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Managing the environmental problems of irrigated agriculture through the appraisal of groundwater recharge

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ABSTRACT

This study employed an easy groundwater recharge model which requires input values that are effectively on hand or attainable and exactly measured. The estimated long-term seasonal groundwater recharges have been used for the assessment of environmental issues of agricultural lands in an irrigated semiarid area of northwest India, where groundwater level has risen. The groundwater recharge model performed very nicely in calculating the watertable depths in the course of the entire study period (1996–2016) which is also substantiated statistically through the lower values of root mean squared error (0.2133 m) and mean error (−0.0325 m) and high model efficiency (0.88) and regression coefficient (0.979). Various scenarios have been studied to look at the impact of model's input variation on its output. The analysis of various recharge components shows an average annual watertable rise of 0.08 m in the command due to a higher positive average net recharge in the monsoon season which cannot be fully counterbalanced by a lower negative mean net recharge during the winter season. Among the scenarios analyzed, the better agricultural practices with modified cropping pattern have delivered the best effects for containing the environmental issues of salinization and waterlogging.

1. Introduction

The provision of irrigation is integral for accomplishing food protection in arid and semiarid areas where annual precipitation is unreliable and poorly distributed to guarantee a harvestable crop (Duarte et al., 2016; Adhikari et al., 2017; Phondani et al., 2016; Das et al., 2015; Herrmann, 2016; Singh, 2015a; Masunga, 2016). Though irrigation water transportation from outside of the natural hydrological cycle will increase the food production, it additionally reasons the environmental issues, i.e., salinization and waterlogging, in irrigated areas (Zhou et al., 2016; Emna et al., 2016; Singh, 2017a,b). Agricultural production methods have to be sustainable in environmental and social terms to supply food and fiber for the growing global populace (Xie et al., 2018; Lomba et al., 2017; Srivastava et al., 2016; Davijani et al., 2016; Li and Zhang 2015; Singh, 2012; Singh, 2014a; Singh, 2017c; Karandish et al., 2015; Mekonnen and Hoekstra 2014) which is projected to expand by some other 2.3 billion people to touch the 9.7 billion mark by 2050 (United Nations, 2015).

Current agricultural intensification has resulted in declining biodiversity and other environmental issues in agroecosystems (Foley et al., 2005; Singh and Panda, 2012a,b; Singh, 2011). For example, over 33 percent of the world's irrigated land is affected by salinization/waterlogging and this situation poses a risk to food protection and environmental conservation (Almpanidou et al., 2016; Wichelns and Oster 2006; Singh et al., 2016; Sleimi et al., 2015; Singh, 2015b; Singh, 2016a,b). Accurate estimation of groundwater recharge is indispensable for inspecting the environmental issues of irrigated lands (Singh, 2014b). It is additionally necessary for sustainable groundwater management and grasp the system dynamics of the problems (Singh, 2014c,d).

Various techniques exist for estimating groundwater recharge (Masciopinto et al., 2017; Korbel and Hose 2017; Lee et al., 2008; Rushton et al., 2006). Generally, techniques for estimating groundwater recharge are subdivided into specific types primarily based on the hydrologic sources from which data are obtained (Scanlon et al., 2002). Tracer techniques are extensively used in arid and semiarid regions to estimate groundwater recharge from precipitation and irrigation (Cook and Solomon 1997; Sami and Hughes 1996). But, they do not measure water flow directly, which may reason an under or over-estimation of recharge (Lerner et al., 1990).

Analysis of watertable fluctuations is a beneficial tool for finding out the size of both short and long-term alterations in groundwater recharge and has been broadly utilized under various climatic conditions (Avery et al., 1999). Groundwater Estimation Committee (India) has also advocated this approach for estimation of groundwater recharge. However, use of this approach is restricted in areas, where groundwater

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stage monitoring is carried out regularly, and where enough data about groundwater fluctuations is on hand (Sharda et al., 2006). Furthermore, using a single representative value of specific yield limits the usefulness of the watertable fluctuation approach for estimating groundwater recharge (Scanlon et al., 2002).

The hydrological budget approach is significantly used for estimating groundwater recharge (Ahmed and Umar 2008; Marechal et al., 2006). However, assigning a representative value of specific yield leads to over/under estimation of groundwater recharge (Sophocleous, 1985). Since every method is associated with some limitations, the use of more than one methods was encouraged to estimate the groundwater recharge (Risser et al., 2009; Healy and Cook 2002). In most cases, specific methods synchronize each other and help refine the conceptual model of recharge processes.

Considering the reviews of the previous researches and the current necessity as stated above, the current study employed an easy groundwater recharge model, which combines the groundwater budget and seasonal watertable fluctuations. The model requires input values that are effectively on hand or attainable and exactly measured. The estimated long-term seasonal groundwater recharges have been used for the assessment of environmental issues of agricultural lands in an irrigated semiarid area of northwest India, where groundwater level has risen (Cell, 2015a). The outcomes are evaluated to give an impression of the system dynamics that guided to imbalance of the system.

2. Study system

The model was applied in the command of Ismaila Distributary which is administratively placed in Rohtak district of Haryana State in India. Ismaila Distributary lies between 28°42′N to 28°51′N latitude and 76°39′E to 76°46′E longitude and covers an area of 4679 ha. The elevation of the command ranges between 214 and 222 m above the mean sea level, with an average of 217 m. The study area features semiarid climatic conditions with 483 mm mean yearly rainfall. An ordinary year features 33–39 wet days whereas the largest dry spell inside the monsoon season ranges between 36-45 days. The month-to-month pan evaporation values surpass the corresponding rainfall for all the months of a year barring July-August as shown in Fig. 1. The mean temperature suggests a large variance throughout the year with a minimum temperature of about 3 °C during December-January months of the winter and a maximum temperature around 46 °C at some stage in May-June months of the summer. The average relative humidity varies from 36 to 45% in winter to 78–84% in summer and monsoon seasons.

The soil in the command is mostly of fine loam to sandy loam with clay content between eleven and seventeen percent. 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 characteristically divided into two predominant crop seasons monsoon and winter. The monsoon season begins in July whilst the winter begins in November. Wheat is the primary crop of the command and covers over 75% of the net cultivated area in the winter. The second primary crop of the command is rice and it is grown in about 51% of the net cultivated area in monsoon. The different crops cultivated in the command area consists of millets, sorghum, gram, and mustard. Barley, pulses, vegetables, and fruits are additionally grown in tiny areas. The current seasonal cropping pattern of the command area is furnished in Table 1.

Table 1
Existing seasonal cropping pattern.

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

Ismaila Distributary supplies the canal water, to the command area, which is of high-quality (Singh, 2016c). 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 monsoon.

3. Groundwater recharge model

3.1. Brief description

The typical accounting of water losses and gains, per unit time, of a study region can be presented as:

$$(R + I + Rp + Rc) - (RO + Qw + ETc) + (Qin - Qout) = \Delta S \quad (1)$$

wherein R = rainfall (m3); I = irrigation (m3); Rp = percolation from field (m3); Rc = seepage from canal networks (m3); RO = surface runoff (m3); Qw = tubewells withdrawal (m3); ETc = crop evapotranspiration (m3); Qin = lateral influx into the study region (m3); $Qout$ = lateral outflow from the study region (m3); and ΔS = change in groundwater storage, which is referred as net groundwater recharge (m3).

The lateral outflows ($Qout$) and influxes (Qin) from and to the system can be regarded insignificant for the regional studies (Hassan and Bhutta, 1996). Likewise, the surface runoff from and to the region was also supposed to be non-significant. Thus Eq. (1) can be modified as:

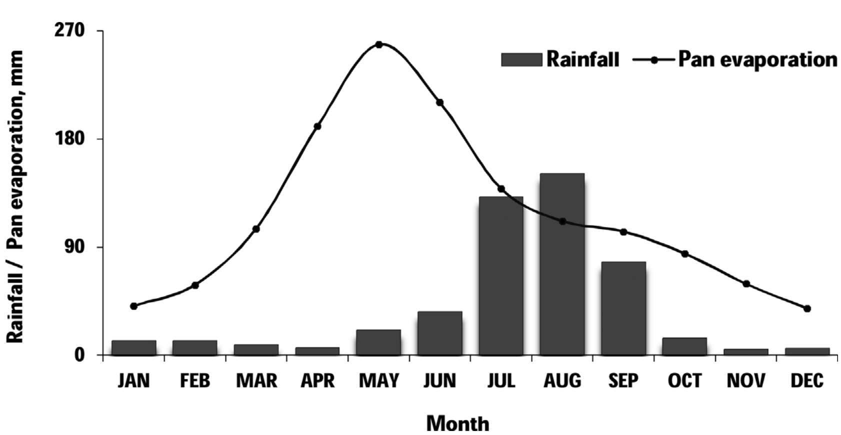

Fig. 1. Mean monthly rainfall and pan evaporation.

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