

Computation of groundwater resources and recharge in Chithar River Basin, South India

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Abstract Groundwater recharge and available groundwater resources in Chithar River basin, Tamil Nadu, India spread over an area of 1,722 km² have been estimated by considering various hydrological, geological, and hydrogeological parameters, such as rainfall infiltration, drainage, geomorphic units, land use, rock types, depth of weathered and fractured zones, nature of soil, water level fluctuation, saturated thickness of aquifer, and groundwater abstraction. The digital ground elevation models indicate that the regional slope of the basin is towards east. The Proterozoic (Post-Archaean) basement of the study area consists of quartzite, calc-granulite, crystalline limestone, charnockite, and biotite gneiss with or without garnet. Three major soil types were identified namely, black cotton, deep red, and red sandy soils. The rainfall intensity gradually decreases from west to east. Groundwater occurs under water table conditions in the weathered zone and fluctuates between 0 and 25 m. The water table gains maximum during January after northeast monsoon and attains low during October. Groundwater abstraction for domestic/stock and irrigational needs in Chithar River basin has been estimated as 148.84 MCM (million m³). Groundwater recharge due to monsoon rainfall infiltration has been estimated as 170.05 MCM based on the water level rise during monsoon period. It is also estimated as 173.9 MCM using rainfall infiltration factor. An amount of 53.8 MCM of water is contributed to groundwater from

surface water bodies. Recharge of groundwater due to return flow from irrigation has been computed as 147.6 MCM. The static groundwater reserve in Chithar River basin is estimated as 466.66 MCM and the dynamic reserve is about 187.7 MCM. In the present scenario, the aquifer is under safe condition for extraction of groundwater for domestic and irrigation purposes. If the existing water bodies are maintained properly, the extraction rate can be increased in future about 10 % to 15 %.

Keywords

Introduction

Geological and tectonic setting of an area is vital, since it decides the occurrence of various mineral deposits and groundwater. Groundwater recharge and its movement are also influenced by the prevailing geological and hydrogeological settings of an area. Salama et al. (1994) have studied the basin geomorphological controls to understand the mechanism of recharge and discharge in Western Australia. Sreedevi et al. (2001) have used the remote sensing and GIS (Geographic Information System) techniques to study the occurrence of groundwater in various geomorphological units of Pageru River basin, Cuddapah district, Andhra Pradesh, India. They have prepared various thematic maps namely, drainage map, hydrogeomorphological map, and lineament map from satellite imageries. Naik and Awasthi (2003) have estimated the groundwater recharge due to monsoon rainfall and the

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available groundwater reserve in Koyna River basin, India using simple and straightforward methods. Some of the previous works carried out in Chithar River basin are groundwater level fluctuation and quality monitoring by the Indian Public Works Department (2002) and climatological studies by Rammohan (1984). However, the recharge of groundwater and the available groundwater reserve in Chithar River basin have not been estimated in their study. As the ground water is being continuously exploited in this basin to meet the demand for water supply and irrigation, it is essential to understand the geological and hydrogeological setting of the basin and also it is very much needed to assess the available groundwater resources. Hence, the present work was carried out with the objectives of understanding the hydrogeological setting of the basin and estimating the groundwater recharge, abstraction, and reserve.

Study area description

Location

The Chithar River basin is located in between latitudes $08^{\circ} 48'$ to $09^{\circ} 14'$ N and longitudes $77^{\circ} 11'$ to $77^{\circ} 46'$ E in Tirunelveli District, Tamil Nadu, India (Fig. 1). It covers an area of $1,722 \text{ km}^2$. Chithar River is an important tributary of Tamirabarani River. The trunk stream of the former originates near Coutrallam with five beautiful falls in Poigaimalai and confluences with the latter after a run of nearly 80 km. Azhuthakanni Ar, Intharuvi, Harihara Nathi, Hanuman Nathi, Gundar, and Karuppa Nathi are the major tributaries of Chithar River in the hill ranges of Western Ghats. This river is non-perennial and it carries water only during the months of November and December.

Climate and rainfall

The areas adjacent to Western Ghats are of dry to moist sub-humid climatic types (Rammohan 1984). The plain lands of this basin fall under semi-arid climatic type. Hence, the study area experiences mostly dry climate. The average maximum temperature recorded during April/May is about 39°C . The average minimum temperature is about 24°C recorded usually during the month of November/December. The average annual rainfall calculated from 70 years

data (1933–2002) of eight rain gauge stations spread over the study area is about 918 mm (Fig. 2). Almost 70 % of the total rainfall is contributed by northeast monsoon, which is from October to December. Rest of the rainfall is received during the southwest monsoon from June to September and transitional period.

Topography and drainage

The maximum elevation is 1,621 m above-mean-sea level (a.m.s.l.) in the northwestern part of the study area. The minimum elevation is 38.64 m a.m.s.l. Three-dimensional digital elevation models (DEM) of Chithar River basin have been developed from the elevation contours. The DEM excluding major peaks and valleys indicates that the regional slope of the basin is towards east. Drainage pattern is one of the most important indicators of hydrogeological features, since it is controlled by underlying lithology (Charon 1974). A well-developed dendritic type of drainage system (Fig. 3) indicates the occurrence of rocks of uniform resistance (Thornbury 1969). Fine textured patterns noticed in the hill slopes indicate high-surface runoff and low-rainfall infiltration. The coarser patterns in the plains, however, are indicative of high-rainfall infiltration (Lillesand and Kiefer 1994).

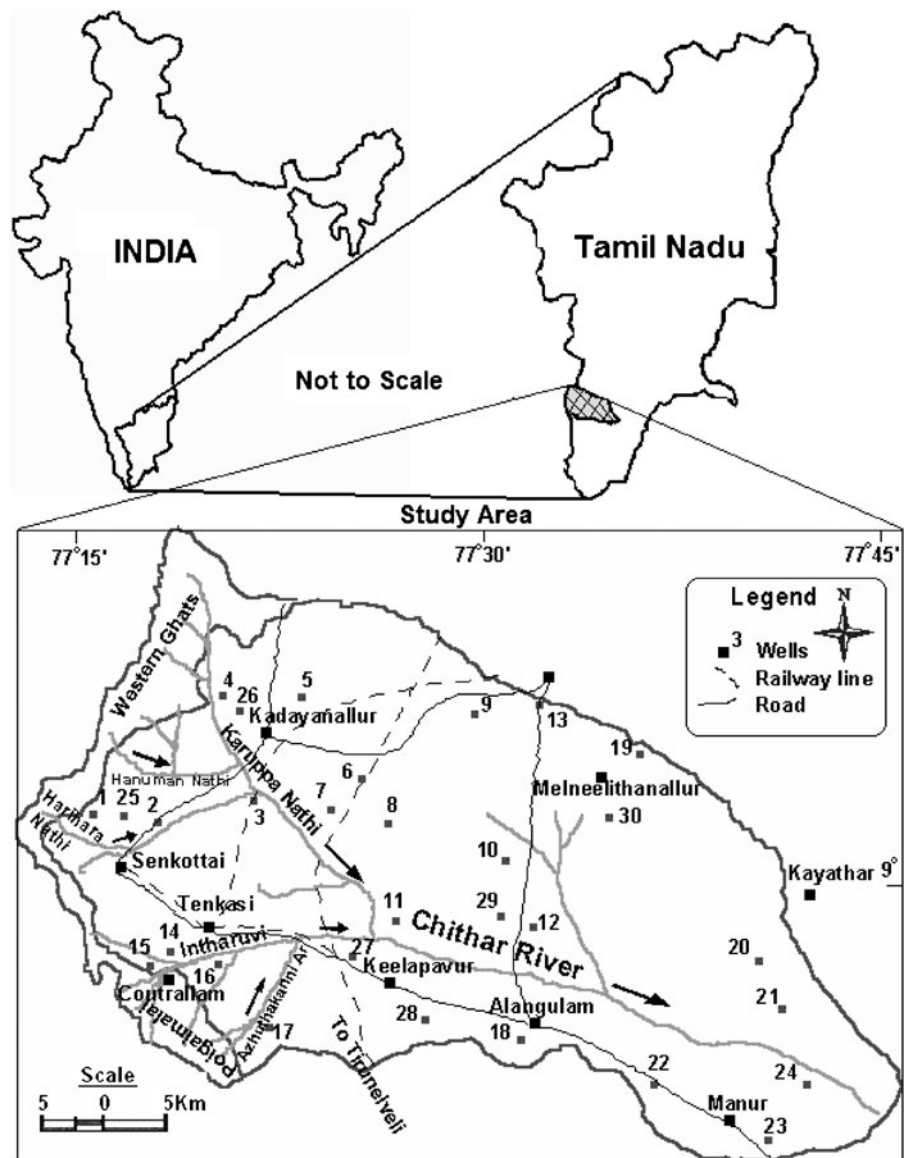
Land use

The areas adjacent to the Chithar River and major tanks are of intensively irrigated (Fig. 4). Sparsely irrigated areas are noticed along some of the tributaries of Chithar River, where the groundwater is effectively utilized. More cultivable fertile agricultural lands are seen in the western part of the basin than in the eastern part. Banana and sugarcane are the common wet crops. Paddy is also cultivated in most of the places during monsoon seasons. Uncultivable lands including forest, scrub, and barren rocky outcrops occupy nearly 35 % of the total area of the basin. Dry crops are also sowed frequently in most of the places.

Field and laboratory methods

Various thematic maps pertaining to groundwater studies namely, river basin map, drainage map, land use

Fig. 1 Chithar River basin and location of monitoring wells



map, hydrogeomorphological map, soil map, and geology map were prepared with the help of Survey of India toposheets and satellite imageries. Detailed field survey was carried out in Chithar River basin and the map details were verified in the field. Well inventory survey was also carried out. Details, such as type of well, total depth of the well, diameter of the well, pump used for groundwater extraction, usage, depth of water table, etc., were collected from the wells spread over the study area. Subsurface lithological cross sections were plotted from 33 bore wells drilled by the Indian Public Works Department (2002). Hydrographs were also prepared for 23

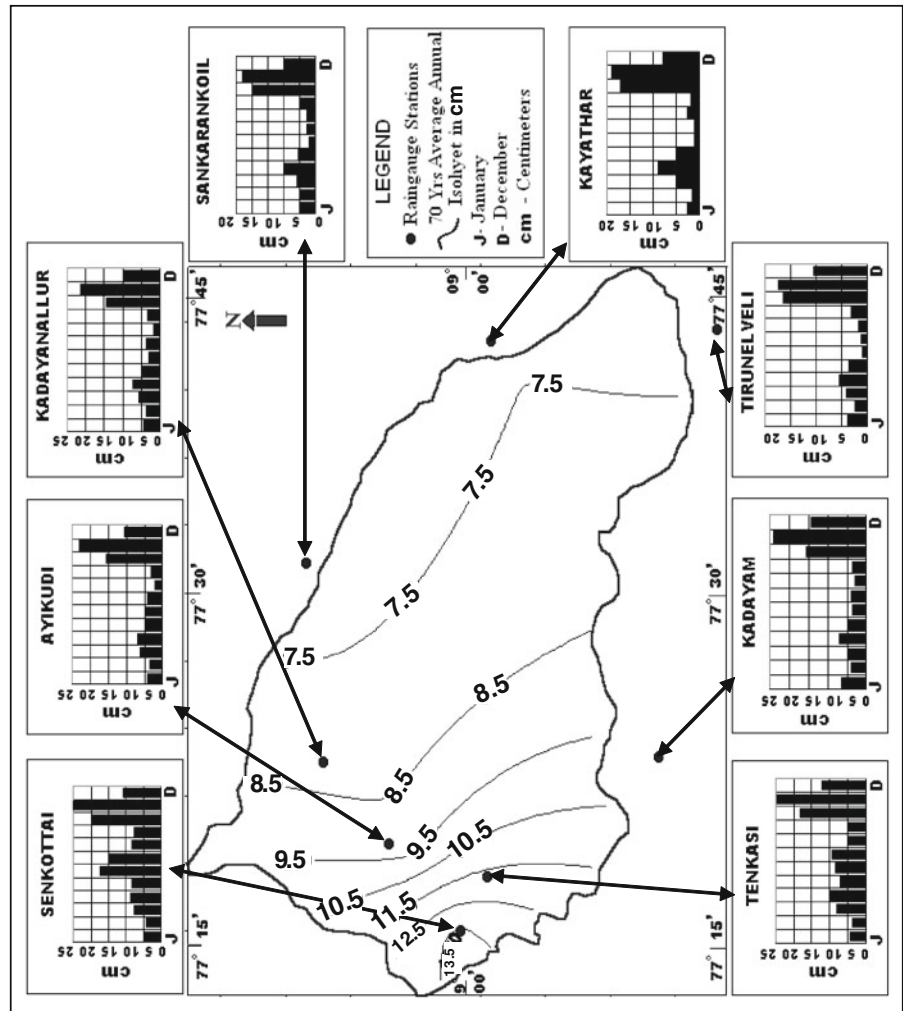
wells to understand the groundwater level fluctuation and recharge mechanism. Finally, groundwater recharge and groundwater reserve were estimated using various methods.

Geological and hydrogeological investigations

Geomorphology and lineament

Various geomorphological units such as, flood plains, bajadas, valley fills, shallow pediments, deep

Fig. 2 Isohyet of average annual rainfall distribution for 70 years (1933–2002)



pediments, and alluvial fans were demarcated from the IRS-1D-LISS-III satellite images (Fig. 5). The

available borehole lithology record reveals that a thin layer of alluvial flood plain deposits mainly

Fig. 3 Drainage map of Chithar River basin

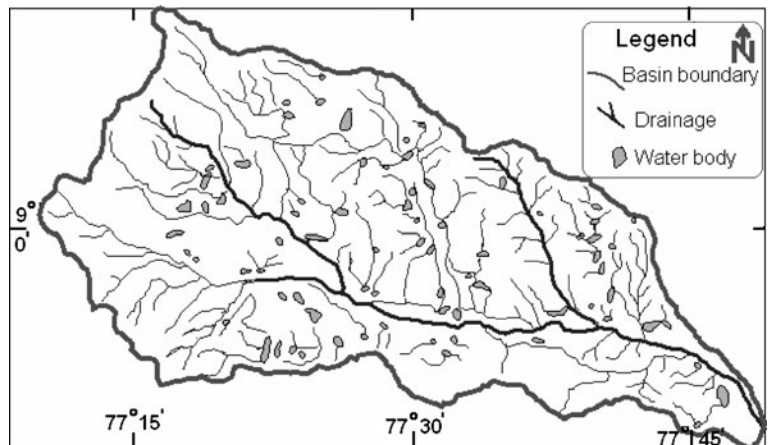
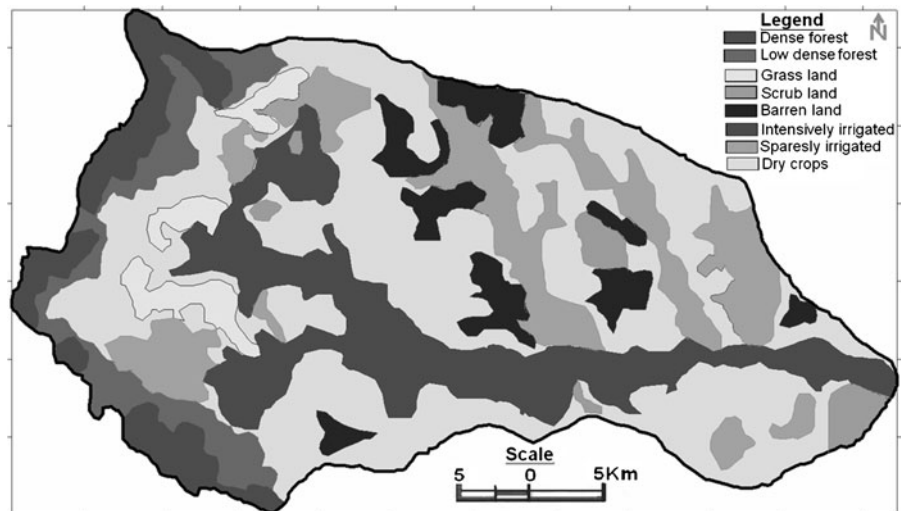


Fig. 4 Land use map of Chithar River basin

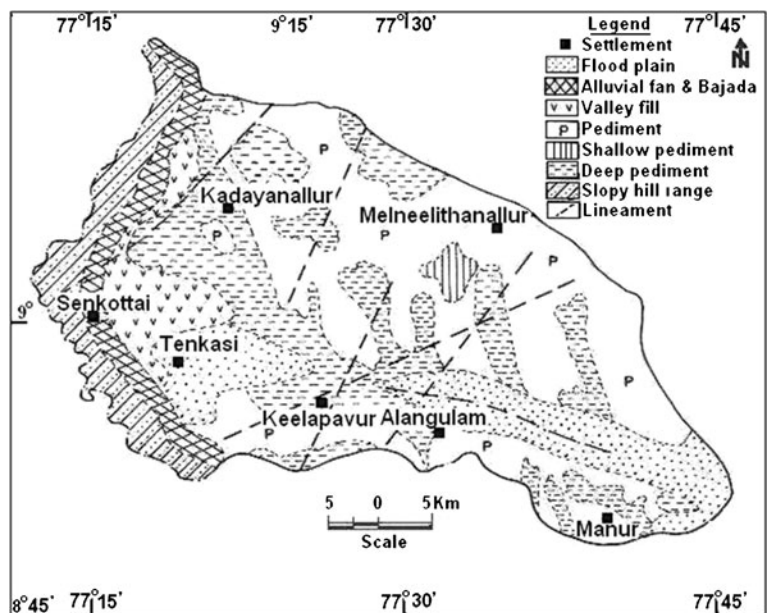


comprising sand are found along the banks of the Chithar River. The thickness of alluvial deposits in bajada and valley fills, which are located in the foothills of Western Ghats varies from 10 to 15 m in most of the places. Pediment occupies nearly 50 % of the basin area. Lineaments generally reflect orientations of joints and faults in a variety of geological settings (Lattman and Nickelsen 1958; Boyer and McQueen 1964). Major fracture lineaments were identified and delineated with the help of IRS-1D-LISS-III satellite images, where most of the lineaments trend in the NE-SW direction (Fig. 5).

Geological setting

The Proterozoic (Post-Archaean) basement of the area consists of quartzite, calc-granulite, crystalline limestone, charnockite, and biotite gneiss with or without garnet (Yoshida 1992; Jayananda et al. 1995). Granitic intrusions, quartz veins, pegmatite, and pyroxene granulite dykes can be observed in some places. Kankar (lime rich top soil) observed in few places are of recent to sub-recent in age. Quartzite shows NW-SE trend in most of the places with numerous NS minor joints. In some

Fig. 5 Geomorphological and lineament map



places, it is associated with calc-granulite and crystalline limestone. Calc-granulite and crystalline limestone also show the NW-SE trend. Calcitic- and dolomitic-limestones are being quarried in a few places for cement industries. Charnockite outcrops as massive hills in the western part of the basin (Narayanasami and Poorna 1967). Garnetiferous charnockites are also noticed in a few well cuttings in the eastern part.

Most of the study area is composed of biotite gneiss with or without garnet. Strike of this rock is NW-SE and the dip is towards SW. The dip amount varies from 60° to 75° . Overgrown garnets that are not aligned along the foliation in biotite gneiss are noticed in a few outcrops. This indicates post tectonic phenomena. Granitic intrusions are found in the country rock of biotite gneiss with lot of horizontal and vertical joints. The geology of the study area is illustrated in the Fig. 6 and the stratigraphic succession of the geological formations (GSI 1995) is presented in Table 1. A thin layer of topsoil overlies the basement rocks. Three major soil types were identified in the study area: black cotton, deep red, and red sandy soils (Fig. 7).

The bedrock configuration is one of the important controlling factors as far as the geometry of the aquifer is concern (Jawelraza et al. 2003). The infiltration/runoff relationship is mainly controlled by permeability, which is a turn function of rock

type and fractures in rocks (Edet et al. 1998). Hence, it is essential to understand the subsurface lithological variations with respect to depth. Borehole lithology details available at 33 well sites distributed in various rock types were made use of understanding the nature and thickness of the aquifer. The thickness of topsoil ranges from 1 to 1.5 m in most of the places. Occurrence of weathered zone in the study area is not uniform in both space and depth. It ranges from 8 to 34 m below ground level (b.g.l.). Intensity of weathering is quite higher in gneissic rocks than in charnockite. Bajada and valley fill deposits are underlain by weathered formation up to 20 to 25 m b.g.l. Jointed and fissured rocks extend up to a maximum depth of 42 m in some well locations.

Hydrogeology

Groundwater in the Chithar River basin occurs under water table conditions in weathered crystalline formations. Groundwater recharge, transmission, and discharge of the basin are controlled by the basin geomorphology, geology, and structural patterns (Krishnarao 1971). Groundwater occurrence is higher in gneissic rocks than in charnockite because the intensity of weathering is quite higher in gneissic rocks rather than in charnockite. Dug wells are commonly used for drinking and irrigation purposes. Bore

Fig. 6 Geology of Chithar River basin

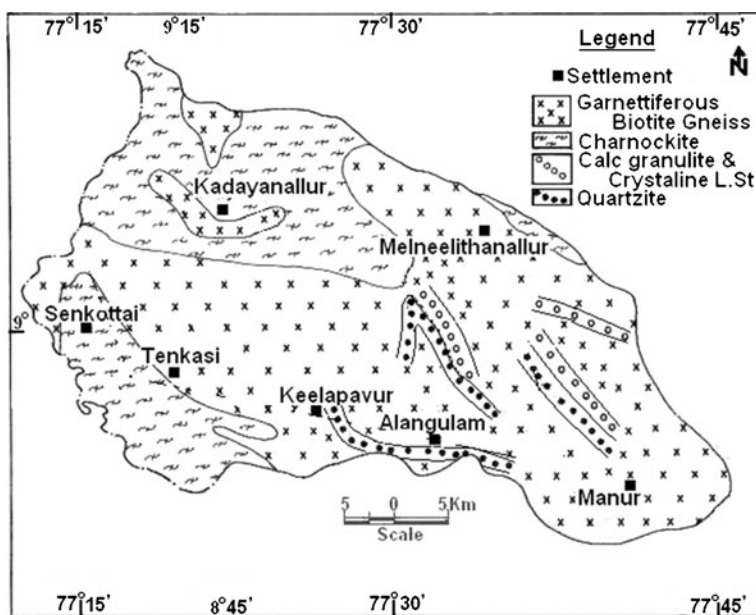


Table 1 Stratigraphic succession of the geological formations

Age	Group	Lithology
Recent to sub- recent	–	Black cotton soil, red soil, red sandy soil and kankar (lime rich deposit)
Post- Archaean (Proterozoic)	Migmatite complex	Younger granitic intrusions Garnitiferous biotite gneiss
	Charnockite	Pyroxene granulite Charnockite
	Khondalite	Calc-granulite and crystalline limestone Quartzite

wells are also used for irrigation but, exclusively used for drinking purposes. Some of the dug wells constructed in this basin go dry in summer.

Aquifer parameters of various formations were established by conducting pump tests from 33 bore wells spread over the study area (PWD 2002) are presented in Table 2. Higher hydraulic conductivity and transmissivity values are found in thick alluvial deposits as well as in buried pediments. The spatial variation of hydraulic conductivity and transmissivity are illustrated in the Fig. 8. Hydrographs relating groundwater level fluctuation and rainfall recharge were prepared for 23 wells. Overall view of groundwater level fluctuation and the hydrographs indicate that the groundwater table rises during November and December to reach peak in January and declines from February onwards to reach a low in September or October. Rainfall infiltration rate in red and red sandy soils

(Fig. 9a) is quite higher than black cotton soil (Fig. 9b).

Estimation of groundwater recharge

Downward movement of water reaching the water table, forming an addition to the groundwater reservoir is termed as groundwater recharge (Devries and Simmers 2002). Groundwater recharge occurs in Chithar River basin mainly due to percolation of rainwater, return flow from irrigation, and percolation from the surface water bodies. Groundwater inflow from the adjoining river basins to the Chithar River basin is considered negligible. A number of methods are formulated for estimating groundwater recharge. Selection of an appropriate method depends on several factors including field

Fig. 7 Soil map of Chithar River basin

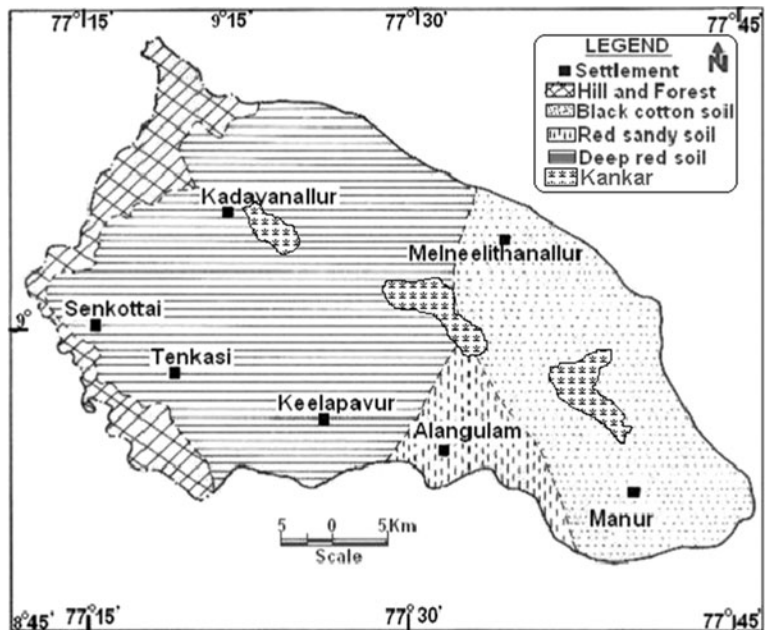


Table 2 Aquifer parameters of various geological formations

Geological formation	Hydraulic conductivity (m/d)	Transmissivity (m ² /d)	Yield (lps)
Hard rock	0.1 to 24	3 to 197	0.13 to 6
Bajada	5 to 18	11 to 228	3.5 to 18
Alluvium	4 to 32	16 to 743	2 to 30

constrains and availability of field data (Scanlon et al. 2002).

Recharge due to monsoon rainfall

Rain is almost the sole contribution to the precipitation, which is the primary source of water in this basin. Even though a number of methods are available for estimating groundwater recharge, the ones based on water table fluctuations are among the most widely applied (Healy and Cook 2002). The annual groundwater recharge due to rainfall infiltration has been estimated using the following equation (Naik and Awasthi 2003):

$$G_r = A_e \times WL_r \times S_y$$

where G_r is the total groundwater recharge due to monsoon rainfall, A_e is the effective area for groundwater recharge, WL_r is the average groundwater level rise during the period of recharge, and S_y is the regional specific yield of the formation.

The average groundwater level rise in wells spread over the study area observed between May and November 2002 is found to be 3.95 m. Basin area under consideration is 1,772 km². The regional specific yield of the formation is taken as 2.5 % based on the pump test results available at 33 locations, and also considering the values of 3 % and 2 % suggested by the Groundwater Estimation Committee (GEC 1997) for gneissic rocks with low clay content and significant clay content respectively. Groundwater level rise between May and November has been considered for recharge estimation since the rainfall occurs mainly during the monsoon period. The annual minimum replenishable groundwater recharge due to monsoon for the year 2002 is estimated as 170.05 MCM (million m³) using the above formula. It is also estimated based on the rainfall infiltration factor of 11 %

suggested by the GEC (1997) for gneissic rock with low clay content. It is amounting to 173.9 MCM. The average annual rainfall is taken as whole (918 mm) without separately considering command and non-command areas.

Recharge due to surface water bodies

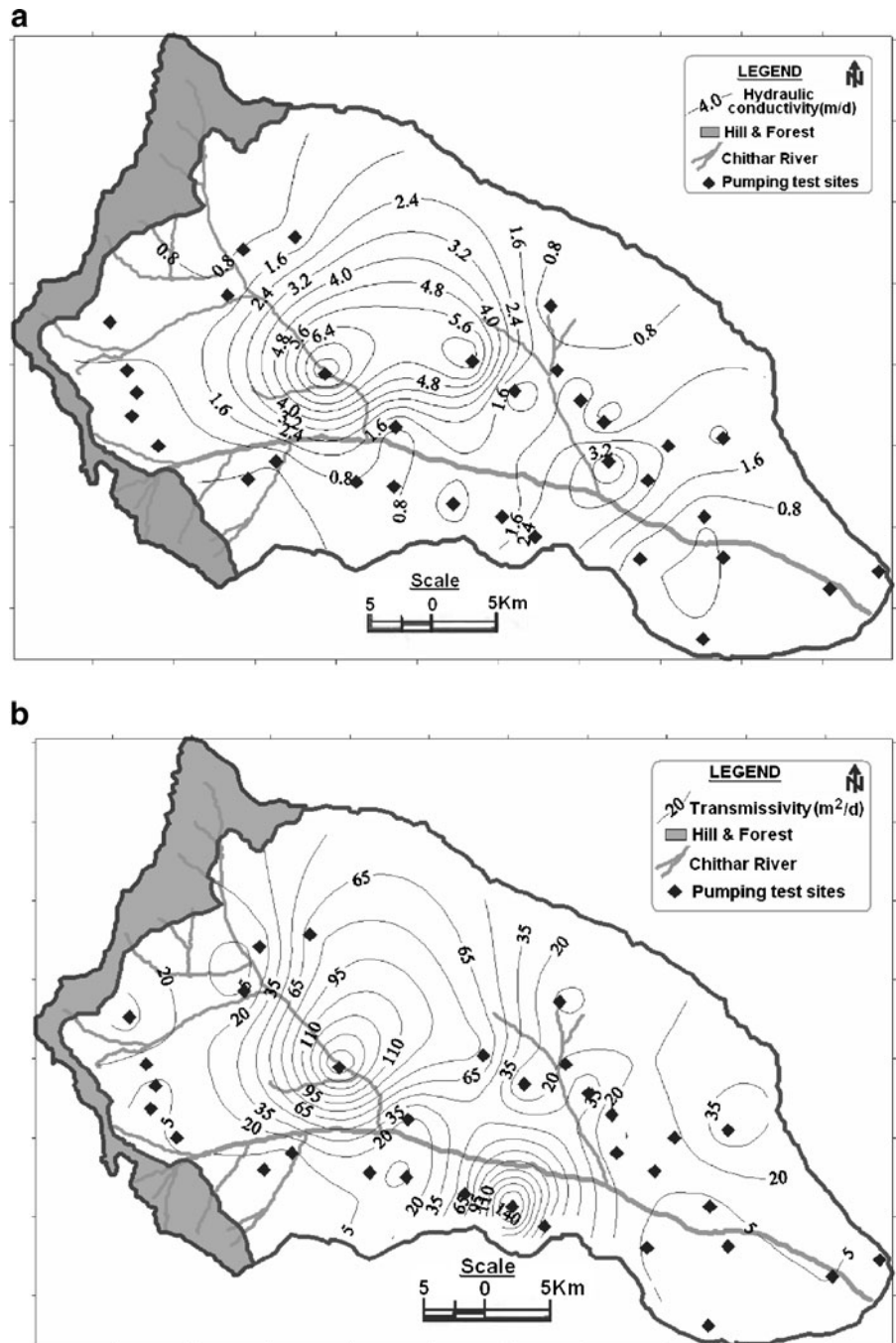
The Chithar River basin has 4 major reservoirs of 11 MCM maximum storage capacity, 316 irrigation tanks of 95 MCM storage capacity connected with 17 weirs, and 350 smaller rain-fed tanks of 163 MCM capacity (PWD 2002). These water bodies have a cumulative average annual gross storage of 107.6 MCM. About 50 % of the gross storage in these water bodies may be contributing towards groundwater recharge (GEC 1997). Thus, the groundwater recharge due to surface water bodies is estimated as 53.8 MCM.

Recharge due to return flow from irrigation

GEC (1997) has suggested three parameters namely, source of irrigation (surface water or groundwater), type of crop (paddy or non-paddy) and depth of groundwater table below ground level (b.g.l.) for estimating the groundwater recharge due to return flow from irrigation. It is found that the area of 262.27 km² has been effectively used for paddy cultivation in the year 2002. In this, the depth of groundwater table is less than 10 m with respect to b.g.l. over 162.78 km² area and in the rest of 99.49 km² area, the depth of groundwater table is from 10 to 25 m. An area of 133.12 km² was put in use for the other crops during the same year. In this, the depth of groundwater table is less than 10 m over 75.72 km² areas and it is greater than 10 m over 57.4 km² areas.

From the available data, the water requirement for paddy and non-paddy crop has been estimated as 1.1 and 0.52 m, respectively. Hence, water applied for paddy field and non-paddy field has been estimated as 288.497 MCM and 69.222 MCM for the year 2002. As per the GEC (1997) norms, return flow from irrigation has been assumed that 50 % and 40 % of the water applied for the paddy field goes to groundwater where, the depth of groundwater table is within 10 m b.g.l. and 10–25 m b.g.l., respectively. Similarly, it is assumed as 25 % and 15 % for the non-paddy crop area for the above mentioned water table conditions. Thus, the net groundwater recharge due to return flow

Fig. 8 Spatial variation of hydraulic conductivity and transmissivity



of water applied for irrigation has been computed as 147.6 MCM where, 133.31 MCM of water goes to groundwater under the paddy field and the rest of 14.32 MCM under the non-paddy field.

The total groundwater recharge also depends on evapotranspiration, groundwater extraction due to

domestic and stock needs, leakage to deeper aquifers, spring discharge, and base flow. Since the base flow is a part of the total runoff, it is not taken into consideration in the above equation. It is also difficult to estimate the exact amount of leakage to deeper aquifers (Naik and Awasthi 2003).

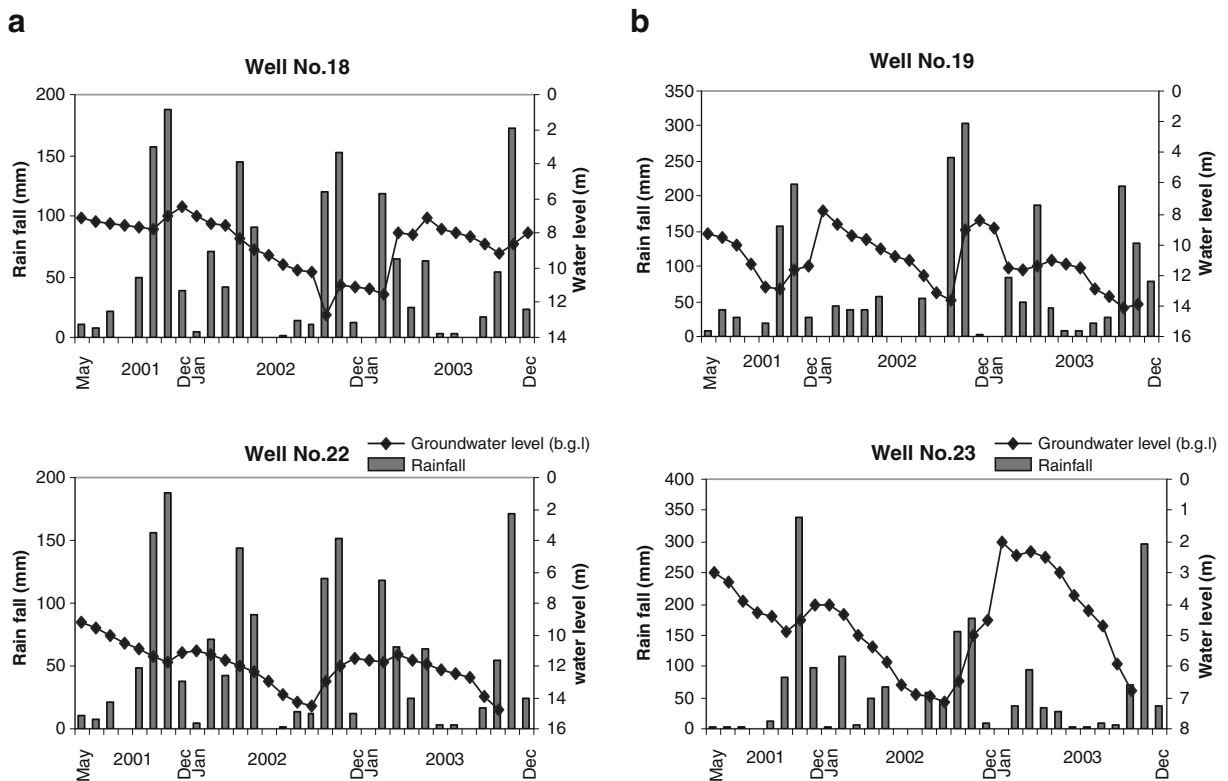


Fig. 9 Rainfall and groundwater level variation in **a)** red sandy soil and **b)** black cotton soil

Estimation of groundwater abstraction

Since Chithar River is a non-perennial, groundwater is the major source for domestic and agricultural needs. The water consumption rates recommended by the Government of India are 40 l/day per person and 50 l/day per animal (CGWB 1984). Based on these statistics, the annual consumption of groundwater for human and stock population has been estimated as 14.42 MCM for the year 2002. Water applied for irrigation has already been estimated as 357.72 MCM where, 288.5 MCM of water has been applied for paddy field and 69.22 MCM of water for non-paddy field. It is also found that groundwater is applied for 25 % of paddy crop and 90 % of non-paddy crop through dug wells and bore wells fitted with 3- to 5-hp (horse power) electric driven centrifugal pumps and 5 hp diesel driven centrifugal pumps. An estimated number of 4,687 electric pumps and 1,246 diesel pumps are used for agricultural practice in this basin. It is computed that 134.42 MCM of groundwater has been abstracted for irrigational purposes in the year

2002 including both 72.12 MCM of groundwater abstracted for paddy cultivation and 62.3 MCM of water abstracted for the cultivation of other crops. Thus, 148.84 MCM of groundwater has been abstracted for domestic and irrigational purposes during the year 2002.

Estimation of groundwater reserve

Dynamic groundwater reserve

Groundwater is extensively exploited in Chithar River basin for irrigation from the beginning of November to the end of April next year. The exploitable groundwater reserve is defined as the long-term average annual recharge under conditions of maximum groundwater use (Karanth 1999; Naik and Awasthi 2003). It has been estimated using the equation:

$$G_{re} = WL_d \times A_e \times S_y$$

where G_{re} is exploitable groundwater reserve and WL_d is average groundwater level decline between November

and May next year; A_e and S_y were already defined. The average water level fluctuation observed in the wells during November 2002–May 2003 is 4.36 m. Hence, the dynamic groundwater reserve for the hydrological year 2002–2003 is estimated as 187.7 MCM.

Static groundwater reserve

Static groundwater reserve is defined as the water available below the natural/dynamic water level fluctuation. It has been estimated using the equation (Naik and Awasthi 2003):

$$G_{rs} = B \times A_e \times S_y$$

where G_{rs} is the static groundwater reserve and B is the saturated thickness of the aquifer below the deepest level of water in the pre-monsoon period; A_e and S_y were already defined. The borehole lithological data and well inventory survey indicate that the thickness of water bearing formations below the zone of dynamic water level fluctuation is 10.84 m. Thus, the static groundwater reserve in Chithar River basin is estimated as 466.66 MCM based on the above equation.

Conclusions

The Chithar River basin, Tamil Nadu, India comprises of Quartzite, calc-granulite, crystalline limestone, chano-kite, and biotite gneiss of proterozoic age. Groundwater occurs under water table conditions in the weathered crystalline formations. Occurrence of weathered zone ranges from 8 to 34 m below ground level. Fractured and jointed rocks extend up to 40 m. The average annual rainfall of the basin is 918 mm. Almost 70 % of the total rainfall is received within three months (October–December). Therefore, water table gains drastically during October to December and reaches the peak in January. It declines gradually from February to reach a low in October. The depth of water table is almost zero in the western part of the basin during December–January. The rainfall intensity is high in the western part and gradually decreases towards east.

Water used for cultivation during the year 2002 has been estimated as 357.72 MCM. Out of this 134.42 MCM of water has been utilized from the groundwater recourse. Groundwater used for domestic/stock needs has been estimated as 14.42 MCM. Thus, the net

groundwater abstraction has been computed as 148.84 MCM for the year 2002. Groundwater recharge due to monsoon rainfall infiltration has been quantified as 170.05 MCM and 173.9 MCM, respectively, from water level fluctuation method and rainfall infiltration factor method. It is found that 53.8 MCM of water has been contributed to groundwater system from the surface water bodies during the year 2002. Groundwater recharge due to return flow from irrigation has been estimated as 147.6 MCM. The static groundwater reserve in Chithar River basin is estimated as 466.66 MCM and the dynamic reserve is about 187.7 MCM. Thus, the total groundwater reserve for the year 2002 is 654.36 MCM.

This study concludes that the aquifer system is not under stress, and suggests that extraction rate can be increased about 5 % to 10 %. To meet the future demand, it is also recommended to increase the groundwater recharge by properly maintaining/desilting the existing water bodies. There is no necessity of constructing new percolation ponds since the study area contains numerous water bodies. However, the water bodies should be linked with the river channels to avoid the excess surface runoff during northeast monsoon season and also to augment the groundwater resources. In such case, groundwater extraction rate can be increased from 10 % to 15 % throughout the basin and the maximum of 20 % in the western part.

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References

- Boyer, R. F., & McQueen, J. E. (1964). Comparison of map rock fractures and air photo linear features. *Photogrammetric Engineering*, 30, 630–635.
- CGWB. (1984). *Groundwater resources of the Upper Betwa River basin, India. Indo-British, Tech Ser, Bulletin 1*. New Delhi: Central Ground Water Board, Ministry of Water Recourses, Government of India.
- Charon, J. E. (1974). Hydrogeological applications of ERTS satellite imagery. In *Proc UN/FAO Regional seminar on remote sensing of earth resources and environment* (pp. 439–456). Cairo: Commonwealth Science Council.
- Devries, J. J., & Simmers, I. (2002). Groundwater recharge: an overview of processes and challenges. *Hydrogeology Journal*, 10(1), 5–17.

- Edet, A. E., Okereke, C. S., Sc, T., & Esu, E. O. (1998). Application of remote sensing data to groundwater exploration: a case study of the Cross River State, southern Nigeria. *Hydrogeology Journal*, 6(3), 394–404.
- GEC. (1997). *Report on groundwater resources estimation methodology—1997*. New Delhi: Groundwater Resource Estimation Committee, Ministry of Water Resources, Government of India.
- GSI (1995) Geological and mineral map of Tamil Nadu and Pondichery: Map published in 1: 500,000 scale by the Director General, Geological Survey of India.
- Healy, R. W., & Cook, P. G. (2002). Using groundwater levels to estimate recharge. *Hydrogeology Journal*, 10(2), 91–109.
- Jawelraza, I. S. H., Md, A., & Shekhar, S. (2003). Groundwater resource development in Jamui District, Bihar, India: an overview. *Hydrogeology Journal*, 11(3), 396–400.
- Jayananda, M., Janardhan, A. S., Sivasubramaniam, P., & Pencay, J. J. (1995). Geochronologic and isotopic constraints on granulite formation in the Kodaikanal area, southern India. *Journal of the Geological Society of India*, 34, 373–390.
- Karanth, K. R. (1999). *Groundwater assessment, development and management* (p. 720). New Delhi: Tata McGraw Hill.
- Krishnarao P. R. (1971) Hydrometeorological aspects of estimating groundwater potential. Sm.Vol. Groundwater potential of hard rock areas of India, Bangalore, pp1–2.
- >Lattman, L. H., & Nickelsen, R. P. (1958). Photographic feature-trace mapping in Appalachian, Plateau. *American Association of Petroleum Geologists*, 42, 2238–2245.
- Lillesand T. M., & Kiefer R. W. (1994) Remote sensing and image interpretation, 3rd edn., Wiley, New York
- Naik, P. K., & Awasthi, A. K. (2003). Groundwater resources assessment of the Koyna River basin, India. *Hydrogeology Journal*, 11(5), 582–594.
- Narayanasami, S., & Poorna, L. (1967). Charnockite rocks of Tirunelveli District. *Journal of the Geological Society of India*, 8, 38–50.
- PWD. (2002). *Groundwater perspectives: A profile of Tirunelveli district*. Tamil Nadu: Public Works Department, Tamil Nadu, India.
- Rammohan, H. S. (1984). *A Climatological assessment of water recourses of Tamil Nadu*. *Indian Jour. Power and River Valley Development* (pp. 58–63).
- Salama, R. B., Tapley, I., Ishii, T., & Hawkes, G. (1994). Identification of areas of recharge and discharge using Landsat-TM satellite imagery and aerial photography mapping techniques. *Journal of Hydrology*, 162, 119–141.
- Scanlon, B. R., Healy, R. W., & Cook, P. G. (2002). Choosing appropriate techniques for quantifying groundwater recharge. *Hydrogeology Journal*, 10(1), 18–39.
- Sreedevi, P. D., Srinivasalu, S., & Kesavaraju, K. (2001). Hydrogeomorphological and groundwater prospects of the Pageru River basin by using remote sensing data. *Journal of Environmental Geology*, 40, 1088–1094.
- Thornbury, W. D. (1969). *Principles of geomorphology*. New York: Wiley.
- Yoshida M. (1992 Precambrian tectonothermal events in east Gondwana land crustal fragments and their correlation (IGCP-288), In: R. Tsudhi (ed.), Japan contribution to the IGCP, Osaka:51–62.