Indian Journal of Agricultural Sciences **92** (3): 367–71, March 2022/Article
https://doi.org/10.56093/ijas.v92i3.122696

Estimation of replenishable groundwater resources and their utilization status in hard rock terrain

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Received: 18 April 2020; Accepted: 08 September 2021

ABSTRACT

For an efficient management and development of groundwater resources, it is imperative to have a reliable database on groundwater resources. In this regard, present study was conducted during 2015–18 in Mahatma Gandhi Chitrakoot Vishwavidyalaya, Chitrakoot, Satna, Madhya Pradesh, India. Dynamic groundwater resources of study area have been estimated by using the guidelines of the groundwater resources estimation committee (GEC-1997), Ministry of Water Resources, Government of India. In this study, rainwater infiltration factor (RIF) techniques and different conventional norms were used for groundwater recharge estimation. The assessments of groundwater units were categorized based on stage of groundwater development for the year 2016. The annual groundwater draft for all uses such as domestic and irrigation was 5931.54 ha m. The annual groundwater recharge in the study area was 8666.81 ha m and net annual groundwater availability was 8318.85 ha m. The groundwater utilization and stage of groundwater development had also been determined and the overall stage of groundwater development of Babina block was found to be 71.30%. There was no significant rise or fall of water levels during both the pre-monsoon and post-monsoon intervals in the study area. Considering the stage of groundwater development, it has been categorized that Babina block of Jhansi district, a part of Bundelkhand region falls under 'SAFE' category of groundwater development with excellent potential for the future groundwater development.

Keywords: Annual groundwater availability, Bundelkhand, Groundwater draft, Groundwater development, Rainfall Infiltration Factor (RIF)

In many Asian countries, there has been rapid development in agriculture and industry in the last couple of decades. This has led to an ever-increasing demand for groundwater to meet the domestic requirement, as also agriculture and industry. Over the past few years, the increasing dependence on groundwater has led to an imbalance in groundwater availability and withdrawal for longer periods has been exceeding long-term recharge, causing groundwater levels to decline (Prasad and Rao 2018). Indiscriminate exploitation of groundwater fulfils such demands, in the absence of any groundwater legislation. The over-exploitation of groundwater in such a situation leads to progressive depletion of its potential (as a consequence, progressive decline in groundwater level), year after year. Therefore, groundwater has emerged as an important source to meet the water requirements of various sectors including irrigation, domestic and industries. Sustainable development of groundwater requires an accurate quantitative assessment based on the reasonably valid scientific process. Kumar and Sitapati (2002) have conducted groundwater balance studies and quantification of groundwater resources in various hard rock areas of India.

In the present study, the dynamic groundwater resources have been estimated based on guidelines of groundwater resources estimation committee-1997 (GEC-1997). The basic principle in this method is to determine the current state of groundwater use, estimate annual groundwater recharge from rainfall and other sources. The other sources include recharge from canals, recharge from irrigation water applied by surface water irrigation, recharge from irrigation water applied by groundwater irrigation, recharge from tank and ponds, both from command and non-command area of the Babina block, Jhansi district, Uttar Pradesh, India. In the present attempt of study, huge field data were collected to determine the net groundwater availability of Babina block, Jhansi district and stage of groundwater development. Similar good efforts have already been made by (Lee *et al*. 2006, Prasad *et al*. 2007, Chatterjee and Roy 2016, Sethi *et al.* 2009, Chattrejee and Purohit 2009, Tiwari *et al.* 2021, Joshi *et al.* 2021, Varalakshmi *et al.*2014, Prasad

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and Rao 2018, Jasrotia and Kumar 2014) for the estimation of groundwater resources.

MATERIALS AND METHODS

In this regard, present study was conducted during 2015–18 in Mahatma Gandhi Chitrakoot Vishwavidyalaya, Chitrakoot, Satna, Madhya Pradesh, India.

Study area: The study area Babina block (Jhansi District) falls between latitude 25º07'54" to 25º32'44"N and longitude 78º17'15" to 78º34'3"E. It is a part of Bundelkhand region, Uttar Pradesh. Total geographical area of the Babina block is 68144 ha. The area is covered by hard rock formations such as Bundelkhand granites and gneisses, having water scarcity both for irrigation as well as drinking water purposes.

The rock composition mostly consists of granitic gneisses, basic dykes and quartzites lying as part of Bundelkhand Granitic-Gnessic complex (Tiwari *et al.* 2021, Joshi *et al.* 2021 and CGWB 2017). The study area shows a general low relief but at places has steep slopes. The drainage pattern is mostly in the NE-SW direction and also at places enriched with dendritic pattern and trellis pattern. The tributaries flowing themselves suggest them being on hard rock terrain and mostly structurally controlled (Tiwari *et al*. 2019). Typical tropical climate dominates the region having hot summers and cold winters. The climate is semi-arid and is characterized by hot summer months and pleasant monsoon of winter season. The temperature varies from 20–42°C during summer and 16–28°C during winter season. The area receives annual rainfall approx. 680 mm. The study area was classified into different groundwater assessment units, detailed description is presented in Table 1.

Data used: We compiled additional datasets such as census data, water conservation structures and irrigation data from the District Statistical Diary, Government of Uttar Pradesh (GoUP 2017). The rainfall data have been compiled from the Indian Meteorological Department, Government of India. The groundwater observation wells data and specific yield information of aquifers have been collected from CGWB, Government of India (CGWB 2009, 2011). Further, we used Groundwater Resources Estimation Committee-1997 (GEC-97), unit draft approach (detail method can be seen in CGWB 2009, 2017, Joshi *et al.* 2021, Tiwari *et al.* 2021) to estimate groundwater recharge and abstraction based on census-based statistics for Babina block.

Table 1 Groundwater assessment unit of study area

Groundwater Assessment Unit (GWAU)/Block	Babina
Ref. No of Survey of India Toposheet(s) of 1:50,000 Scale in which the GWAU unit is located	54K/6, 54K/7, 54K/8, 54K/10, 54K/11, 54K/12
Total Area of the GWAU (ha)	68144
Hilly Area (ha)	22802
Area of the portion of the GWAU in which GW recharge is possible (ha)	45342

Dynamic groundwater resources of the Babina block were estimated using GEC- 1997 norms. The time period taken for the groundwater recharge estimation was groundwater year (12 calendar months). The annual groundwater draft of the study area has been calculated from data on domestic use wells and irrigation wells in the command and non-command area. The unit draft for the assessment of Babina block has been computed by discharge observation of the individual well. The canal data has been collected from the observation made for the individual canals. The groundwater trends were determined by taking the observation from the well data pre-monsoon and post-monsoon for 26 years. All the above data have been integrated to determine groundwater condition of the Babina block in terms of replenishable groundwater resources and future development prospects. Whereas the value for the return flow factor for irrigation (both surface and groundwater irrigation are) norms for canal seepage factor was taken as per norms recommended by groundwater estimation committee-1997 (GEC-97) (CGWB 2009, 2011)

The proposed methodology for the resource estimation categorization of annual replenishable groundwater resources is shown in the flow chart (Fig 1).

RESULTS AND DISCUSSION

Gross groundwater draft computations: In the present study, the gross groundwater draft has been estimated from all shallow tube wells, tube wells and dug wells for irrigation use, and hand pump and deep tube wells for domestic and industrial uses in the study area. The annual unit groundwater draft from domestic use wells and hand pump and irrigation wells in the command area has been computed. There are number of shallow tube well, dug wells and hand pumps in the study area. The estimated net groundwater draft was approximately 5931.54 ha m during the study period. About 89.7% groundwater draft has been used for agriculture and 10.3% remains for domestic and industrial purpose. Groundwater draft for irrigation was about 1348.48 ha m during monsoon season and 3973.94 ha m during non-monsoon season. The estimated groundwater draft for domestic and industrial use was about 152.25 ha m during monsoon season and 456.84 ha m during non-monsoon season. Similarly, Joshi *et al*. (2021), Tiwari *et al.* (2021) have reported higher groundwater abstraction during non-monsoon season for irrigation practices.

Recharge from other uses: The recharge from other uses (other than rainfall) including the recharge from the canals, recharge from irrigation water applied by surface water irrigation, and by groundwater irrigation, recharge from tanks and ponds was determined and summarized.

Recharge from canals: The seepage from the irrigation canal is the major source of groundwater recharge (CGWB 2017)**.** Recharge from canals was computed separately for the monsoon and non-monsoon seasons of the groundwater

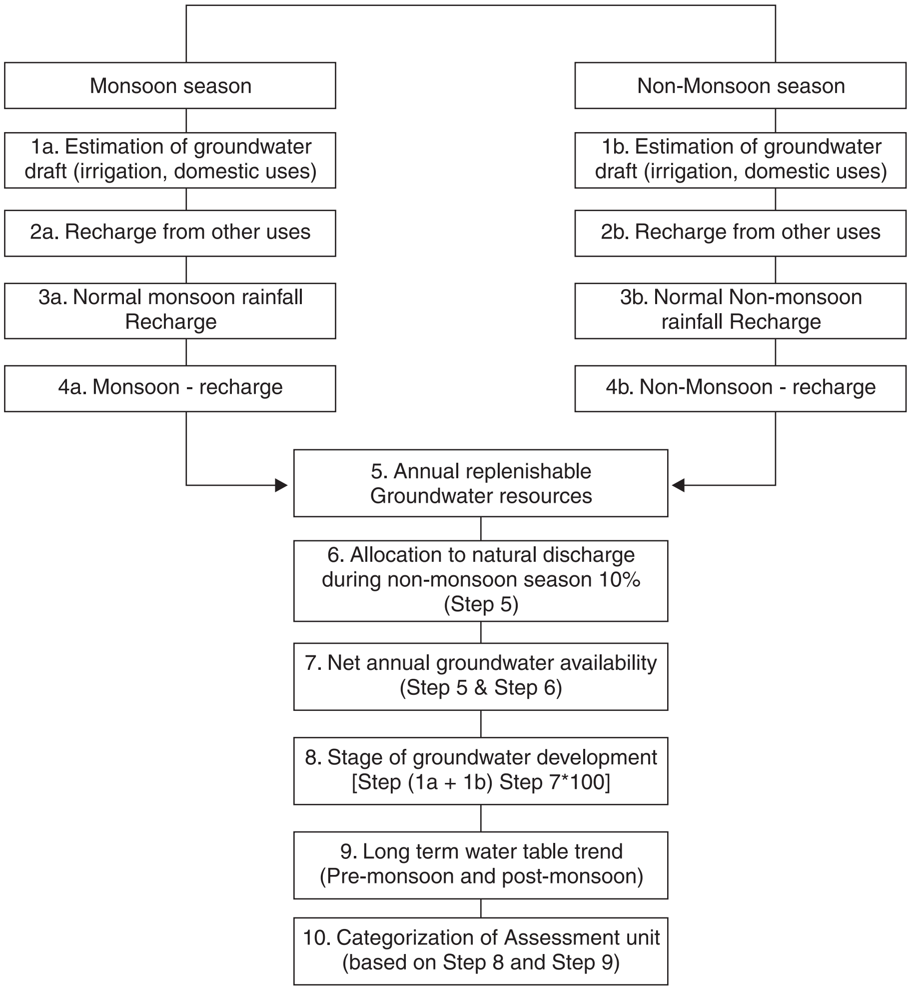

Fig 1 Methodology adopted in the study modified after Chatterjee and Purohit (2009).

assessment year, apply only for the command area. The recharge from the canal segments in ha m was computed by the product of the seepage factor expressed in ha m per day million square meters, which depends upon whether the canal was lined or unlined with soil type, wetted area in million square meters and the number of days the canal segment was in operation. The average depth of flow in a canal segment during the duration in which it was in operation considered to be 0.6 times the design depth of flow of that canal (CGWB 2009, 2011). The wetted area in the million square meters for each canal segment was computed from data on length, base width, side slope and design depth of the flow. The recharge from the canals was calculated by wetted area and canal seepage factor along with the number of days the canal segments were in operation during monsoon and non-monsoon season. Estimated recharge from canal during the monsoon season was 542.4 ha m. Similarly, Joshi *et al.* 2021, Tiwari *et al*., 2021 have reported recharge from canal using GEC-97 norms.

Recharge from irrigation water applied by surface water irrigation: It was computed for monsoon and non-monsoon season of the one groundwater assessment year. The computation of recharge from irrigation water applied by surface water irrigation was calculated by water released from the outlet in ha m multiplying return flow factor as a fraction taken as per norms recommended by groundwater estimation committee-1997 (CGWB, 2009, 2011). The return flow factor depends upon (GEC-1997) value for the return flow factor for computing recharge from irrigation water applied by surface water irrigation in command area. The recharge from irrigation water applied by surface water irrigation from different canal segments in assessment unit (block) for non-monsoon season was calculated as 11008.0 ha m.

Recharge from irrigation water applied by groundwater irrigation: The groundwater is the primary source for irrigation (Joshi *et al.* 2021). The recharge from irrigation water applied by groundwater irrigation in groundwater assessment unit for both command and non command area was obtained by the irrigation water applied by groundwater irrigation in command and non command area separately for the monsoon season and non-monsoon season in ha m multiplying return flow factor for computing recharge from irrigation water applied by groundwater irrigation area as a fraction. The return flow was based on the cropping pattern which is taken from the GEC-97 norms. (CGWB 2009, 2011). The annual recharge from irrigation water applied by groundwater irrigation in command and non command area was 1348.48 ha m and 3973.94 ha m, respectively. Similar studies have been reported by Joshi *et al.* (2021) and Tiwari *et al.* (2021).

Recharge from tanks and ponds: Recharge from tanks and ponds was computed for the monsoon and non-monsoon seasons of the current groundwater assessment year. There are number of ponds in the study area. The water-spread area in hectare of each tank/pond was taken as 0.6 times (GEC-1997). The recharge from each tank/pond in ha m during the monsoon and non monsoon seasons of the groundwater assessment year was computed as the product of the average water spread area, the number of days water was available and a factor of 0.0014m/d. The total recharge from the tank and ponds in non command area in monsoon and non-monsoon season was 639.83 ha m and 755.06 ha m, respectively.

Recharge from rainfall: Rainfall is the natural phenomenon showing considerable variations from year to year. The rainfall infiltration factor method was employed for the calculation of recharge from rainfall. The normal rainfall is the data most appropriate for computing the rainfall recharge. The recharge from rainfall was computed as:

R= f×A× [Normal rainfall of the season under computation]

where, R is recharge from rainfall, f is rainfall infiltration factor, A is area for computation of recharge.

Due to unconsolidated loss sediments and sandy alluvial soil, the rainfall infiltration factor in Babina block for both command and non command area was taken as 0.22 from the GEC-97 norms (CGWB 2009, 2011). As per the data of the Indian Meteorological Department (IMD), Lucknow, the annual normal rainfall of the Babina block was 678.74 mm whereas seasonal rainfall was 616.654 mm for the monsoon and 62.09 mm for the non-monsoon season.

Replenishable groundwater resources: The annual replenishable groundwater resources in the command and non-command area of the Babina block was calculated by recharge from other sources in the monsoon and non-monsoon and recharge from rainfall in the monsoon and non-monsoon season. The annual replenishable groundwater resources in the command and non-command area were 11550.4 ha m and 5087.3 ha m, respectively.

Net annual groundwater availability: The net groundwater availability has been obtained by subtracting the natural discharge from the replenishable groundwater resources. The natural discharge like base flow, evaporation from groundwater reservoir etc. have been left unaccounted while obtaining total annual groundwater recharge. The unaccounted natural discharge was assigned as 10% of the total replenishable groundwater resources as per GEC-97 norms (CGWB 2009, 2011). The net annual groundwater availability was to be calculated between domestic, industrial and irrigation uses. Net groundwater availability of Babina block (Jhansi district) was 8318.85 ha m.

Long term groundwater trend: The long-term groundwater fluctuation has been determined by the data of the 31 observation wells in the command and non-command area of the Babina block. Based on the groundwater level data, the average water level fluctuation below ground level (bgl) between the pre-monsoon and the post-monsoon season of the 12 consecutive years from (2005–16) were found 1.79 m, 1.21 m, 1.61 m, 4.05 m, 1.80 m, 4.07 m, 4.86 m, 5.01 m, 4.82 m, 1.13 m, 0.22 m and 3.97 m whereas, rainfall during these years, have a small difference which signifies that in the long groundwater trend there was no significant rise or fall of water levels, in both the pre-monsoon and the post-monsoon seasons.

Categorization for future groundwater development: The stage of groundwater development was computed as given below.

$$\text{Stage of development} = \frac{\text{Existing gross draft for all uses}}{\text{Net annual availability}} \times 100$$

For the categorization for future groundwater development recommended by GEC-97 norms (CGWB, 2009) stage of groundwater development ≤70% is safe, >70% and ≤90% is safe if there is no change in water table trend during pre-monsoon and post-monsoon, >90% and ≤100% semi-critical if any changes in water table trend pre and post-monsoon, >90% and ≤100% critical if water table trend changes in pre and post-monsoon both >100% over exploited. The stage of groundwater development of the Babina block (Jhansi district) is 71.30% [(5931.54/8318.85)*100], and categorized as safe for future groundwater development Babina block. Similar findings have been reported earlier (CGWB 2017, Joshi *et al.* 2021, Tiwari *et al.* 2021).

The increasing demand for water has put tremendous pressure on groundwater resources in the regions where groundwater is a major source of water. The groundwater resource estimation in the study area was calculated by using "Groundwater Estimation Methodology 1997 (GEC- 1997)". The stage of groundwater development in the Babina block was calculated 71.30% with no significant decline of water levels during both the pre-monsoon and post-monsoon intervals hence the Babina block is categorized as 'Safe' for future groundwater development. While estimating the replenishable groundwater resource it is essential to have a good database and idea of the different recharge mechanisms and their importance in the study area. Groundwater resources estimation is a continuous process, since the natural discharge and recharge pattern of the aquifer changes with the changing groundwater scenario. Therefore, there is an urgent need for the formulation of long term assessment plan of periodical reassessment of the groundwater resources in the study area. These would include the intensified monitoring of the measured data like water level, rainfall canal discharge, well, base flow, etc. and spatial studies on estimation of parameters like specific yield, rainfall infiltration factor, canal seepage factor, return flow factor etc. Consequently, a well-planned programme of groundwater development to meet both drinking and irrigation water requirement can be safely initiated in the Babina block to optimally utilize the groundwater potential at the same time and ensure that the groundwater development is both sustainable and has no adverse environmental impacts.

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