SIMULATING THE DOMESTIC WATER DEMAND BEHAVIOUR USING AGENT BASED MODELLING

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ABSTRACT

The sustainable evolution of the urban water system requires managing both water supply and demand. In order to successfully manage these, the creation of an integrated urban cycle management framework is necessary using tools that analyse and simulate the natural, technical and social components. However, one of the main challenges of simulating the complete urban water cycle is the modelling of the urban household's water demand behaviour. For this purpose, Agent Based Modelling (ABM) may be applied. ABM is an artificial intelligence tool that allows the study of macro phenomena through the autonomous action of the micro components of the system.

This work presents the design of an ABM tool for addressing the social dimension of the urban water system. The created tool, called Urban Water Agents' Behaviour (UWAB) model, was implemented, using the NetLogo agent programming language. The main aim of the UWAB model is to capture the effects of policies and environmental pressures to water conservation behaviour of urban households. The model consists of agents representing urban households that are linked to each other creating a social network that influences the water conservation behaviour of its members. Household agents are influenced as well by policies and environmental pressures, such as drought. The final outcome of the model is the distribution of different conservation levels (no, low, high) to the selected urban population.

In addition, the created ABM tool is combined with an existing urban water management tool, the Urban Water Optioneering Tool (UWOT), which simulates the physical and technical dimensions of the urban water system. The methodological integration of these tools creates a modelling platform for simulating the "complete" socio-technical urban water system.

The effectiveness of the proposed modelling platform is assessed using the Athens drought period of 1988-1994 as a case study.

Keywords: Agent based modelling, domestic water demand behaviour, urban water demand management, water conservation

1. Introduction

The urban water system is a complex system that is composed by technical, environmental and social components which act autonomously, interact with each other and evolve in time, thus increasing the uncertainty regarding its response to change. The sustainable evolution of the urban water system requires managing both supply and demand. An integrated urban cycle management framework needs to use tools which analyse and simulate the urban natural, technical and social environments (Rozos and Makropoulos 2013).

One of the main challenges of simulating the complete urban water cycle is the modelling of the urban household's water demand behaviour and the effect of water demand management policies to it. Agent Based Modelling (ABM) is a promising approach able to represent the social component of the urban water system (Koutiva and Makropoulos, 2011). ABM is an artificial intelligence tool that allows the study of macro-phenomena through the autonomous action of the micro-components of the system.

The aim of this research is to design a tool for addressing the social dimension of the urban water system and combine it with existing urban water management tools that simulate the physical and technical dimensions of the system. The methodological integration of these tools creates a modelling platform for the "complete" socio-technical urban water system aiming to facilitate an adaptive approach of water resources management. The proposed modelling platform is tested using the Athens drought period of 1988-1994 as a case study.

2. Methods and Tools

2.1. Urban Water Agents' Behaviour (UWAB) model

The Urban Water Agents' Behaviour (UWAB) model was created for the purposes of this research, using the NetLogo agent programming language (Wilensky, 1999), to capture the effects of policies and environmental pressures to water demand behaviour of urban households focusing on water conservation behaviour.

The model consists of household agents that are linked to each other creating a social network that influences its members regarding the level (low, high or zero) of water conservation a household agent will apply. This effect is calculated using Latane's social impact theory (1981) including statistical mechanics of micro-sociological behaviour (Bahr and Passerini, 1998).

A utility function, composed by the attitudes, subjective norms, and perceived behavioural control, calculates the behavioural intention to consume water in a certain manner based on the theory of planned behaviour (TPB) (Ajzen, 1991). The stronger the intention the more likely is a behaviour to be performed (Ajzen, 1991). Based on the results of a socio-psychological research held in 2013 and on the findings of an extensive literature review the shapers of water demand behaviour that are used to calculate the utilities of the behavioural intention of zero, low and high conservation levels are presented in Figure 1.

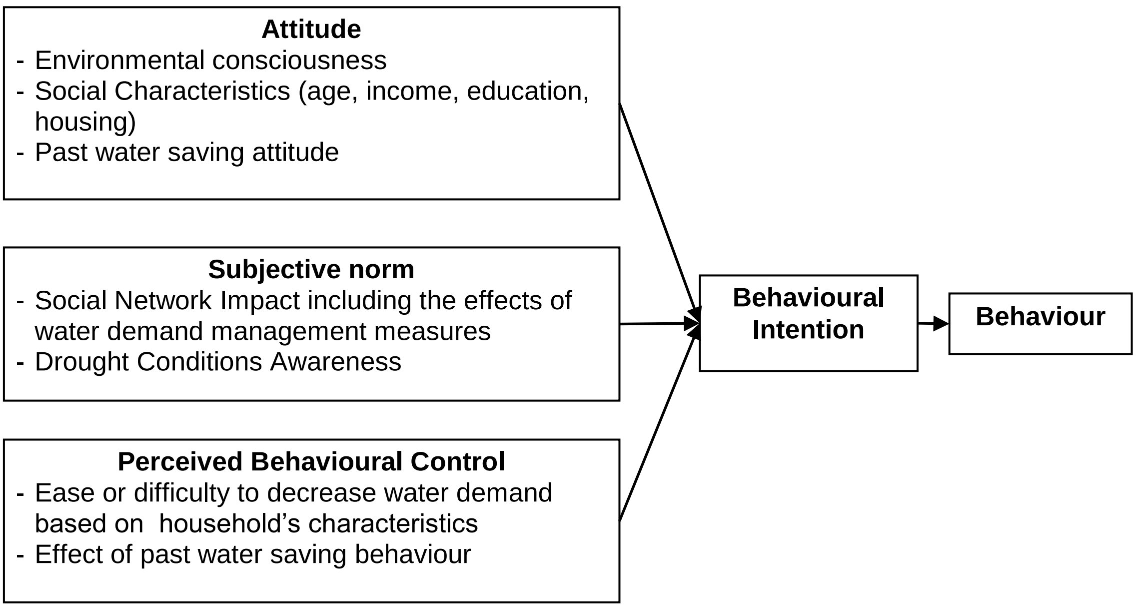

Figure 1: Shaping factors of an urban household's water demand behaviour

Every household agent estimates its behavioural intention, or the "energy", for each water conservation level, every three months. The values of the behavioural intention's components have been selected in a way that the higher behaviour intention would correspond to a higher probability for water conservation. In order to choose one of these microstates a number is randomly selected from a uniform distribution on [0, 1]. The household agent selects the microstate whose probability is more than or equal to the random number.

In every time step the UWAB model calculates the number of household agents that have selected to behave in one of the water conservation levels.

2.2. Urban Water Optioneering Tool

The urban water system is made up by three main components: water supply, wastewater disposal and rainwater drainage (Makropoulos *et al*., 2008). The Urban Water Optioneering Tool (UWOT) is a decision support tool that simulates the urban water cycle utilising a bottom up approach. The urban water system components are represented inside UWOT using a three level hierarchical structure, modelling individual water uses (Lower Level), domestic water technologies (Central Level) and aggregating their combined effects at development scale (Higher Level). The main purpose of UWOT in this proposed modelling methodology is to simulate the evolution in time of the domestic water demand of the different water conservation levels (low, high and zero conservation). Thus only the lower level of the UWOT model is used which estimates domestic water demand by applying frequencies of use to the in-house household water appliances (e.g. toilets, washing machines, shower heads, outside uses etc).

2.3. Integrating UWAB with UWOT

After setting up and running the two models two types of data are available:

- UWOT results: water demand time series per household water demand type and
- UWAB results: number of households' time series per household water demand type (no conservation, low conservation and high conservation)

These results are then integrated by multiplying the water demand of each water demand type by the number of households following it in order to produce the total monthly water demand in litres per person per day for the area under investigation.

3. The case of Athens 1988 – 1994 drought period

During the drought period of 1988 – 1994 Athens' water runoff reached the lowest record ever, and remained for a long time so low (less than 50% of the long term average) that by the end of 1994 water reserves were barely enough to satisfy the demand of less than a year (Mamassis and Koutsoyiannis, 2007).

The main response to this drought pressure in terms of water demand management was the substantial increase of water prices, an average of 240% across all levels of consumption, and extensive water saving awareness campaigns in 1990, 1992 and 1993 (EYDAP, 2009, Kanakoudis and Tsitsifli, 2008).

The effect of these policy measures was an approximate 33% drop of domestic water demand, namely from an average volume of 150 litres per inhabitant per day in 1989 to 100 litres per inhabitant per day in 1993 (Mamassis and Koutsoyiannis, 2007)

3.1. Implementation of the UWAB-UWOT modelling platform to the Athens drought period of 1988-1994

The evolution of domestic water demand during the Athens 1988-1994 drought period was used in order to test the efficiency of the developed modelling framework. The necessary data for setting up the two models were collected mainly from the National Statistical Office and Athens Water and Sewage Company (EYDAP). Several parameters of UWAB lacked available data for Athens and it was necessary to make assumptions based on other scientific studies (i.e. for social impact parameters and social network structure). Mean monthly domestic water demand and water price changes were provided by EYDAP.

However, the frequencies of use of the in-house appliances for all three conservation types (zero, low and high) were not available so the necessary data derived from an online questionnaire that was held during December 2013.

Figure 3 presents the results from the application of the UWOT-UWAB modelling platform to the Athens 1988-1994 drought period.

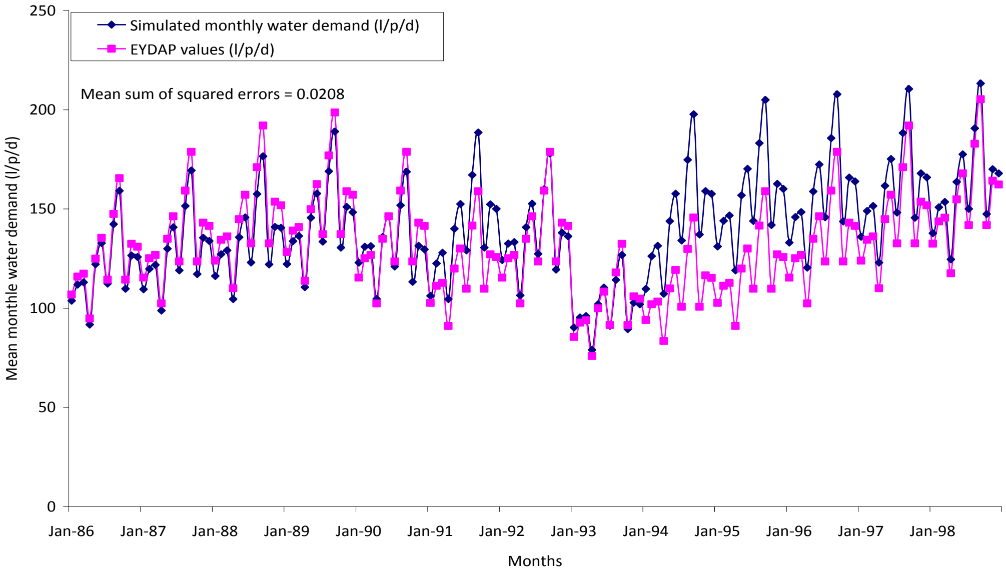

Figure 2: Comparison of simulated and actual domestic water demand in Athens

The designed agent procedures, the parameterisation of the UWAB – UWOT modelling platform and the model's calibration led to a well fit approximation of the mean monthly water demand of the Athenian households of the 1988-1994 drought period.

4. Discussion and conclusion

This work introduces the Urban Water Agents' Behaviour model that simulates the urban household's water demand behaviour. Additionally, the Urban Water Optioneering Tool is used in estimating the evolution of domestic water demand by simulating the use of the in-house water appliances. Finally, the linking of the two models is presented which leads to the creation of a modelling platform for the "complete" socio-technical urban water system aiming to facilitate an adaptive approach of water resources management. The proposed methodology is tested using as a case study Athens' 1988 – 1994 drought period.

The main advantage of this approach is that this integration may allow the investigation of the effects of different policies to an urban population's water demand behaviour and ultimately the effects of these policies to the domestic water demand.

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