Smart Water Management for Irrigation Purposes: The SWSOIP Pproject

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Abstract. It seems that the future scenarios for water resources management are characterized by increasing demand and by the short-term unsustainability of many reservoirs in the Mediterranean basin. To address these scenarios, improved management of water resources was needed for water economy, and water recycling policies. Furthermore, agriculture characterized as the largest water user worldwide and the monitoring of the agriculture via remote sensing techniques is an enormous subject where it used for special scientific applications such as irrigation, precision farming, yield prediction, estimation of evapotranspiration etc. The main objective of this paper is to present the current situation of water resources in the Mediterranean region and present the methodology and main objectives of the SWSOIP project which aims to develop a smart watering system for the irrigation process based on the estimation of evapotranspiration using both in-situ data (spectroradiometric, LAI, CH and meteorological) and Sentinel satellite data.

Keywords: water management; agriculture; remote sensing; smart watering system.

1 Introduction

It is indisputable that water is an invaluable element for the smooth running of our planet's life. It is the vital resource for ecosystems while at the same time, the basic needs of the human population are met by it, thus being the key to the development of fisheries, agriculture, energy production, industry, transport and tourism. While water characterized as a renewable resource, it cannot be considered inexhaustible. The seeming abundance of water has resulted in a man being considered a given good and being replaced by nature for free, leading to irrational use and pollution (*Fragkou and Kallis, 2010*).

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According to IPCC (2008), the term climate change refers to the difference in the state of the global climate, which is expressed by significant fluctuations in the average meteorological conditions that extend over decades or even more years. These changes, have a direct impact on water resources and the global hydrological cycle, exacerbating the water crisis caused by poor management with a high cost to people who do not already have access to clean water (*UNFCCC*, *1992*).

The impact of climate change is harmful to agriculture. The degradation of agricultural water resources as well as the loss of fertile soil, are events that require the adoption of strategies aimed at ensuring protect food security and rural vitality. These strategies, achieved by limiting the consumption of natural resources through the promotion of agro-environmental practices, alternative agricultural methods, crop diversification and water and soil conservation while limiting the use of natural resources fulfil (*FAO and Plan Bleu*, *2018*).

Agriculture existed several thousand years ago, and its development is mostly guided and influenced by the climatic differences of cultures and the existing technology in them. However, agriculture inextricably linked to the techniques for expanding and managing soils suitable for growing domesticated plant species. Furthermore, a significant link exists between agriculture and water also, where according to the Food and Agriculture Organization of the United Nations, agriculture characterized as the largest water user worldwide (*Dubois*, *2011*). Future estimations indicate that the world population will reach between 8.4 and 8.6 billion people by 2030 and 9.5 and 13.3 billion in 2100 (*Nations*, *2015*), thus before that happened, to fulfil the growing needs, global agriculture production will have to increase by 60 per cent from 2005/2007 levels (*Alexandratos and Bruinsma*, *2012*). However, the expected increase in agricultural production must be followed up by vital management of agrarian lands since it has adverse effects to the quality/quantity of water and soil resources, biodiversity, greenhouse gas emission or land degradation (*Gomiero et al.*, *2011*).

In agriculture processes, the optimal management of water in agrarian lands has always been of great importance, specifically to the most water-intensive ones. Crop health problems are more likely to relate to the lack of or overflowing in water irrigation. Thus, estimation of evapotranspiration (ET) tends to be a necessary process, to face water management problems and find a viable solution in croplands.

ET from agriculture lands, “plays” crucial role to the terrestrial hydrological cycle. Definition of ET is the loss of water from the ground, lake or vegetation regions to the atmosphere through the evaporation of liquid water. Therefore, evaporation and transpiration are the component key of ET in agroecosystems. It is momentous to keep a water balance between protecting the sustainability and productivity of the agroecosystems (*Irmak*, *2008*).

Monitoring water resources traditionally determined by collecting samples from the field campaigns, where the biological, physical, and chemical properties of water examined through laboratory analyses of these samples. Although these in-situ measurements provide high accuracy, they lag in spatial analysis and present difficulties of successive and integrated sampling. Also, traditional methods cannot determine spatio-temporal variations in water quality required for a comprehensive assessment and management of water resources. In other words, there cannot provide a simultaneous database corresponding to a regional or a broader scale (*Duan et al.*, *2013a*, *2013b*; *Gholizadeh et al.*, *2016*).

A significant problem nowadays since climate change began is water scarcity and drought. Water scarcity refers to the non-existence of water in a water supply system which may lead to limitations on consumptions which caused by drought and human activities such as overpopulation or unfair access to water (*El Kharraz et al.*, *2012*). Drought and scarcity have a massive impact on the environmental and socio-economic aspects of the Mediterranean countries. The Middle East is the area with the most severe water scarcity in the world while at the same time, critical water shortages located in the Eastern Mediterranean region (*Jägerskog*, *2003*; *Tropp and Jagerskog*, *2006*). Innovative water strategies required to encounter the environmental issues in the Mediterranean region (*Ferragina*, *2010*).

For the prevention and suppression of the problems mentioned above; near-real-time monitoring needed. Remote sensing is a vital tool to handle this situation, which is used since the 1970s and continues widely used up to date. Remote sensing techniques can effectively and efficiently monitor water resources and detect any problems from local to a global scale with high spatial-temporal analysis. (*Anding and Kauth*, *1970*; *Giardino et al.*, *2014*; *Hadjimitsis and Clayton*, *2009*; *Saad El-Din et al.*, *2013*).

Although the era of satellite remote sensing began in 1957 by the Russians with the launch of Sputnik-1, the first satellite explicitly designed for Earth observation was Vanguard-2, which replaced by TIROS meteorological satellite series in 1960 and continued with Landsat multispectral and thermal sensors since 1972 (*Tatem et al.*, *2008*). These sensors were the start for mapping, analyze and estimate ET across broad spatial and temporal scales. From that moment, a variety of satellites mission launched, and numerous scientific researches took place trying to estimate evapotranspiration accurately. Many different models conducted to measure ET. Specifically, there are temperature-based ET models and conductance-based ET models. The latter category has been discovered first, where *Penman* (*1948*) combined the effects of atmospheric drying power and available energy on evapotranspiration. Then Monteith modified the Penman equation by including stomatal resistance, surface control and replacing wind speed dependent coefficient, to make the equation more suitable for terrestrial surfaces, creating the Penman-Monteith ET model (*Monteith*, *1973*). On the other hand, the first temperature-based model conducted with the help of a thermal scanner mounted on an airplane (*Bartholic et al.*, *1972*).

A vast number of empirical methods have been deployed since Penman made a start and numerous scientists and specialists worldwide tried to estimate evapotranspiration from areas with a different climate. Some early studies used the Penman-Monteith model to derive ET from croplands via meteorological conditions (wind speed, radiation, temperature humidity) by scaling it using a crop coefficient (*Bausch*, *1993*; *Choudhury et al.*, *1994*; *Jackson et al.*, *1980*). In 1990, FAO organized a conference with experts and researchers where the Penman-Monteith combination method recommended as the new standard for reference evapotranspiration. Also, an update made in the procedures for calculation of the various parameters (*Allen et al.*, *1998*). In the sequel, this method became the basis on which a lot of alternative methods were developed (*Allen et al.*, *1998*; *Arain et al.*, *2002*; *Liu et al.*, *2003*) and comparisons made (*Luo et al.*, *2018*).

2 The SWSOIP Project

As mentioned above, water is a very important factor in agriculture. The savings of water in areas that are facing with water scarcity problems like Cyprus, requires the adoption of measures that will serve to conserve water. Agriculture characterized as the largest water user worldwide and the monitoring of the agriculture via remote sensing techniques is an enormous subject where it used for special scientific applications such as irrigation, precision farming, yield prediction, estimation of evapotranspiration etc. For these purposes, to protect the water resources, the SWSOIP project was used on a pilot basis. The SWSOIP project is based on remote sensing techniques and focuses on water management.

SWSOIP is used in this paper as the abbreviation of the: 'Smart Watering System for Optimizing Irrigation Process'. The main goal of the SWSOIP Project aims to provide 'new' irrigation data based on the indirect estimation of evapotranspiration using both satellite and meteorological inputs. This data can be used to inform the producers and the decision–makers for the water demand of their crops aiming to better and more rational management of irrigation water. The 'Smart Watering System' will automatically estimate the water demand for irrigation purposes and will release automatically the optimum water quantity for each crop-type through the 'Smart CropWATER Valve' without any human intervention.

SWSOIP platform (https://www.swsoip.com/) consists from the frontend and backend system. The SWSOIP frontend aims to communicate with the farmers in order to collect inputs related to the farmers and their crops such as farmers' id; crop type; cultivation date; plot area; etc. and provide outputs to the farmers related to the water needs of their crops. The SWSOIP backend aims to gather and process all the data such as satellite; meteorological and in-situ (spectroradiometric; LAI; CH) based on the inputs of the farmers. Then the backend system will be able to estimate the irrigation demand for each farmer and plot and will communicate this output both with the frontend system to inform the farmer and the WISENSE Platform which will transfer this information to the CropWATER Valve to provide automatically the estimated water quantity to the crops without any human intervention.

The proposed product is expected to contribute and have an effective impact on water saving and smart management of water resources since lack of water is one of the most serious problems that Cyprus has been facing for centuries and agriculture accounts for about 69% of the total water consumption.

3 Methodology

The proposed 'Smart Watering System' will consist of 3 Stages. The processing workflow shown in Fig. 1 is divided into 10 steps. The 3 Stages are defined as follows: (i) Input (Steps 1-3) (ii) Reading / Processing (Steps 4-7) and (iii) Output (Steps 8-10). The overall methodology consists of the following 10 steps:

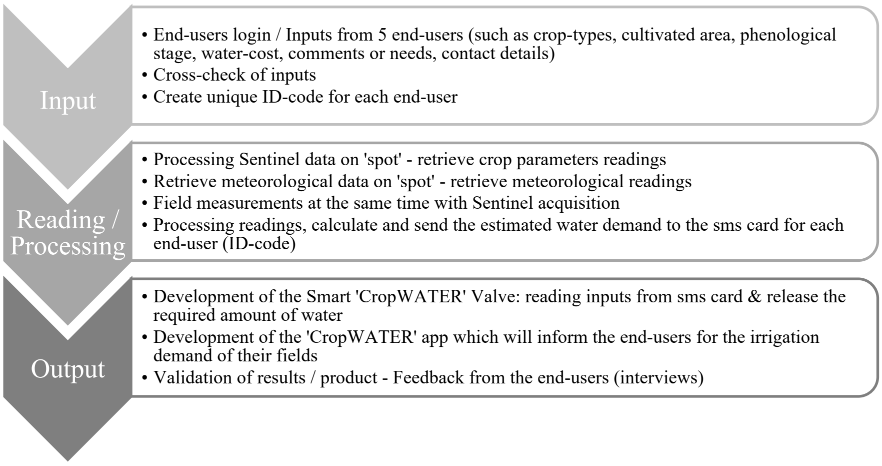

Fig. 1. Flow chart of the proposed methodology.

The methodology will be applied for selected crop types. The Penman-Monteith algorithm will be applied individually for each crop employing the necessary crop parameters using Sentinel data. The input parameters will differ according to the crop type for example leaf area index (LAI), crop height (CH), albedo (crop parameters) takes various values. Since Sentinel images will be acquired every week the development stages of the crops will be immediately identified. For the implementation of this study, selected farmers will collaborate with Agricultural Research Institute (ARI) and all the necessary parameters such as the crop-type, planting day, phenological stage and crop area will be given. The steps for the implementation of the SWSOIP is given in Fig. 2.

List of input parameters:

Monteith (Monteith and Unsworth, 1990), is a function of climate data such as temperature (T), humidity (RH%), solar radiation (Rs) and wind speed (U) and crop parameters, such as the surface albedo (a), the leaf area index (LAI) and the crop height (CH) which can be used to predict ETc:

$$ETc = f\,(\,a, LAI\,, CH, T, RH\%, Rs, U\,) \qquad (1)$$

Penman-Monteith adapted to satellite data algorithm:

Penman-Monteith method adapted to satellite data will be used to estimate ETc in mm/day. The specific equation needs both meteorological and remotely sensed data to be applied. The ETc is estimated using remote sensing after CH and LAI maps are created to specify these parameters spatially through Vegetation Indices. The algorithm provides at the end of the procedure, direct values of daily ETc through maps of evapotranspiration.

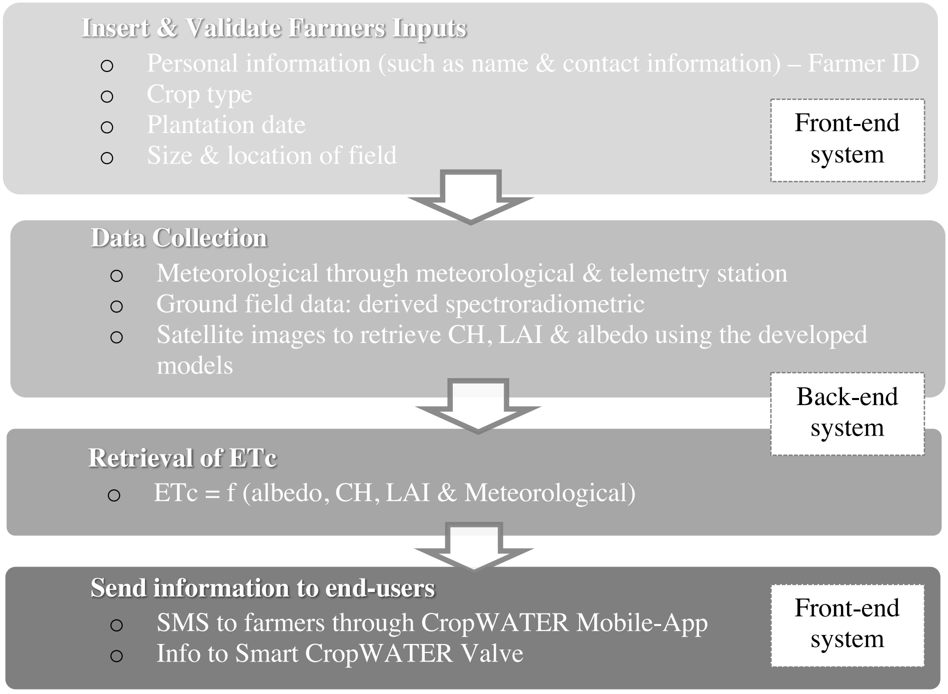

Fig. 2. Implementation plan of the methodology.

4 Current Status of the project

4.1 Contact frontiers farmers and start registered them to the SWSOIP Platform

Experimental fields were selected after the evaluation of farmers' questionnaire. Farmers growing potatoes, onions, alpha-alpha, ground nuts, black-eyed beans and beans in large plots (< 50m X 50m) where asked and agreed to add their field in to SWSOIP experimental plan. Farmer were trained to add their fields into the SWSOIP platform following the JOIN SWSOIP menu button which is available through the SWSOIP website (swsoip.com) (see Fig. 3). The link is provided both in Greek and English language. Farmers were asked to add their full name and email address, type of crop, date of planting and expected date of harvesting and finally to add a kmz or kml file indicating with a polygon the cultivated surface are of the crop. Farmers agreed to provide all necessary information regarding the crop cultivation, irrigation and nutrition stages. Furthermore, farmers agreed to provide access to SWSOIP researchers into their plots in order to collect ground data (Spectroradiometric / LAI /

CH) and install necessary equipment (smart irrigation system combined with a 2”electric valve connected with a 2”hydrometer and a controller).

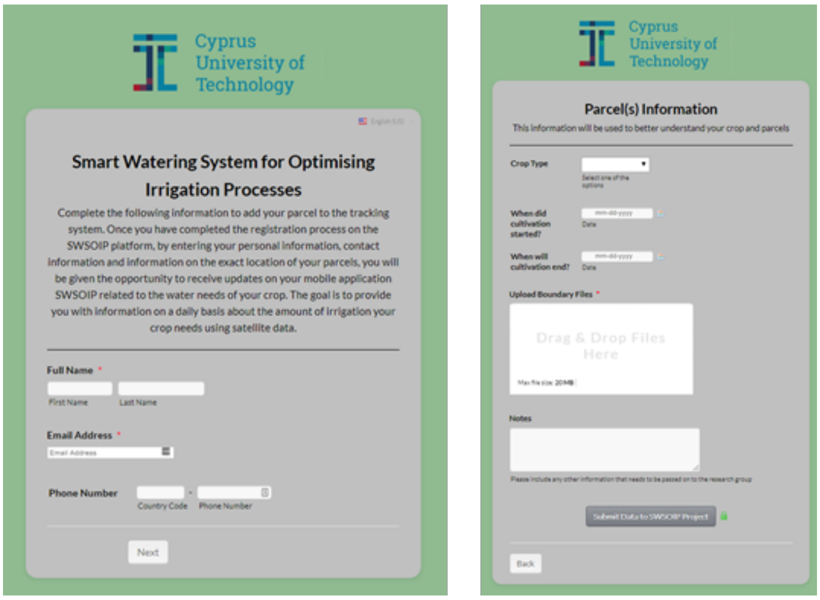

Fig. 3. Front End-User Registration form.

4.2 Collecting field data

During the SWSOIP project the following crops will be examined: potatoes, ground nuts, beans, alpha-alpha, onions and black-eyed beans. The selection of the crops was based on the input received by the frontiers farmers and are the crops more frequently cultivated by the farmers during the study period in the selected study area which is the Mandria village in Paphos, Cyprus. The crops phenological cycles was observed following the BBCH Monograph. The extended BBCH-scale is a system for a uniform coding of phenologically similar growth stages of all mono- and dicotyledonous plant species (Hack et al., 1992).

Data were collected in different plots within the study site area as also from fields in different cultivations areas in Cyprus. Observations began after the seeding date of each crop. The seeding time depends on the microclimate of each area. Field measurements including LAI, spectroradiomeric and CH data (Fig. 4) have been completed covering the phenological cycle for potatoes and onions; they are on-going for ground-nuts and they will start according to the plantation period for the rest of the crops. The spectral signatures of the potatoes, onions and ground nuts related to the BBCH are presented in Fig. 5.

Fig. 4. (a) Potato: LAI data collection below canopy and inter row; (b) Potato: Data collection using a GER1500 spectroradiometer in potatoes during BBCH19 (left) and BBCH 39 (right); (c) Potato BBCH 38: 80% of plants meet between rows, measuring plant diameter

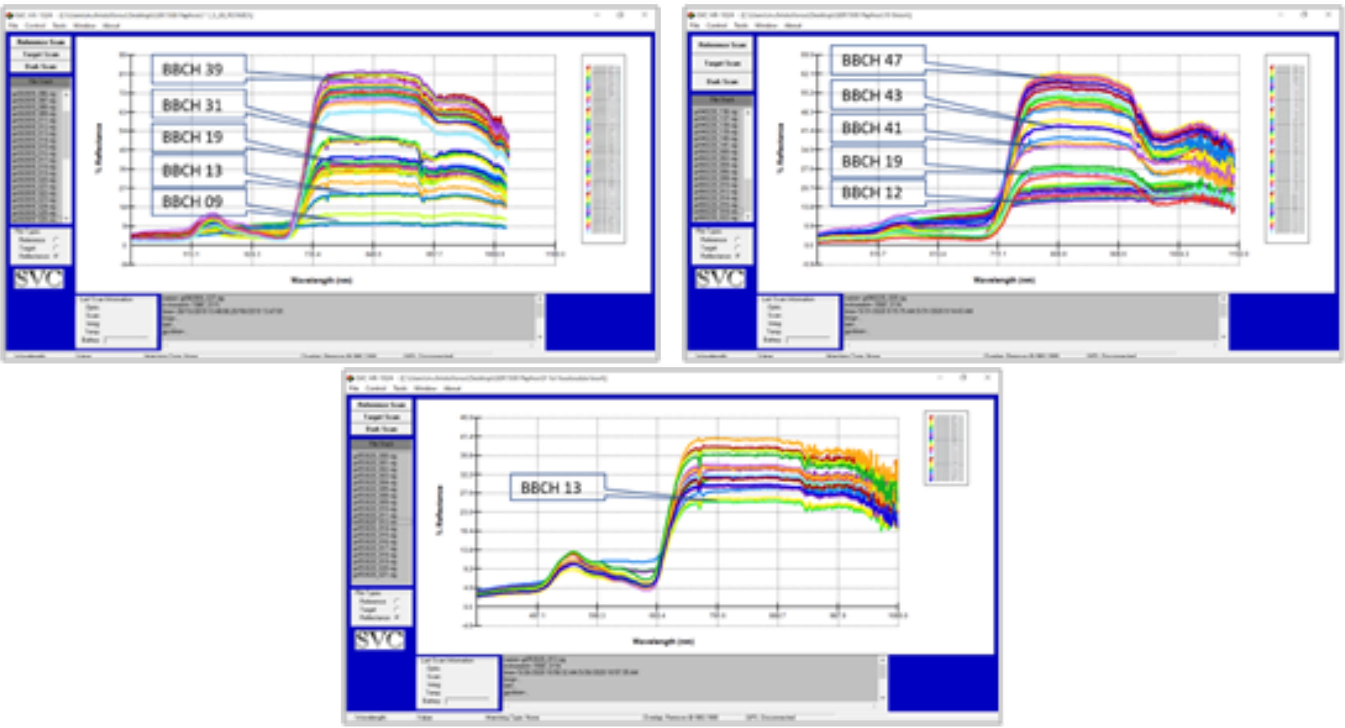

Fig. 5. Spectral signatures following the BBCH phenological cycle: (a) Potato; (b) Onions and (c) Ground nuts.

4.3 System Architecture

Following you can see a presentation of the SWSOIP software system architecture. In Fig. 6 the high-level overview of the system is presented.

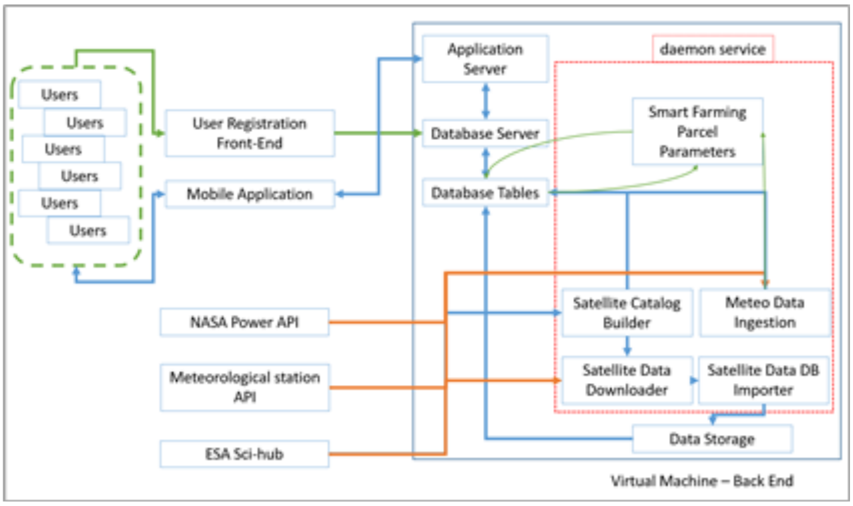

Fig. 6. SWSOIP software system architecture.

Up to now, the following sub-systems have already been developed:

i. The User Registration Front-End is the system that registers the farmers and their crops to the SWSOIP system. Due to lack of technological adoption by the farmers, it was found that the most practical way to register farmers together with their parcels (as geometries) requires a very simplified approach. For this reason, the form type registration was chosen instead of an interactive complex webGIS tool.

ii. Currently a total of 21 farmers have been registered and imported to the SWSOIP system through the above described front-end.

iii. The Mobile Application has been designed and is now on the implementation phase and the 'beta-release of CropWATER Mobile-app. Based on the user responses, a simple parcel oriented mobile app is needed. The mobile app screens are the following: Login Screen; User information overview; Parcel(s) information overview; Current Parcels status; Past parcels status and Notification page

iv. The components of the Virtual Machine – Back End System such as the Application Server; the Database Server and Storage and the Daemon Service and scripts are currently under design and development phase.

5 Conclusions

The main goal of the SWSOIP Project aims to provide 'new' irrigation data based on the indirect estimation of evapotranspiration using both satellite and meteorological inputs. The ultimate goal is the development of a Smart Irrigation System for EFFICIENT and EFFECTIVE Water Resources Management. The 'Smart Watering System' will automatically estimate the water demand for irrigation purposes and will automatically release the optimum water quantity for each crop-type without any human intervention through the 'Smart CropWATER Valve'. The proposed product is expected to contribute and have an effective impact on water saving and smart management of water resources since lack of water is one of the most serious problems that Cyprus has been facing for centuries and agriculture accounts for about 69% of the total water consumption.

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