BIOSYSTEMS ENGINEERING 97 (2007) 283–293

ELSEVIER

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Biosystems Engineering

Research Paper: SW—Soil and Water

Linear regressions and neural approaches to water demand forecasting in irrigation districts with telemetry systems

Inmaculada Pulido-Calvo[a,*], *Pilar Montesinos*[b], *José Roldán*[b], *Francisco Ruiz-Navarro*[b]

[a]*Dpto. Ciencias Agroforestales, EPS, Campus de La Rábida, Universidad de Huelva, 21819 Palos de la Frontera (Huelva), Spain*
[b]*Dpto. Agronomía, ETSIAM, Universidad de Córdoba, Apdo. 3048, 14080 Córdoba, Spain*

ARTICLE INFO

Article history:
Received 2 June 2006
Accepted 6 March 2007
Available online 21 May 2007

Information regarding water demand is key to managing consumption in irrigation districts. Forecasting water demand is one of the main problems for designers and managers of water delivery systems. This paper evaluates the performance of linear multiple regressions and feed forward computational neural networks (CNNs) trained with the Levenberg–Marquardt algorithm for the purpose of irrigation demand modelling. The models are established using data recorded from an irrigation water distribution system located in Andalusia, southern Spain, during two irrigation seasons (2001/2002, 2002/2003). A commercial telemetry system was installed on 28 farms of the irrigation network to record water volumes in real time. The input or independent variables used in various CNN and multiple regression models are: (a) water demands from previous days; (b) water demands and climatic data (rainfall, maximum, minimum and average temperatures, relative humidity and wind speed) from previous days. Good predictions were obtained when water demand original data were modified in the calibration period by a smoothing process to reduce the noise in the data acquisition during the start-up of the research project. The best predictions were obtained when water demand recorded during the two previous days was used as input data.

1. Introduction

Demands for water are increasing in both quantity and quality; a phenomenon that is conditioned by social, political and environmental factors. The pressures to meet growing demands have led to greater competition for available water resources among traditional water consumers, namely agriculture, industry and cities. These competing interests are already limiting social, industrial and rural development actions of many countries. Furthermore, the fact that this growing demand for water is not coupled or sychronised with increased resources is giving rise to greater competition between regions or countries for access to water (FAO, 1993; Ohlsson, 1995; Sumpsi *et al.*, 1998).

The current concern for environmental protection has given rise to a new factor affecting competition for water. Certain non-consumptive uses for recreational, ecological or landscaping purposes are now being considered when assigning water for consumptive uses. Thus, not only has competition increased in terms of the amount demanded, but also the quality.

As a result of these different factors affecting competition for water resources, water is increasingly considered a scarce and valuable resource requiring rigorous management and extreme caution to prevent its depletion. One of the keys to solving these problems lies in the agricultural sector given that irrigated agriculture is the largest user of water throughout the world, accounting for 87% of consumptive uses (ONU, 1997; Sumpsi *et al.*, 1998).

*Corresponding author.
E-mail addresses: ipulido@uhu.es (I. Pulido-Calvo), pmontesinos@uco.es (P. Montesinos), jroldan@uco.es (J. Roldán).
1537-5110/$ - see front matter
doi:10.1016/j.biosystemseng.2007.03.003

The improvement of water management in an irrigation district requires the analysis of water demand in order to determine ways in which it may be modified and rationalised with a view to making water management policy more efficient. Information regarding water demand in irrigated areas is key to the development of policies on irrigation water consumption. These data can provide us with information regarding the marginal value of water and the response level to different irrigation water rates. This also provides reference data for the design, modernisation and exploitation of water-delivery systems (Kadra & Lamaddalena, 2006).

Daily water requirements for crop irrigation can be estimated by the rates of percolation and evapotranspiration and used for irrigation planning. Many models have been used to simulate these water requirements, from empirical or functional (Doorenbos & Pruit, 1977; Doorenbos & Kassam, 1979; Allen *et al.*, 1998) to mechanistic (Van Aelst *et al.*, 1988). However, water requirements calculated for irrigation planning are not always suitable for predicting actual use (i.e., consumer demand) due to changes in the field environment such as weather conditions and farm management practices, which can influence the actual amounts of water needed.

Additionally, to facilitate data acquisition and irrigation system management and operation, recently developed tools, such as remote sensing and geographic information systems GIS (Hartkamp *et al.*, 1999; Kite, 2000; Kite & Droogers, 2000; Lorite *et al.*, 2004), and monitoring and controlling systems (Leib *et al.*, 2003; Mareels *et al.*, 2005; Miranda *et al.*, 2005), have been combined with hydrologic models to assess and to improve the behaviour of irrigation schemes.

Despite these advances water management in some irrigation districts is carried out using only the experience and knowledge of the administrator although there is always a need to forecast daily water demand. Significant progress in the field of forecasting has recently been made possible through advances in a branch of nonlinear system theory modelling called artificial or computational neural networks (ANNs or CNNs). The neural approaches are increasingly being applied in many fields of science and engineering and usually providing highly satisfactory results.

Some of the applications of CNNs for the management of water resources include modelling the rainfall-runoff process (Hsu *et al.*, 1995; Lorrai & Sechi, 1995; Mason *et al.*, 1996; Abrahart *et al.*, 1999; Tokar & Johnson, 1999; Thirumalaiah & Deo, 2000; Tokar & Markus, 2000; Chiang *et al.*, 2004; Moradkhani *et al.*, 2004; Anctil & Rat, 2005; Agarwal *et al.*, 2006), short-term river stage forecasting (Thirumalaiah & Deo, 1998, 2000; Abrahart & See, 2000, 2002; See & Openshaw, 2000; Cameron *et al.*, 2002; Nayebi *et al.*, 2006; Pulido-Calvo & Portela, 2007), rainfall forecasting (French *et al.*, 1992; Zhang *et al.*, 1997; Kuligowski & Barros, 1998), groundwater modelling (Roger & Dowla, 1994; Yang *et al.*, 1997), predicting the soil water contents (Givi *et al.*, 2004) and nitrate-nitrogen in drainage water (Sharma *et al.*, 2003), and drought analysis (Shin & Salas, 2000), among others. Previous works on water demand forecasting both in urban supply systems and irrigation districts (Griñó, 1992; Pulido-Calvo *et al.*, 2002, 2003) show that the use of CNNs provide very satisfactory results.

The objective of this paper was to forecast consumer demands of an irrigation area using on-farm water-use information from supervisory control system and approaches based on linear regression, traditional forecasting methods, and on computational neural networks; heuristic models included in the knowledge field known as soft-computing. The purpose of forecasting is the real-time control of the daily water uses at the farm-scale for the various crops, as proposal of improvement water supply management in on-demand irrigation districts.

2. Material and methods

2.1. *Study area*

The methods developed in this paper were applied to the Genil-Cabra irrigation district for purposes of comparison. The district currently comprises about 15,000 irrigated hectares belonging to the Guadalquivir River basin in the provinces of Córdoba and Seville (southern Spain) (Fig. 1). The water used to irrigate the district is supplied from the Iznájar reservoir, which has a maximum storage capacity of 0.978 km^3. The water is then transported by the Genil River to the Cordobilla dam, with a capacity of 0.034 km^3. This is where the main pumping station that lifts the water to the principal canal is located. This canal conveys water to several pumping stations. The main pipe networks (pressurised or gravity-fed according to hydrant elevations) distribute water from these pumping stations to the different sectors where it is delivered to the farms by secondary pipe networks. This water distribution system permits farmers to use irrigation water throughout the year 24 h a day, as long as they do not exceed the preset maximum instantaneous flow value.

The predominant crops in the district include olive, cotton and winter cereals. Although crops such as sunflower predominated in the past, accounting for 45% of the surface area during the 1992/1993 irrigation season, during the 2002/2003 season sunflower crops accounted for less than 5% of the total surface area due to market fluctuations and European Agricultural Policy. Maize growing is rising accounting for almost 10% of the cropping area during the 2002/2003 season as compared to less than 0.5% in the 1992/1993 season. During this same season, olive crops accounted for almost 16% of the cropping area and currently occupy the largest percentage—some 34%.

One of the main problems when managing water resources in irrigated districts is the lack of reliable and comparable information on consumption. For this reason, an observation network was established in this study as an indispensable condition for the global and integrated management of water resources in irrigated areas. The network selected is a commercial telemetry system known as SIGA (Sistema Integral de Gestión del Agua—Integral Water Management System in English). This network consists of a telemetric system with the corresponding software for its control and the management and treatment of the data obtained, thus permitting irrigation water distribution systems to be monitored. Specifically, this system was installed on 28 farms located in sectors II–VII of the irrigation network to record