ISS-EWATUS an example of integrated system for efficient water management

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Abstract. The ISS-EWATUS: Integrated Support System for Efficient Water Usage and resources management is a project funded by the 7th Framework Programme and is realised by the international consortium. The members of the consortium are universities, research institutes, municipal water companies and SME from Poland, Netherlands, Great Britain, Spain and Greece. The project proposes several innovative ICT methods to achieve a multi-factor computer system capable of optimising water management and reducing water usage at the household and urban level. At household level, ISS-EWATUS proposes a low cost, mobile-device oriented set of tools supporting households in water conservation. At the urban level, the main goal of the ISS-EWATUS is to reduce water leaks within the water delivery system by adaptive-to-demand control over the pressure in the water delivery system. A social-media platform (SMP) (watersocial.org) is a part of the ISS-EWATUS. It is able to support the promotion of water efficiency in a holistic approach. The adaptive pricing system is a module for policy makers to assess the impact of pricing schemes.

1 Introduction

Integrated Support System for Efficient Water Usage and resources management (ISS-EWATUS) is a project implemented by an international consortium. Funded by the 7th Framework Programme, the project proposes several innovative ICT methods to achieve a multi-factor system capable of optimising water management and reducing water usage at the household and urban levels. In the paper the following modules of the ISS-EWATUS system are presented:

1. DSS at household level - a low cost, mobile-device oriented set of tools supporting households in water conservation.
2. DSS at urban level - the main goal of the ISS-EWATUS is to reduce water leaks within the water delivery system by adaptive-to-demand control over the pressure in the water delivery system.

3. The adaptive pricing system is a module for policy makers to assess the impact of pricing schemes. It allows stakeholders to assess the impact of pricing on water consumption and total revenues.

2 The Decision Support System (DSS) at household level

The Decision Support System (DSS) at household level is a data gathering and information system designed to promote efficient water usage among residential consumers. At the current pilot stage of the project, sensors have been attached to water appliances (such as kitchen taps and washing machines) in volunteer homes. The home Wi-Fi system sends data collected by these sensors to a remote server which records the water flow rate and water temperature associated with each appliance. A tablet computer has been deployed in each home. This tablet will provide access to a novel app which offers feedback on the household's water use; equally, other mobile devices or computers could be used. The app allows users to view their household's water consumption, broken down by appliance, across the past 24 hours or at a daily, weekly or monthly level. Users can set themselves a target for reducing their overall water consumption and the app will give them feedback on their progress towards this goal. A key component of the DSS is a News function which provides personalized information on saving water around the home. Bespoke tips are generated in response to the household's recent, as well as predicted, water consumption. The graphical format of the DSS display has been designed to appeal to children as well as adults. To complement the automated feedback, a water diary function is provided to encourage households to come together and identify the water consumption associated with individual household members. An additional function uses information on a user's showering and laundry habits, and household appliance efficiency, to highlight where a consumer's water use practices do not align with their level of environmental concern.

2.1 DSS Architecture

The DSS system consists of four parts: a wireless water consumption measuring system [Yang et. al., 2005]; a local DSS; a (remote back-end) DSS server and external applications (third-party add-on services such as social network functions). This architecture provides three water consumption feedback loops.

1. The local DSS uses real-time and short-term spatio-temporal water consumption data to present instant feedback.
2. The DSS server processes long-term spatio-temporal water consumption data as well as historic data from household water bills. A water consumption benchmark is constructed using spatio-temporal water consumption data.
3. External applications will harness social network and community power.

A content aggregator pattern is employed to simplify implementation and increase flexibility. The local DSS, DSS server and third-party applications are designated as content sources. The local DSS also performs an aggregator function by aggregating content from these sources and interacting with end users. A dedicated tablet is designated as the primary device for hosting the local DSS for pilot households. In addition, household members could access the local DSS via a PC, laptop or smart phone.

2.2 Tips Service

The Tips Service is a component of the DSS at household level providing the ability to generate water-related tips. These tips are predefined in the database and involve multiple behaviours of the users. The tips generation service consists of:

- additional tables for the DSS:
- a Java-based application serving the purpose of a scheduler and tips generator: and
- R-project scripts implementing sophisticated water-usage models.

As the name suggests, the Tips Service works as a service which, at specified periods of time, analyses the household's water usage users and provides tips. Tips are generated using a variety of forecasting algorithms, namely:

- SQL queries which analyse the water usage directly using the database;
- R-project scripts which compute the ARIMA models; and
- Java based Linear Regression.

The latter two of these algorithms produce a forecast for the next period of time. Using the forecast, the user is given tips regarding their expected behaviour. For example, if the Linear Regression model predicts that expected water usage will dramatically increase in the relevant period, the user is presented with a warning which forms the tip. The display language of the generated tips is dynamically chosen for each user. The end user is only presented with tips which are relevant to their situation (e.g., if someone uses too much water during a shower, they will be presented with shower-related tips).

2.3 WaterDiary

The WaterDiary prompts household members to identify their personal water usage in a fixed range of time (e.g., daily or weekly). The need to identify usage is signalled by an alarm. In the first WaterDiary screen the user provides data about each water usage. In the column "Behaviour" the diary user specifies the purpose that the water was used for (behaviours are placed in a dropdown list). In the column "Family member" (family members are placed in dropdown list) the diary user specifies who used the water.

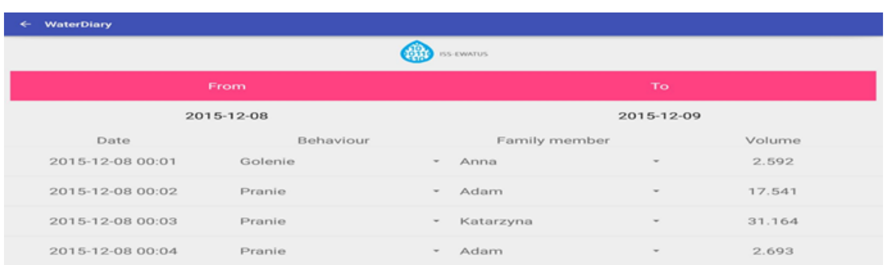

Figure 1: All Readings in the Chosen Period

3 Water Management DSS at Urban Level

Developing a water management DSS at urban level is an intricate, challenging task due to the high-level complexity of water network management, the open-ended set of functionalities involved and the conflicting interests between different competent authorities associated. For that reason, our primary goal was to design a successful system based in optimal planning, careful synthesizing of heterogeneous information of high spatial resolution and user friendly graphical user interface in order to assist decision makers in controlling water sources for areas under study.

The aforementioned DSS is a framework that integrates various water engineering and soft computing models, quality of data, a data gathering component via web services and a reporting component that can be applied in a number of urban water management contexts. Currently the DSS has been applied for two case studies (Sosnowiec, Poland and Skiathos Island, Greece) to: (a) Evaluate various water demand profiles and water reducing scenarios by regulating the water network pressure, (b) Infer the right water source that needs to be exploited according to the projected water demand, (c) Reduce the overall network leakage by diminishing the pressure during periods of low consumption and (d) Help competent authorities to manage water resources. The system is a web-based model-driven application that provides a monitoring, forecasting and advisory tool to simulate and control the efficacy of sustainable urban water management practices.

Due to the spatial peculiarities of the two case studies (i.e. small water networks) the networks studied have not been reticulated into a set of District Meter Areas (DMA). More specifically for the case of Sosnowiec we deal with a set of ~250 water meters and for the case of Skiathos ~3500 water meters many of which become inactive during the winter months due to the fact that most of them serve summer houses. Therefore, for both cases only one flow-controlled pressure reducing valve (PRV) was installed which is fed by a single water main [Girard, 2007]. The two areas introduce diverse characteristics in the overall water demand profile due to seasonality anomalies, socioeconomic residential statue and land morphology. For the city of Sosnowiec we have a small relatively flat area with no drastic pressure fluctuations occupied by residential divisions and small-scale business/factories. The water network is relatively new experiencing a very small leakage percentage of the total flow. On the other hand, the city of Skiathos presents a rather old water network with high leakage percentages which experiences a very high rise in consumption due to high increase in population during summer (from 6,000 to 80,000 for 3 months at least) thus faces serious water shortages, with aquifer salinization and deteriorating groundwater quality. Furthermore, the morphology of the island is such that, there are elevation fluctuations with differences reaching the 300 m. Despite the above difficulties, the system has been proven able to capture these variations and provide the user with a useful advisory tool. The DSS comprises of the following major components:

- Water meter consumption monitoring: All historical meter consumption-readings as well as new consumption data are stored in a spatiotemporal database. All meters can be monitored according to the readings (either monthly for Sosnowiec or trimonthly for Skiathos).
- Land zone management and monitoring: The water network can be divided into land zones according to the water company operations. All land zones can be monitored based on the aggregated water spent.

- Real time monitoring and management water pressure and flow: The system integrates all water network devices that capture the water pressure and flow real time (PRV's, Cello systems, PMAC administration program).
- Alarm system: Residents can initiate alarms related to the network functionality and failures. The administrator can respond online and change the state of the alarm after repairs occur.
- Web services: the system integrates several web services for the consolidation of meteorological, socioeconomic and touristic (arrivals to the city, change in population) data.
- Forecasting methodology repository: A set of various artificial intelligence techniques for water demand forecasting is integrated in the DSS for comparison and accurate predictions.
- Water disaggregation methodologies: used for subdividing the totality pf daily consumption into representative land zones as nodes to the pressure prediction model.
- Pressure prediction: integration of the EPANET hydraulic model to calculate the pressure-flow curve of the network.
- Inference module: the module follows a sophisticated via the use of genetic algorithms to select the most appropriate source of water exploitation according to demand predictions.

Figure 2 illustrates the logical architecture of the DSS which comprises three major parts: (a) the core DSS with all components described previously, (b) the subsystem that gathers and handles the morphology of heterogeneous data coming from various water network devices and intercommunicates with the spatiotemporal database and (c) the user interface either on the administrator or on the simple resident level.

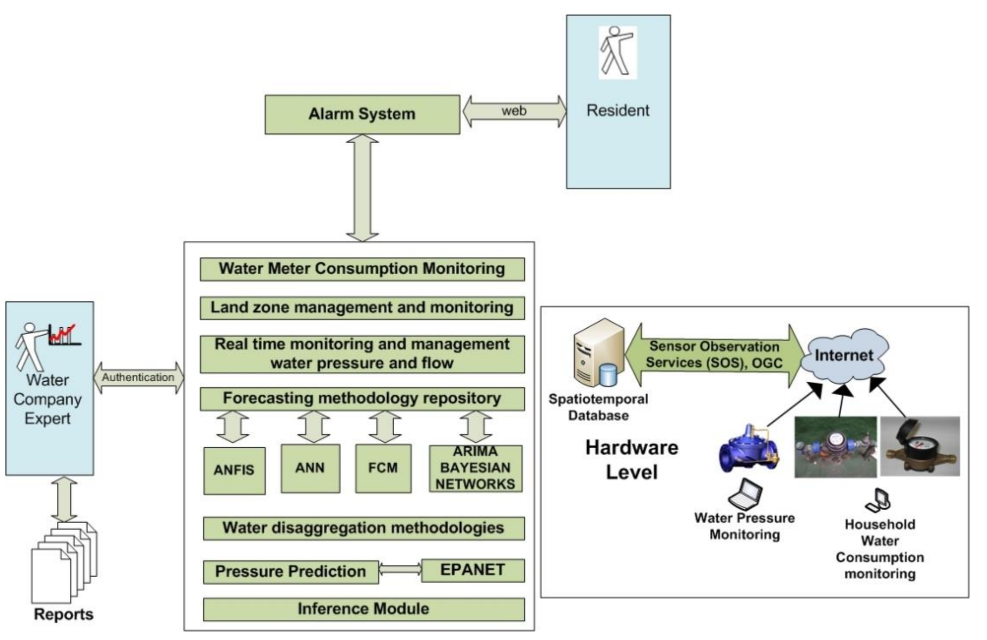

Figure 2: The logical architecture of the DSS

The DSS benefits from innovative soft computing forecasting techniques and the use of the EPANET hydraulic model to produce the spatiotemporal interdependency curve between water demand and water pressure at urban level. It gives the ability to experienced users to perform simulations on water demand practices for each case scenario in a variety of time scales and using various intelligent forecasting methodologies on historical data. Fuzzy Cognitive Maps, ANN and adaptive neuro-fuzzy inference systems were applied for multivariate analysis of seasonal demand affected by meteorological and socio-economic variables. For univariate analysis of weekend demand pattern availability, other time series forecasting methods, like ARIMA and Bayesian networks have been used. These methodologies come up with near optimal predictions of water demand. The results are used for providing input to a hydraulic model for the water distribution network based on the EPANET well known simulation tool in order to induce management practices to be applied to the water user categories within each service area according to selected parameters. The system is able to provide simulation results in thematic maps exactly on the GIS layers that are dynamically created and ultimately create heat maps of water demand for various seasonality-oriented parameters. Furthermore, it gives the ability to the water company expert user to construct alternative scenarios and to evaluate alternative strategies for forecasting water demand and predicting water pressure of the distribution network. By a set of Service Oriented Architecture (SOA) and Representational State Transfer (RESTful) oriented web services, the system provides the necessary interoperability between the participating modules. This methodology enables the water company expert to access and visualize all historical data and additionally, it offers a common language (XML, JSON) to represent all data before promoting them to the soft computing component [Kokkinos et al. 2016].

4 Adaptive pricing for water

Water has become the subject of an increasingly intense debate as it is forecasted that with the existing climate change scenario, almost half of the world's population will be living in areas of high water stress by 2030 [World Water Development Report, 2012]. This warrants research on decisions concerning the allocation of water resources, including regulations, information programs, the introduction of low consumption technologies, and pricing measures [Goldberg, 1998]. The ISS EWATUS adaptive pricing system focuses specifically on the pricing of domestic water consumption, since this is usually the most important use in an urban context [Herrington, 1999]. The pricing mechanism can be very important for guiding future policies, which require estimates of the way in which the demand for water changes with variations in price.

The adaptive pricing system is a module for policy makers to assess the impact of pricing schemes. It allows stakeholders to assess the impact of pricing on water consumption and total revenues. In doing so, it is important to evaluate the fairness of pricing schemes by identifying the households that are affected most as well. The module can be used to design pricing schemes that create incentives to reduce the water consumption while maintaining the revenues, or to increase revenues while maintaining the water consumption levels. The module identifies how difficult these objectives are to achieve and is able to generate optimal pricing schemes that satisfy predefined criteria.

We present results on a study aimed at assessing the impact of different pricing schemes on the residential water demand for the island of Skiathos (Greece). The number of parameters in the model consists of the number of brackets for different prices, the size of each brackets, the prices per each bracket, the fixed price, and the value of the demand price elasticity index. It is clear that the number of different hypothetical combinations is enormous. In this paper, we look at three variants of the pricing schemes: demand management oriented variants, income oriented variants, and a hypothetical switch to a single volumetric price.

In the demand management variant, the use of water tariffs is used as a tool to reduce the total water consumption. The aim was to reduce the total annual water demand by 20%, which seems to be substantial in the water balance. The module shows that a realistic increase of water tariffs has limited influence on the water demand. The associated consequences of reducing water consumption by 20% requires a serious increase of water tariffs that are not affordable due to political and social reasons (under both high and low price elasticity).

In the income management variant, the use of water tariffs is used as a tool to generate more revenues. These additional revenues can be used to improve the water infrastructure by reducing water leakages or by replacing components in the networks, leading to better services. The aim was to increase the revenues by 10%. The module shows that achieving such a target will lead to an increase in annual expenditure for water by 10% to 13%. A typical household will see an increase of approximately 3%, whereas the most sensitive household will face an increase of at least 16%.

In the last variant we replace the complex water tariff consisting of a fixed charge plus 8 different volumetric price brackets with a simple fixed charge plus a single volumetric price. When the equivalent price is calculated under this policy, it turns out that small households are affected more heavily than others. Such households can be protected by reducing the fixed charge and increasing the volumetric price. Moreover, it turns out that instead of having a single volumetric price a tariff with 2 brackets (low consumption versus high consumption households) protects the smaller households while also achieves the lowest increase in annual charges.

The adaptive pricing module is able to evaluate many other pricing strategies. It incorporates modeling techniques that offer a new perspective on water demand analysis and the dependency on pricing schemes. The module is thus an important tool for long-term strategic water management that is relevant for stakeholders that define water policies.

5 Social-media platform

A social-media platform (SMP) (watersocial.org) is a part of the ISS-EWATUS. It is able to support the promotion of water efficiency in a holistic approach. This includes its impact on local, national and international levels across Europe and its target audiences of water stakeholders at different levels of individuals, households, green NPOs, water managers, researchers and policy makers. The SMP aims to ease the communication and the creation of relationships between stakeholders and to produce a sustainable impact for the communities involved. Apart from supporting mainstream social networking activities such as sharing, communications, be friends, ask and answer, discussion. The SMP allows users to share water tips and photos under different environmental scenes and the share content can be pinned on a global map. Gamification enables the whole SMP to be used as a platform with gaming elements, which involve game task, competition and rewarding. The game tasks can be any user tasks on the social networks or any water use related offline activities such as recording down water use activities. Each of these user tasks can be rewarded upon its accomplishment.

6 Conclusions

A detailed description of the all functionalities of the ISS-EWATUS system is significantly beyond the scope of this paper. More information is available on the project website: http://issewatus.eu . The latest release of the SMP can be accessed on two platforms:

1. Web: www.watersocial.org
2. Mobile: https://play.google.com/store/apps/details?id=com.ega

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