Pulse responses of an unconfined granite aquifer to precipitation – A recharge evaluation through transient water-level fluctuation

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Natural recharge is an important parameter to be known for groundwater budgeting and management. Principal source of recharge to the groundwater aquifer system is the percolation of a fraction of rainfall during the monsoon season through the vadose zone. Rainfall recharge is highly variable at a given place and the variability is essentially due to rainfall pattern, soil characteristics remaining the same. Estimation of recharge to an unconfined granite aquifer was made by studying the groundwater response to various rainfall pulses of 2004 monsoon through analysis of continuous hydrograph data, after filtering out extraneous noises like tidal effects. Water-level fluctuation was utilized with precipitation events to evaluate transient recharge rate and cumulative recharge rate was found to be in good agreement with the estimates made by tritium injection method over the monsoon period.

Keywords: Groundwater fluctuation, natural recharge rate, pulse precipitation, tides.

NATURAL groundwater recharge is the process whereby infiltrated water percolates through the vadose zone and reaches the groundwater system. Rainfall is the principal source for replenishment of moisture in the vadose zone and subsequent recharge of groundwater. The amount of infiltrated moisture that will eventually reach the water table is the natural groundwater recharge, which depends on intensity, duration, amount of rainfall, infiltration capacity of the topsoil zone, antecedent soil moisture conditions and water table depth. Estimating the rate of natural recharge is difficult in the groundwater resources evaluation. The methods commonly in use for estimating natural groundwater recharge are soil water balance method, zero flux plane method, one-dimensional soil water flow model, inverse modelling technique, groundwater-level fluctuation method, hybrid water fluctuation method, groundwater balance method, isotope and solute profile techniques[1]. Groundwater-level fluctuation method is an indirect method of deducing recharge to the shallow weathered zone aquifer system. Rise in the water table during rainy season can be used to estimate the recharge rate, provided there is a distinct rainy season with the remainder of the year being relatively dry. The rainfall recharge R_r is given by,

$$R_r = S_Y \Delta s + T_P - R_i, \quad (1)$$

where S_Y is the specific yield, R_i, the return flows due to seepage, surface flow, etc. which occur during rainy season; T_P, the abstraction during the rainy season divided by the study area and Δs the water-level fluctuation.

In an area where rise in water-level is primarily due to rainfall and not influenced by nearby pumping well or return flow due to applied irrigation, the effective recharge rate can be deduced using the simplified relation

$$R_r = S_Y \Delta s. \quad (2)$$

Central and State Groundwater Departments in India are using the indirect method of deducing recharge[2]. The basic limitation of the method is that it neglects the subsurface inflow and outflow, and assumes that every inflow and outflow is uniformly distributed over the area.

Water-level in an unconfined granitic aquifer was continuously monitored using an automatic water-level recorder (IN-SITU, Minitroll waterlogger, USA) installed in a bore well of 60 m depth, at 20 m below the water-level (water-level at the time of installation was 9.66 m below ground level), to monitor the response of water-level to the precipitation pulses during monsoon. The bore well is located at a secluded place in the campus of the National Geophysical Research Institute, Hyderabad (Figure 1). The logger is basically a pressure sensor, which registers the height of water column existing above it. This height is subtracted from the depth of placement of sensor from the ground level to get the actual water-level from the ground level. Cyclic water-level change was prominently seen within a day record, indicating the effect of semi-diurnal TIDES[3,4]. Spectral analysis was carried out to filter the tidal effect to see the response of water-level to various rainfall events. Hydrograph of observation well for the entire monsoon period of 2004 along with spectral analysis and tidal-corrected hydrograph are presented (Figure 2 *a–c*). A rain gauge is placed about 50 m away from the borewell for monitoring daily rainfall during rainy season.

The study area experiences monsoonal rainfall from the month of June to September every year, which varies from 550 to 700 mm. During the observational period, daily rainfall record was carefully analysed to see the response of the aquifer. The only pumping well located in the near vicinity of the observation bore well is 200 m away. The borewell is used occasionally to supplement water supply to the laboratory during summer months. It was found that the pumping well does not influence water-level of the observation well. Water-level data retrieved from the observation bore well were subjected to filtering of tidal effects. The filtered hydrograph data showed certain prominent changes in level (rise/fall in water-level) during the monsoon months of July and August 2004. In general, there is a steady rise in water-level through the monsoon period, indicating the effect of natural recharge. The month of July with rainfall

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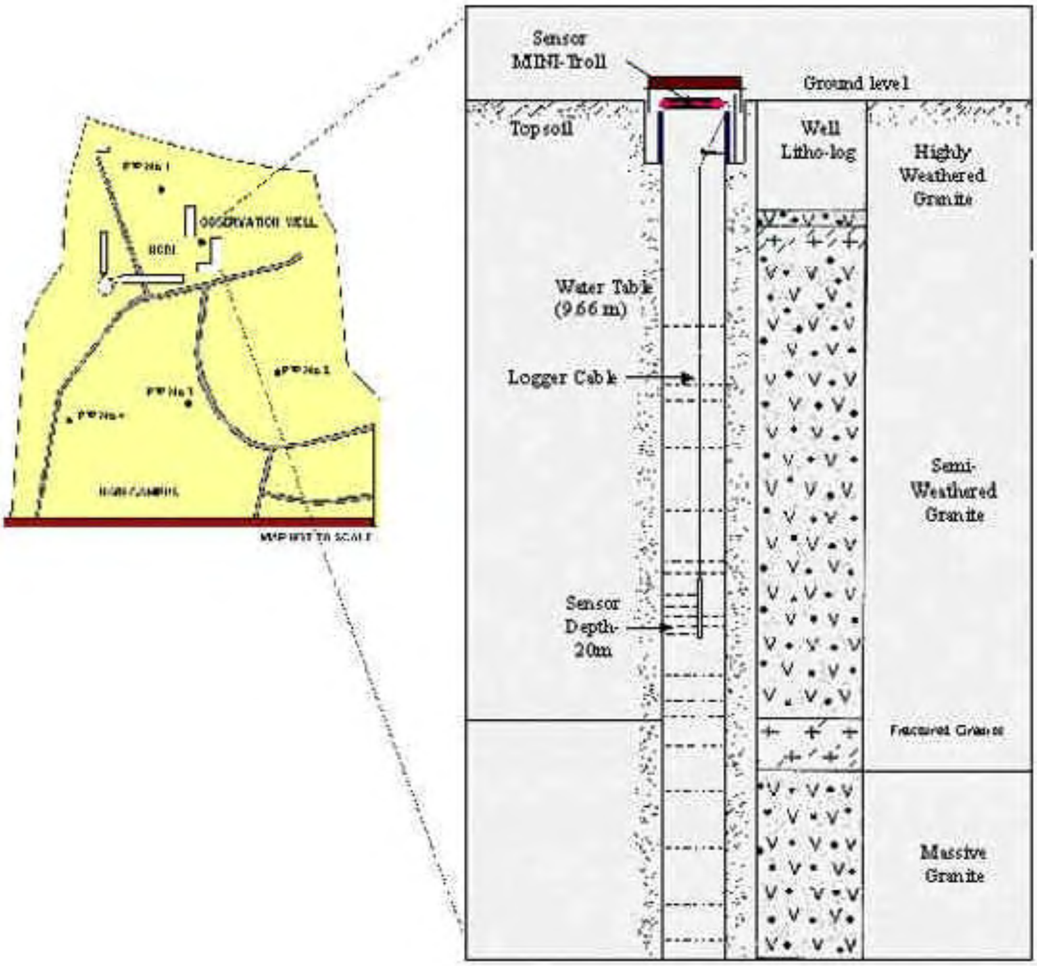

Figure 1. Location map and schematic geologic cross-section of the observation bore well at NGRI campus, Hyderabad.

Table 1. Events of rainfall (≥ 10 mm) during monsoon months in 2004

Month	Day	Rainfall (mm)	Water-level fluctuation (mm)
May	16	53.6	138
June	4	68.6	135
July	1	24.2	30
July	4	12.6	71
July	11	19.6	11
July	12	26.2	121
July	15	10	64
July	26	47.8	102
July	28	11.6	52
July	29	20.2	110
August	2	13.2	32
August	12	11.6	23
August	15	18	42
September	–	–	–
Total		337.2	

of 172.2 mm is considered for pulse recharge analysis. Ten rainy days with varying rainfall between 10 and 40 mm and with a net rise of 0.627 m in water-level were subjected to study the response of water-level to rainfall by selecting a window between two consecutive rainfall events (Figure 3).

Since the observation bore well does not show any significant influence to the nearby occasional pumping and also because of its isolated location within the research campus area, the effects of pumping and irrigation return are considered to have negligible influence on water-level response. Analysis for each rainy day of ≥ 10 mm during the monsoon months and resultant water-level fluctuation response seen from filtered water-level data are presented in Table 1. The correlation between rainfall and water-level fluctuation for all events (≥ 10 mm) with coefficient of 0.73 is shown in Figure 4. Though a correlation coefficient of 73% satisfies the relation, a closer analysis indicates a complex relation for rainy days with less than 20 mm rainfall, probably depicting the threshold level of rainfall required for recharge.

Natural recharge measurement was carried out at two sites in the study area using injected tritium tracer technique during the study period. Both these sites are located within a radius of 150 m from the observation well. The injected tritium method was extensively used for natural recharge

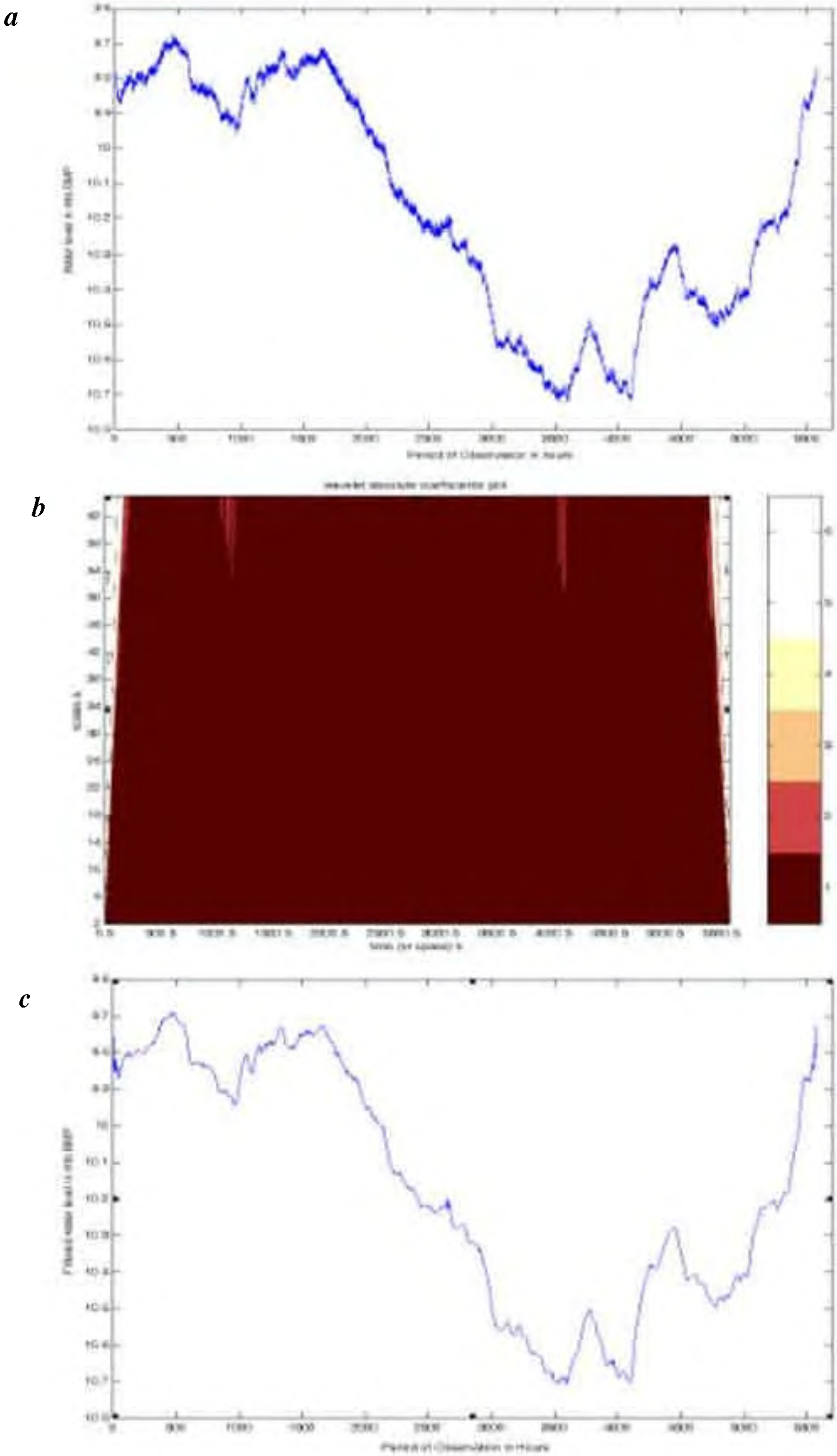

Figure 2. ***a***, Observed water-level data with tidal effects. ***b***, Data subjected to wavelet analysis for filtering tidal effects. ***c***, Filtered water-level data.

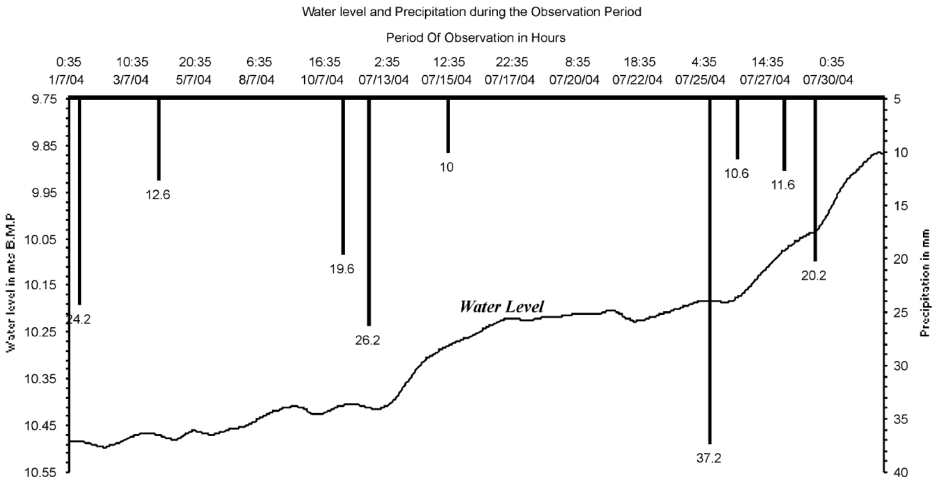

Figure 3. Water-level (m) and rainfall (mm) plot for July 2004.

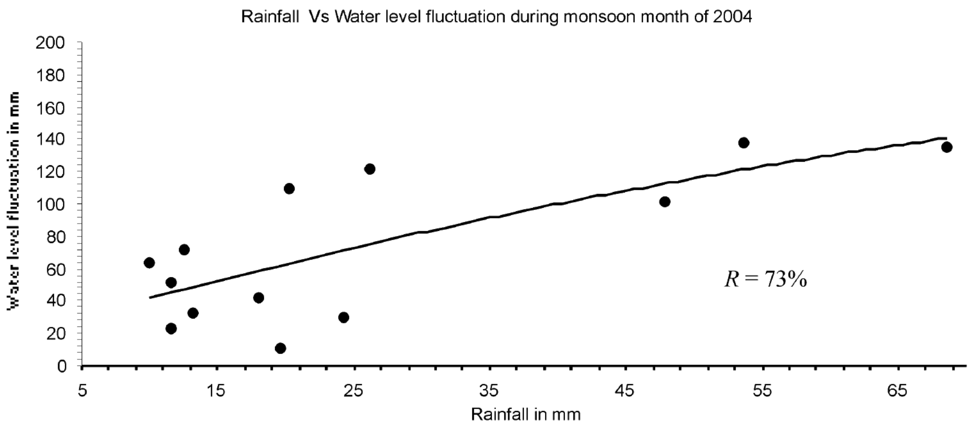

Figure 4. Rainfall (≥ 10 mm) vs water-level fluctuation.

evaluation over watersheds and basins of India[5–8]. Natural recharge flux is evaluated based on change in moisture influx in the tracer-displaced soil zone below the rooting depth[9].

Specific yield of unconfined aquifer at the recharge study site was calculated from the moisture influx obtained from injected tritium method and water-level change observed in nearby open well using the equations

$$R_R = \{(R_K/R_{KF})*R_{OF}\}, \tag{3}$$

$$S_Y = R_R/\Delta s, \tag{4}$$

where R_R is the rainfall recharge for the observation period, R_K the measured rainfall recharge from moisture influx measurement, R_{KF} the total rainfall measured, R_{OF} the rainfall during observational period, S_Y the specific yield and Δs the water-level fluctuation.

The value of recharge computed from eq. (3) was applied in eq. (4) to deduce the specific yield. The average specific yield obtained at the two sites was 3.9%. Specific yield estimated in one of the bore wells near the injected tritium sites yielded a value of 3% (pers. commun., NGRI). The integrated geohydrological studies over Aurepalli watershed located in a similar granitic terrain, situated 50 km from the study area, yielded an average specific yield[10] of 2.6%. A specific yield value of 3.1% derived by taking an average from these three measurements is considered to be representative for the observational well site. Using the derived specific yield value, rainfall recharge for the month of July 2004 is computed and shown as an example.

$$R_r = S_Y\Delta s$$

$$R_r = 3.1/100*(627) \text{ mm}$$

$$= 19.8 \text{ mm}.$$

This value is in good agreement with the recharge value of 17.9 mm estimated at two tritium-injected sites using moisture influx measurement for July 2004, with a rainfall of

Table 2. Rainfall recharge for monsoonal months in 2004

Month	Total rainfall (mm)	Water-level fluctuation (m)	Specific yield (%)	Rainfall recharge (mm)
May	53.6	0.20	3.1	6.2
June	81.6	0.41	3.1	12.7
July	172.2	0.63	3.1	19.8
August	53.1	0.13	3.1	4.0
September	25.4	0.04	3.1	1.2

172.2 mm. The values obtained by the two methods are in agreement and within the error limit of ± 10%. Recharge for other monsoonal months during 2004 is determined in similar way and presented in Table 2. The analysis shows that the technique of pulse response in water-level fluctuation obtained from automatic water-level recorder can be used for evaluating monthly natural recharge more precisely.

The water-level fluctuation data recorded by an automatic waterlogger, after removal of extraneous noise due to tidal effects, can be more potentially utilized in estimation of natural recharge due to pulse-mode precipitation pattern over the semi-arid tropical region. The recharge values derived from this method are found to be in good agreement with those obtained through tritium injection technique over the entire monsoon period. Long-term study of water-level with rainfall and correlation of results with moisture flux measurement through tritium technique would yield good and reliable results to model different catchments located under varying climatic and geological terrains.

1. Allison, G. B., A review of some of the physical, chemical and isotopic techniques available for estimating groundwater recharge. In *Estimation of Natural Groundwater Recharge* (ed. Simmers, I.), NATO ASI Series, 1988, vol. 222.
2. Anon, Groundwater estimation Methodology. Report of the Groundwater Estimation Committee, Central Groundwater Board, Ministry of Irrigation, New Delhi, 1983.
3. Marechal, J. C., Sharma, M. P., Ahmed, S. and Lachassange, P., Establishment of earth tide effect on water-level fluctuation in an unconfined hard rock aquifer using spectral analysis. *Curr. Sci.*, **83**, 61–64.
4. Palumbo, A., Atmospheric tides. *J. Atmos. Solar–Terr. Phys.*, 1998, **60**, 279–287.
5. Athavale, R. N., Murti, C. S. and Chand, R., Estimation of recharge to the phreatic aquifers of Lower Maner Basin, India by using the tritium injection method. *J. Hydrol.*, 1980, **45**, 185–202.
6. Athavale, R. N., Chand, R. and Rangarajan, R., Groundwater recharge estimates for two basins in the Deccan trap basalt formation. *Hydrol. Sci. J.*, 1983, **28**, 525–538.
7. Athavale, R. N., Rangarajan, R. and Muralidharan, D., Influx and efflux of moisture in a desert soil during a 1 year period. *Water Resour. Res.*, 1998, **34**, 2871–2877.
8. Rangarajan, R. and Athavale, R. N., Annual replenishable groundwater potential of India – An estimate based on injected tritium studies. *J. Hydrol.*, 2000, **234**, 38–53.
9. Munnich, K. O., Moisture movement measurement by isotope tagging. In *Guide Book on Nuclear Techniques in Hydrology*, IAEA, 1968, pp. 112–117.
10. Muralidharan, D., Geohydrology of Aurepalle watershed in semi-arid India. Ph D thesis, Karnataka University, 1991.

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Zooplankton studies with special reference to krill *Euphausia superba* Dana from fishing area 58 of Indian Ocean sector in Southern Ocean

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Distribution, abundance and species composition of zooplankton collected during the First Indian Antarctic Krill Expedition were studied. Zooplankton biomass values ranged from 9.79 to 303.62 ml 100 m^{-3} ($\bar{x}$ = 142.14 ± 77.02). High standing stock values were recorded in the study area, where copepods, chaetognaths, euphausiids and salps were dominant taxa. Copepods and chaetognaths formed the major constituents of zooplankton community and comprised more than 70% of zooplankton catch. Swarms of krill and salps were observed during the study period (austral summer), which were the prime cause for high standing stock of zooplankton. The prevailing physico-chemical parameters with rich food supply were important factors influencing the geographical distribution of different zooplankton groups. The study revealed that the present investigation site falls under potential krill fishing ground.

Keywords: Antarctica krill, austral summer, copepods, Southern Ocean, zooplankton.

THE Antarctic pelagic system is one of the most intriguing ecosystems, with its extreme environmental conditions and wide seasonal fluctuations. The typical conditions of the Antarctic waters have large implications for zooplankton stock and special life strategies have been developed to survive under extremely cold, dark winter conditions and to profit

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