556.362.6:551.579.5 (282.253)

Comparative study of groundwater recharge rates in parts of Indo-Gangetic and Sabarmati alluvial plains

P. S. DATTA, B. I. DESAI* and S. K. GUPTA

Physical Research Laboratory, Ahmedabad

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ABSTRACT. Tritium tracing data of soil moisture movement for groundwater recharge estimation from four river basins in India have been examined. Of the two commonly used empirical formulae, viz., Amritsar and Chaturvedi formulae, the former gives consistently higher estimate of groundwater recharge in all the four regions. The Chaturvedi formula gives reasonable estimates of groundwater recharge for sandy loam soils in parts of Indo-Gangetic plains, but gives significantly higher values of groundwater recharge for similar soils in Sabarmati basin. For each basin based on tritium tracing of soil moisture movement, empirical relations have been developed to estimate regional groundwater recharge. Since the hydrometeorological factors vary significantly from basin to basin and within parts of a basin, it is desirable to investigate each region individually.

1. Introduction

Estimation of recharge rates for aquifers is essential for evaluation of groundwater resources. Conventionally, quantity of recharge is estimated from groundwater level fluctuations. However, it is difficult to estimate accurately the parameters needed for this transformation. Non-availability and uncertain nature of hydrological data, e.g., evapotranspiration, runoff, etc, in many areas restrict the use of water balance equation for groundwater recharge estimation. Direct tracing of water movement by tracer techniques is, therefore, being increasingly preferred over traditional methods. Sukhija and Rama (1973) have successfully tested the applicability of environmental tritium method in semi-arid regions of Gujarat. The limitations in this method and various other conventional methods have been briefly described by Datta et al. (1977). Tracing of soil moisture by artificially produced tritium (Datta et al. 1973; Datta 1975; Datta et al. 1977) is one of the most direct method for estimating groundwater recharge in the sense that it obviates the shortcomings in other methods to some extent, Its limitation, however, is that the estimates of recharge obtained by this method are commonly based on studies over a period of 1-2 years.

In most places, major source of recharge to aquifers is precipitation. Since precipitation is irregularly distributed in time and place, so is the recharge from it. The amount of precipitation that reaches the zone of saturation depends on several factors, such as, physical properties of the soil, the topography, vegetation cover, land use, soil moisture deficit, the depth of watertable the intensity, duration and seasonal distribution of rainfall, the air temperature and other meteorological factors, e.g., humidity, wind velocity, evaporation etc.

In the present paper we compare results of groundwater recharge investigations in four river basins in India. The basins investigated are : (i) Upper Indus basin (in Punjab), (ii) Upper Yamuna basin (in Haryana and parts of western Uttar Pradesh), (iii) Ganga-Ramganga basin (in western Uttar Pradesh) and (iv) Sabarmati basin (in Gujarat).

2. Characteristics of basins

The Upper Indus, Upper Yamuna and the Ganga-Ramganga basins all form part of Indo-Gangetic alluvial plains. The groundwater aquifers in these regions have extensive lateral extent and thickness and occur under both confined and unconfined conditions. The soils underlying the area are derived from alluvial deposits of quaternary age. These deposits consist of a succession of clay, sand and silt layers. The region is relatively flat with a slope varying from 0.2 m/km to 0.9 m/km. Soils in Sabarmati basin (except in rocky areas in northeast) are also derived from alluvial deposits of quaternary age. Predominant

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*Present address : Gujarat Water Resources Development Corpn. Ltd., Gandhinagar.
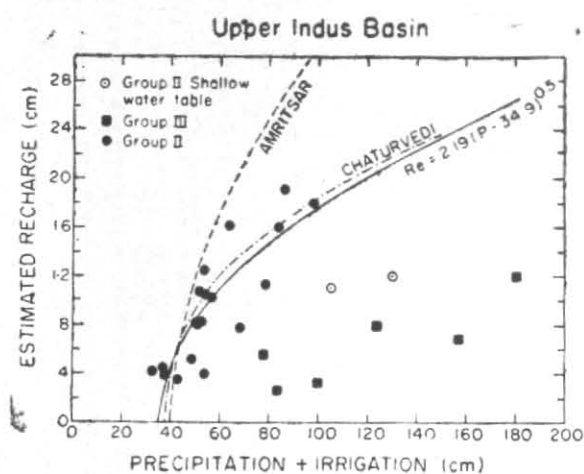
Fig. 1. Observed relationship of estimated vertical recharge to phreatic aquifers with precipitations irrigation in Upper Indus basin (in Punjab). Curves based on Amritsar and Chaturvedi formulae are also shown. Data of tritium tracing experiments from Datta (1975)
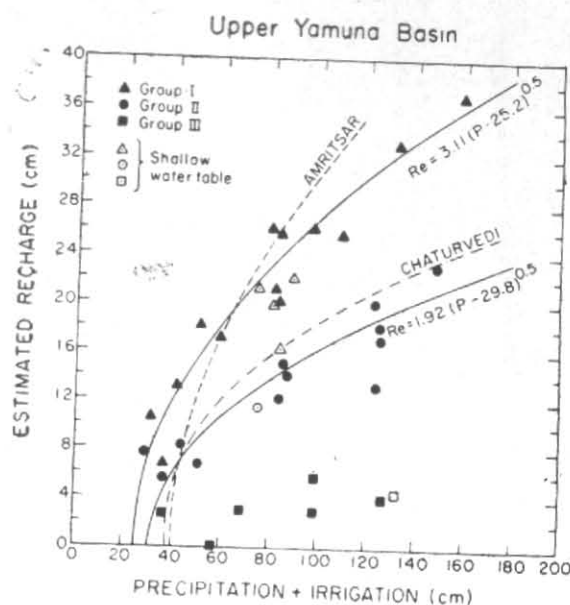

Fig. 2. Observed relationship of estimated vertical recharge to phreatic aquifers with precipitation+ irrigation in Upper Yamuna basin (in Haryana and parts of western Uttar Pradesh). Data of tritium tracing experiments from Datta (1975)
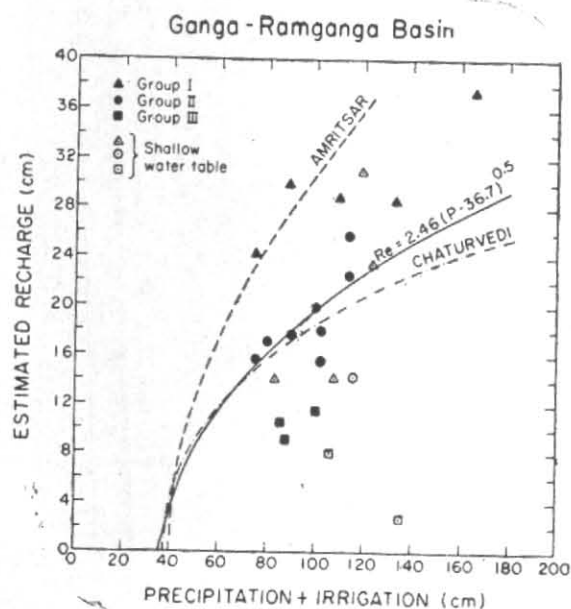

Fig. 3. Observed relationship of estimated vertical recharge to phreatic aquifers with precipitation+ irrigation in Ganga-Ramganga basin (in western Uttar Pradesh), Data of tritium tracing experiments from Datta (1975)
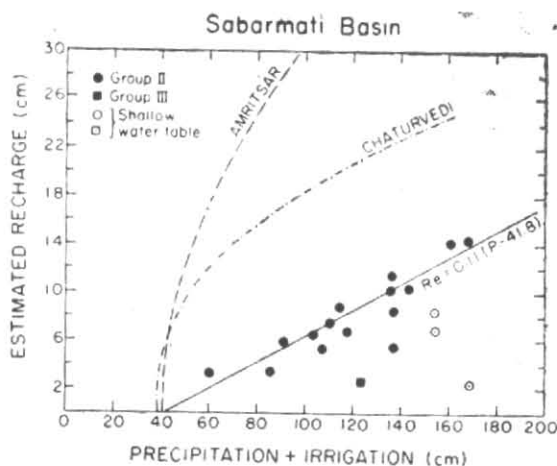

Fig. 4. Observed relationship of estimated vertical recharge to phreatic aquifers with precipitation+ irrigation in Sabarmati basin (in Gujarat). Data of tritium tracing experiments from Datta *et al.* (1977)

soil in the basin may be classified as sandy loam (Guajrat State Agricultural Atlas, 1968). Unlike in the Indo-Gangetic basin, there is practically no rainfall in the winter season. Average temperatures and evapotranspiration in Sabarmati basin is significantly higher than that in the other basins under investigation. Some pertinent hydrometeorological characteristics of the river basins under investigation are given in Table 1.

3. Results and discussion

Present sudy is based on the groundwater recharge estimated by using tritium tagging method (Zimmerman et al. 1967, Datta et al. 1973, Datta 1975, Datta et al. 1977). The method has advantage in tracing soil water movement as tritium forms part of water molecule and the tracer input function is well defined both in time and space. Briefly the method consists of labelling a layer of soil moisture (below root zone) with tritiated water and subsequent (after a pre-determined period) sampling of soil at the place of experiment. Moisture from soil samples is then extracted and its tritium content determined in laboratory. Groundwater recharge during the period of experiment is computed from the observed displacement of tritium peak. For details of experimental procedure and computation of recharge reference is made to Datta et al. (1973), Datta (1975) and Datta et al. (1977).

Data of groundwater recharge in Indo-Gangetic plains is from the tritium tracing experiment done by Datta (1975); Datta and Goel (1977) and Goel et al. (1977). Estimation of groundwater recharge in Sabarmati basin is from the tritium tracing experiments conducted by the Groundwater Cell, Physical Research Laboratory, Ahmedabad (Annual Report, Groundwater Cell PRL, 1977, Datta et al. 1977).

To estimate regional groundwater recharge from the spot studies of tritium tracing experiments, it is useful to determine a regional relationship between the water input (precipitation+irrigation) and estimated groundwater recharge applicable for each major soil group in the study area. It is expected that wherever such regional relationships can be established, long term average groundwater recharge can be estimated from a limited number (both in time and space) of tritium tracing experiment.

Based on clay content in the top 1 m section, soil of all the tritium tracing stations (105 in number) from the investigated areas have been grouped as follows :

Group I   (Sandy) — Clay$<$10 per cent

Group II   (Sandy loam) — Clay 10-20%

Group III   (Clayey) — Clay$>$20 per cent

Results of tritium tracing experiments for each of the four basins are plotted separately in Figs. 1-4.

It is seen from Figs. 1-4 that the groundwater recharge decreases with increase in clay content of the top soil. This is as it should be as the permeability is inversely related to the clay content of the soils. In Indo-Gangetic plain an empirical exponential relationship (Eqn. 1) between fractional recharge and the average clay content of the soil has been shown to hold (Datta 1975, Goel et al. 1977).

$$F = 0.40 \ \exp \ (-0.046. \ A_{cp}) \tag{1}$$

where, F=Recharge/water input

A_{cp}=Average clay content of soil in per cent

It is also seen from Figs. 1-4 that for station with shallow water table ($<$4 m deep) recharge for a given water input is comparatively lower than in regions with similar other characteristics, but deep watertable. Empirical relationship of the type :

$$R_e = k_1 \ (p - k_2)^{k_3} \tag{2}$$

have been fitted to the data points for soils of Group I and Group II in each case. In the above relationship R_e is estimated recharge in cm, P is water input in cm, k_1, k_2 and k_3 are constants. Best fit relationships (least square deviation) for each basin are given in Table 2. It is seen that in Indo-Gangetic plains relationships with the value of exponent 0.5 fit the data points reasonably well. The data points of Sabarmati basin, however, seem to fit better by a linear relationship:

$$R_e = 0.13 \ (p - 39) \tag{3}$$

It is not possible to compare the results of the tritium tracing experiments and the given empirical relations between the actual rainfall and recharge estimates as the same are not available from other independent studies in all the basins. However, it is worth mentioning that studies made by Satish Chandra and Saksena (1975) show that in Ganga-Ramganga basin the estimate of groundwater recharge by tritium tracing method, Chaturvedi formula and water balance method are in close ($\pm$17 per cent) agreement with each other.

In Figs. 1-4 we have also plotted the empirical relations (commonly known as Amritsar formula and the Chaturvedi formula) used for estimation of groundwater recharge.

Amritsar formula (Sehgal 1973)

$$R_e = 3.9 \ (p - 40.6)^{1/2} \tag{4}$$

Chaturvedi formula (Chaturvedi 1946)

$$R_e = 3.5 \ (p - 38)^{2/5} \tag{5}$$

where, R_e =Estimated groundwater recharge in cm.

p = Precipitation + supplemental irrigation in cm.

It is seen that the Amritsar formula gives in general a consistently higher estimate of groundwater recharge while the Chaturvedi formula seems largely applicable to the Group II soils in the Upper Indus and the Ganga-Ramganga basins. The Chaturvedi formula may also be applicable to Group II type of soils in Upper Yamuna basin with minor adjustments. Even in these regions better estimate of long term average groundwater recharge may be made by using the empirical relations given in Table 2.

In Sabarmati basin, however, both Amritsar and Chaturvedi formula give higher estimate of groundwater recharge than obtained by tritium tracing data, even though the soils at most of the experimental stations are of Group II type. It is also interesting to note that extrapolation of all the above relationships (Eqns. 2 & 3) based on the results of tritium tracing experiments in the investigated areas indicate that on an annual basis there is practically no groundwater recharge if the water input is less than k_2. It is seen from Table 2 that in Indo-Gangetic plains the average value of k_2 is between 30-37 cm while in Sabarmati basin it is about 39 cm. The uncertainty in these estimates is large as indicated by the chi-square parameter computed for each basin.

Since soil conditions in all the four basins are more or less similar, the large difference observed in the groundwater recharge rates in Indo-Gangetic and the Sabarmati alluvial plains may be ascribed to hydrometeorological factors, such as rainfall distribution, temperature and evapotranspiration etc. While it would be desirable to undertake a detailed factor analysis to determine the relative importance of various hydrometeorological parameters in controlling the soil moisture movement and hence groundwater recharge, present data are not sufficient enough to undertake such studies.

It can be seen from Table 1 that in Indo-Gangetic plains, significant part (10-16 per cent) of the average annual rainfall occurs during post-monsoon and winter months. While in Sabarmati basin only 4 per cent of the average annual rainfall occurs during the same period (Dhar and Rakhecha 1975). Both during the monsoon (June-September) as well as during the non-monsoon period average temperature and pan evaporation values are also significantly higher in Sabarmati basin (Rao *et al.* 1971). These hydrometeorological factors may cause higher moisture deficit in the upper soil layers. As a result of the higher moisture deficit at the beginning of monsoon, more water input is needed to fulfil the same before actual groundwater recharge can take place. This is indicated by the parameter k_2 in Table 2. Higher potential evapo-

TABLE 1

Hydrometeorological characteristics of the river basins

River basin	Annual average values			Average rainfall† during postmonsoon and winter months (% Annual average)
	Rainfall* (cm)	Temp.* (°C)	Pan** evaporation (cm)	
1 Upper Indus basin (in Punjab)	55	22.5	250	16
2 Upper Yamuna basin (in Haryana† part of western Uttar Pradesh)	70	24.0	260	12
3 Main Ganga basin including Ramganga (western Uttar Pradesh)	128	22.0	200	11
4 Sabarmati	70	27.5	350	4

*Based on maps given by Chaturvedi (1976)
**Based on maps given by Rao *et al.* (1971)
†Based on data given by Dhar & Rakhecha (1975)

TABLE 2

Least square fit empirical relations for estimation of groundwater recharge based on tracing of soil moisture movement

Basin/Sub-basin	Soil* group	Empirical relation	No. of points	
1 Upper Yamuna	I	$3.11\,(p\text{-}25.2)^{0.5}$	14	5.26
2 Upper Yamuna	II	$1.92\,(p\text{-}29.8)^{0.5}$	10	2.60
3 Upper Indus	II	$2.19\,(p\text{-}34.9)^{0.5}$	18	8.92
4 Ganga-Ramganga	II	$2.46\,(p\text{-}36.7)^{0.5}$	8	7.14
5 Sabarmati	II	$0.13\,(p\text{-}39)$	15	3.20

*Soil Group I : Clay < 10 per cent
Soil Group II : Clay 10-20 per cent

ration during monsoon in Sabarmati basin may also be expected to reduce the net groundwater recharge for a given amount of water input.

4. Conclusions

This comparative study has brought out that it is possible to develop empirical relationships to estimate groundwater recharge for each region within which soil characteristics and hydrometeorological factors can be reasonably taken to be uniform. Since these factors vary significantly from basin to basin and within parts of a basin; extrapolation of such empirical formula developed for a given region to other regions may lead to erroneous estimates. Development of a comprehensive formula incorporating all variable factors controlling groundwater recharge is rather difficult and till this is accomplished it is desirable to treat each region individually.

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