Estimation of alluvial aquifer parameters by a single-well dilution technique using isotopic and chemical tracers: a comparison

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Abstract The unconfined aquifer hydraulic conductivity (*K*) values are estimated using a single well tracer dilution technique at different sites located along the banks of the River Ganges, India. The whole water column labelling approach was adopted for field experiments. Tritium was used as a radiotracer and NaCl as a chemical tracer. When compared, the *K* values estimated by the NaCl tracer are lower than those estimated by the tritium tracer. However, the relationship between the *K* values estimated by the two methods is linear and is expressed by a simple equation. The relationship can be used to obtain comparatively accurate values of *K* for unconfined alluvial aquifers, when the NaCl tracer is used.

INTRODUCTION

The vast Gangetic plains occupying most of northern India pose a challenge to the hydrogeologist, as the heterogeneity of the aquifers requires information on the spatial variation of the aquifer parameters. Nautiyal (1991), who presented hydraulic conductivity (*K*) values of unconfined aquifer from over 200 sites in the upper Ganga basin, reported that the *K* values show large spatial variations. The most commonly adopted method for the determination of alluvial aquifer *K* is a pumping test, that is time consuming, costly and requires a specific field set-up. The other two common methods viz.: column drainage and particle size analysis, do not yield reliable results. The single well tracer dilution technique, that has a definite advantage over the above methods has been under-used in the Indian sub-continent.

The basic theory and experimental details for the single well tracer dilution technique are well-established (Drost, 1983; Bedmar, 1983). The technique involves introduction of a known quantity of tracer in a suitable well and monitoring of the tracer concentration over a time period. The filtration velocity (V_f) in m day^{-1} can be estimated using the following relationship (Drost, 1983):

$$V_f = \frac{\pi r_1}{2\alpha t}\ln\left(\frac{C_0}{C}\right) \qquad (1)$$

where, r_1 is the internal radius of the well (m), t is time (days), C_0 and C are the tracer concentration at time $t = 0$, and at time $= t$. α is the correction factor to eliminate the distortion of the groundwater flow lines caused by the presence of the well. For a well constructed with plastic screens and without gravel pack, α can be calculated using the following relationship (Drost & Klotz, 1983):

$$\alpha = \frac{4K_1}{K_1\left[1+\left(\frac{r_1}{r_2}\right)^2\right]+K\left[1-\left(\frac{r_1}{r_2}\right)^2\right]} \tag{2}$$

Where, K_1 is the hydraulic conductivity of the well screen, r_1 and r_2 are the internal and external radius of the well screen, respectively. The uncommon term K_1 (cm s^{-1}) can be estimated as $0.1f$ (Drost & Klotz, 1983), where f is the percentage perforation of the well screen. Calculation of α requires prior information about K, the hydraulic conductivity of the aquifer. However, the influence of K on α will be negligible when $K << K_1$. The method can be used to estimate K values of the aquifer if the hydraulic gradient (I) near the well is known, by using the Darcy's equation, $V_f = KI$.

In the present study the results obtained using a radiotracer (^3H) and a chemical tracer (NaCl) are compared.

METHOD

Tracer dilution experiments were conducted at four sites located on the banks of the River Ganges in the vast Gangetic plains, viz.: Balawali, Rawalighat, Brijghat and Rajghat (Fig. 1). Piezometers installed on either side of the River Ganges were selected for the experiment. Kumar & Nachiappan (1992) have presented the construction details of the wells. A known quantity of ^3H and NaCl solutions were introduced into the wells near the water table to label the whole column of water. A special device fabricated for the purpose was used to thoroughly mix the water column as well as to collect water samples from the well. The samples were then transported to the laboratory for analysis. The tritium activity was measured using a liquid scintillation counter, and the concentration of the NaCl using an electrical conductivity meter.

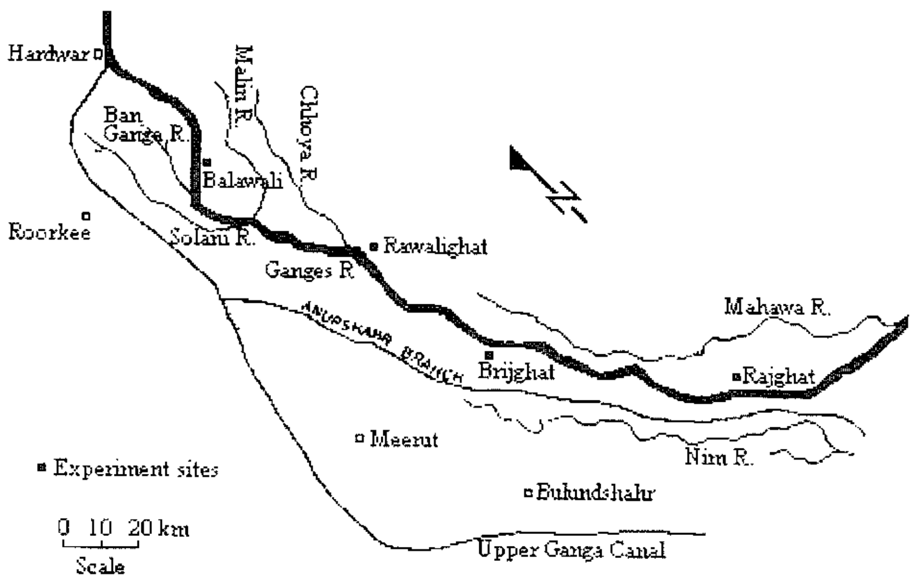

Fig. 1 Map of the Ganges River reach between Hardwar and Narora showing the location of the experimental sites.

Table 1 Hydraulic gradient, initial hydraulic conductivity (by Hazen's method) and results of tracer dilution techniques adopted at sites along the River Ganges, India.

Site	Well	Hydraulic gradient, I	K_p ($m\ s^{-1}$)	Tritium tracer: $[\ln(C_0/C)]/t$	V_f ($m\ s^{-1}$)	K_T ($m\ s^{-1}$)	NaCl tracer: $[\ln(C_0/C)]/t$	V_f ($m\ s^{-1}$)	K_N ($m\ s^{-1}$)
Balawali	BR1	0.340	1.93×10^{-5}	2.939	9.50×10^{-7}	2.72×10^{-6}			
Rawalighat	RL1	5.180	2.36×10^{-5}	4.768	1.50×10^{-6}	2.89×10^{-7}	0.915	2.88×10^{-7}	5.79×10^{-8}
	RR1	4.160	2.36×10^{-5}	4.367	1.37×10^{-6}	3.36×10^{-7}	2.775	8.73×10^{-7}	2.08×10^{-7}
Brijghat	GL1	0.310	2.16×10^{-5}	2.674	8.42×10^{-7}	2.72×10^{-6}	0.667	2.10×10^{-7}	6.83×10^{-7}
	GR1	0.260	2.16×10^{-5}	3.253	1.02×10^{-6}	3.94×10^{-6}	2.770	8.72×10^{-7}	3.36×10^{-6}
Rajghat	NL1	0.052	2.11×10^{-5}	6.442	2.03×10^{-6}	3.90×10^{-5}	5.882	1.85×10^{-6}	3.56×10^{-5}
	NR1	0.054	2.11×10^{-5}	4.121	1.30×10^{-6}	2.40×10^{-5}	3.004	9.46×10^{-7}	1.75×10^{-5}

The slopes of the tracer concentration *vs* time plots are shown in Table 1. In the present study, as all the wells that were used for the experiment had the same construction geometry, a linear relationship between α and K was obtained using the calculated K_1 value (equation (2)) to facilitate a quick estimation of α values:

$$\alpha = -0.00039K + 2.166 \quad (3)$$

It is clear from equation (3) that α values are not sensitive to K values, as $K_1 >> K$ and α typically ranges from 2.16 to 2.17 for K values 0.0001 to 25 m day^{-1} in this study. Preliminary estimates of hydraulic conductivity (K_p) values at different sites were made using the particle size data and Hazen's method (Fetter, 1988). The estimated V_f values were then used in the Darcy's equation to back-calculate K values. The correct values of K were then determined using an iterative procedure. The K values, estimated by both tracers, are shown in Table 1.

DISCUSSION

The results (Table 1) show that Hazen's method using particle size data overestimates the K values, in the present study. From Table 1, it is also clear that the K values determined using the NaCl tracer (K_N) are lower than those determined using ^{3}H tracer (K_T). Since tritium is part of the water molecule itself and acts as a perfect tracer of groundwater movement, the results of the tritium dilution can be considered as the standard ones. The linear relation between the K_N and K_T (both in m s^{-1}) is shown in Fig. 2, and can be expressed by the following equation:

$$K_T = (1.11 \times K_N) + (1.1 \times 10^{-6}) \quad (4)$$

Since the radioactive tracers are not favoured by the field agencies due to the need for costly equipment and safety training of staff, the common salt tracer and electrical conductivity measurements can be adopted for preliminary investigations of projects aimed at determination of aquifer parameters. However, the present investigations have limited statistical accuracy due to the limited number of data points. More experiments of a similar nature are required to establish a more reliable relationship between K_N and K_T.

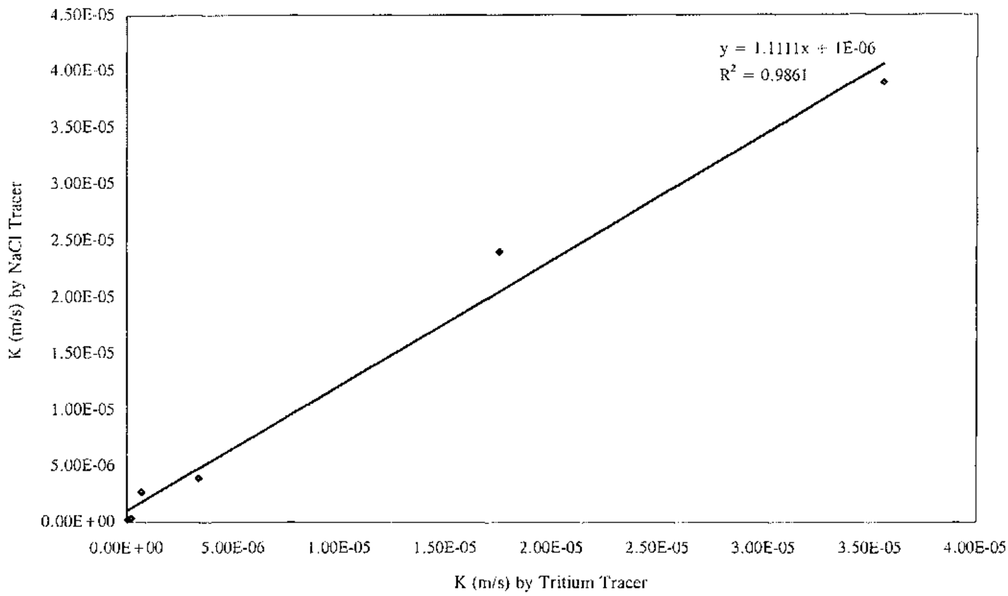

Fig. 2 Linear relation between the hydraulic conductivity values estimated by tritium (K_T) and NaCl (K_N) tracers.

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