Roman rooftop is flat, with more than 20 thousand rooftops that cover the city. This value represents almost 400 hectares of potential green lung in terms of rainwater harvesting, reduction of pollution, caption of particulate matter and reduction of the heat island effect and flooding.

CONCLUSION AND DISCUSSION

Reordering land use, layout of neighborhoods and design of buildings helps to reshape the environmental profile of the resource's use, to compare different territorial potentials and to identify strategies that could allow urban regeneration, supporting competitiveness and sustainable development. However, the urban system's sustainability depends on the sustainability of each of its internal cells and the connections among all the parts, in this way we can talk about cities as organisms, with their own metabolic systems, balanced by the equilibrium of all its parts. This study tries to fill this gap, proposing a methodology that appropriately downscales urban metabolism principles to drive current sustainability challenges. Optimize urban metabolic networks by regulating their processes to increase their efficiency: on the results of this research, it will be possible to identify and regulate key water issues and their related processes, as well as the relations between these local water issues and the fluxes in each process.

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