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Water wise – a digital water solution for smart cities and water management entities

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Abstract

Efficient water management of the urban water cycle is one of the current concerns with the increase of (peri) urban areas due to the population growth, economic development, and possibility of water scarcity due to climate change. To face the increase of the water demand it is imperative the creation of digital water solutions to provide a real-time monitoring, decision support system, to manage the water supply network efficiently and optimize the water-energy nexus. This paper presents a Water Wise System – W2S, results from a R&D project supported by an EU and Portuguese Government Grant. The paper provides a preliminary study of an architecture solution to Water Wise System software, focuses on the water challenges, present technology, digital water, IoT and the future of smart cities. The solution aims to support a paradigm shift in the management of water distribution networks, with predictive and analytical convergence supported in Machine Learning, Deep Learning and an integration with SCADA, GIS and EPANET.

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Keywords: digital water; water utility; water distribution systems; climate change; smart city; SCADA; Deep Learning; Machine Learning; Big Data.

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1. Introduction

1.1. Context and challenges

Water stress is one of the major concerns worldwide, due to the high population density in cities, expanding urbanization, economic development and other factors, urban water supply is particularly vulnerable. United Nations estimated that by 2050, a decline in urban water availability in of at least 10%, due to climate change [1]. Climate change challenges conventional water infrastructure solutions and is therefore critical to sustainable development that need the adaptation and mitigation through efficient water management. In this context, it is possible to face some challenges in urban and peri-urban water supply [1-2]:

- Changing water consumption patterns;
- Establishing local predictions for changes in weather patterns;
- Setting and enabling service and acceptance levels;
- Developing emergency plans for extreme events;
- Optimizing the system for water demand.

There is a call for action to implement new strategies and technologies, creating future scenarios for the increase of water demand and water stress, which means, the emergency of ready-to-market digital water solutions. In Europe, the future-proof European model for a water-smart society entails a paradigm shift in the way our future society will be organized and managed regarding water [3]. A digital water solution is capable of providing a water solution for sustainable and climate-resilient development.

2. Water Distribution System and Digital Water

2.1. Water Distribution System

The urban water cycle integrates the engineer infrastructures to provide potable water to the consumers, as well as water collection, water treatment, and discharge residual water into the environment after use. A water supply system (WSS) integrate a section of the urban water cycle, it delivers water from sources to customers, involving various steps, namely water collection, water treatment, storage and distribution of water between water storage and water consumers (domestic, commercial and industry consumers). The focus on this paper is the water distribution system (WDS), Fig. 1 [4], that is the hydraulic infrastructure from the reservoir or storage tank to the consumers. WDS is composed of several elements, such as pipes, pumps, valves, reservoirs, storage tanks and various types of sensors like the flow meter or pressure meter. The operation of bringing water to consumers is complex, therefore, is necessary to consider parameters like water pressure, flow and water quality.

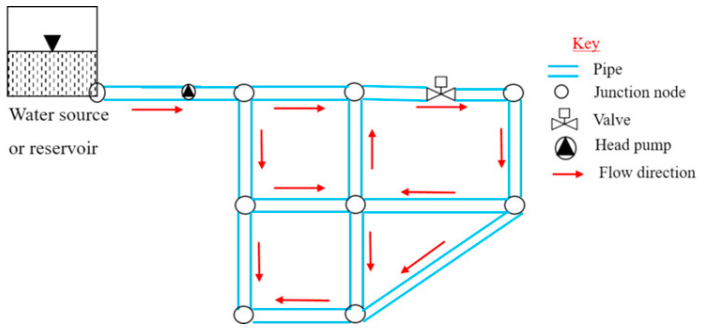


Fig. 1. Water Distribution Systems (WDS) [4].

Therefore, District Meter Area (DMA), Fig. 2 [5], is a discrete area of the WDS where it is possible to monitor water inflow and outflow and water pressure (DMA bulk meter), regarding to analyze the level of leakages and bursts. DMA's are created by water management entities for control water losses and abnormal demand. Smart meters or intelligent sensors applied in DMA for flow and pressure control have become more widely used to facilitate zone-based asset management [5-6].

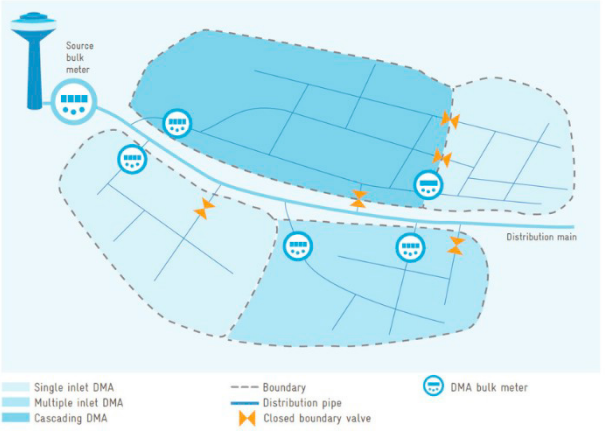


Fig. 2. Typical DMA layouts [5].

From a smart metering or intelligent sensor, results a data (such as flow and pressure), obtained from a DMA bulk meter in the form of a time series, which is, a data stream consisting of one or more variables whose value is a function of time (data series). Currently, the challenge focus on data-driven methods, based on prediction and understand the normal variability of a specific time series and then to use this in areas such as demand forecasting or abnormality detection [6]. In this paper, a solution of an architecture that supports Water Wise System is presented forward, and it is based on IoT, Big Data and Artificial Intelligence technologies.

Therefore, water losses are the current main concern worldwide, because are one of the main sources of inefficiency of water supply management entities. For this purpose, the International Water Association (IWA) water balance is a method applied worldwide for determining and analyzing water losses in water distribution systems. The global volume of Non-Revenue Water (NRW) has been estimated to be 346 million cubic meters per day or 126 billion cubic meters per year [7].

In Portugal, ERSAR - The Portuguese Water and Waste Services Regulation Authority, shows in their reports the indicator of Non-Revenue Water (NRW) in water distribution systems (simplified water distribution networks in population centers) was around 29.4%, while in the water treatment (simplified systems for capitation, treatment, transport to population centers and storage) was about 5.1% [8]. In this indicator, the values obtained for non-revenue water reach an enormous dispersion, varying between the 82,1% of Macedo de Cavaleiros, north of Portugal, up to 1.1% of Águas de Santo André, south of Portugal. Facing this reality, WDS in Portugal are still largely obsolete, where the application of digital technologies is not enough to satisfy the mentioned gaps.

2.2. Digital Water

Digital Water, Smart Water, Internet of Water or Water 4.0, there are countless terms being used to define the exciting transformation taking place in the water sector at the present time [9]. Water supply systems in Portugal are often equipped with some technological intelligence, such as the SCADA (Supervisory Control and Data Acquisition), some control stations and GIS systems. Although, the efficient management does not correspond to the resources available in most management entities, requiring time for extensive analysis of the vast amount of information (Big Data) existing in the water system [10]. More recently, two systems emerged and were accepted by companies:

Automatic Meter Reading (AMR) and Advanced Metering Infrastructure (AMI), widening the base concept for big client's telemetry and extending it to all end clients. A relevant detail that is transversal to all the artificial intelligence mechanisms described is the Internet of Things (IoT). It allows through sensors scattered throughout the water system, to capture huge amounts of data that will be taken into account by the algorithms.

Through the IoT paradigm, numerous data are collected throughout the WDS and then sent on a regular time basis (structured in a format called Time Serie [10-11]) to a central system that can be used for insights regarding the network, eventual problems and its management, turning it into a very useful approach to the water management entity. This large amount of data can be used to power an artificial intelligence-based support system and transforming it into a digital water system.

A ML model, Support Vector Machines (SVM), is also applied for problems in a urban context being used in water supply, energy and health, it's important for this paper to highlight the article "Livingston, S.J., et al., A hybrid approach to water, Artificial Intelligence, Machine Learning and Deep Learning used in smart cities with machine learning techniques. International Journal of Innovative Technology and Exploring Engineering, 2019. 8 (6): p. 488-493" [11].

Deep Learning, Fig. 3 [12], differs from other artificial intelligence mechanisms because it is capable of learning alone about data characteristics and classify them, consequently enriching decision making. It is precisely with this purpose that it is intended to verify the usefulness of DL in the water sector, creating the digital solution Water Wise System, that can be applied to a city under the paradigm of Smart Cities, explained further. For a DL algorithm to work effectively, a large volume of data requires has to be used and placed through a data modeling process to be categorized and capable of making decisions further by automatically interacting with the equipment on the WDS and ultimately, optimizing decision making [10].

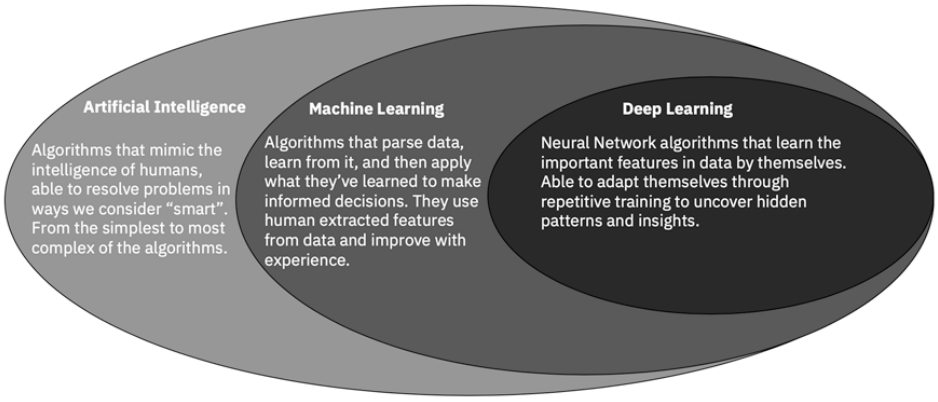


Fig. 3. Artificial Intelligence, Machine Learning and Deep Learning [12].

DL can contribute positively to hydraulic modelling simulations that consists in a computer mathematical model and logic-based representations of real WDS and it can be used with simulation programs, such as EPANET [13]. Nowadays, hydraulic modelling can be extremely helpful to make decisions and evaluate the condition of the water systems, for the present and the future scenarios of the water system.

3. Water Wise System

3.1. History and definition

The Water Wise System - W2S, results of a R&D project supported by an EU and Portuguese Government Grant. The solution aims to support a paradigm shift in the management of water distribution networks. In July 2018 and after being selected to the ten finalists of +50 innovative proposals the W2S was one of the three winning projects of

H2O Challenge, held in Ciudad del Saber in Panama and organized by IE Business School and the Foundation Ciudad del Saber with the sponsorship of SENACYT-National Secretariat of Science, Technology and Innovation, CONAGUA - Consejo Nacional del Agua, Panamanian government agencies and the World Bank Group Water Global Practice.

The W2S-Water Wise System focuses on the ability to monitor, control and manage in real-time water supply networks by creating operational intelligence, converging real-time analytical and predictive vectors over a geo-referenced view of all data from the network and external sources. W2S, as a situation management solution, is agnostic to equipment manufacturers and communication protocols. In this way the W2S provides an aggregate view of the whole ecosystem that constitutes the reality of a water network management entity.

Being a Digital Water solution, it enables a smart water network promotes cost reduction and increased operational efficiency by monitoring and remote control through sensors, devices, and automation. It is a value proposal focusing on the integral management of the water cycle, transforming data into knowledge, through the convergency of analytical and predictive models supported in Machine Learning and Deep Learning, for identification of anomalies in real time. It delivers a holistic view of the water network in order to respond and prevent service interruptions, losses and fraud, asset conditions and failures, communication problems, balancing supply and demand, pressure and flow management and water quality.

As it was focused on the previous point, the automatic data gathering and data characteristics of Water Wise System arises using a DL architecture, Fig. 4, which consists of several levels of data representation in a non-linear way. The output of one level will serve as input for the next level and each level can be trained individually in order to obtain a higher level of abstraction of the processed data.

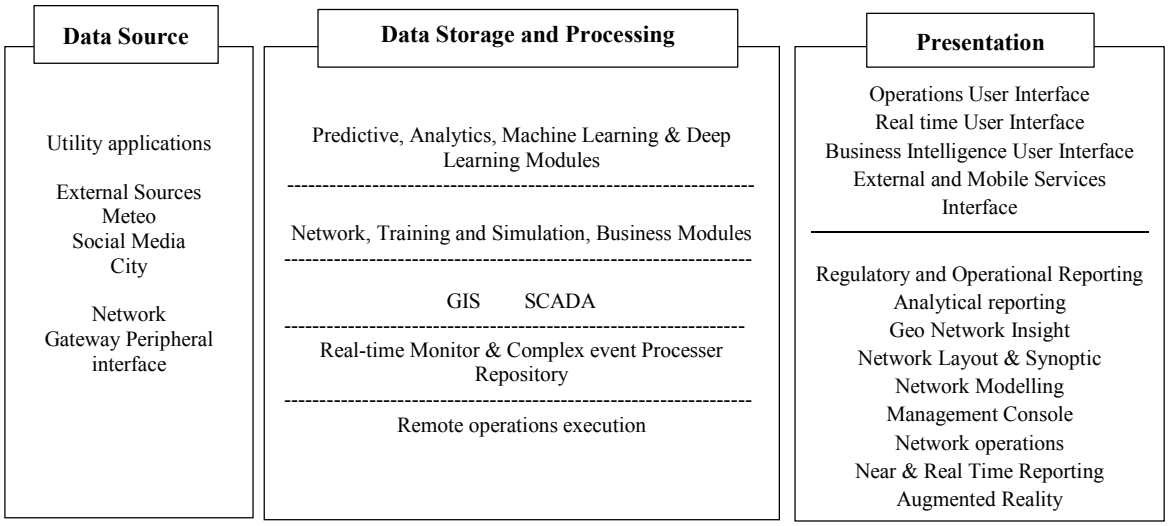


Fig. 4. Water Wise System logical architecture.

In the context of Water Wise System R&D process it was also possible to create a new hardware sensor to be incorporated in some critical points of the water network, namely an hydrogenator with an energy controlling system that can be applied in the current DMAs in order to give them a constant and safe energy independency thereby assuring the possibility of installing other energy or battery dependent sensors that till this point it would be costly or not feasibly in terms of energy supply. In this process the DMAs entry points can have greater number of remote

network maneuverable and analysis sensors, thus transforming the concept of DMAs into IOZ (Intelligent Operation Zones). In this context, some highlights of W2S:

- Integrated into a SCADA management system
- Front-end with a 360°real-time geo-analytical view on O&M;
- Promotes efficient and automated management through transforming data into knowledge;
- Transform DMA into Intelligent Operation Zones by increasing automation;
- Faster operational decisions with smart alarms and events;
- Comprehensive Digital Water Balance optimizing the water-energy nexus;
- Predictive and analytical convergence supported in Machine Learning / Deep Learning;
- Integration: SCADA, GIS, EPANET, Workforce management and ERP.

Therefore, as previously mentioned, Water Wise System requires smart technological equipment, such as intelligent sensors and/or smart meters, or in most cases, equipment with SCADA. In this matter, if the system isn't equipped with SCADA, the Water Wise System can address this issue by fulfilling the gap and addressing the SCADA functionalities.

3.2. Applications

Intelligent data analysis allows water entities to classify different types of consumers, water end users, businesses, or public fountains, it also helps to identify water consumption anomalies, which could mean a leak, or a problem in the water distribution system. Intelligent data analysis come from the smart meters, that transmits meter readings and information to the monitoring system, using a radio protocol specifically created. Consequently, the monitoring system receives the data series sent by the smart meters and sends them to a cloud platform. This platform processes the data-series received, to return useful near real-time information to the end users [6]. For this process, an architecture solution is presented, applied in Water Wise System, Fig. 5.

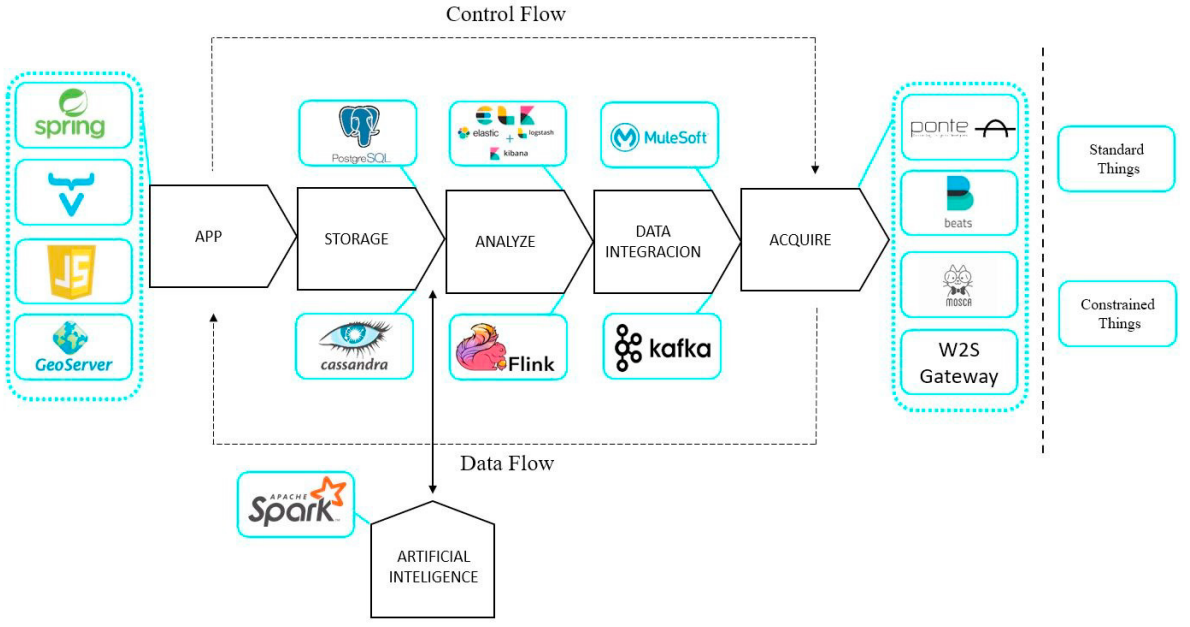


Fig. 5. Water Wise System architecture.

The architecture, Fig.5, has several layers starting from the acquirement of data going through the application that is used by the final user. The chosen technologies are Open Source and are used by the industry making them trustable for the water utility sector. In order to understand the architecture, a description for the layers:

- Acquire: the layer is the one responsible for collecting the water sensor (standard and constrained sensors) data and sending those data to the next layer. In order to send and receive data, the IoT used technologies are Eclipse Ponte (a multi-transport IoT/Machine to Machine broker), Beats (safe mechanism of file transfer), MOSCA (MQTT protocol broker) and custom gateways (created specifically for a water utility when the other technologies cannot be used).
- Data Integration: this level has the goal of integration using for that purpose the sensor's data and third-party related data like for instance weather systems. To process all this continuous amount of data, namely those send by the water sensors, a stream of data must be created. The Kafka technology stack was chosen for managing the streaming of data and the Mulesoft Enterprise Service Bus (community edition) to communicate with the external entities.
- Analyze: here, is crucial to analyze the data to detect events that are of main importance to help manage the water network. Using the Apache Flink, a complex event processing, detecting real time events and using the ELK (Elastic Logstash and Kibana) Stack have the possibility of searching the huge amount of data logging.
- Storage: this level has two database systems: PostgreSQL and Cassandra. The first one is used to support the application and the second one is a Big Data repository that stores all the received data.
- Artificial intelligence: using all the amount of data available and recorded at the storage level, several machine learning models are trained to give useful insights to improve the management of the water network. The Apache Spark stack was selected to support Machine Learning and Deep Learning.
- App: through the use of several front end and back end technologies, it's possible to build an application that displays information about water sensors and allows the end user the management of water assets. The user has the possibility of displaying the same data in several ways: synoptic view, geographical view and analytics view. For building this layer, is presented the following frameworks: Spring, Vaadin, Javascript (several) and GeoServer.

Finally, two workflows are also visible: the Data Flow and the Control Flow. The first flow is responsible to deliver the data to the application while passing through all the layers while the latter flow is responsible to deliver instructions to the water assets. The final layout of Water Wise (demo) on hands of the end-users is represented on Fig. 6.

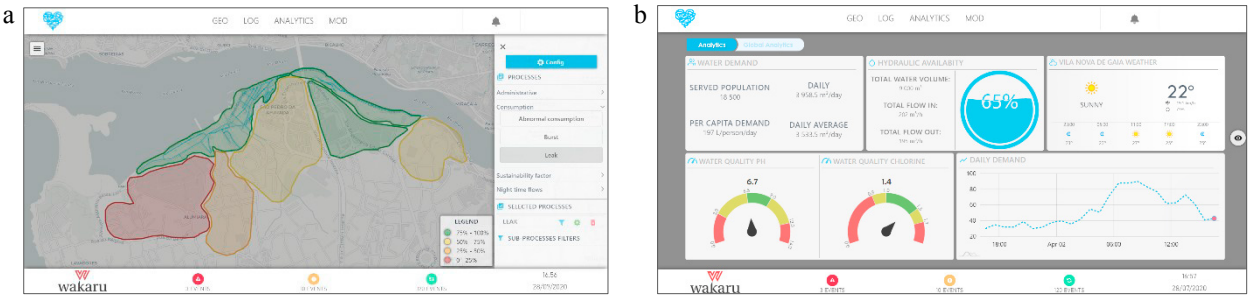


Fig. 6. (a) Water Wise System Geo view; (b) Water Wise Global Analytics View.

It has been proved in community science that smart solutions for water systems have a high potential to improve water efficiency and water quality control [6][14]. Related to currently results, the water wise systems sought to develop an architecture to management a water system that combines advanced digital metering technology with Machine Learning to provide water entities a solution to the challenges faced.

4. Conclusions

At this point, it's possible to understand the concept of Digital Water linked to Water Wise System and as a relevant theme of Artificial Intelligence, applied to the universe of the urban management and, consequently, to the paradigm of Smart Cities. The term Smart City has been increasingly used and to better understand this concept, is essential to understand the origin through two major factors: urbanization and the digital revolution, i.e. technological evolution [15].

This paper presents a Water Wise System, a digital water solution for control and monitoring in real time water distribution systems. Consequently, an architecture of the solution was represented as a preliminary study result. Further studies are essential and planned, to develop and validate the architecture presented, for Machine Learning optimization methods and evaluation procedures. Thereby, Water Wise System requires a water management entity to acquire a pilot project and test the solution *in situ*. Presently, Wakaru Consulting have a demo of the Water Wise System running in a cloud system using simulated water data.

Water Wise System is capable to integrate the universe of a Smart City, however, it has been verified in scientific community and throughout this paper, the water systems currently require more research and smart technological equipment to become more efficient. Additionally, some dogmas will have to be overcome in water management entities, because of the static management through decades. Therefore, believing in digital revolution it is crucial to continue looking forward, analyzing the W2S solution to adapt the concept and the architecture developed through this paper, for the present issues and the future problems to contribute for digitization of the water sector.

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