

Assesment of Natural Groundwater Recharge from Rainfall through Modelling

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ABSTRACT: Water is indispensable to all life on earth. However, fresh water is constantly formed newly through a phenomenon known as hydrological cycle. Ground water recharge is the process by which water percolates down the soil and reaches the water table. Estimation of groundwater recharge from precipitation is vital for water resources assessment and planning. It is particularly important in regions like Puducherry where there is large demand for ground water supplies. Where such resources are the key to economic development. Recharge is a fundamental component of groundwater systems, and in groundwater-modeling exercises recharge is either measured and specified or estimated during model calibration. The most appropriate way to represent recharge in a groundwater model depends upon physical factors, availability of data and study objectives. In this paper soil water balance technique was used, which we define here as the quantity of water that flows into the aquifer after the natural losses like evapotranspiration, runoff and soil moisture content. For calculating the average monthly evapotranspiration and runoff, we adopted Food and Agricultural Organization Penman-Monteith (FAO56 – PM) equation and SCS runoff curve number.

KEYWORDS: Evapotranspiration, Runoff, Recharge, Soil texture

I. INTRODUCTION

Groundwater, which constitutes 22% of fresh water of the world, is potable at source available in-situ and has a low temporal variability. These characteristics have made groundwater the most important source of water for the current generation. Globally, over two billion people depend directly upon groundwater for drinking water. Moreover, about 40% of the world's irrigated agriculture depending largely on it (UNESCO, 2004). Owing to increased demand and natural climate change, groundwater is often abstracted beyond its natural recharging capacity resulting in depletion of the resource. The amount of water potentially to be extracted from an aquifer without causing depletion is primarily dependent on the groundwater recharge. Thus, a quantitative evaluation of the resource is a pre-requisite especially in developing countries like India, where most people rely on it as a source of potable water and domestic uses. The quantities of water going through various individual paths of the hydrological cycle can be described by the continuity equation known as water-budget equation or hydrologic equation.

For a given area, say a catchment, in an interval of time 't',

$$\text{Mass inflow} - \text{mass outflow} = \text{change in mass storage}$$

Various phases of the hydrological cycle, such as rainfall, runoff, evaporation and transpiration are all non-uniformly distributed both in time and space. Rainfall is the principal means for replenishment of moisture in the soil water system and recharge to ground water. The amount of moisture that will eventually reach the water table is defined as natural ground water recharge. The amount of this recharge depends upon the duration of rainfall, evapotranspiration, runoff, the antecedent soil moisture conditions and the soil type. In hydrology, it is found that evaporation and transpiration processes can be considered advantageously under one head as evapotranspiration (ET_0). Evaporation and transpiration occur simultaneously and it is difficult to distinguish accurately between the two processes. Both processes depend on solar radiation, air temperature, relative humidity (i.e., vapor pressure deficit) and wind speed. Several models had been proposed by many authors to estimate evapotranspiration, but FAO-56 PM model gives fine result. Jensen-Haise and Hargreaves models underestimated ET_0 under limited data input when compared with those computed using FAO-56 PM model (Omotayo B. et al., 2009). Average monthly runoff was calculated by using "soil

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conservation service” popularly known as “SCS Runoff Curve Number” method. There are studies showing “SCS Runoff Curve Number” method will give better results when compared to other methods (Ponce and Hawkins 1996).

II. MATERIALS AND METHODS

Study Area

Puducherry is the capital of the Union Territory of Puducherry. It is located on the Coromandel coast of Bay of Bengal, at a distance of 162 km south from Chennai. It is situated between 11° 46' and 12° 30' of north latitude and between 79° 36' and 79° 52' of east longitude. It is bounded on the east by the Bay of Bengal and on the other three sides by Cuddalore and Villupuram districts of Tamil Nadu.

Data Collected

Puducherry soil profile data, monthly meteorological parameters like: rainfall, sun shine duration, maximum air temperature, minimum air temperature, mean air temperature, relative humidity and wind speed were obtained from the Public Works Department, Puducherry, India.

Model Description

A consultation of experts and researchers was organized by FAO in May 1990, in collaboration with the International Commission for Irrigation and Drainage and with the World Meteorological Organization, to review the FAO methodologies on crop water requirements and to advice on the revision and update of procedures. The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters.

The FAO Penman-Monteith method to estimate ET_o ,

$$ET_o = \frac{0.408\Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

Where,

ET_o = reference evapotranspiration [mm day^{-1}];

R_n = net radiation at the crop surface [$\text{MJ m}^{-2} \text{day}^{-1}$]; G = soil heat flux density [$\text{MJ m}^{-2} \text{day}^{-1}$];

T = mean daily air temperature at 2 m height [$^{\circ}\text{C}$]; u_2 = wind speed at 2 m height [m s^{-1}];

e_s = saturation vapour pressure [kPa]; e_a = actual vapour pressure [kPa];

$e_s - e_a$ = saturation vapour pressure deficit [kPa]; Δ = slope vapour pressure curve [$\text{kPa } ^{\circ}\text{C}^{-1}$];

γ = psychrometric constant [$\text{kPa } ^{\circ}\text{C}^{-1}$].

The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The curve number method was developed by the USDA Natural Resources Conservation Service, which was formerly called the Soil Conservation Service or SCS — the number is still popularly known as a “SCS runoff curve number” in the literature. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. The runoff curve number is based on the area’s hydrologic soil group, land use, treatment and hydrologic condition. USDA indicates the runoff curve numbers for characteristic land cover descriptions and a hydrologic soil group.

The runoff equation is:

$$Q = \begin{cases} 0 & \text{for } P \leq I_a \\ \frac{(P - I_a)^2}{P - I_a + S} & \text{for } P > I_a \end{cases}$$

Where,

Q = runoff (mm); P = rainfall (mm);

S = potential maximum soil moisture retention after runoff begins (mm)

I_a = initial abstraction (mm); historically, it has generally been assumed that $I_a = 0.2S$

The runoff curve number, CN, is related

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$$S = \frac{1000}{CN} - 10$$

CN has a range from 30 to 100; lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential. The lower the curve number, the more permeable the soil is. The curve number is related to soil texture, soil infiltration capability, land use, and the depth of the seasonal high water table. To account for different soils ability to infiltrate, NRCS has divided soils into four hydrologic soil groups (HSGs). Puducherry region soil profile is mainly divided into three main groups: pure sand, sandy clay, clayey sand. For pure sand HSG Group 'A', for sandy clay HSG Group 'B' and for clayey sand HSG Group 'C' are selected. Soil moisture content is a factor influencing the infiltration rate. Soil moisture content indicates the amount of water present in the soil. Soil moisture content differs from place to place because of the type of soil present in that place.

III. RESULTS AND DISCUSSION

Results of average monthly evapotranspiration, derived from 'Penman Monteith Method' by considering temperature, solar radiation and wind speed are given in Table 1.

Table: 1. Average monthly evapotranspiration

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Temperature (^o c)	24.50	25.20	27.20	29.60	31.75	32.10	30.80	30.00	29.60	27.95	25.95	24.70
Solar radiation (Kwh/m ² /day)	4.69	5.65	6.37	6.14	5.87	5.32	4.95	5.10	5.29	4.37	3.90	4.09
Wind speed (m/s)	1.9	2.1	2.5	2.9	3.0	3.2	2.8	2.7	2.2	1.9	1.8	1.9
Evapo- transpiration (ET ₀) (mm)	3.195	4.095	5.044	5.133	5.397	5.513	5.052	5.003	4.739	3.744	3.241	3.265

Soil moisture content is one of the factor influencing the infiltration rate. The soil moisture content will vary from place to place because it depends on the soil texture present in that area. Soil water content is derived by conducting a laboratory modelling of different percentages of sand and clay. For pure sand, sandy clay and clayey sand, the modelling is carried out by varying percentage of sand and clay. Soil water content values observed from modelling are as follows: 0.0216 mm for pure sand, 0.0228 mm for sandy clay and 0.0288 mm for clayey sand. From the obtained values it is clear that if the percentage of sand is more means the soil water content will less and vice versa for clay. Critical analysis of results has yielded the following observations: (i) Evapotranspiration values are high in the month

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of June and low in the month of January. (ii) For all three types of soil i.e., pure sand, sandy clay and clayey sand it was observed that recharge is more in the month of November and less in the month of March.

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Precipitation (mm)	32	9	9	18	50	45	82	154	114	229	285	144
Evapo-transpiration (ET ₀) (mm)	3.195	4.095	5.044	5.133	5.397	5.513	5.052	5.003	4.739	3.744	3.241	3.265
Runoff (mm)	0	0	0	0	1.7063	0.8963	11.5724	52.0136	27.246	107.6039	153.6870	45.4046
Soil moisture content (mm)	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216
Recharge (mm)	28.7828	4.8834	3.9338	12.8448	42.8744	38.5683	65.3531	96.961	81.9929	117.6305	128.0498	95.308

Table: 2. Average monthly recharge for pure sand

Results of average monthly runoff, derived by 'SCS Curve Number' for pure sand are given in the Table 2.

Table: 3. Average monthly recharge for sandy clay

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Precipitation (mm)	32	9	9	18	50	45	82	154	114	229	285	144
Evapo-transpiration (ET ₀) (mm)	3.195	4.095	5.044	5.133	5.397	5.513	5.052	5.003	4.739	3.744	3.241	3.265
Runoff (mm)	2.2761	0	0	0.0133	9.2871	6.9876	28.2747	84.7291	51.8448	151.5579	203.7226	76.256
Soil moisture content (mm)	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228
Recharge (mm)	26.5055	4.8822	3.9326	12.8303	35.2924	32.4758	48.6496	64.2443	57.3929	73.6753	78.013	64.4554

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Results of average monthly runoff, derived by ‘SCS Curve Number’ for sandy clay and clayey sand are given in the Table 3 and 4.

Table: 4. Average monthly recharge for clayey sand

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Precipitation (mm)	32	9	9	18	50	45	82	154	114	229	285	144
Evapo-transpiration (ET ₀) (mm)	3.195	4.095	5.044	5.133	5.397	5.513	5.052	5.003	4.739	3.744	3.241	3.265
Runoff (mm)	6.3346	0	0	0.9675	17.1119	13.8171	41.465	105.4067	68.9629	176.5723	230.8575	96.1521
Soil moisture content (mm)	0.0288	0.0288	0.0288	0.0288	0.0288	0.0288	0.0288	0.0288	0.0288	0.0288	0.0288	0.0288
Recharge (mm)	22.441	4.8762	3.9266	11.8701	27.4616	25.6403	35.4533	43.5607	40.2688	48.6549	50.8721	44.5533

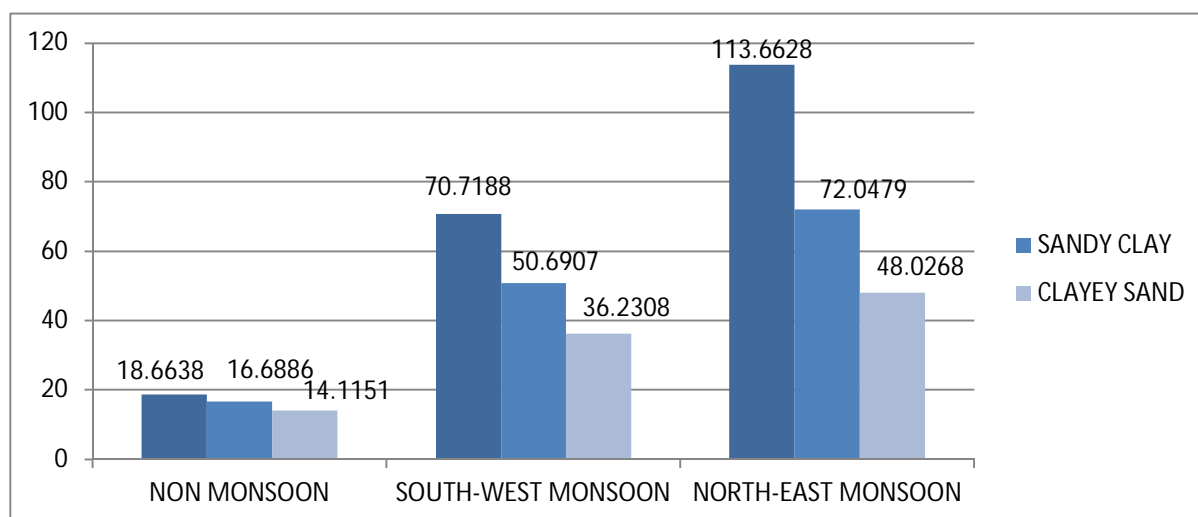


Figure: 1. Average seasonal groundwater recharge

In India, water year is divided into three seasons: south-west monsoon, north-east monsoon and non-monsoon seasons. South-west monsoon is from June to September, north-east monsoon is from October to December and non-monsoon is from January to May. India receives maximum rainfall from south-west monsoon and north-east monsoon. Groundwater recharge will vary from season to season. So the average recharge for all the three seasons is shown in Figure 1.

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IV. CONCLUSION

A methodology has been presented with step-by-step procedure to estimate the natural groundwater recharge from rainfall based upon soil moisture balance approach. The methodology incorporates the theory of SCS method for finding the storage index. This methodology is expected to give better estimates of ground water recharge. However, to improve the reliability of ground water recharge estimates, we must monitor aquifer behaviour on a continuous or periodic basis.

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