SPATIO-TEMPORAL VARIATION IN NATURAL RECHARGE OF GROUNDWATER : A CASE STUDY

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Introduction

Groundwater recharge is a complex phenomenon governed by several factors. Simply put, groundwater recharge is the addition of surface water to an aquifer (saturated zone). The recharge may be natural (deep percolation of rain-water or from streambeds), induced (from water reservoirs, irrigation/drainage channels, bays, etc.) or artificial, with natural recharge by far the most important. Quantifying the rate of natural groundwater recharge is a prerequisite for proper management of scarce groundwater resources. However, direct measurement of natural recharge is extremely difficult, and hence recharges are generally estimated indirectly. This paper describes the estimation of natural groundwater recharge in the Takaoka groundwater basin of Tosa city, Japan by using an analytical recharge model proposed by Su (1994). This model was chosen because of its simplicity and suitability for the study area.

Model Application to the Study Area

Given a time series of water table levels at a particular location, the model estimates time-varying local recharge rates, and requires fewer data than the traditional water-balance method. At the same time, the model also estimates groundwater discharge rates in the absence of recharges. Mathematically, the selected model is expressed as (Su, 1994) :

$$R(x,t) = S_y \frac{\Delta h(x,t)}{\Delta t}\left(\frac{h(x,t)}{e}\right) - \left(\frac{S_y H_0^2}{2e}\right)\cos(\epsilon x)\left(\epsilon^2 k + \frac{K^2\lambda^2}{4T\,S_y}\right)\exp\left[\frac{K\lambda}{2T}x - \left(\epsilon^2 k + \frac{K^2\lambda^2}{4T\,S_y}\right)t\right] \quad \text{... (1)}$$

$$\text{where, } \epsilon = \frac{1}{L}\arccos\left[\left(\frac{H_L}{H_0}\right)^2 \exp\left(\frac{-K\lambda}{2T}L\right)\right]; \quad \text{... (2)}$$

$R(x,t)$ = recharge rate as a function of space and time [L/T]; S_y = specific yield; $\Delta h(x,t)$ = change in water table level during time Δt [L]; $h(x,t)$ = water table height above the aquifer base as a function of space and time [L]; e = mean saturated aquifer thickness [L]; k = aquifer diffusivity [L^2/T]; K = mean hydraulic conductivity of the aquifer [L/T]; T = aquifer transmissivity [L^2/T]; λ = slope of the aquifer base; L = length of the aquifer [L]; H_0, H_L = water table heights above the aquifer base at upstream (i.e., $x = 0$) and downstream (i.e., $x = L$) ends of the aquifer, respectively [L].

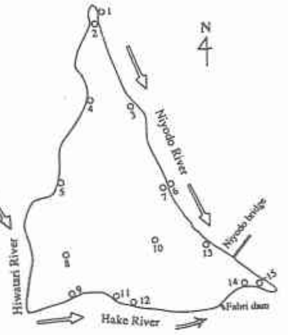

Fig. 1. Takaoka groundwater basin

Table 1. Values of the salient model parameters for the basin

Parameter	Value	Site	x (m)
S_y	15%	2	400
K	9.35×10^2 m/d	3	1300
e	14.5 m	7	2300
L	3700 m	8	3060
λ	1/700	9	3470
		10	2950

Using the above analytical model (Eq. 1), spatio-temporal variations of natural groundwater recharge in the Takaoka groundwater basin (Fig. 1) were estimated for the 1989-1992 period. Two sets of the water table data (5-day average and daily) were used and the recharge analysis was carried out for one-year time period. The boundary conditions (H_0 and H_L) were considered to vary with the month, but to remain constant within a month. The term, $(h(x,t)/e)$ in Eq. 1 was assumed to be 1 in order to avoid unrealistically large recharge/discharge rates due to unusual rise/fall of water table. The values of salient model parameters are given in Table 1.

Results and Discussion

The model indicated that the recharge estimates based on the 5-day average water table data were considerably less than those based on the daily water table data. Fig. 2 displays a sample calculation of daily recharges/discharges at four sites for the year 1990. Obviously, the recharge rate varies with the rainfall and the site. Sites 2, 3 and 7 contribute to greater aquifer recharge compared to site 10. Except for site 10, usually the recharge occurs one day after an effective storm and is larger than the actual rainfall. This is due to the fact that the groundwater recharge is an integrated downslope recharge from multi-dimensional flow. The monthly recharge in the basin varies significantly within a year as well as among the years observed (Fig. 3). The monthly peak recharges occur in August/September when heavy storms are most likely. It is also clear that apart from the site-specific factors, recharge rate is also dependent on the magnitude and pattern of rainfall over a year.

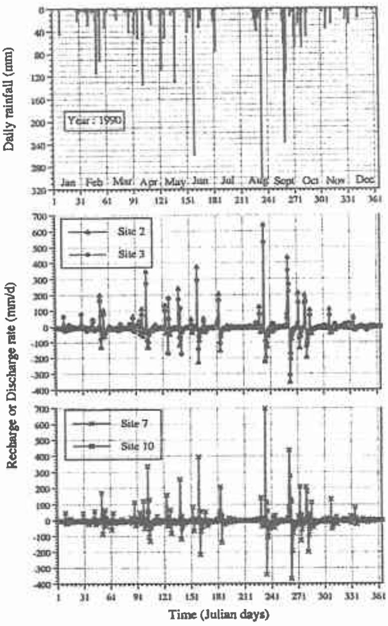

Fig. 2. Spatio-temporal variation in recharge for 1990

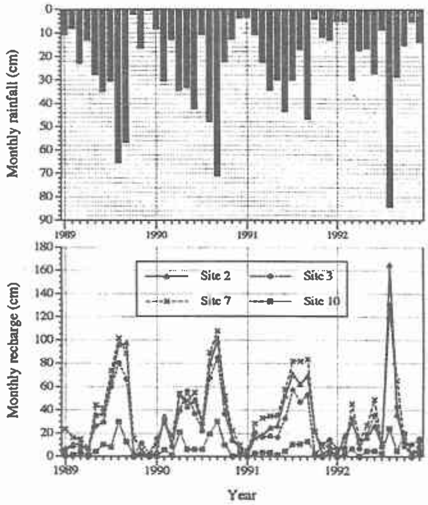

Fig. 3. Monthly recharge for 1989-1992 period

Furthermore, the estimated daily recharge and the corresponding daily rainfall for the 1989-1992 period were found to be not highly correlated, suggesting that only rainfall is not responsible for the groundwater recharge in the Takaoka basin. On the other hand, a strong correlation was found between the daily streamflows of $\leq$ 50 m^3/s in the Niyodo River at Ino station and the corresponding daily groundwater levels at three sites. Thus, it is apparent that the rise of water table over the basin is caused not only by the rainfall, but also by the seepage from the Niyodo River.

On the whole, it is concluded that recharge rates are highly variable over the basin as well as among the years. Although both the rainfall and seepage from the Niyodo River contribute to the aquifer recharge, the long-term effect of the natural groundwater recharge is not discernible because of excessive groundwater extractions from the Takaoka aquifer (Jha et al., 1994). It is also emphasized that the groundwater level be measured at various other sites so that the total natural recharge in the basin could be estimated.

References

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2. Su, N. (1994). A formula for computation of time-varying recharge of groundwater. Journal of Hydrology, 160 : 123-135.