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Assessment of different strategies for managing the water resources problems of irrigated agriculture

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ABSTRACT

The intensification of irrigated agriculture is required for attaining food security. It could result, however, in water resources problems of waterlogging and secondary salinization. To assess different management strategies in solving the problems, the current study used a simulation model SaltMod in a command area of north-west India which faced the problems of salinization and waterlogging. Following the thriving testing in the course of calibration and validation, it was used for studying various water management alternatives for the command area. The analysis of different scenarios shows that watertables in the command would persist to go up under the normal conditions. Thus, right management alternatives, for example, increased groundwater use, rice area reduction, and reduced canal water use are recommended. The ideal scenario revealed that small changes of 3–6% in input values would contain the problems of the study region.

1. Introduction

The water and soil resources are limited and they experience gradual degradation (Chitsaz and Azarnivand, 2017; Singh, 2018a, 2016a). Besides, farm production requires to be increased using these limited resources for feeding the burgeoning global population (Xie et al., 2018; Lomba et al., 2017; Li and Zhang, 2015; Singh, 2018b, 2014; Liu et al., 2016; Davijani et al., 2016). The intensification of irrigated agriculture is required for realizing food security (Das et al., 2015; Singh et al., 2016) in dry regions given that normal rainfall in these areas is highly unreliable (Herrmann et al., 2016; Adhikari et al., 2017; Postel, 1999). This intensification, however, could result in water resources problems of rising watertables and secondary salinization (Tilman et al., 2002; Houk et al., 2006; Singh, 2012, 2017a,b). Abbas et al. (2013) stated that soil salinization is growing globally at an average annual rate of over 2 million ha. In recent times, the Food and Agriculture Organization FAO reported that more than 19 percent of the total irrigated territory is suffered by salinization (FAO, 2016).

The simulation models can predict the possible impacts of a specific management option. In recent past, researchers across the world, i.e., Rezaeianzadeh et al. (2017), Kacimov et al. (2016), Mao et al. (2017), Droogers et al. (2000), Xu et al. (2011), Sedki and Ouazar (2011), Xie and Cui (2011), and Yazdi and Salehi Neyshabouri (2012) have used a large number of simulation models for studying various aspects of water resources problems. A physical-based 1-D simulation model SWASALT was used by Singh (2010) for mitigating the rising watertable and salinity problems in north-west India. The study reported that a poor quality water of 7.5 dS/m salinity can safely be used for crop production in most soils and climatic conditions in waterlogged areas. Later, Chandio et al. (2012) used a 3-D simulation model in an irrigated area of Pakistan. In all the earlier studies some groundwater withdrawal increase or recharge reduction measures are suggested to manage the salinization and waterlogging problems. Nevertheless, the majority of these models entail specific soil characteristics as inputs, i.e., osmotic and matric soil-water potential, soil moisture content of root-zone, and dispersivity and hydraulic conductivity, which measurement is difficult.

Having considered findings of the previous studies and the current need as discussed, the current study used a water and salt balance model SaltMod (Oosterbaan, 2008). The model needs inputs that are usually obtainable (Srinivasulu et al., 2004). The model was used in a command of north-west India which faces the hydrological problems of water resources, i.e., salinization and waterlogging (Groundwater Cell, 2014a). Previously the SaltMod was used by Vanegas Chacon (1993) in Leziria Grande Polder, Portugal. Later, it was applied in Nagarjuna Sagar Command of India by Srinivasulu et al. (2005), in Krishna district of India by Sarangi et al. (2006), and in the Plain of Konya-Cumra, Turkey by Bahceci et al. (2006) among others.

In almost all the preceding studies, the model SaltMod was used in areas which are equipped with the drainage system. There is no indication of model application for the long-term evaluation of water and salt balances in irrigated lands under different hydrological conditions. In this paper, an attempt has been made to analyse the long-term water and salt balances under various management strategies. The study is

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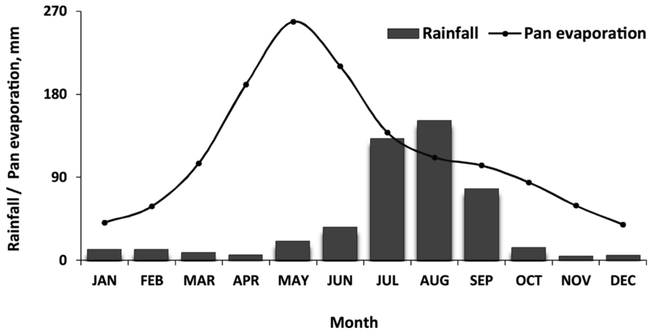

Fig. 1. Distribution of mean monthly rainfall and pan evaporation.

first of its kind in the selected canal command and it will give an impression of the progression dynamics that lead to a system disparity. The paper is prepared as: Section 1 provides a succinct overview of water resources problems and the implication of the study; Section 2 briefly describes the study system and data analysis. The model description is presented in Section 3. Section 4 presents the results and discussion. Finally, conclusions and some suggestions are provided in Section 5.

2. Study system and data

2.1. Location and hydrometeorology

The Ismaila Distributary is situated in Rohtak district of Haryana State in north-west India and lies between 28°42 to 28°51′N latitude and 76°39–76°27′E longitude. The command area covers about 4679 ha. The altitude of the command ranges between 214 m and 222 m from the mean sea level. The climatic conditions of the command are semiarid with normal annual rainfall of 483 mm. The values of pan evaporation surpass the matching rainfall for each month of a year excluding July and August as shown in Fig. 1.

2.2. Soil and cropping system

The soil in the command is largely of sandy loam with the specific yield values of 0.09-0.23. The hydraulic conductivity ranges between 4.7 m d^{-1} and 11.2 m d^{-1}. The year is normally divided into two major crop seasons, i.e., *winter* and *monsoon*. The *winter* season starts in November while the *monsoon* starts in July. Wheat and rice are the main crops grown in *winter* and *monsoon* seasons, respectively. Millets, sorghum, mustard, and gram are the other crops grown in the area. Besides, pulses, barley, vegetables, and fruits are grown in tiny areas (Table 1).

Table 1
Existing seasonalcropping pattern in the command area.

Crop	Area (ha)	
	Monsoon	Winter
Rice	1253	–
Millets	640	–
Sorghum	469	–
Pulses	52	–
Wheat	–	2758
Mustard	–	540
Gram	–	232
Barley	–	86
Vegetables, fruits etc.	26	79

2.3. Data collection

The data on aquifer, canals, crops, and climate were obtained from different State and Central Government departments such as Irrigation Department, Groundwater Cell, etc. The data analysis is briefly described as:

Irrigation system and groundwater

Ismaila Distributary supplies the canal water, to the command area, which is of high-quality. More than 800 shallow tubewells pump the groundwater; over 90% of which are operated via the diesel engines. In the command, the watertable varies from a depth of 4.85 m during the summer to 1.15 m in the monsoon.

Water requirement

The method suggested by Allen et al. (1998) was used to calculate the water requirement of each crop. The reference evapotranspiration (*ETo*; mm d^{-1}) was initially computed from the climate statistics using Hargreaves and Samani approach (1985) as:

$$ETo = 0.0023 \times (T_{avg} + 17.8) \times R_a \times \sqrt{T_{\max} - T_{\min}} \quad (1)$$

wherein T_{avg}, $T_{min,}$ and T_{max} are daily mean, minimum, and maximum air temperatures (°C) and R_a is the extraterrestrial solar radiation (mm d^{-1}).

From the Eq. (1), the potential evapotranspiration (ETc) of each crop was computed by the use of pertinent crop coefficients (*Kc*) as:

$$ETc = ETo \times K_c \quad (2)$$

The water requirements of crops were computed at 648, 413, 399, 301, 481, and 413 mm for rice, millets, gram, mustard, wheat, and sorghum, correspondingly.

The FAO method suggested by Dastane (1978) was employed to find out the effective rainfall (R_{eff}) of each season. The R_{eff} was computed from daily rainfall (*R*) data using the equations below:

$$R_{eff}\ (t) = 0.8\ R(t), \text{ for rice crop} \quad (3)$$

$$R_{eff}(t) = 0.7\ R(t), \text{ for other crops} \quad (4)$$

The net crop irrigation requirement (*NIR*) was computed using the equation (Eq. (5)) as:

$$NIR = ETc - Reff \quad (5)$$

Canal seepage

The seepage through canals was computed using Eq. (6) as:

$$R_c = WP_c \times L_c \times SF \times N_d \times 86{,}400 \quad (6)$$

wherein WP_c and L_c are wetted perimeter and canal length (m), N_d is the seasonal canal running days (d), SF is the seepage factor (-), and R_c is the seasonal canal seepage (m^3). For the command area, the SF was suggested at 2.5–3.0 and 0.62-0.75 m^3 per second per million m^2 of the wetted area for unlined and lined canals, correspondingly (Irrigation Department, 2015).

Tubewell draft

The Groundwater Cell (2014b) recommended the guidelines for the estimation of tubewell draft. Accordingly, the normal discharge of a tubewell in the command was taken at 0.006-0.010 m^3 s^{-1}.

3. Model description

3.1. Principle

SaltMod is a computer program for the forecast and simulation of the salinity of soil moisture, drainage water and groundwater, the watertable depth, and leaching of salts and drain discharge in irrigated areas under various agro-geo-hydrological conditions, several crop rotations, and a range of water management scenarios (Oosterbaan, 2008). SaltMod is based on seasonal salt and water balances of cropped areas. The SaltMod program, description of principles, user's manual,