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Estimation of groundwater recharge through neutron moisture probe in Hayatnagar micro-watershed, India

Ramesh Chand*, N. C. Mondal and V. S. Singh

National Geophysical Research Institute, Uppal Road, Hyderabad 500 007, India

This communication presents a simple technique to measure groundwater recharge through neutron depth moisture gauge under *in situ* conditions that are based on soil moisture content and groundwater-level data. The water-table fluctuation method may be the most widely used technique for estimating recharge, but needs knowledge of specific yield and changes in water-level over a time. The present technique is not dependent on the mechanism of water flow in the vadose zone.

Storativity values, otherwise called 'coefficient of storage' that is analogous to the 'specific yield' in the case of water-table aquifer condition, are estimated in Hayatnagar micro-watershed area using soil moisture content and rise in water-table of the region. Using average values of several such estimates for various depths of the saturated zone, the calibrated storativity value is obtained. This value is further used to translate the water-table rise during certain rainfall periods to quantify the groundwater recharge.

Keywords: Groundwater recharge, neutron moisture probe, storativity, vadose zone.

ESTIMATION of groundwater recharge in hard rock terrain is difficult in view of wide spatio-temporal variations in hydrological and hydrometeorological conditions. The groundwater-level fluctuation approach, when applied in isolation, requires values of specific yield. There are various other methods (including hydrogeological, hydrological, tracer, etc.) that are suitable to study spatial and temporal variations of recharge[1–7]. For arid- and semi-arid regions, most of these methods provide long-term averages of recharge.

Estimation of recharge using injected tritium method, however, is comparatively easier. But, recharge measured by this technique over the years in the same area differs even when the quantum of total precipitation remains almost the same[8–11]. This is because of the variation in rainfall pattern and its intensity.

Meyer[12] used neutron logs to determine the specific yield of unconfined aquifers measuring the log response against a falling water-table. Karanth[13] also used neutron logs mainly for measurement of moisture content above the water-table and total porosity below the water-table. Estimation of recharge by studying movement of moisture in the vadose zone establishes the potential of neutron depth moisture

*For correspondence. (e-mail: rameshtyagi@yahoo.com)

gauge[14–16]. Measurement of soil moisture variation using neutron moisture probe and water-level fluctuation has provided a suitable technique for making reliable estimate of recharge in the Hayatnagar micro-watershed.

The study area – a micro-watershed in an experimental research farm of Central Research Institute for Dry land Agriculture (CRIDA), Hayatnagar, Ranga Reddy District, Andhra Pradesh, India, is located about 25 km east of Hyderabad city. The farm having an area of about 250 ha is basically used for research in dry-land farming. The terrain is undulating with a regional southeastward slope. Land elevation varies from 511 to 519 m amsl (Figure 1). Most of the rainfall is during the southwest monsoon spread from June to September. The average annual precipitation is 720 mm. The watershed selected for the present study (area = 4.50 ha) is divided into six micro-zones having catchment areas varying from 0.25 to 0.81 ha of land depending upon the slope. These are designed to monitor the run-off of each individual zone. Each zone is separated by bunds and run-off storage ponds. Overflow of water from these ponds joins the drain towards NE of the watershed. Streams in the area are ephemeral, flowing only for a short duration after heavy rainfall. The drainage is sub-dendritic.

The chief rock type of the area is grey to dark-grey, medium-grained granite, occasionally weathered, but intensively traversed by quartz, apatite and pegmatite veins. The joints and fractures are often filled by secondary calcareous material. Lithologs of the bore wells are used in preparing the fence diagram to depict subsurface litho-units (Figure 2 *a*, T. V. Rao *et al.*, unpublished data). Groundwater occurs both under unconfined and semi-confined conditions. The piezometric contour map based on water-level measurements recorded during January 1998 is shown in Figure 2 *b*. The piezometric surface has a gentle slope of 0.06 to 0.20% in contrast to the topographic slope of 2 to 3%. Although different fractures at different depths may form different aquifers with different piezometric heads, we have found one fracture zone forming aquifer in the area, as shown in Figure 2 *a*. In this zone, various fractures may have been interconnected and hence do not exhibit different piezometric levels. However, the groundwater flow direction broadly matches with surface drainage pattern.

Bore wells (50.8 mm diameter) were drilled in upstream and downstream parts of the watershed to carry out soil moisture studies and water-level measurements. Aluminum access tubes were installed in the bores drilled for soil moisture studies. In total, a network of eight aluminum access tubes were installed for measuring soil moisture and further nine piezometers were constructed for recording fluctuations in water-table. Six out of eight access tubes have penetrated the aquifer zone. Five additional wells were drilled for carrying out pumping tests. Pumping tests were carried out at test sites P2, P4 and P5 to determine the characteristics of the aquifer. The T and S values arrived from these tests[17] are shown in Table 1. These values and well yield are found to be highly variable and strongly influenced by the boundaries. Specific yield value could not be estimated due to inadequate data.

A carefully calibrated neutron probe was used to monitor moisture from the ground surface to the water-table. Measurements between two time instants were used for the estimation of actual amount of water reaching the water-table. However, only two measurements were selected for reference sake here. It is presumed that the flow is due to vertical component only. Figure 3 *a* and *b* shows examples of moisture profiles in the study area for different dates (one is upstream and other downstream). Actual amount of water added to the aquifer is computed using variation in moisture content data between respective water-level positions. The quantum of water added to the system is divided by the water-table rise to get effective storativity value of the aquifer at that depth. These measurements were taken at eight locations in an area of 4.50 ha at regular intervals employing neutron probe in 10-cm sections. The term 'storativity' (or fillable porosity) is used here to define the amount of water that an unconfined aquifer can store per unit area per unit rise in water-table, i.e.

$$\text{Effective storativity} = \frac{\text{Area of wetted region}}{\text{Rise in water table}}$$

$$= Q/\mathrm{A}\Delta h$$

where Q is the quantity of water stored, A the area of cross-section and Δh the water-table rise.

For studying soil moisture, aluminum access tubes installed were sealed at the bottom with expandable stretching-type dummy made out of rubberized neoprene with adhesive. Aluminum tubes of 6 m length were joined together using buckkale-type coupling without hampering inside clearance for the neutron logger.

Comparing the rise in water-table with some specific precipitation events, we could obtain storativity values of the aquifer for each recharge event. The time lag between the recharge causing rainfall and the corresponding water-table rise is usually small. However, intensity and frequency of rainfall play an important role in the process. Recharge estimated under *in situ* conditions is the net effect of all the processes and does not require computation of run-off, evapotranspiration, soil moisture storage, base flow, groundwater draft, etc. The rise in water-level as reflected in the measurements is the water added to the aquifer from precipitation after the draft from various draft components. However, the groundwater draft in this study area is negligi-

Table 1. Aquifer parameters

Test site	T (m^2/day)	S
P2	2100	0.0035
P4	245	0.000021
P5	1700	0.003

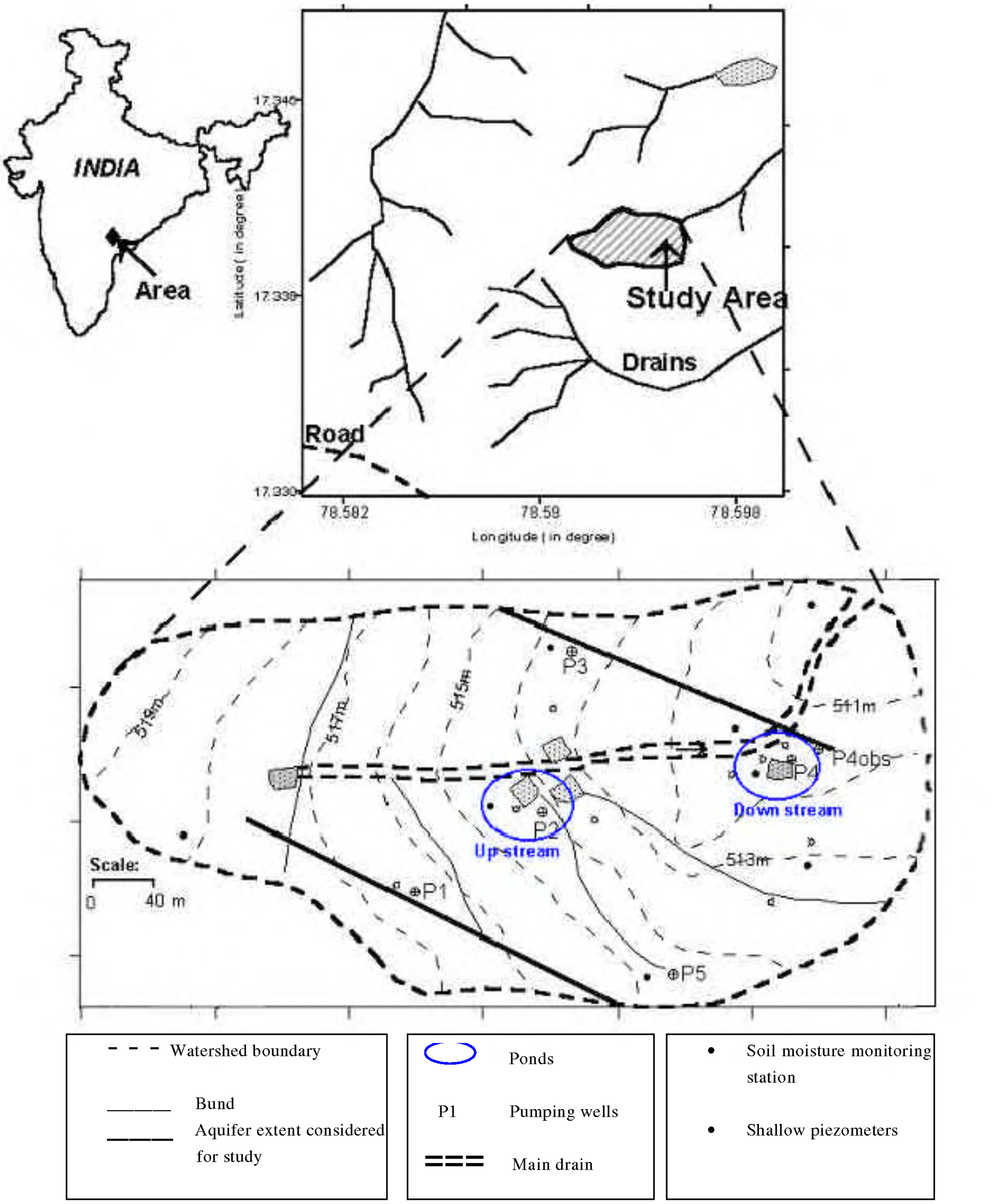

Figure 1. Location map of watershed.

ble, as there are no pumping wells. This area is dry land and only rainfed crops are grown.

The relatively small zone of water-table fluctuation and high soil-water content together probably indicate the level of uniformity and/or variation, if any, in the coefficient of storativity. Moisture measurements taken at regular intervals for varying depths from ground surface up to the water-table provide information on the quantum of water in the vadose zone. Thus the storativity values were assigned to the aquifer for its specified depth and recharge was computed from data on the fluctuation of water-levels. The specific yields can also be obtained using trend analysis of water-table fluctuation from the well hydrographs in weathered and fractured rock aquifers[18].

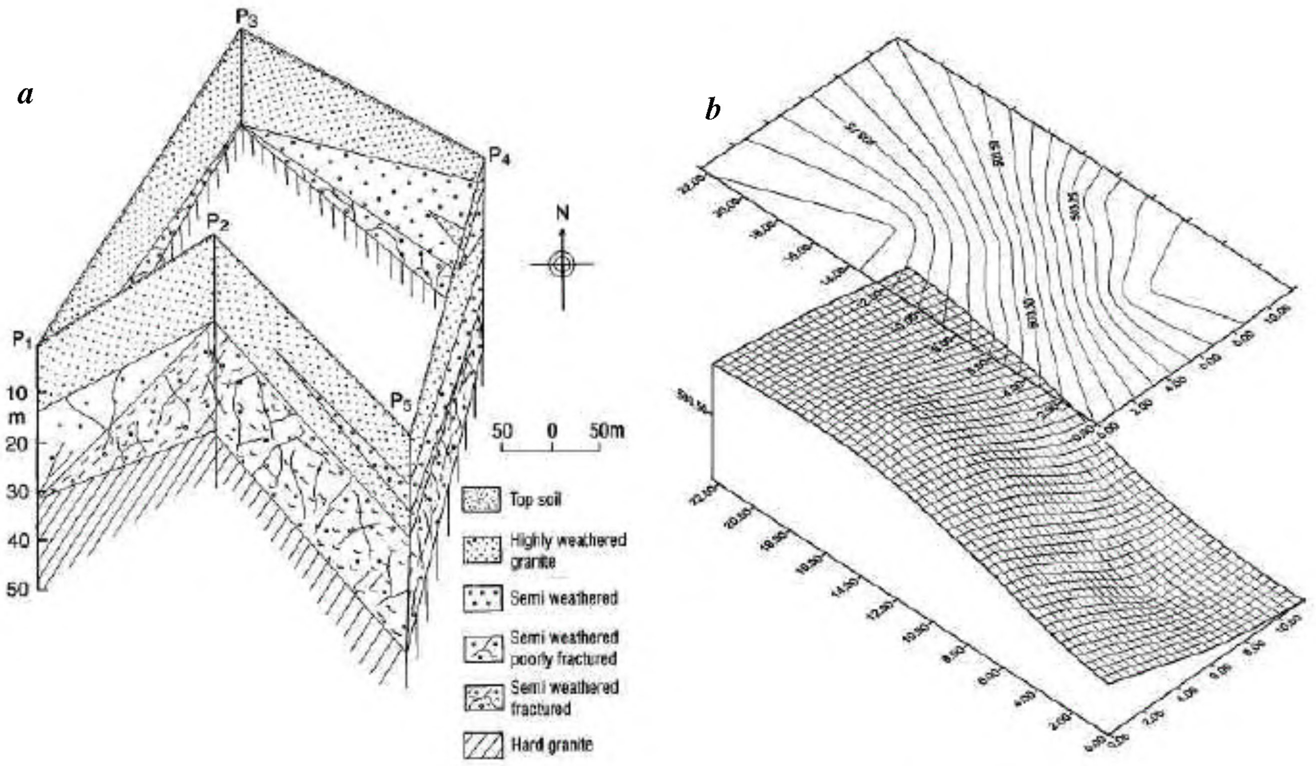

Figure 2. ***a***, Fence diagram; ***b***, Piezometric contour map (m amsl).

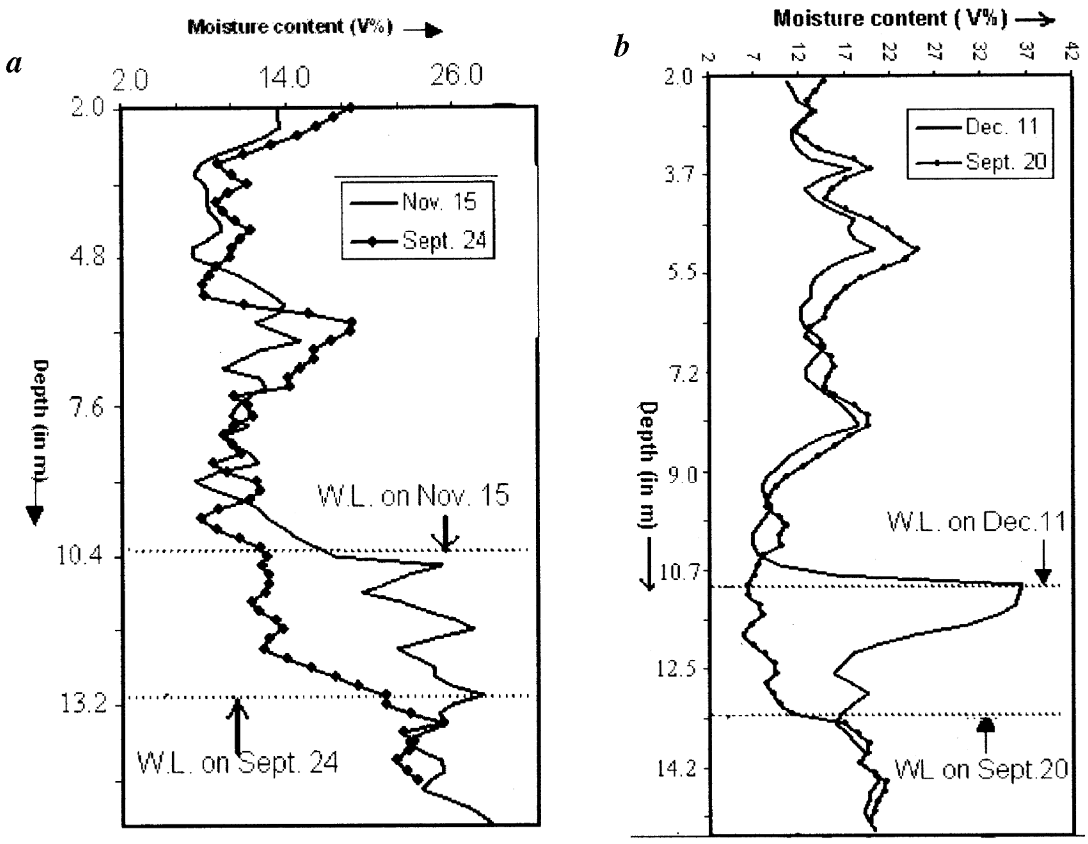

Figure 3. Moisture profile in upstream part (***a***) and downstream part (***b***) of the watershed.

For estimating the storativity values of the aquifer, data on moisture (vol%) vs depth were plotted (Figure 3 *a* and *b*). Calculating the area enclosed between two profiles of the wetted region resulting from the water-table rise from position one to another, and dividing it by the water-table rise, fillable porosity of the saturated zone was estimated.

Although the coefficient of variation is large and despite the large spatial separation of sites, the time variability of storativity value is similar for all sites, which means that the storativity of the aquifer is approximately homogeneous in the study area. The vertical recharge component is high; probably the groundwater system is sustaining itself.

The soil moisture values were obtained using neutron moisture probe for eight sites at Hayatnagar micro-watershed (in a typical granitic terrain) at regular intervals of time for two hydrogeological cycles. The total volume of water (recharge) as a result of rise in water-level has been estimated. It is found to vary from 0.22 to 0.37 m, with an average of 0.30 m. This gives an annual input of about 0.0135 MCM.

The effective specific storativity component as a result of rise in water-level has been estimated. The specific storativity varies from 6.9 to 10.6%, with an average value of 9.0%. The storativity values found for two hydrological cycles in the study area are in agreement. However, values are high compared to the results obtained by pumping tests (order of $\approx 10^{-3}$), that represent a composite system of aquifers (partially unconfined and partially confined).

This is a simple, practical and less expensive technique than the pumping test method and provides reliable estimates of groundwater recharge.

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