Opportunities and requirements for implementing an irrigation monitoring and management platform in Costa Rica

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Abstract

Concerns about deficient climate resilience of current irrigated agricultural production imply that the efficiency and effectiveness of irrigation systems should be increased. This short paper reports on the development of a web app for reporting failures of an irrigation system as well as web processing services for soil-crop water balance computations in Costa Rica. The effort provided a means for assessing GI educational and infrastructural requirements in Costa Rica. SENARA —the national service for groundwater, irrigation and drainage— aims to incorporate geo-spatial functionalities in a strategically important integrated water resource management system. Technical advancements and available free software solutions greatly facilitated the development of a prototype web app for an irrigation project "Llano Grande" that serves 121 farms. The used system design readily supports upscaling to other projects on a national scale. However, operationalization of an irrigation monitoring and management platform that includes the soil-crop water balance will require substantial progress concerning access to spatial data layers and meteorological data, the quality of spatial data layers and the technical and organizational geo-infrastructure. Furthermore, universities should accommodate programmes for training spatial data scientists and geo-informaticians that are needed to innovate and maintain such infrastructure.
Keywords: water resources management, web GIS, spatial data infrastructure, academic curriculum development.

1 Introduction

The Costa Rican national service for groundwater, irrigation and drainage (SENARA) works along four major lines of action: irrigation, drainage, flood prevention and groundwater research and conservation. It aims to optimally utilize and manage water resources for supporting national production and for developing and improving the quality of life of the country's inhabitants (Herrera-Cairol 2002). SENARA uses Geographical Information Systems (GIS) for presenting its projects but currently GIS is not being used for system design nor for the daily management of irrigation systems.

Several studies have demonstrated potential benefits of using Information and Communication Technologies (ICT)—including GIS—for water management purposes. For example, in a large irrigation district in Spain, Soto-Garcia et al. (2013) found that a GIS-supported decision support system reduced water and energy consumption while it increased the transparency of water distribution and consequently avoided conflicts amongst farmers. On the other hand, they experienced an increase in the staffing and maintenance costs, mainly owing to the complexity of the technical infrastructure and the associated need to have more qualified personnel. Ojeda-Bustamante et al. (2007) described a real-time irrigation forecast system named "Spriter-GIS" that had been adopted successfully by several Mexican Water User Associations. They found the system to be a suitable tool for irrigation scheduling, planning and forecasting irrigation demands. Such system was particularly needed to cope with recent severe water shortages faced by Mexican irrigation districts in arid and semiarid regions of the country.

Also Costa Rica has perceived intensifying droughts over the past two decades (Carvajal-Montoya 2014). Such observations are consistent with significant drying trends in the Caribbean Central-American region observed in both satellite data and a multi-model ensemble of global warming simulations (Neelin et al. 2006). In view of expected recurring and intensifying water shortages, SENARA aspires to modernize its irrigation monitoring and management practices using geospatially-enabled technology.

This paper reports on a case study concerning an irrigation project "Llano Grande" that was conducted (1) to demonstrate the potentials of using geo-spatial technology for irrigation purposes in Costa Rica, and (2) to assess the requirements of developing and maintaining such technology in terms of infrastructure, academic education and human resources. The research was conducted during a three-months sabbatical leave of the first author spent at the University of Costa Rica in cooperation with SENARA.

2 Methods

The recent Llano Grande irrigation project serves over 121 farms; it is located north of the city of Cartago and comprises one of the lowest rainfall areas in Costa Rica (Waylen et al. 1996). At the time of the research, the project had not yet been delivered to the water users association.

Our case study involved two prototype applications: (1) web app and geo-spatial services supporting community assisted monitoring of leaks and persistent discharges of pressure relief valves; (2) geo-spatial services for evaluating water deficits and their effect on crop growth. There are existing solutions providing such functionality (). However, while using these would allow demonstrating the potentials of geo-spatial technology, it would hamper assessment of the infrastructural, educational and human resources requirements supporting technical innovation on the long run.

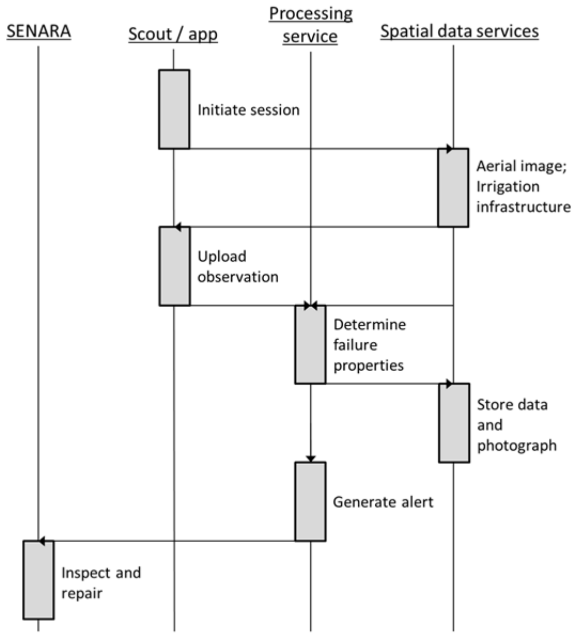
2.1 Community assisted reporting system

The prototype for community assisted monitoring consists of a web app running on a smart phone supplemented by services for geo-spatial analysis and for feeding the app with spatial data. Figure 1 is a sequence diagram of the system. A registered scout observing a failure of the irrigation system initiates a session on a smart phone. The web app shows an aerial image with an overlay of the irrigation infrastructure centred around the current location. The scout drags an icon representing a valve or a broken pipe to the location of the incident to indicate either a pressure relief discharge or a leakage. Optionally, the scout makes a photograph of the situation and types a note. After pressing a button, the observation is uploaded to the server. On the server, a spatial buffer is applied to the observation point and the resultant disk is overlain with layers representing the irrigation network, which were provided by SENARA. Water users affected by the failure are identified by a search over the topological network. Finally, an alert is issued to SENARA and the water users association indicating the name of the observer, the type and characteristics of the failure (including the optional photograph) and the names of affected users.

The system requires accurate data on the irrigation infrastructure. To allow tracing the users affected by system failure, existing CAD data of the infrastructural design were converted into a topologically correct network. This process involved both automated steps (using neighbourhoods) and meticulous manual editing of remaining topological errors.

The web app was implemented using html5, Java script and the Google maps API (https://developers.google.com/maps/), while the server side was programmed in Python 2.7 using the osgeo (https://trac.osgeo.org/gdal) library. The used set-up can easily be extended to cover multiple irrigation projects simultaneously. Owing to technical and organizational issues delaying hosting at the University of Costa Rica, the system was hosted on a server in The Netherlands.

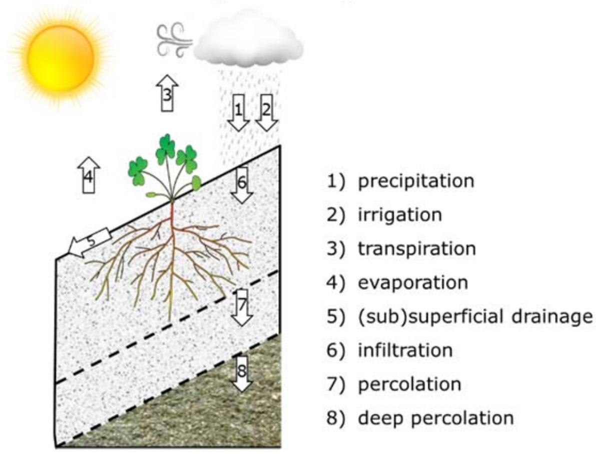
Figure 1: Sequence diagram showing actors, workflow and dataflow involved in community assisted monitoring.



2.2 Soil-crop water balance

We implemented a conceptual soil-crop water balance as schematized in Figure 2. The model was extracted from the WOFOST crop growth model (van Diepen et al. 1989) and it is similar to FAO's AquaCrop (Steduto et al. 2009) of which very recently an open source version has been published (Foster et al. 2017). Groundwater is assumed to be beyond the depth supporting capillary rise to the root zone and hence it does not contribute to water availability for the crop. In agreement with this assumption of free drainage, we disregarded water accumulation in local depressions in the terrain; any deep percolating water and (sub)superficial drainage is assumed to leave the system.

Figure 2: Conceptual soil-crop water balance.



Evapotranspiration is calculated by the Penman-Monteith equation using data on minimum and maximum temperature, wind speed, relative humidity and solar radiation along with a crop coefficient. Weather data were assumed to be provided from either of the three nearby meteorological stations. Soil water retention, drainage and percolation are to be assessed based on hydraulic properties of the soil or if absent they can be predicted based on soil texture. The soil parameters can be calibrated using field observations of soil moisture and meteorological variables.

As a result of partial stomatal closure, limited water availability reduces crop transpiration and thus photo-synthesis. In our model a linear response is assumed, see Equation 1:

$$R_a = R_p \times \frac{T_a}{T_p}, \quad (1)$$

where R_a [kg ha^{-1} d^{-1}] refers to the actual assimilation rate, R_p is the potential assimilation rate, while T_a and T_p are the actual and the potential crop transpiration [mm d^{-1}], respectively. The latter (T_a and T_p) are calculated by methods detailed in http://supit.net/. Our scripts are based on an version of the WOFOST methods in Python by Allard de Wit, which is available at https://github.com/ajwdewit/pcse.

3 Results and discussion

3.1 Community assisted reporting system

Figure 3 shows a screen shot of the prototype web app for community assisted monitoring and table 1 summarizes the data used for its implementation. SENARA expressed sincere interest in the prototype and is keen on seeing such system implemented for all its projects.

Figure 3: Screenshot of the prototype web app for community assisted monitoring of irrigation system failures.

Table 1: Data used for the prototype web app.

Data layer	Provider
Irrigation infrastructure	SENARA
Aerial image	Google
Names water users	SENARA, water user association

The provided irrigation network data of the Llano Grande project (CAD data) initially contained several missing nodes, spatial gaps, multi-geometries and other geometry errors which required careful manual editing before a topologically correct (c.f. Ramírez-Núñez and Mora-Vargas, 2015) network graph of the system could be constructed. It is to be expected that similar geometry editing will be needed if the system is to be implemented for other existing irrigation projects. For future projects, such errors are to be avoided by accounting for future data needs during the design phase. The needed know-how on data preparation, quality control, documentation and spatial analysis require further development of geo-spatial data expertise in Costa Rica.

Owing to time constraints, unclear application procedures, partial expertise dispersed over several organizational units and technical issues (e.g. lacking SSL support and problems with the installation of software) it turned out to be infeasible to implement the services on a local server in due time. Fortunately, a server at Wageningen University & Research in The Netherlands could be used. Ambitions to strengthen geo-spatial competences at the University of Costa Rica require substantial enhancement of the technical and organizational geo-ICT infrastructure.

3.2 Soil-crop water balance

Scripts implementing the soil-crop water balance were implemented in Python with an interface to MySQL to demonstrate database connectivity as well as a method for storing snapshots of the system.

Unfortunately, we were unable to connect to a live stream of near real-time weather data because no such service is currently provided by the National Meteorological Institute (IMN) nor by the Costa Rican Electricity Institute (ICE) that also collects weather data in the study area. Even for SENARA, which is a public entity, access to data from IMN and ICE (also public entities) requires lengthy administrative procedures that could not be arranged in due time. Note that elsewhere such boundaries are being removed by providing open access to hydro-meteorological data (e.g. http://tahmo.org/about-tahmo/).

Notwithstanding their utility for irrigation scheduling (Ojeda-Bustamante et al. 2007, Soto-Garcia et al. 2013), crop data including per-crop acreage and seeding and harvesting dates and the irrigation timing and amounts are not routinely being collected in the study area. By consequence, we could not give an operational demonstration of the soil-crop water balance.

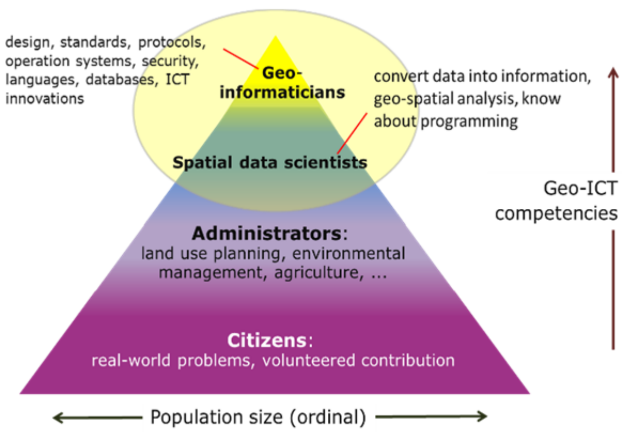
Continued efforts to organize data access are foreseen to take place within thesis research at the University of Costa Rica in cooperation with public institutes. This research could also consider using the recently published open source version of AquaCrop (Foster et al. 2017).

Despite the existence of a national spatial data infrastructure (http://www.snitcr.go.cr/), access to many spatial data sources in Costa Rica is still hindered by institutional boundaries and bureaucracy. These barriers need to be eliminated to give a boost to the use of geospatially-enabled technology with applications in water resource management as well as other domains.

4 Conclusions

(1) With today's technology, free software and existing solutions, it is relatively easy to create a prototype demonstrating the potential of geospatially-enabled technology for irrigation management.
(2) The prototype community assisted reporting system for the Llano Grande irrigation system has potential to be scaled-up for use at national level.
(3) In Costa Rica, the use of meteorological data and other (spatial) data collected by public institutions is obstructed by institutional boundaries and bureaucracy.
(4) Innovation and maintenance of geo-spatial services in Costa Rica require development of both organizational and technical infrastructures, easy access to properly documented data as well as training and education in the Geo-ICT domain.
(5) The University of Costa Rica can contribute to the above through academic education and by carrying out applied research projects in cooperation with institutes such as SENARA. Education programmes are proposed to focus on the upper part of the geo-ICT pyramid shown in Figure 4, since there appears to be a shortage of the corresponding competencies in the country, while the base of the pyramid is well-developed.

Figure 4: Geo-ICT competencies pyramid. The highlighted ellipse indicates proposed priority competencies for Costa Rica.



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