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Performance evaluation study and hydrologic and productive analysis of irrigation systems at the Qazvin irrigation network (Iran)

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ABSTRACT

The objective of this work is to develop a combined approach for performance evaluation of different irrigation practices based on the classical and neoclassical concept of irrigation efficiency, preliminary water accounting and water productivity. For this purpose, 2000 ha of land under Qazvin irrigation network in Iran with various types of irrigation systems were selected. Classical irrigation efficiency for furrow irrigation system was found 5.9% and 27.8% in primary and middle growth stages, respectively. The lowest classical efficiency for sprinkler systems was for linear-move system (11.8% and 45.6% in primary and middle growth stages, respectively). The values of effective efficiency were less than net efficiency in all studied irrigation systems in both evaluation stages. Obtained results showed that effective efficiency could define irrigation management at farm scale, whereas net efficiency considered the concept of beneficial reuse at larger scales. The total beneficial fraction in all sprinkler irrigation systems was higher than in furrow irrigation system. Overall, the values of depleted beneficial fraction were lower for the furrow irrigation system, which was due to large deep percolation values. The maximum and minimum values of net water productivity were for the center pivot with height-regulated sprinklers (9652 Rials m^{-3}) and furrow irrigation system (1391.4 Rials m^{-3}).

1. Introduction

Iran is a country with arid and semi-arid climate (an average annual rainfall of 240 mm) and many of its parts suffer from water scarcity issues. As a result, conservation of water resources must be made efficiently and optimally. Major part of available water resources is used for agricultural purposes. Thus, irrigation practices have an essential role in efficient use of water resources. Over the past years, sprinkler irrigation systems have been developed for increasing water-use efficiency and reducing irrigation losses. Policy makers follow water conservation activities in irrigated area especially during drought periods. The main objectives of such programs are improvement of irrigation performance in order to reduce gross diversion requirements.

Evaluation of irrigation systems will become more important in improving the performance of irrigation networks in order to achieve optimal productivity in the context of increasing food demand and competition for limited freshwater resources (Burt et al., 1997; Molden et al., 1998). Such assessments should analyze the irrigation performance indicators as well as hydrological and productive impacts of irrigation systems to support agents involved in crop production, water management and water policy (Perry et al., 2009; Molden et al., 2010; Lecina et al., 2011; van Halsema and Vincent, 2012).

Assessment of irrigation performance is required in order to improve water management on farms and irrigation districts (Clemmens and Dedrick, 1994; Burt et al., 1997). The efficiency concept has traditionally been used to design irrigation systems and to schedule irrigation. However, there is broad consensus that current irrigation efficiency is too low and a large part of future water needs could be met by increasing the irrigation efficiency without development of additional water supplies. While there is considerable potential to save water by increasing efficiency, it is not large enough to do so. The most commonly used concepts of water-use efficiency highly underestimate the true efficiency of existing irrigation systems. As part of the irrigation water losses are recycled through the hydrological system, the real water use efficiency increases. Therefore, such interpretation of classical irrigation efficiency is inappropriate and erroneous, which has led to major problems in planning and managing irrigation and water resources.

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Classic concept of irrigation efficiency is not an appropriate concept for assessing the hydrological impact of irrigation in irrigated area (Willardson et al., 1994; Seckler, 1996; Perry, 1999; Seckler et al., 2003; Jensen, 2007; Perry, 2007; Molden et al., 2010). Classic efficiency does not consider issues such as water reuse, distinction between total water use and water consumption, effect of use location in an irrigated district or a basin and water quality. However, these issues are particularly important for water management especially in a context of water scarcity. Huffaker (2008) and Ward and Pulido-Velázquez (2008) reported examples of misunderstandings in water management practices and water conservation programs due to an inadequate use of the classic efficiency concept. van Halsema and Vincent (2012) studied the use and abuse of definitions and applications of concepts of irrigation efficiency, water use efficiency and water productivity.

Several authors (Keller et al., 1996; Seckler et al., 2003; Haie and Keller, 2008; Mateos, 2008) have proposed distinction between the classical concept of irrigation efficiency and a neoclassical concept, which includes the above-mentioned hydrological issues in new formulations called effective efficiency and net efficiency. However, these terminologies could lead to misconceptions despite their proper hydrological basis (Perry, 2007; Perry et al., 2009).

Irrigation water management is also related to hydrology in the irrigation districts. Water accounting has been proposed as an alternative to the irrigation efficiency approaches for hydrological purposes (Willardson et al., 1994; Molden and Sakthivadivel, 1999; Clemmens et al., 2008; Perry et al., 2009). This methodology utilizes the law of mass conservation through water balance. The balance identifies the destination of the water used and makes a distinction between consumptive and non-consumptive uses (Molden and Sakthivadivel, 1999; Clemmens et al., 2008; Perry et al., 2009). Several fractions among balance components have been proposed to characterize the performance of irrigation systems. Water accounting aims to remove the limitations and hydrological misunderstandings of traditional analysis based on irrigation efficiency to evaluate irrigation systems in water scarcity and competitive agricultural markets (Lecina et al., 2011). Lankford (2012) discussed two paradigms of “basin allocation irrigation efficiency” utilizing fractions and effective efficiency, and “socialized localized irrigation efficiency” utilizing classical efficiency. Irrigation water management is also linked to crop production and farmers’ income (Clemmens et al., 2008). A number of indices have been proposed to estimate water productivity (Molden et al., 1998, 2003, 2010; Hussain et al., 2007), are used to describe overall performance and to support decision-making processes.

In previous literatures, proper discussions were done on definitions, conceptions, misconceptions and some challenges in related to irrigation efficiency and on proposed indices (classic and neoclassic efficiency, hydrological fractions) (Perry et al., 2009; Molden et al., 2010; Lankford, 2012; van Halsema and Vincent, 2012). However, application of these concepts for evaluating irrigation systems and quantitative analysis of these different indices was done in a few studies (Haie and Keller, 2008; Lecina et al., 2011). Therefore, the objective of this work is evaluation of different irrigation systems based on the classical and neoclassical concepts of irrigation efficiency, preliminary water accounting and water productivity. Analyses of irrigation efficiency, water accounting and productivity are intended to assess how well water is used in irrigation practices and hydrological and productive impacts of irrigation water use, respectively. They are mainly addressed to water user associations, irrigation district authorities and agricultural entrepreneurs, respectively. Analysis and interpretation of these concepts and their ability and limitation in presenting reality of irrigation practices performance constitutes a secondary objective of this study.

2. Materials and methods

2.1. Characterization of the study area

Qazvin irrigation network is located in the Qazvin plain, in western north of Iran. Annual precipitation and evaporation in this region are 312 and 1345 mm, respectively, and the average annual temperature is 13.2 °C. The network covers an area of 57,000 ha, and its water is supplied from the Taleghan Dam and integrated wells scattered over the network area. Irrigation systems commonly used across the network are furrow, border and sprinkler types. The present study was conducted in two agriculture companies, namely, Magsal and Hezarjolfa, including 2000 ha of lands under the Qazvin irrigation network with various types of irrigation systems. The evaluated irrigation systems included center pivot with height-regulated and height-fixed sprinklers, linear-move, solid-set and furrow. Fig. 1 shows the location of the irrigation network, the study area and irrigation evaluations.

2.2. Basic data collection

Table 1 shows specifications of the studied fields and irrigation systems. Evaluation of the irrigation systems were performed in two stages, initial and mid crop growth stages, during the summer season in 2012. During the irrigation evaluations, farmers carried out their conventional cultivation and irrigation practices. A soil survey was carried out to obtain total available water (TAW) and water content before irrigations. Soil sampling was done just before irrigations using an auger in three depths at the plant root zone (0–0.9 m) in the studied fields (Fig. 1) for both evaluation stages.

According to Ayers and Westcot (1985) and Allen et al. (1998), leaching fraction (LF) and drainage water depth (D_d) were calculated using measured data of EC_i, EC_e and D_i, as follows:

$$LF = \frac{EC_i}{(5EC_e - EC_i)} \quad (1)$$

$$D_d = LF \times D_i \quad (2)$$

where EC_i is electrical conductivity of irrigation water, EC_e is electrical conductivity of soil saturation extract and D_i is total depth of irrigation water. Required LF was calculated using Eq. (1) based on crop salinity threshold in which yield begins to decrease (for maize is 1.8 dS m^{-1} (Allen et al., 1998)). However, real LF occurred in the studied irrigation fields were calculated by Eq. (1) based on measured root zone soil salinity. EC_i and EC_e (after soil sampling in the root zone) were determined by EC Meter device. For measuring root zone depth, a plant sample was extracted slowly from the soil and then its root depth was determined by a ruler.

The required meteorological data such as pan evaporation (E_{pan}), wind speed (u) and minimum relative humidity (RH_{min}) were daily recorded in the meteorological station located in the study area (Fig. 1). Crop coefficient (K_c), basal crop coefficient (K_{cb}) and fraction of TAW that a crop can uptake water from the root zone without suffering water stress (P), were adopted from FAO 56 tables (Allen et al., 1998). Then, they were modified according to meteorological data (Allen et al., 1998).

2.3. Determination of water balance components

The inflow discharge of the furrow irrigation system was measured using Washigton State College (WSC) Flume (Chamberlain, 1952). Geometric properties of the furrow were determined by the profilemeter method (Elliott and Walker, 1982). The advance phase was determined by recording the water advance times at reference points located every 10 m along the furrow. After irrigation cutoff time, recession times were recorded at the reference points.