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Integrated Support System for Efficient Water Usage and Resources Management (ISS-EWATUS)

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Abstract

ISS-EWATUS is a new, EU-funded project, coordinated by the University of Silesia in Poland. The main objective of the project is to exploit the untapped potential for saving water in municipalities and individual households. To increase the awareness of water consumption at the household level, an information system for gathering, interpreting, and sharing data about water usage is planned. A household decision support system will be developed to reduce water consumption. At the urban level, to reduce leakages from water distribution systems, an innovative system for dynamic control over the water pressure is planned. The validation of all ISS-EWATUS outcomes will be conducted in Greece and in Poland, where pilot installations are planned.

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Keywords: saving water; decision support systems; information technology.

1. Introduction

As water resources become scarce, the conservation of water has a high priority around the globe, and water management and conservation have become important topics of research. Only approximately 0.01% of the water is available for use on a sustainable basis [1]. Growing water demand in large urban centers, population growth, industrialization, and inadequate pricing policies make adequate access to water an issue, especially for low-income households. In particular, the problem is important for countries with relatively low water resources. It is also worth mentioning that the right to equal and non-discriminatory access to sufficient amounts of safe drinking water for personal and domestic uses has been recognized as a fundamental human right by the United Nations since September

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2010. To meet the growing demand for the conservation of water resources, novel and interdisciplinary solutions must be developed and implemented.

The untapped potential for saving water should be pursued to the maximum extent possible. The water-saving potential can be differentiated with respect to sector, e.g., households, agriculture, and tourism, or with respect to the instruments used to achieve savings, e.g., technical instruments and non-technical instruments, such as social and economic approaches. Fostering general awareness of excessive water usage may be seen as a preliminary step towards water conservation. On the basis of this awareness, consumers can be motivated to change their water consumption behavior patterns. Such modification of behavior must include equipping households with water-saving appliances. Certain relatively simple devices may reduce water usage in households significantly, e.g., shorter showers, the installation of water-saving shower heads, and the use of low-flow faucet aerators. Also optimization of water consumption practices, such as switching off taps when the water is not being used, is an important water-saving factor. Unfortunately, these cheap and simple solutions are not commonly used at present.

Pricing is another factor that has a significant influence on water consumption. Economic instruments can be used to promote the economically efficient usage of water. Independent of other measures, adaptive pricing can provide signals to induce behavioral changes or the application of more efficient water-saving techniques. The adjustment of water prices is an important consideration in determining water-saving possibilities.

Another untapped water-saving potential is the reduction of water leaks within the systems that are used to deliver water in urban areas. The first problem is to identify places where leaks occur. Different types must be used to estimate the location of leaks. Leaks can be reduced by the appropriate control of the water pressure within the pipeline system. Demand modelling and forecasting methods will be required to accomplish efficient control of water pressure.

Thorough recognition of the untapped potential for saving water is a key step that can lead to the substantial reduction of water consumption. This is just the first goal of the ISS-EWATUS project. The recognized potential will be addressed by developing an innovative, multi-factor system that is capable of optimizing water management and reducing water usage. ISS-EWATUS is an interdisciplinary effort of specialists from water management and ICT research, and the goal of the effort is to develop an intelligent, integrated support system for efficient water usage and effective resource management.

The reminder of this paper is organized as follows. In section 2, an overview is given of existing work related to the conservation of water and addressed by ISS-EWATUS. A general overview of the ISS-EWATUS methodology is presented in section 3. The planned validation and evaluations of project results are described in section 4. Section 5 concludes the paper by summarizing the expected outcomes of the ISS-EWATUS project and giving examples of the research challenges that must be undertaken.

2. An overview of existing work

There are several known methods for saving water at the household level. The first one is the detection of leakages through detailed pattern analyses of the signals generated by water meters [2]. The second method, which was mentioned in Introduction, is the application of water-saving appliances, and the third is related to the modification of consumers' behaviors. Such behavioral changes can be categorized as follows [3]:

- those that require no degree of personal sacrifice, e.g., turning the tap off when brushing teeth or washing dishes,
- those that require limited personal sacrifice, e.g., turning off the water while soaping up in the shower and reducing the amount of toilet flushing,
- those that require more significant personal sacrifice, including reducing the number of baths and showers.

Recently, the dishwashing habits in four European countries were analyzed to gather common habits in end-use of water in households [4]. Empirical data based on water consumption measurements in households and simultaneous webcam observation of the kitchen sink made it possible to assign the metered consumption data to specific uses of water, such as cleaning, drinking, or cooking. In this way, it was possible to estimate the extent to which particular tasks in the kitchen influence water consumption. Further research sought to determine an optimal way to clean dishes by hand [5]. A mathematical model of water consumption was presented by [6]. The results of [6] showed that males used more water than females, while single-female households used the lowest quantities of water. It also has been shown that the manner in which water is used and wasted while washing dishes is derived partly from cultural, behavioral, and geographical circumstances [7]. A model of domestic water use based on people's behaviors was proposed by [8]. A review of existing studies on the sustainable handling of resources at the household level was presented by [5].

Information generated by smart meters can be used to display instantaneous consumption to the occupants of a household. While this is undoubtedly a step in the right direction, the actual reductions in water demand provided by the current generation of smart water meters may be as little as 1% [9], and interim results from the current large-scale trials of smart meters have not yet shown any statistically significant reductions [10]. The poor impact can be explained because smart meters can address only certain aspects of water use in the home. Existing sociology and anthropology studies [11] have shown conclusively that people do not think in terms of water use; rather, they think in terms of specific practices and the values they associate with those practices. There have been many studies of water consumption over the last few decades, but intervention studies in the EU have been limited [12]. The focus of the past studies has been on the end use of water resources without any connection to water consumption related to domestic practices. Social science studies conducted in the Nordic countries have emphasized that people's domestic practices must be understood and taken into account in planning how to reduce water consumption [13,14]. The interface of householders with technology and information concerning water consumption is a key to the development of effective strategies and interventions that can be used to produce significant reductions in the demand for water resources. Regarding the potential for saving water at the urban level, a common procedure of the implementation of IT services in water companies includes the purchase of different software designed for the solution of single tasks. Systems based on numerical maps have been implemented in most water companies; in addition, hydraulic models of the network also are available in some of these companies. However, those tools are rarely interconnected to form one platform/system, so decisions made based on their individual solutions may be free of errors.

One tool that is commonly used is the supervisory control and data acquisition (SCADA) system. It is a tool that can allow the operator to visualize the technical and automatic aspects of the network by showing the subsystems and objects within the system. SCADA may be used for collecting and processing data, undertaking actions within the system, and sounding alarms. Thus, by using the SCADA system, the operator can conduct and control the operation of the entire water distribution network. In turn, mathematical modelling of water distribution systems may be crucial for planning, design, and operational maintenance. The majority of mathematical models in environmental sciences are deterministic, and a deterministic approach is usually used to describe the work of a water distribution system. One of the models, known as EPANET, is a software program that models the piping systems that distribute water [15]. EPANET performs simulations of water movement within pressurized pipe networks over extended periods. Pipe networks consist of pipes, nodes (junctions), pumps, valves, and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of the water in each tank, and the type of chemical concentration throughout the network during the simulation period. EPANET is a public domain software program that can be copied and distributed freely. The EPANET model has been used in many studies [16,17]. For instance, it was used along with demand-driven analysis and pressure-driven analysis in [18,19]. The aim was the optimization of the water distribution network resulting in the reduction of costs. It also is worth mentioning that the EPANET toolkit can be used in forecasting mode. However, it requires the establishment of initial and boundary conditions based on archival or forecasted data. So, those parameters may be fraught with high uncertainty and affect the quality of the forecast for water demand. To reduce bias or excessive errors, it is better to perform prognosis based on probabilistic methods.

One of the issues addressed by ISS-EWATUS is the forecasting of water demand in a given urban area. Such forecasting is important over longer periods of time for planning and designing systems, and, over shorter periods of time, to assist managers in balancing the needs of different consumers. Forecasting short-term water demand (e.g., hourly and daily timescales) is a key component in facilitating real-time control decisions. Many data-driven techniques have been developed for predicting future water demand using past observations of measured water demand, climatic variables, and economic factors. Methods used for predicting water demand include artificial neural networks (ANNs), autoregressive models, time-series models, and, more recently, genetic programming, random forests, and more advanced regressive techniques, including multivariate adaptive regression splines [20, 21]. In recent studies, ANN models have become prominent for forecasting water demand because they have been found to outperform regression and time-series models in some studies [22, 23].

3. Contributions of ISS-EWATUS

ISS-EWATUS is intended to focus on the potential for saving water in household and urban environments. At the household level, ISS-EWATUS proposes a low cost, mobile device-oriented set of tools to support households with water conservation. ISS-EWATUS will make users aware of their water consumption by providing near real-time access to their household water meters. On the basis of data gathered individually for every household, ISS-EWATUS will assess the existing potential for saving water and develop a decision support system that can provide advice regarding behaviors that would save water in households.

The constraints of making the above multi-factor system widely available are its cost to end-users and the likely benefit that an average user can expect. For this reason ISS-EWATUS will pay special attention to the economic aspects of its work. The planned household information system and decision support system will work at different levels of spatial and temporal data granularity. At the most general level, it will rely on only one water meter that gathers data for the entire household, while, at the more specific level, it will analyze data gathered from different places in the house (e.g., bathroom, kitchen, and others). Also the frequency of measurements and their accuracy influence the cost of data gathering. Research on finding a trade-off between the cost of the system and benefits coming from its use is planned.

There are three key aspects of the research on water conservation at the household level. The first is the technical issue of enabling the transmission of information concerning water consumption to and from the trial homes with sufficient detail to create a platform upon which the most appropriate intervention measures can be built. The second aspect is the investigation of domestic practices. The engineering analysis of water use in homes will be synchronized with a social sciences study of water use practices, mediated by human-technical interface expertise. The other aspect to be addressed is the development of a ‘low effort’ water reduction intervention approach with households, with subsequent implementation and demonstration of effectiveness in realistic trials. In addition, a new methodology for the design of successful intervention measures that can be used to reduce water consumption will be developed. To address these issues, the planned household DSS will contain the following elements:

Consumption model: A data-based model will describe water consumption. The application of different representation methods of time series and related decision processes will be considered. The model also will provide baseline measures for determining the differences in consumption behavior before and after intervention.

Practice model: The model will describe the meanings and values associated with water consumption articulated by the participants, and, going beyond this, it will identify the diverse meanings embedded in the sensory information. The practice and behavior study will present continuous observations, from establishing and understanding water related practice to identifying good and bad practices, exploring householders’ responses, and their reactions to DSS’s advice (intervention strategies).

Intervention strategies: A new behavioral intervention approach will be developed and used to create interventions that lead to behavioral changes. Combined information from the data model and the practice model will be used to produce an understanding of how to design interventions for reducing the demand for water in homes. The information system for households and the associated DSS will take into account the different granularity of the available data and, thus, the differentiated investment required for water meters.

The other work package of ISS-EWATUS will investigate social issues related to water conservation. The planned social-media platform will enable water stakeholders to share experiences. Different types of stakeholders will be selected, e.g., single users, families or groups, and “water experts.” Specific thresholds for ‘above average,’ ‘average,’ and ‘below average’ water use will be defined to mark excessive, average, and limited consumption, respectively. The social-media platform will be used for interaction among those different categories of water stakeholders in order to transmit feedback from those who were successful in reducing water consumption. In this way, the users in a certain category will increase their awareness of their water consumption, and they will help users in the same or other categories to manage their water consumption better. By pushing the hi-tech envelope in a user-friendly way, even consumers who are tech-resistant and don’t follow the trends will understand the impact of their actions on consumption and face the social challenge of supporting large-scale, behavioral change regarding water use by households.

Summary of the household level:

- An information system is planned to gather data about water usage to increase the awareness of water consumption. The interpreted data will be presented to those who consume water in households in an understandable way using mobile devices (smartphones, tablets).
- A household decision support system to reduce water consumption will be developed for use on mobile devices. Recommendations regarding water-saving devices and behaviors will be produced.
- A social media platform will be developed to reinforce the water-saving behavior of consumers by means of social interactions among people and also to link consumers and experts on water-saving techniques.

At the urban level, the main goal of ISS-EWATUS is to reduce water leaks within the water delivery system by maintaining the water pressure within appropriate bounds. Data collected from water distribution systems will be used to analyze consumption patterns to provide evidence of leaks and trigger alerts; the data will also be used to predict future water consumption based on historical consumption and other pertinent parameters. The urban DSS will help water companies identify leaks and suggest emergency actions, assess demands in the medium and the long term, and manage the demands through an optimal balance between supply and demand measures.

A new solution will be proposed, i.e., a system that can forecast water demand and predict water pressure in the pipeline. Fuzzy cognitive maps and/or Bayesian networks will be investigated when seeking a new method for the estimation of future water demand, and research will be conducted on the enhancement of those methods. The planned model will be used to predict future water consumption based on the residents' historical water consumption and other pertinent parameters.

The other work package of ISS-EWATUS will be devoted to the development of adaptive pricing policy. It will involve a detailed analysis of residential water consumption for the purpose of building a decision support system. The results of this work package will surpass the current state of the art in adaptive pricing in water management by the following key elements: a) the use of data to identify key influencers and to estimate essential marginal changes in water demand and usage, b) development of adaptive pricing models that relate the present to future developments in water levels, thereby ensuring sustainability, c) design of a DSS to support policymakers based on current water measurements. The adaptive pricing models result in high-dimensional models that are not analytically tractable. Therefore, different means are required to assess the impact of alternative pricing mechanisms. A simulation model will be developed to assess the pricing mechanisms.

Summary of the urban level:

- An innovative decision support system for reducing leaks in the water delivery system by dynamic modifications of pumping or tank filling/emptying schedules will be developed to reduce leakages at the urban level.
- An adaptive pricing policy will be developed as an economic instrument to induce water-saving behavior and reduce peaks in water and energy distribution loads.

4. Planned validation and evaluation

One of the goals of ISS-EWATUS is to develop a universal decision support system for every house and water delivery company in Europe; therefore it will be necessary to differentiate validation places appropriately.

4.1 Greek pilot on Skiathos Island

The first validation place will be Skiathos, Greece. The Skiathos Water Company uses a small network that has a length of about 30 km. It is an old network with extensive leakages. (About 30 to 40% of the water is lost as non-revenue water through leakage, with this being the biggest problem.) Water comes exclusively from groundwater and is considered "non-potable" due to its poor quality (high salinity due to groundwater over-withdrawal and saline water intrusion into the aquifer). Thus, the inhabitants of Skiathos rely on bottled water for drinking, and they use tap water for all other purposes. There is one tank in which water is stored and distributed to the city; the pressure and flow rate data are measured at the tank. Pressure readings also are taken at one other location in the city. The main problem within the water network is the regulation of the water pressure. Water is supplied to an area on the island of Skiathos (Kotroni) that is at an altitude of 45 m. In order to distribute water to this more higher-altitude area, it is necessary to increase the water pressure in the network, and this obviously results in increased leakage. Although it would be better to operate the entire network at a pressure of 3 to 4 bar in the network, it is operated at 6 bar in order to supply Kotroni with water, and this proves disastrous from the standpoint of wasting water due to leakages. ISS-EWATUS will include the specific case of Skiathos and address the following issues:

- reduction of non-drinkable water consumption at household level in houses,
- reduction of leaks taking into account the existing, simple water delivery system.

4.2 Polish pilot in Sosnowiec

The second validation place of ISS-EWATUS is located in Sosnowiec, Poland. Due to the lack of its own water, the city of Sosnowiec must rely on water purchased from other companies and water producers. Water is distributed through water transport pipes to the Sosnowiec distribution station. The length of the entire water distribution network is about 578 km. In order to monitor water pump stations and hydrophore stations, two solutions are used. First, technology based on GSM technology transfers information by SMS. Second, using GPRS, the technology can control the situation in the entire network in real-time mode. All water meters are connected to data recorders. All collected data will be analyzed and archived. Hence, the water distribution company conducts continuous monitoring of the water distribution network that has 28 water-meter chambers installed on the water pipes. At households, old water meters that measured water consumption have been replaced by new water meters that use radio transmission to send data records. ISS-EWATUS will take into account the specific case of Sosnowiec and propose to resolve the following problems efficiently:

- the need to reduce water consumption in the city,
- the need to reduce leaks, taking into account the complex water delivery system.

Table 1: Main outcomes of the ISS-EWATUS Project

	Main outcomes of the project
1	**Information system for households**, low-cost, run on mobile devices, making people aware of their water usage profile.
2	**Decision support system for households**, based on the information analysis delivered by 1, run on mobile devices.
3	**Social media-platform for the induction of water-saving behavior**. The platform will use information coming from 1, 2, 4, and 5.
4	**Decision support system for the reduction of leaks** within urban water distribution system.
5	**Decision support system for the evaluation of different water pricing schemes**. The software will provide policy makers with an effective tool to assess different scenarios under alternative pricing schemes.

5. Conclusions

The planned outcomes of the ISS-EWATUS project are summarized in Table 1. The exemplary research challenges considered by ISS-EWATUS are the following:

1. How to present the data on water consumption in the form of a spatio-temporal representation?

2. How to present data on water usage to make it easy to interpret the data and improve people's awareness of excessive water consumption?
3. How to detect excessive water usage, e.g., in time series gathered from households?
4. How to associate excessive water usage with people's particular behaviors and give appropriate advice concerning to water-saving activities?
5. How to reinforce water-saving behavior by mutual interaction between people, e.g., by personal persuasion, presentation of positive behaviors, and others?
6. How to decrease the prediction errors generated by currently available water demand prediction systems?

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