Utilizing IoT Technologies to Reuse Treated Wastewater for Irrigation: A Precision Agriculture Pilot Case

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Abstract

The AUGEIAS project is expected to reduce the usage of conventional irrigation water and fertilizers, promoting the sustainable use of treated wastewater, while properly incentivizing farmers through the incorporation of an intelligent dynamic pricing scheme for its use. As part of the project, a pilot installation of AUGEIAS was carried out in a chosen field for the verification and optimization of the functionality of the AUGEIAS system. During the pilot, IoT sensors were deployed in the field to evaluate its characteristics both with and without the use of treated wastewater from the exit of the Waste Water Treatment Plant (WWTP). This work presents the implementation plan for the pilot case of the AUGEIAS project. We will discuss the functional requirements that led to cultivation of the proposed crop, the irrigation plan and the required IoT equipment.

Keywords

Smart water management, treated wastewater re-use, precision agriculture, IoT, pilot case

1. Introduction

Water is a prerequisite for protecting public health and human well-being, while playing a critical role in agriculture, industry and energy production. Only 3% of total water on earth is considered as freshwater resources and approximately 30% is accessible as groundwater. Climate change in conjunction with increasing urbanization, associated pollution and rising demand for agricultural products will put even more strain to land, water, energy and other natural resources already stressed. Thus, an efficient and sustainable management of water resources is urgently necessitated. Sustainable water management can only be realized with rigorous evidence-based decision making. Information and communication technologies (ICT), such as Internet of Things (IoT) [1] combined with wireless sensor networks (WSN), low power wide area networks (LPWAN) [2], cloud computing, data analytics, artificial intelligence [3], have the potential to efficiently support decision making process, laying the foundations of a water smart society. At the same time, the viability of agro-livestock enterprises demands their shift from maximizing profit to reducing production costs and improving product quality. The integration of new information and communication technologies in the production process allows the monitoring and recording of critical parameters, their processing and exploitation to generate new knowledge and efficiently support decision making. This reduces total costs and reduces errors by making possible a rational management of the production cycle.

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To this end, smart management and re-use of up to now un-exploitable treated wastewater in agriculture is important both in economic and environmental terms. Motivated by the above, AUGEIAS develops an integrated intelligent ecosystem consisting of an innovative, easy-to-install and fully-parameterized low power wide area network, IoT end-devices, which will provide real time measurements from the wastewater treatment infrastructure and the agriculture sites, analyze and correlate collected data with reliable open data (e.g. meteorological data), exploit advanced machine learning techniques and predictive analytics in order to support informed decision making, optimizing the usage of treated wastewater in a safe and efficient manner for agricultural purposes. AUGEIAS is expected to reduce the usage of conventional irrigation water as well as of fertilizers, promoting sustainable use of treated wastewater, while properly incentivizing farmers through the incorporation of an intelligent dynamic pricing scheme for its use. Quality and quantity of crops is guaranteed by the proposed AUGEIAS intelligent water management engine that defines the appropriate mixing ratio of conventional water with treated wastewater, taking into account crop needs, soil status and imposed legislation limitations.

2. AUGEIAS Functional Requirements

Nowadays, the use of treated wastewater in agriculture for irrigation is a widespread technique. However, its usage has various risks associated with the composition of the treated wastewater and the possible presence of pathogens, microorganisms and pollutants. Therefore, the quality characteristics (microbiological, conventional and chemical) of the treated water must not exceed the safety limits set by Greek legislation [4]. AUGEIAS monitors specific quality characteristics of the treated water in real-time, while other are analyzed in a lab from samples taken at intervals specified by the relevant legislation [4] for restricted irrigation, ensuring that the values are within set limits. Furthermore, it is necessary to detect heavy metals contained in the treated water and the maximum safety limits [4] must not be exceeded. In addition, AUGEIAS collects data to optimize the irrigation using treated wastewater which are related to environmental / weather data, soil state, water safety and quality data as well as the current soil and crop status.

Table 1
Recommended Guidelines for microbiological and conventional parameters for agricultural wastewater reuse in Greece [4]

	E. coli (EC/100ml)	BOD5 (mg/l)	SS (mg/l)	Turbidity (NTU)	Minimum required treatment	Minimum Sampling Frequency
Restricted Irrigation	≤200 median	25 for 80% of samples	35 for 80% of samples	-	a) Secondary biological treatment b) Disinfection	BOD5, TSS, N, P: according to CMD 5673/400/97 EC: one/week. Cl_2: continuous (If chlorination is applied)

3. Pilot Description

The pilot program will be implemented in a field located in north-western Greece, near the city of Kozani and its WWTP, as shown in Figure 1.

The overall area of the field is about 0.35ha with the pilot area covering a total area of 0.128ha and the selected crop being sunflower. The experimental plot is divided in three areas that will receive different irrigation treatments. A first area of 0.045ha, will receive no irrigation, a second area of

0.061ha will be irrigated with treated wastewater and the third area of 0.022ha will be irrigated using conventional water from the town's supply system.

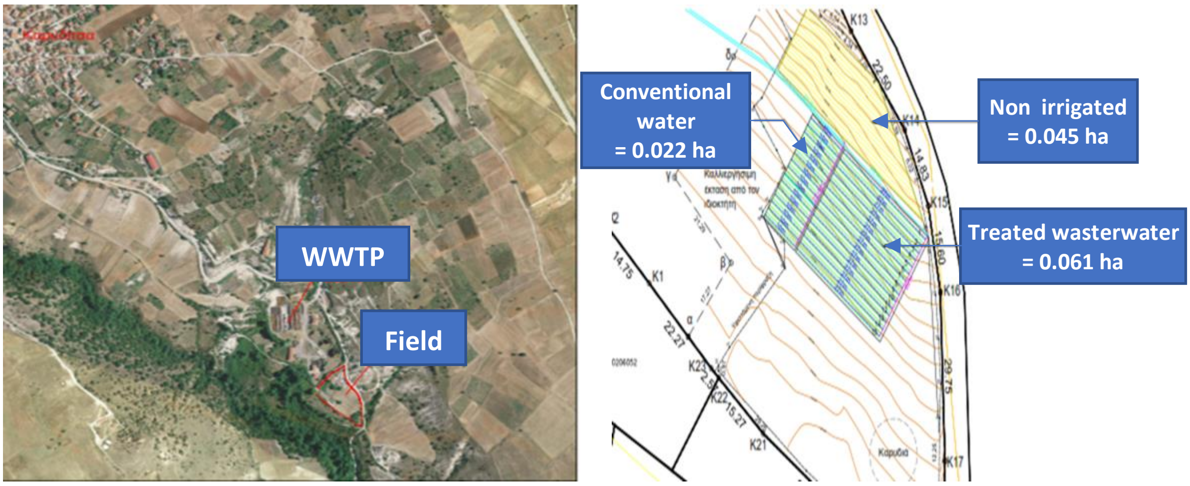

Figure1: The broader pilot area and a layout of the experimental sunflower field with the two treatments irrigated (water from WWTP and water from the town's supply system) and non-irrigated.

3.1. Field Characteristics

The terrain of the experimental field is sloping with a height difference of about 6% -10%. In the upper part of the field, there are higher surface slopes which are directed towards to the middle of the field, while in the lower part the slopes are reduced significantly, maintaining a uniform direction.

As far as the soil texture of the experimental field is concerned, two representative samples from the upper and the lower part of the field were taken analysed. The soil is characterized as a Loam Clay which is ideal for a sunflower crop. The concentration of the organic substance in the soil is quite significant but the salt concentration is significantly low. The soil pH is neutral to alkaline which is ideal for the cultivation of sunflower. The high levels of calcium (high calcium carbonate concentration) may create problems in the availability of certain trace elements while zinc and boron which are present in the soil at low levels could be added to the required amounts by foliar fertilization.

3.2. Sunflower Cultivation

Sunflower (*Helianthus annuus* L.) was selected among other energy crops, such as sorghum or corn, as the most economic and resistant crop which could be ideally adapted to the soil and climatic conditions of the experimental area.

The sunflower crop has a relatively short developmental period of 100-150 days from sowing to physiological maturation, depending on the hybrid, cultivation technique and usage (seed production or animal feed). The plants are resistant to drought, except during the flowering period. On average, it takes 6-10 days from sowing to germination, 30-40 days from germination to the appearance of the inflorescence, 20-30 days from the appearance of the inflorescence to the beginning of flowering, 7-12 days from the beginning to the end of flowering and finally another 30 days from the end of flowering to normal maturation [5].

3.3. Irrigation Plan

Two drop irrigation systems were designed to irrigate the sunflower crop. The first system will use treated wastewater coming from the exit of the WWTP while the second system will use conventional water from the town's supply system. When the water of the WWTP does not meet certain irrigation and quality standards then the two types of water will be mixed in a plastic tank in order to irrigate the sunflower crop.

Generally, the drop irrigation systems were designed based on the irrigation needs of the crop, the soil characteristics, the availability and the quality of the irrigation water. Based on this, the irrigation systems will consist of several application pipes (external diameter 20mm), a distribution pipe (external diameter 25mm) and a transmission pipe (external diameter 32mm) which will follow the soil slope. Each irrigation network will have a pump and all the hydraulic equipment required for the proper operation of the network.

According to the preliminary irrigation study, the irrigation of the sunflower crop will be repeated every 4 to 5 days with 21mm of water and for maximum time of 7 hr according to the needs of the crop. The total amount of the irrigated water is calculated at about 20m^3 starting just before sowing if it's necessary root moisture should be equal to the field capacity (FC).

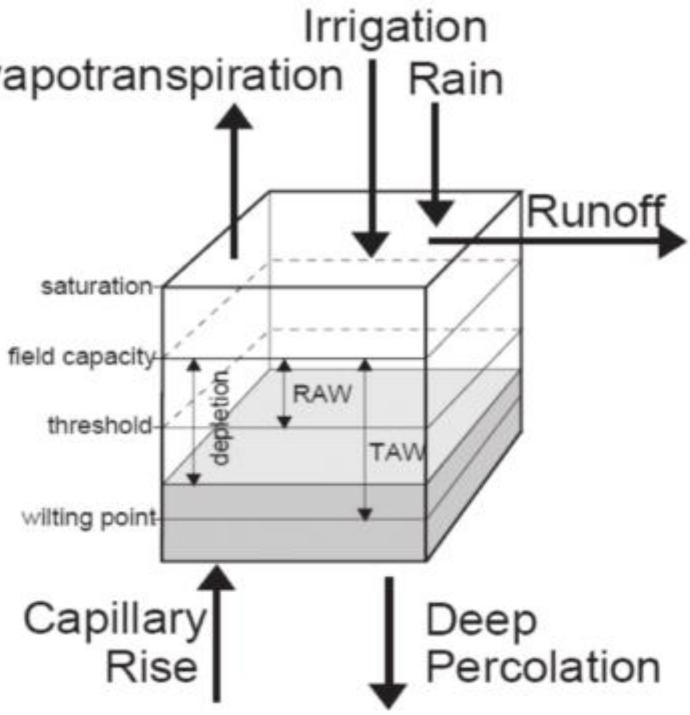

Figure 2: Water balance of the root zone [6] (RAW=readily available water, TAW=total available water)

It is obvious that soil moisture and the irrigation plan will be affected by rainfall during the irrigation season. The data coming from the meteorological station and the moisture sensors installed in the field will use the Equation (1) that describes the water balance of the root zone (Figure 2), affecting the irrigation schedule.

The daily water balance, expressed in terms of depletion at the end of the day is:

$$D_S = S_2 - S_1 = R + I + CP - Et - D - DP - RO \quad (1)$$

where D_S is the change in soil moisture, S_1 and S_2 are the soil moisture storage at previous and at next observation day, respectively, R is the rainfall, I is the irrigation, CP is the capillary rise, Et is the evapotranspiration, D is the drainage, DP is the deep percolation and RO is the runoff.

Rainfall, irrigation, and capillary rise of groundwater towards the root zone add water to the root zone and decrease the root zone depletion. Soil evaporation, crop transpiration and percolation losses remove water from the root zone and increase the depletion.

3.4. Required IoT Equipment

The project's functional requirements led to the final selection of the IoT equipment required for the pilot. Specifically, LoRaWAN sensors are installed both at the exit of the WWTP and in both parts of the field. Two external LoRaWAN gateways are used, within the coverage area of all end-devices. One gateway is powered by a solar panel, while the other one has a constant power supply. We use the first gateway to evaluate the performance of the novel energy efficient communication protocol that has been developed and the second one as a backup. A processed quality measuring station has been installed to measure the quality characteristics of the treated wastewater from the exit of the WWTP in real-time. Quality is monitored, for the existence of disease-bearing micro-organisms (pathogens) such as coliforms, biological oxygen demand (BOD), chemical oxygen demand (COD) and nitrates. Moreover, additional water characteristics such as temperature, pH, oxidation-reduction potential (ORP), conductivity, dissolved oxygen, turbidity, and total suspended solids (TSS) are measured. For pollutants, such as heavy metals and organic materials, that cannot be measured in real-time by the station's sensors, the WWTP personnel takes samples at regular interval, and analyzes them in a lab.

Concerning the irrigated part of the field with treated water of WWTP, a station is installed consisting of a meteorological station, a system for measuring soil parameters as well as an NDVI measuring system. Specifically, the meteorological station measures air temperature, gust windspeed, precipitation, relative humidity levels, solar radiation, wind direction and windspeed and soil parameters such as conductivity, humidity and temperature at three different depths (5, 15 and 25cm) respectively. An additional soil sensor has been installed in the part of the field that is irrigated with conventional water, to monitor soil volumetric water content (VWC), temperature and bulk electrical conductivity (EC_b).

Finally, in order to better serve the needs of the project, an additional agrometeorological station of the Telecommunication Networks and Advanced Services Laboratory (TELNAS) of the University of Western Macedonia (UOWM) is also installed in the non-irrigated area of the field. This station measures: air temperature, relative humidity, precipitation, windspeed, leaf moisture as well as soil salinity, humidity, and temperature at three different depths (5, 15 and 25cm) respectively.

4. AUGEIAS Ecosystem Evaluation and Next Steps

AUGEIAS ecosystem aims to improve sustainable water management and reduce the waste of water resources by using treated wastewater in agriculture. An immediate effect is the increase in profits for both the WWTP managing authorities and the farmers, as well as the quality and quantity of the production. Over-irrigation is also reduced by monitoring soil moisture and forecasting weather in order to optimize the irrigation plan. Additionally, the nutrients contained in the treated wastewater, can reduce the applications of fertilizers, that are typically used by farmers to improve the quality of crops. The treated wastewater relevant subsystems, such as monitoring of characteristics, risk assessment of the use of treated wastewater and possible mixing of treated wastewater with conventional water to optimize production, will also participate in the second phase of the project. A single integrated ecosystem will be implemented that will make real-time decisions regarding the irrigation needs of the field, as well as the mixing and pricing of the treated water from the exit of the WWTP.

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