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Introducing UWAB 2.0. and exploring next steps for agent based modelling in domestic water demand.

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Abstract Domestic water consumption projections are needed to manage the urban water supply system in different spatiotemporal resolutions depending on the type of the supported decision. For instance, operational decisions require predictions of fine resolution (hourly or lower), while tactical and strategic decisions are satisfied with predictions of coarser resolutions (monthly or even annual). This work explores the development of the new version of the Urban Water Agents' Behaviour (UWAB) model, the UWAB 2.0. and its structural changes. These changes are expected to enable the linking of UWAB with machine learning techniques to enhance its projection capacity to support tactical and strategic decisions. UWAB is an agent based modelling tool, which simulates the water demand behaviour of urban households incorporating the effects of climate, water demand management policies and social network to water saving behaviour. This work will present the results of the structural changes of UWAB and the way forward for its development and pilot testing.
Keywords: agent based modelling, water demand

1. Introduction

Urban water systems are under continuous pressures due to climatic changes, population changes and infrastructure aging (Ferguson et al., 2011). Amongst others, water management requires dynamic information able to show the effects of its actions to the actual behavior of the urban water system. For instance, decisions regarding the upgrade of the urban water system require to predict future water demand in monthly time steps while operational decisions require water consumption data in daily, hourly or even lower time steps. Recent studies were able to utilize smart meters installed in houses to recreate stochastic timeseries of urban water demand in lower than hourly time steps under constant external conditions (Kossieris and Makropoulos, 2018).

The scientific community is intensively developing methods for estimating urban water demand with efforts to focus mainly on bottom-up methods (urban water system) (bottom-up approaches) (Walski et al., 2003). For instance, using the search engine for scientific publications (without patents and citations) google scholar with the terms suggested by House-Peters and Chang, 2011: "urban" + "water demand," "municipal" + "water demand," "water use" + "Urban," and "water consumption" + "urban.", The results per year are: 2019: 507 publications, 2018: 1010 publications, 2017: 985 publications, 2016: 990 publications, etc.

However, to be able to model dynamically changing behaviors, such as urban water demand under changing external conditions, it is necessary to identify a tool that can model the human component. This is where Agent Based Modelling (ABM) comes into play, which is made up of agents, computational objects (essentially AI), that follow specific rules to explore their environment, interact with each other and act autonomously to achieve specified objectives (Wooldridge, 1999). Essentially, ABM is a form of computational social science (Gilbert, 2008), with the complex behaviors of the system being recreated by the interaction of its simple components, creating emergent phenomena. This ABM ability, to recreate bottom-up behaviors, can be used to explore the dynamic interaction between the socio-economic component and the urban water system (Koutiva & Makropoulos, 2011).

In this study we explore several novel structural developments of an ABM already developed and published, the Urban Water Agents' Behaviour (UWAB) tool (Koutiva and Makropoulos, 2016) that could be further developed to support decision makers in their effort to manage urban water systems under changing conditions.

2. Method

UWAB simulates the urban household's water demand behaviour based on: (a) complex network theory (Albert and Barabasi, 2002) representing the links among the domestic water users of a city; (b) Social Impact Theory (Latane, 1981) addressing the effects of society, policies and other external forces on the domestic users' behaviour; (c) the Theory of Planned Behaviour (Ajzen, 1991) deconstructing the domestic water user's behaviour into components for modelling behavioural intention; and (d) statistical mechanics (Shell, 2014) employed to deal with the inherently stochastic nature of human behaviour.

Results on behavioural changes due to demand management policies and environmental pressures were simulated with the UWAB model and were then translated into specific domestic water demands through micro-simulation of in-house water appliances using the Urban Water Optioneering Tool (UWOT) (Makropoulos et al., 2008, Baki et al., 2018).

The UWAB-UWOT modelling platform was then demonstrated using the Athens urban water system as an example. Initially, the UWAB-UWOT modelling platform was calibrated and validated using a major period of drought in Athens, Greece (Koutiva and Makropoulos, 2016). The calibrated UWAB-UWOT modelling platform was then used to develop scenarios of future water demand by modelling the effects of different water demand management strategies on the water cycle of the city of Athens (Koutiva and Makropoulos, 2019). The results suggested that the coupling of the two models provides a new way of planning and assessing water demand management strategies of direct relevance to water regulators and water companies.

However, UWAB should be further developed in order to be efficiently utilized by engineers and decision makers not familiar with ABM and the modelling platform, Netlogo, used to build UWAB (Wilensky, 1999) (see Figure 1.a. for UWAB original user interface).

2.1. UWAB 2.0

The new version of UWAB has been recreated using the Mesa tool (Mesa, 2015) for developing ABM. This tool provides ABM tool developers with built-in basic functions and libraries (such as spatial networks, mathematical algorithms - scipy, etc.) from Python. Additionally, this tool allows to use a predefined model visualization interface using an internet browser, see Figure 1b for the embedded to Mesa user interface. It also allows to integrate the ABM with other popular visualization libraries (i.e. dash by plotly) to recreate a graphical user interface as needed (see Figure 1.c. for a pilot user interface). Finally, one great advantage of Mesa is that the results, and i/o data in general, can be analyzed using Python data analysis tools.

This development enabled the dynamic linkage of the behavior of households (UWAB) with the use of household water appliances (UWOT). For this purpose, a class of intelligent agents was created at UWAB, which represents the household and its water appliances. In this way the ABM is able to receive direct information on the water demand for each intelligent agent. Thus, the behavior of households is now possible to be dynamically translated into the use of water appliances and therefore dynamically estimate the total household water demand considering external (i.e., weather, policies, restrictions) and internal (i.e., age of dwellers, children, household schedule, seasons, holidays etc.) to the household conditions.

The above developments, allowed UWAB 2.0 to be able to represent domestic water users in different geographical areas, allowing to create different groups of agents that share the same socioeconomic characteristics but are influenced by different types of water demand management policies. In practice, this means that UWAB 2.0 can simulate domestic water users in different areas by changing their characteristics.

3. Discussion

This work presented UWAB 2.0. There are several steps remaining yet to be concluded for the validation of UWAB 2.0. and its progression to the next phase, a pilot real life conditions testing.

One of these steps, could be again structural, by linking UWAB 2.0. with Machine Learning Python libraries (i.e. scikit-learn). Such tools could be applied to equip adaptive agents with experience learning or to analyze the outcomes produced by a given ABM (Dahlke, et al., 2020).

This can then be used to simulate user behavior under the influence of different external stressors, such as climatic, economic and managerial conditions (Nazemi and Wheater, 2015). The aim of this fusion would be the creation of dynamic demand time series that can meet the needs of the decision maker for the management of the urban water system. This could be a next step in the development of novel Agent Based Models that could potentially predict urban water demand under dynamically changing conditions

As the field of AI progresses, through the digitization of processes, the development of cloud services and the automation of data collection, it is anticipated that opportunities will arise for the progression of the application of ABM to urban water management.

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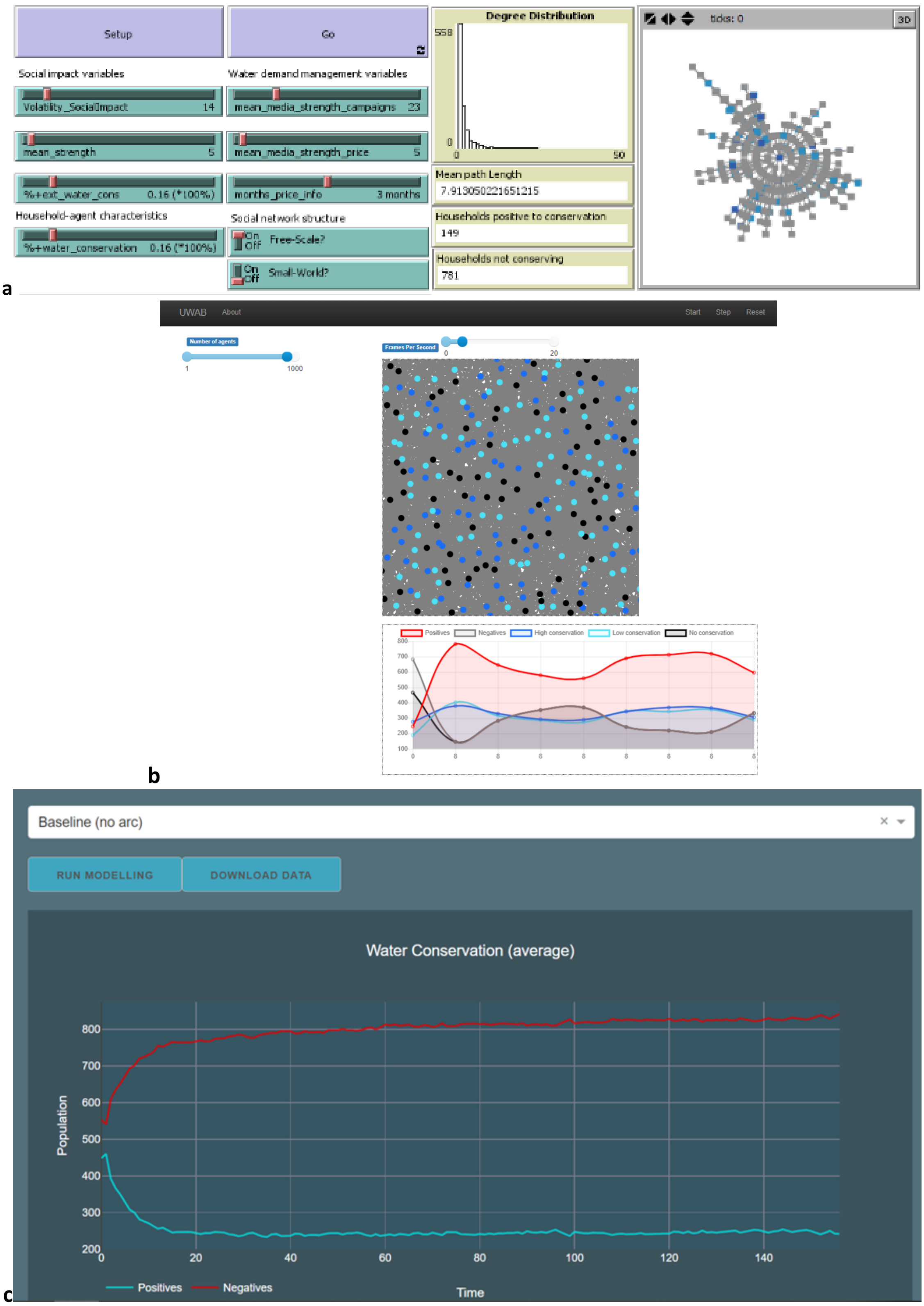

Figure 1. UWAB user interface using a) Netlogo b) Mesa/Python and c) dash integration

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