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Alternative management options for irrigation-induced salinization and waterlogging under different climatic conditions

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ABSTRACT

Arid and semiarid regions cannot meet the demands for food and fiber, at an acceptable environmental cost, without irrigation. However, the escalation of irrigated agriculture could result in environmental problems of soil salinisation and waterlogging. This study attempts to analyse the long-term effect of different management strategies on the watertable depth and groundwater salinities. To evaluate diverse management strategies to solve the environmental problems, the current study used a salt and water balance model SaltMod in an irrigated command area of northwest India which faced with environmental problems of salinization and waterlogging. Following the successful calibration and validation, the model was used for studying various management alternatives for the study region under different climatic and agro-hydrological conditions. The alternative scenarios revealed that the study region would experience continuous rise in groundwater levels in the future under the business as usual scenario. Therefore, appropriate management strategies such as increased groundwater use, reduced rice cultivation, and reduced canal water use are suggested. The optimal scenario revealed that even a small change of two to five percent in various inputs could keep the region from further waterlogging and associated secondary salinisation.

1. Introduction

Good quality natural resources, i.e., water and land, are limited in arid and semiarid regions. Besides, they experience steady degradation (Duarte et al., 2016; Li et al., 2015). Furthermore, agricultural production needs to be maintained using such degraded resources in order to provide food and fibre for the burgeoning global population (Lomba et al., 2017; Srivastava et al., 2016; Liu et al., 2016; Singh, 2014; Mekonnen and Hoekstra, 2014), which is projected to increase by another 2.3 billion people before touching the 9.7 billion mark in 2050 (United Nations, 2015). Arid and semiarid regions cannot meet the demands for food and fiber without irrigation, since average annual precipitation in these areas is highly unreliable, both in quantity and in distribution, to ensure a harvestable crop (Phondani et al., 2016; Das et al., 2015; Sahin et al., 2015; Singh, 2015a; Shamir et al., 2015). However, the intensification of irrigated agriculture could result in environmental problems in agro-ecosystems (Han et al., 2011; Tilman et al., 2002). For example, more than one-third of the world's irrigated land is affected by salinization or/and waterlogging and this condition poses a food security threat (Heuperman et al., 2002; Houk et al., 2006).

Abbas et al. (2013) reported that soil salinization is increasing at a rate of over 2 million ha per annum globally. Earlier, Tanji and Kielen (2002) reported that over 20% of all cultivated land is degraded to some degree and this area increases by over 5 million ha annually. Bakker et al. (2010) estimated that more than 80 million ha area is affected to some extent by salinization and waterlogging problems. Elbeih (2015) and El Baroudy (2011) have reported the severity of salinity and waterlogging problems in the Nile Delta region. Sleimi et al. (2015) reported that over 400 million ha agricultural land is affected by salinity and this area increases every day owing to poor irrigation practices. Of late FAO estimated that in excess of 19% of the total irrigated land is salt affected (FAO, 2016). The majority of these affected areas are the result of mismanagement of irrigation water. In India alone, more than 8.4 million ha area is affected by soil salinity and alkalinity, of which over 5.5 million ha is waterlogged.

A broad range of solutions could be considered to tackle the problems of salinization and waterlogging. The efficacy of all the solutions and their permutations, however, cannot be verified with field experiments. Because of their predictive capacity, the simulation models are often the only feasible means for providing input to management decisions. These models can help to predict the possible impacts of a particular management strategy. Recently, researchers across the world, i.e., Almpanidou et al. (2016), Heydari et al. (2016), Singh (2015b), Xu et al. (2011), Sedki and Ouazar (2011), Xie and Cui (2011), and Konukcu et al. (2006) have used a large number of computer-based

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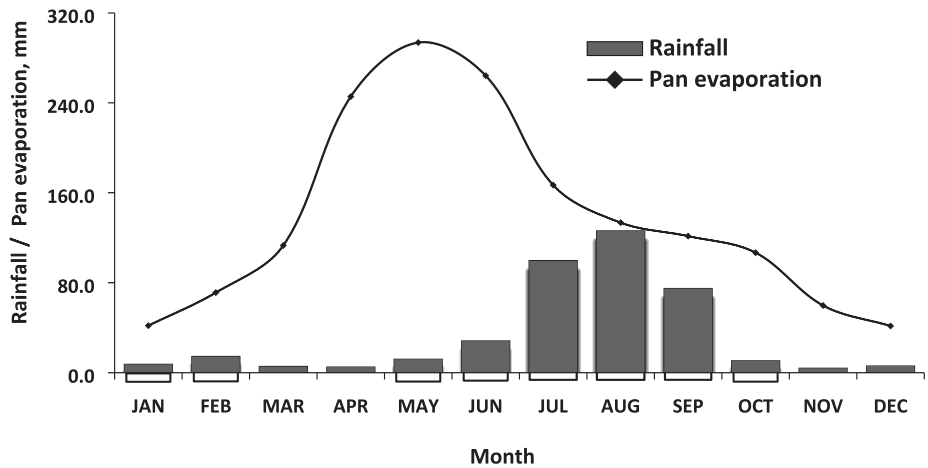

Fig. 1. Mean monthly rainfall and pan evaporation.

numerical models for managing the environmental problems of salinization and waterlogging. Singh (2010) used a one-dimensional simulation model SWASALT for managing the salinization and waterlogging problems in an irrigated area of northwest India. The study reported that poor quality water of up to 7.5 dS/m salinity can safely be used for crop production in most agro-hydro-climatic conditions in waterlogged areas. Later, a three-dimensional simulation model was used by Chandio et al. (2012) in a waterlogged area of the lower Indus Basin, Pakistan. In all the earlier studies some groundwater withdrawal increase and/or recharge reduction actions are suggested to manage the salinization and waterlogging problems. Nonetheless, most of these models need specific input of soil characteristics, i.e., hydraulic conductivity and dispersivity, soil moisture content of root-zone, and matric and osmotic soil-water potential, which are difficult to measure. Also, they use small time-steps and need at least a daily database of hydrologic phenomena.

As a result of the literature review and the current need as discussed, the present study used a simulation model SaltMod (Oosterbaan, 2008) which requires seasonal input data that are generally available or that can be easily determined with reasonable accuracy (Srinivasulu et al., 2005). The model was applied in an irrigated area of Haryana State of India which faced with environmental problems of salinization and waterlogging (Groundwater Cell, 2014a). Previously the model SaltMod was applied in Leziria Grande Polder, Portugal by Vanegas Chacon (1993), Nile Delta of Egypt by Oosterbaan and Abu (1989), in Konanki pilot area of Andhra Pradesh, India by Srinivasulu et al. (2004), in Tungabhandra Irrigation Project, India by Rao et al. (1992), in Konya-Cumra Plain, Turkey by Bahceci et al. (2006), in Krishna district of Andhra Pradesh, India by Sarangi et al. (2006), in the Harran Plain of southeast Turkey by Bahceci and Nacar (2007) and Bahceci et al. (2008), in an irrigated area of Kalaat El Andalous, Tunisia by Ferjani et al. (2013), in a coastal reclaimed agricultural area of eastern China by Yao et al. (2014), and in Hetao Irrigation District of Inner Mongolia, China by Mao et al. (2017).

In nearly all the previous studies, the SaltMod was applied in areas where drainage system was available. Also, the aquifer parameters were not verified and sensitivity analysis of the modeled parameters was not carried out in most of the studies. There is no evidence of using SaltMod for the analysis of long-term salt and water balances in agricultural areas under different climatic conditions. This study attempts to analyse the long-term effect of different management strategies on the water-table depth and groundwater salinities. The study is first of its kind in the selected area and it will provide an improved understanding of the process dynamics that leads to imbalance of the system. The paper is divided in five sections. Section 1 provides a brief introduction of environmental problems of irrigated agriculture and the significance of the study. A brief description of study area and data acquisition and analysis is described in Section 2. Section 3 provides the model description which comprises the principle, calibration and validation, sensitivity analysis, and statistical evaluation. Results and discussion are elaborated in Section 4, which is followed by conclusions of the study (Section 5).

2. Materials and methods

2.1. Study area

The study was conducted in Meham block of Rohtak district of Haryana State of India which covers about 41,952 ha. The culturable command area (CCA) is 32,500 ha. The area is situated between 28°51′N to 29°05′N latitude and 76°13′E to 76°27′E longitude and is a part of the Western Yamuna Canal Irrigation System. The average elevation of the command is 221 m above the mean sea level and it ranges between 218 and 229 m. The study area features semiarid climatic conditions with a mean annual rainfall of 397 mm. More than 76% of the annual rainfall is received from the south-western monsoon between July and September. The 24% of annual rainfall occurs about equally distributed during the remaining nine months of the year. An average year features between 29 and 34 rainy days while the maximum dry spell in the monsoon season ranges between 41 and 49 days. The mean annual pan evaporation was recorded at 1660 mm. The monthly pan evaporation values surpasses the corresponding rainfall for all the months as shown in Fig. 1. The mean temperature shows a wide variance during the year with a minimum temperature of about 2 °C during December–January months of the winter season and a maximum temperature around 46 °C during May–June months of the summer. Generally the relative humidity ranges between 78 and 84% in summer and monsoon seasons and 36–45% in winter. The average sunshine ranges between 9.0 and 10.7 h/day during April, May, September, and October months, and between 6.8 and 8.9 h/day in the remaining months.

The soil texture in the study area is predominantly fine loam to sandy loam with 11–17% clay content. The specific yield of the unconfined aquifer material ranges between 0.09 and 0.23 and soil porosity varies between 43.7 and 53.2%.The hydraulic conductivity varies between 4.7 m/day and 11.2 m/day. The year is normally divided into two key crop seasons *monsoon* (July–October) and *winter* (November–April). Wheat is the major crop of the area and grown over 83% of the net cultivated area in *winter* season. The second main crop of the study area is rice and it is grown in about 44% of the net cultivated area in *monsoon*. The other crops grown in the study area includes millets, cotton, sugarcane, mustard, barley, and gram. Fruits and