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Original Research Article

Estimation of Groundwater Recharge for the Study Area

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A B S T R A C T

Groundwater resource studies require estimates of the quantity of water moving downwards from the soil zone as potential recharge. Any methodology selected for the estimation of potential recharge must be applicable in a wide variety of climatic and hydrological situations. The important physical processes must be represented adequately. Unnecessary complexities should be avoided, with parameter values based on readily available field information. In the present study, Udaipur district is selected as a study area, which is situated in southern part of the largest and driest state (Rajasthan) of India. It lies between 23°45′ and 25°10′ North latitude and 73°0′ and 74°35′ East longitude encompassing a geographical area of about 1269800 ha. The 23 years (1980 – 2002) groundwater recharge of CTAE farm has been estimated with soil moisture balance method. Results shows that the highest recharge 96.8 mm has been found during the year 1991 i.e. 16.4 per cent of annual rainfall and no recharge has been found during the year 1982 due scattered rainfall in the year. From the method the average recharge has been observed that 32.9 mm *i.e.* 6.9 per cent of the average annual rainfall.

Keywords

Infiltration, Groundwater, Rainfall, Recharge and Runoff

Introduction

Water is the very basis of life and is essential for human survival and development. But in the last few decades the consequences of population growth, industrialization and urbanization, have increased the domestic and industrial needs to the extent that the agriculture's share of water use is likely to go down by 10 – 20 per cent from present 83 per cent of the total water use (Choudhary, 1995). Hence, the judicious use of this precious commodity is becoming very important.

Groundwater is an important source of water for irrigation. It is renewable, dependable and safe source of water. About 60 per cent of irrigation land draws water from the groundwater reservoir. However in certain parts of the country over exploitation of groundwater has resulted in lowering of water table and causing decline in yield and productivity of wells, salt water intrusion along the coast, drying of springs and shallow dug wells, increase in cost of water lifting etc.

Recharge is defined as "the entry into the saturated zone of water made available at the water-table surface, together with the associated flow within the saturated zone away from the water-table" (Healy and Cook, 2002). The recharge may be natural (i.e., infiltration of water under natural conditions), induced (from water reservoirs, irrigation/drainage channels, bays, etc.), or artificial (i.e., infiltration enhancement by artificial means), with natural recharge by far the most important. Since the natural recharge is very sensitive to rainfall, global climatic change can have a significant effect on the future local groundwater resources, especially in dry and warm climates.

Recharge is arguably the most difficult hydrologic parameter to quantify with confidence. Recharge is the downward flow of water reaching the water table and the groundwater reservoir. For sufficiently long periods of years and in aquifers not subjected to pumped extractions, the mean annual value of the recharge is equivalent to the rate of discharge. In arid and semiarid regions, recharge rates are highly variable in time, recharge mechanisms vary throughout the basin and a multitude of approaches exist for measuring recharge. In humid regions, recharge is commonly estimated using a water balance approach, where recharge represents the difference between inputs (precipitation) and outputs (evaporation, transpiration and runoff). There are three mechanisms of recharge: direct recharge by percolation through the unsaturated zone, indirect recharge through the beds of surface-water courses and localized or concentrated recharge at points.

The aquifer recharge is expressed as annual volume, which is normally termed the mean annual resources or entry, or as a percentage of precipitation termed as the rate of recharge or effective infiltration. Important considerations in choosing a technique include space-time scales-range and reliability of recharge estimates based on different techniques. Recharge analysis aims at water resource evaluation, evaluation of aquifer vulnerability to contamination. Techniques based on surface-water and unsaturated zone data provide estimates of potential recharge, whereas those based on groundwater data give estimates of actual recharge (Andreo *et al.*, 2008).

Water balance methods used for recharge estimation are based on the fact that water entry should be equal to the amount discharged plus or minus the variation in the volume of water that is stored. In practice, only some components of groundwater balance equation can be measured directly (precipitation), while the rest (potential and real evapotranspiration and effective rainfall) must be estimated indirectly using semi-empirical formulae like those proposed by Thornthwaite (1948).

The problem of estimating groundwater recharge in semiarid areas is that recharge amounts are normally small in comparison with the resolution of the investigation methods (e.g. Allison *et al.*, 1984). The greater the aridity of the climate, the smaller and potentially more variable in space and time is the recharge flux. Direct groundwater recharge from precipitation in semi-arid areas is generally small, usually less than about 5 per cent of the average annual precipitation, with a high temporal and spatial variability (Gieske, 1992).

Estimation of recharge has been a daunting task for arid and semi-arid areas, due to the complexity of the geohydrological settings and the uncertainty associated with the meteorological data of a location. There are three mechanisms of recharge, direct recharge by percolation through the unsaturated zone, indirect recharge through the beds of surface-water courses and localised or concentrated recharge at points. A single mechanism may not characterize groundwater recharge for any given region and the relative contribution of each method will depend on climatic and geologic conditions.

Udaipur district of Rajasthan, the largest and the driest state of India, suffers from extremely high summer temperatures, frequent droughts, uncertain rainfall and recharge. By keeping the above facts in mind, Udaipur district located in semi-arid climatic region was selected for the study for estimating groundwater recharge by using soil moisture balance method.

Materials and Methods

Groundwater resource studies require estimates of the quantity of water moving downwards from the soil zone as potential recharge. Any methodology selected for the estimation of potential recharge must be applicable in a wide variety of climatic and hydrological situations. The important physical processes must be represented adequately. Unnecessary complexities should be avoided, with parameter values based on readily available field information. Estimates are usually required for several decades.

Study Area

In the present study, Udaipur district is selected as a study area, which is situated in southern part of the largest and driest state (Rajasthan) of India (Fig.1). It lies between 23°45′ and 25°10′ North latitude and 73°0′ and 74°35′ East longitude encompassing a geographical area of about 12698 km^2. The climate of Udaipur is tropical, semi-arid with mercury staying between a maximum of 42.3 °C and a minimum of 28.8 °C during summers. Winters are cold with the maximum temperature rising to 28.8 °C and the minimum dipping to 2.5°C. January is the coldest month and May is the hottest month. The mean annual evapotranspiration in the study area is 1380 mm. The mean annual rainfall is 625 mm, precipitating more than 80 per cent during June through September. The rainy season (*i.e.,* wet season) usually starts from mid-June and lasts for about four months up to the end of October. November to May is characterized as the dry period.

Data Collection

In present study, weekly soil moisture data of 23 years (1980-2002) has been collected from the Agro-Meteorological observatory of CTAE, Udaipur. Weekly meteorological parameters, *i.e.,* Evaporation, minimum and maximum temperatures, wind velocity, sunshine hours, rainfall and relative humidity for 23 years (1980-2002) has been collected from Agro-Meteorological observatory of CTAE, Udaipur.

Estimation of groundwater recharge using soil moisture balance method

The groundwater recharge has been estimated with the help of soil moisture balance method. The method described as follows.

Soil moisture balance method has been used to determine weekly groundwater recharge from agricultural fields of CTAE, Udaipur for 23 years (1980-2002). A soil moisture balance method was developed in the 1940s by Thornthwaite (1948) and was later revised. The method is essentially a bookkeeping procedure, which estimates the balance between the inflow and outflow of water. Here, the volume of water required to saturate the soil is expressed as an equivalent depth of water and is called soil water deficit.

The basis of recharge estimation using a soil moisture balance technique is that a soil becomes free draining when the moisture content of the soil reaches a limiting value called the field capacity; excess water then drains through the soil to become recharge. To determine when the soil reaches this critical condition it is necessary to simulate soil moisture conditions on a daily basis throughout the year. This is achieved by representing the appropriate properties of the soil, the ability of crops to collect moisture from the soil and to transpire water to the atmosphere and by including evaporation from bare soil. Infiltration to the soil zone in equals the daily precipitation P (or irrigation) less any interception or runoff RO. Inputs and outputs for the soil moisture balance are shown schematically in Fig. 2(a).

Total soil moisture and soil moisture deficit

The concept of the total moisture stored in the soil is illustrated by the soil moisture distribution on a representative section, Fig. 2(b). This soil moisture distribution is related to the permanent wilting point θ_{WP} which is the soil moisture content below which plant roots cannot extract moisture and field capacity θ_{FC} which is defined as the amount of water that a well-drained soil can hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased.

In the left-hand diagram of Fig. 2(b), the moisture content at the soil surface is just above the moisture content at wilting point; at a depth of 2.0 m the moisture content approaches field capacity. For soil moisture balance calculations, the sum to a depth of 2.0 m of the moisture contents above the wilting point, which is shaded on the left-hand graph of Fig. 2(b), can be represented as shown on the right-hand diagram of Fig. 2(b). This diagram does not imply that there is a sudden change in moisture content at a depth of 0.79 m; rather it is a convenient method of representing the total moisture stored in the soil section. The soil moisture deficit is defined as the depth of water required to bring the soil up to field capacity. This concept of a soil moisture deficit is useful for carrying out calculations; however it makes no assumptions about the variation of moisture content with depth.

The soil water balance can be represented by,

$$SMD = (In + I) - (Q + E_a) \quad (1)$$

Where, SMD = soil moisture deficit (mm); In = infiltration (mm); I = irrigation depth (mm) and E_a = actual evpotranspiration (mm).

$$In = P - RO \quad (2)$$

Where, In = infiltration; P = precipitation; and RO = Surface runoff.

Recharge only occurs if the soil moisture deficit is less than zero. If SMD < 0.0, then

Recharge = -SMD and SMD = 0.0 (3)

Results and Discussion

Soil moisture balance method has been used to estimate groundwater recharge from agricultural fields of CTAE Udaipur for the period 1980 to 2002. In the soil moisture balance approach, recharge is assumed to occur on days when the calculation leads to a negative soil moisture deficit. As the soil moisture deficit becomes zero the soil reaches field capacity and becomes free draining. Consequently, recharge equals the quantity of water in excess of that required to bring the soil to field capacity. The groundwater recharge estimated from soil moisture balance method has been shown in Table 1.

Fig.1 Location map of the study area

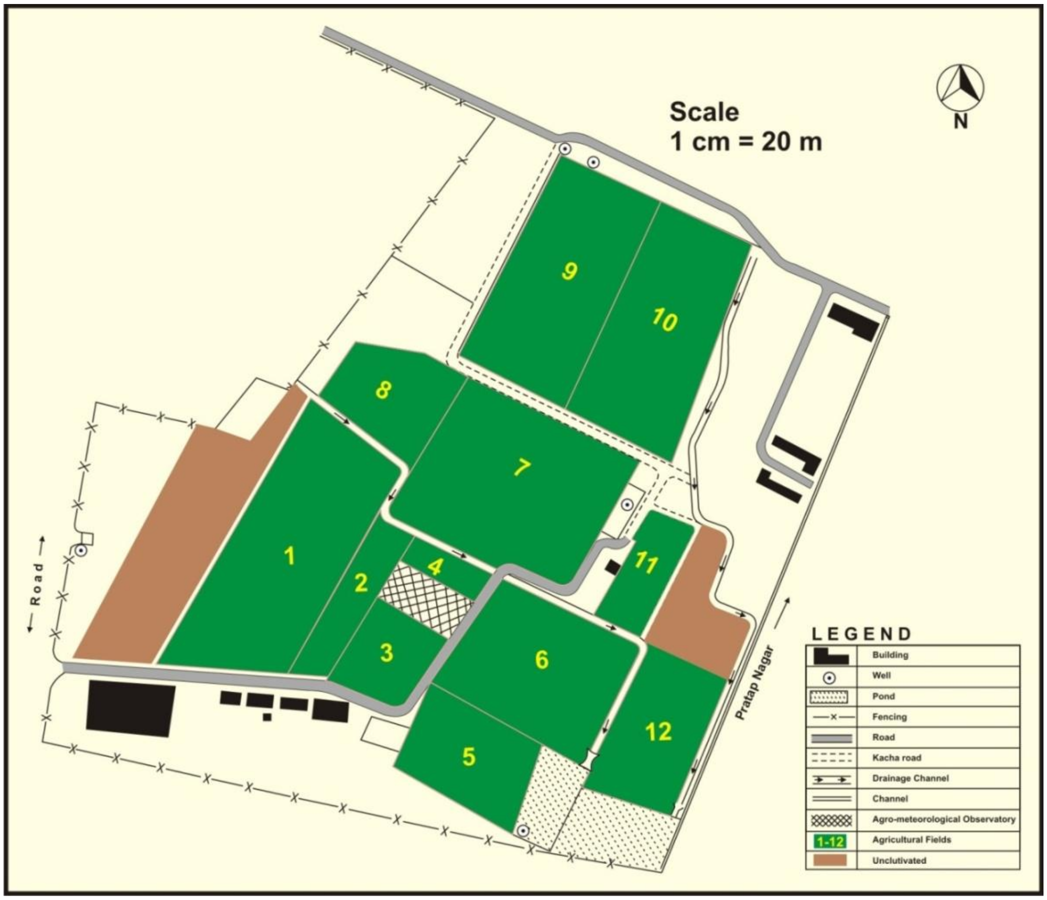

Fig.2 Soil moisture balance: (a) components, (b) soil moisture deficit

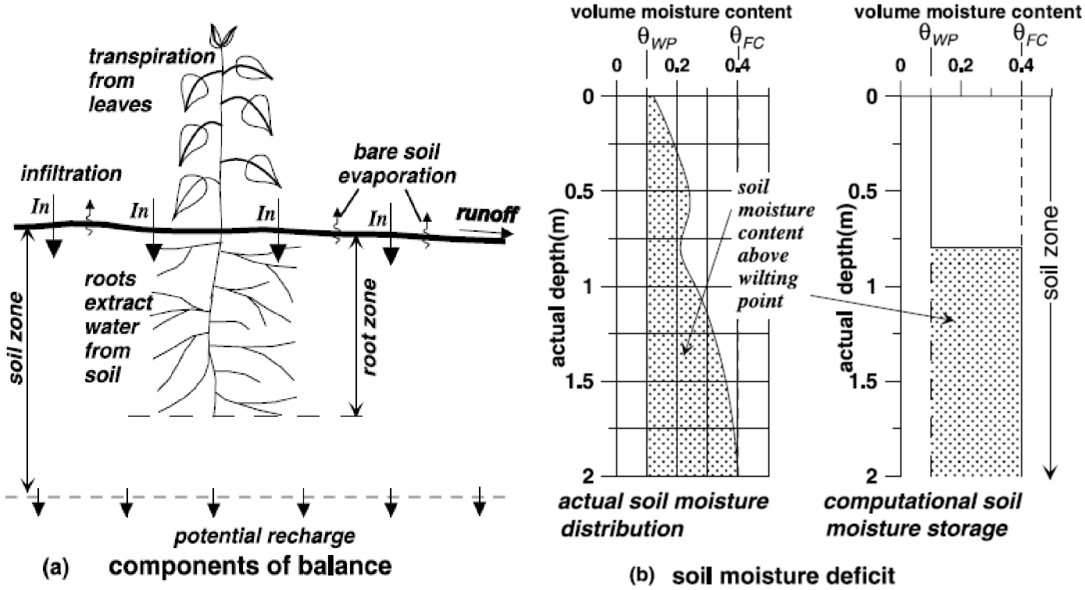

Fig.3 Recharge from agriculture fields by soil moisture balance method

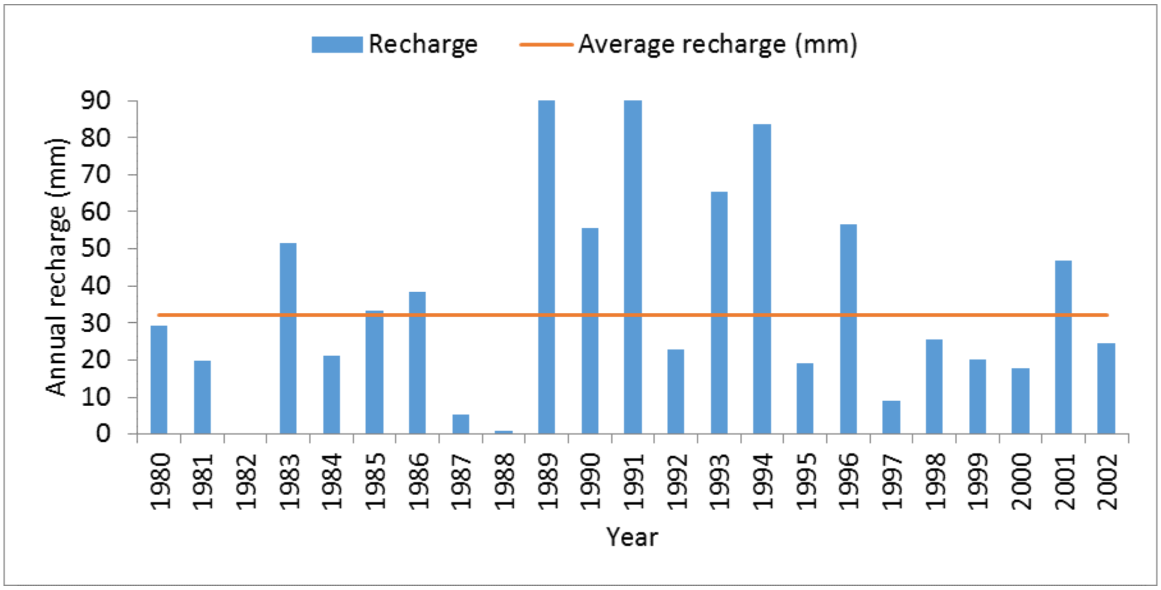

Table.1 Estimated recharge of agricultural fields of CTAE Udaipur for the period of 1980 – 2003

Year	Rainfall (mm)	Groundwater recharge		Runoff	
		mm	Per cent of rainfall	mm	Per cent of rainfall
1980	497.2	29.3	5.9	125.2	25.2
1981	599.4	19.8	3.3	192.9	32.2
1982	344.2	0.0	0.0	98.6	28.6
1983	943.8	51.4	5.4	401.9	42.6
1984	543	21.3	3.9	154.8	28.5
1985	443.5	33.5	7.6	238.9	53.9
1986	356.8	38.5	10.8	129.1	36.2
1987	319.9	5.2	1.6	70.6	22.1
1988	447.8	0.8	0.2	148.7	33.2
1989	895.2	90.4	10.1	287.8	32.2
1990	608.2	55.7	9.2	155.4	25.6
1991	591.9	96.8	16.4	221.5	37.4
1992	694.5	22.8	3.3	327.1	47.1
1993	325.1	65.3	20.1	183.4	56.4
1994	771.9	83.6	10.8	221.3	28.7
1995	290.1	19.0	6.5	49.1	16.9
1996	628.2	56.8	9.0	171.6	27.3
1997	588.6	9.0	1.5	224.2	38.1
1998	513.1	25.5	5.0	140.3	27.3
1999	310.8	20.3	6.5	99.5	32.0
2000	381.5	17.7	4.6	124.1	32.5
2001	522.6	47.0	9.0	174.1	33.3
2002	361.3	24.5	6.8	71.4	19.8
Average	520.8	32.9	6.9	174.4	36.3

Results shows that the highest recharge 96.8 mm has been found during the year 1991 i.e. 16.4 per cent of annual rainfall and no recharge has been found during the year 1982 due scattered rainfall in the year. The highest runoff 401.9 mm has been found during the year 1983 i.e. 42.6 per cent of annual rainfall and the lowest runoff 49.1 mm has been found during the year 1995 i.e. 16.9 per cent of annual rainfall.

From the soil moisture balance method the average recharge has been found that32.9 mm (Fig. 3) i.e. 6.9 per cent of the average annual rainfall and the average annual runoff has been found 174.4 mm i.e. 36.3 per cent of rainfall. Groundwater recharge is the downward flow of water reaching the water table and the groundwater reservoir. For a sufficiently long period of years, and in aquifers not subjected to pumped extractions, the mean annual value of the recharge is equivalent to the rate of discharge. Thus, groundwater recharge over an area is normally equal to infiltration excess.

The 23 years (1980 – 2002) groundwater recharge of CTAE farm has been estimated with soil moisture balance method. The recharge estimated using soil moisture balance method for agricultural plots of CTAE farm during the period of 1980 – 2002. From the soil moisture balance method the average recharge has been found that 32.9 mm *i.e.* 6.9 per cent of the average annual rainfall.

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