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Groundwater resources evaluation in the Piedmont zone of Himalaya, India, using Isotope and GIS techniques

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Abstract

Integrated geohydrological, isotopes and Geographical Information System (GIS) techniques have been used to delineate groundwater resources potential in the Piedmont zone of Himalayan foothill region, Uttaranchal, India. Thematic maps for hydrogeomorphology, slope, and drainage density have been prepared and integrated with the help of GIS by assigning the weights to various attributes controlling occurrence of groundwater to generate the groundwater potential map for the study area. The results indicates that the southern part of the study area has very good groundwater potential whereas the steeply sloping area in the northern part having high relief and high drainage density possesses poor groundwater potential. The groundwater potential zones are found in agreement with the available yield data of tubewell. Vertical component of recharge to groundwater due to precipitation varies from 3 to 13 %, which has been estimated using Tritium Tagging Technique. The estimated recharge to groundwater shows a linear relationship with environmental tritium contents in the water samples. This indicates that the precipitation is the major source of recharge in the study area. On the basis of environmental tritium contents, it has been found that recharge to groundwater is taking place at higher altitudes (300-400m, AMSL) in the Bhabhar region where the shallow and deeper aquifers have good interconnection. The estimated groundwater flow rate for the deeper aquifer is 1.2 m/d. The groundwater flow pattern estimated from isotope techniques has been validated from flow pattern determined by the depth of groundwater table.

Key words: piedmont, Himalayan foothill region, Tritium Tagging Technique, isotopic techniques.

Introduction

Groundwater forms one of the important sources of potable water. It is believed to be safe, free from pathogenic bacteria and from suspended matter. The rate of withdrawal of groundwater is increasing continuously due to faster pace of population growth accompanied by agricultural and industrial development. This has increased the concern on groundwater resource evaluation and its management for sustainable development. The occurrence and movement of groundwater in an area is governed by several factors such as topography, hydrogeomorphology, geology, drainage pattern, land use, climatic conditions and inter relationships among these factors (Pratap et al., 2000). Many authors have used remote and GIS to generate groundwater potential map (Saraf. A.K and Chaudhary, 1998; and Murthy 2000; Krishnamurthy, et al., 1996; Ravi and Mishra, 1993). `The satellite remote sensing data along with Survey of India topographical maps, collateral information and limited field checks, have been used to establish the base line information for groundwater prospective zones (Singh et al., 1993; Chi and Lee, 1994; Haridass

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et al., 1994; Tiwari and Rai, 1996; Das et al., 1997; Ravindran and Jeyaram, 1997; Pratap et al., 1997; Thomas et al., 1999; Harinarayana et al.,2000; Muralidhar et al., 2000; Obi Reddy et al., 2000). Satellite data have been largely used as a surface indicator of subsurface features (groundwater occurrence and movement). To determine groundwater recharge and movement, isotopic and geochemical tracer methods have been used by various worker (Datta et al. 1973; Sukhija and Rama , 1973; Datta, 1975, Sukhija and Shah, 1976; Verhagen et al. 1979; Gupta and Sharma 1984; Athavale and Rangarajan, 1988; Sukhija et al. 1996 a,b). Other methods such as Chloride method and soil moisture methods have also been used to determine vertical groundwater recharge (Allison and Hughes, 1978; Edmunds and Walton, 1980, Sukhija et al. 1988, Sukhija et al 2003). Bradbury, 1991; Rose, 1992 have used environmental isotopes to identify the recharge areas, groundwater flow direction and velocity. Tritium (^3H) has also been used to estimate absolute and relative age of groundwater (Hendry, 1988a; Bradbury, 1991; Simpkins, 1991; Simpkins, and Bradbury, 1992; Simpkins and Parkin, 1993; Simpkins, 1995; Rao et al., 2001 and Zuber, et al., 2003) and to estimate groundwater recharge rates (Knott and Olimpio, 1986; Larson et al., 1987; Daniels et al., 1991). In the present study, an integrated geohydrological, isotopes and GIS techniques have been used for groundwater resources evaluation in the piedmont zone situated in Himalaya foothill region of India.

GIS based data generation for the study area

The Himalaya is skirted by an upper piedmont zone along its southern margin and is referred differently as "Kandi" in the northwestern India and "Bhabhar" in the northern India. The lower piedmont zone located further southward is referred as "Tarai". The piedmont zone is located to the south of Siwalik foothills of Himalayas and presents several difficulties in groundwater exploration and development due to occurrence of thick deposits of poorly sorted unindurated sediments, deep water table, and the associated problems in drilling. Due to these problems, the groundwater availability in the area becomes cost prohibitive and is generally unavailable to the rural users for the societal needs. Further, much of the groundwater is recharged by percolation to deep aquifers situated further downstream, because of the southward gradient of the land surface in the Bhabhar zone. The study area is shown in figure 1, located between Latitude 29° 50' 00" to. 30° 11' 21" North and Longitude 77° 54' 19" to 78° 06' 21" East, falling in Ratmau and Pathri Rao watershed covering an area of approximately 430 km^2.

An integrated geographic database consisting of spatial and non-spatial data has been generated for the study area. The spatial data consists of thematic maps generated from topographic and remote sensing data while the non spatial data comprises of attributes, primarily derived from ground checking during field survey and those available in literature. These data have been stored in GIS environment. The Image processing software ERDAS (ERDAS, 1997) is used to enhance Indian Remote Sensing (IRS), LISS III image for interpretation of the hydrogeological features, which in turn are digitized using GIS (Arc View 3.1 version) software to generate hydrogeomorphology and drainage density thematic maps of the study area. A slope map is prepared from the elevation contours available in the Survey of India (SOI) topo-sheet on 1:50,000 scale.

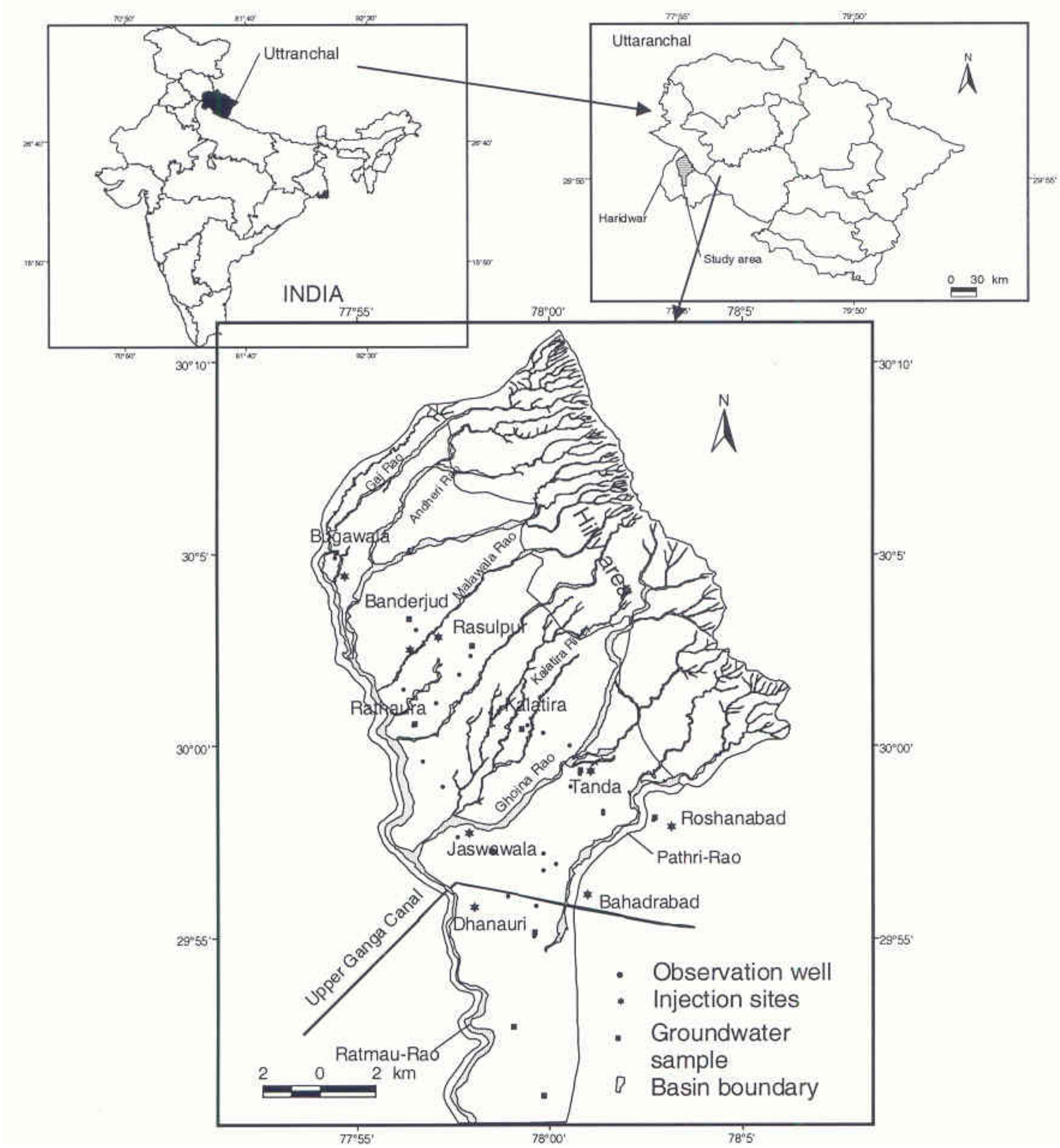


Fig.1: Location map of the study area showing locations of data points.

Based on physiographic characteristics, the area is classified into four geomorphic units. The geomorphic boundaries are digitized on the enhanced image through GIS and the generated hydrogeomorphological map is shown in Fig. 2. The Upper Piedmont zone (covering 194 km² of the study area) also known as Bhabhar, bordering the Siwalik Hills with gentle slope comprise of unconsolidated coarse material. For groundwater point of view this belt provides an excellent hydrogeological setup for recharge and infiltration. The depth to groundwater table monitored in this unit varies from 11 to 29 m. Groundwater prospects in this belt are good to very good. The Lower Piedmont (also known as Tarai) is separated from the Upper Piedmont (Bhabhar) by the spring line along their junction line and is covering about 107 km² of the area. This zone is composed of coarse-grained sand and clays with gravel (boulders and pebbles). The groundwater level monitored in this unit varies from 2 to 7m and the groundwater prospects are very good to excellent.

Topographic information has been collected from SOI topo-sheet on 1:50,000 scale and a Triangulated Irregular Network (TIN) has been generated from elevation contours (20m intervals) and spot elevations. The slope percent map generated from the TIN data for the study area is shown in Fig. 3. Nearly 40 percent of the total area shows slope of 0-1%. Whereas the steep slope (more than 10%) is found in the north and northeastern parts of the study area.

The analysis of drainage pattern of the area has been done to study the runoff/recharge conditions. In general, a dense drainage network indicates a less permeable formation, such as, shale/clay stone, which is less favorable for recharge conditions. A surface drainage map has been generated from SOI toposheet at 1:50,000 scale and Indian remote sensing LISS III data. The drainage pattern is mainly dendritic on higher slopes and sub-dendritic on gentle slopes. Maximum drainage density of 1.9 km/km² is observed in the northern part (covering about 126 km²) and minimum of 0.35 km\km² in the southern part of area particularly in the Lower Piedmont unit (covering about 103 km²). The generated drainage density map of the area is shown in Fig. 4.

The occurrence and movement of groundwater is governed by hydrogeomorphological, geological, slope, and drainage density etc. These features are assigned different weights depending on their influence on the groundwater potential (Srivastava and Bhattacharya, 2000; Obi Reddy, et al., 2000 and Pratap, et al., 2000). The different units in each theme are assigned ranks from 1 to 4 on the basis of their significance with reference to their groundwater potential. The final score of each unit of a theme is equal to the product of rank with their respective weight. The classification of these weights and rank of each theme and unit are shown in table 1.

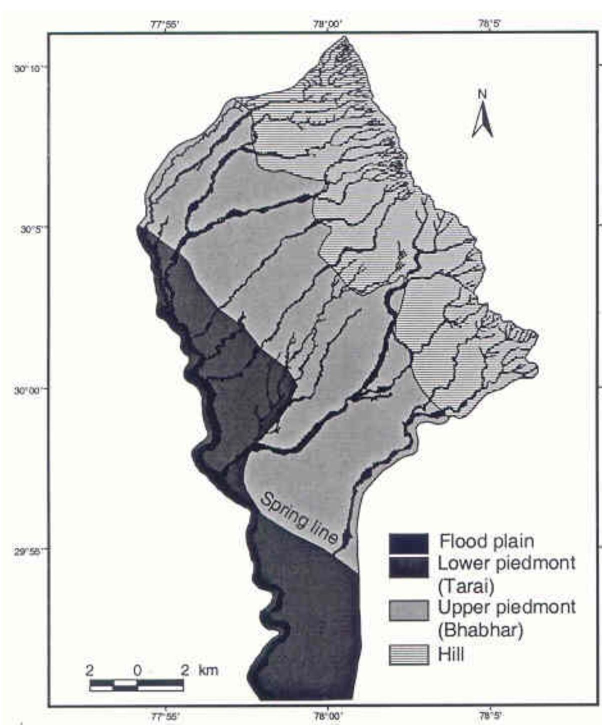


Fig. 2: Hydrogeomorphology of the area

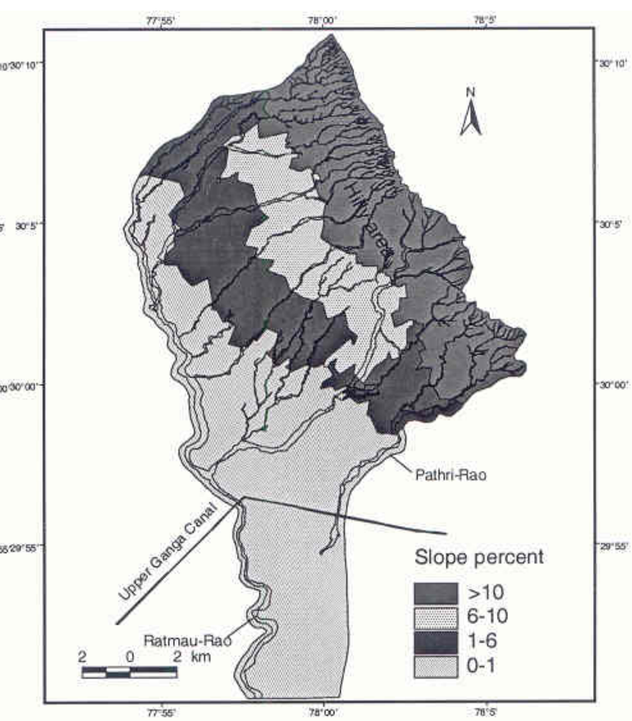
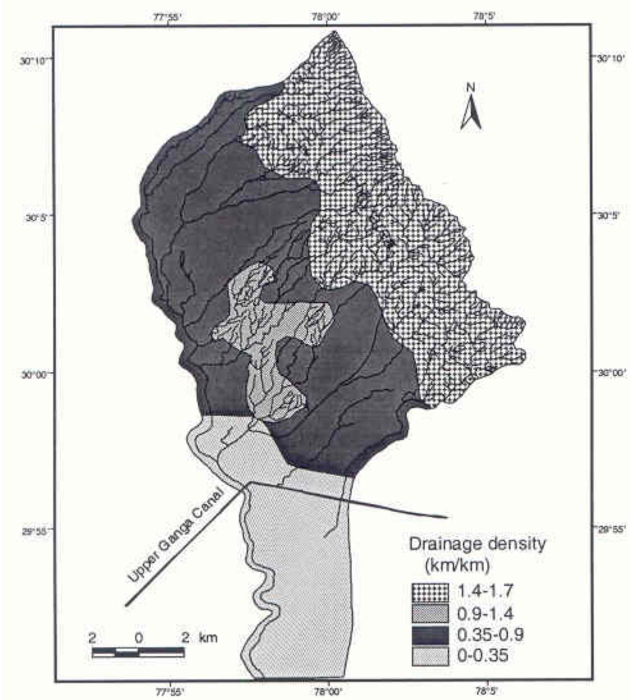


Fig. 3: slope map of the area



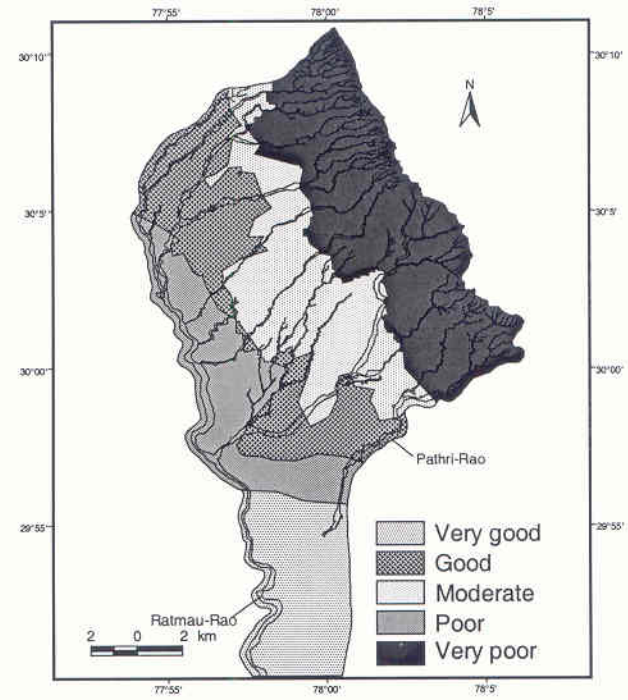


Fig. 4: Drainage density map of the study area **Fig. 5: groundwater potential map**

Finally the thematic maps of each theme are overlaid step by step to generate a composite map of the study area. The composite map is associated with a particular set of parameters considered in the study. The evaluation of groundwater potential is done by adding the scores of various themes. Thus the entire area is qualitatively divided into five zones vis-à-vis their groundwater potentiality namely very good, good, moderate, poor and very poor. The final thematic map showing the various groundwater potential zones in the study area is shown in Fig. 5. From the figure, it can be seen that the groundwater potential in the northern part of the study area (covering about 135 km^2 of the study area) is poor, due to very steep slopes and very high drainage density, resulting in low infiltration and high runoff. The groundwater potential is moderate to good (covering 172 km^2 of the area) in the middle part, due to gentle slope and low drainage density. In the southern part of the study area, about 60 km^2 of area has very good groundwater potential due to gentle slope and very low drainage density in the lower piedmont geomorphic unit while the remaining area (about 63 km^2) has moderate to poor groundwater potential. The generated groundwater potential map is validated from the yield data obtained from 10 tubewells located in the different groundwater potential zones (moderate to very good) shows that a zone of very good potential is having good water yield (121-257 m^3/h) and moderate to good having yield (63-225 m^3/h). It has also been observed that the locations with gentle slope and low drainage density in the piedmont geomorphic unit have comparatively higher water yields than the other locations.

Table 1 Rank, weight and score for attribute for various themes with respect to groundwater potential

Theme	Weight	Classes	Rank	Score
Hydrogeomorphology	5	Lower piedmont	4	20
		Upper piedmont	2	10
		Hill	1	5
Geology	4	Alluvial fan	3	12
		Siwalik hill	1	4
Slope	3	0-1	4	12
		1-5	3	9
		5-10	2	6
		>10	1	3
Drainage density	2	0.0-0.35	4	8
		0.35- 0.9	3	6
		0.9- 1.1	2	4
		1.1-1.9	1	2
Landuse	1	Cultivated	2	2
		Uncultivated	1	1
		Forest	1	1

Estimation of recharge

Tritium Tagging Technique has been used at eight sites (shown in fig. 1) for the estimation of recharge to groundwater due to precipitation (Zimmerman et al., 1967a). The groundwater recharge has been estimated by monitoring the vertical movement of injected tritium at each site during the period from the time of injection i. e. pre-monsoon (before onset of rainy season) to the post-monsoon (after the rainy season). The radioactive tritium obtained from Bhabha Atomic Research Center (BARC), India with specific activity of 40 micro Curie/cc was injected in five holes placed in a circular geometry at each site. The soil samples at each 10 cm level up to a depth of 2.5 meter were collected from the nearby place at each site at the time of injecting tritium and after the rainy season in Oct. 2002 from the injected points. The liquid scintillation counter (LSC) has been used to measure tritium activity (counts per minute) in each sample. The counting rates so obtained are shown with depth for two representative sites in Fig 6.

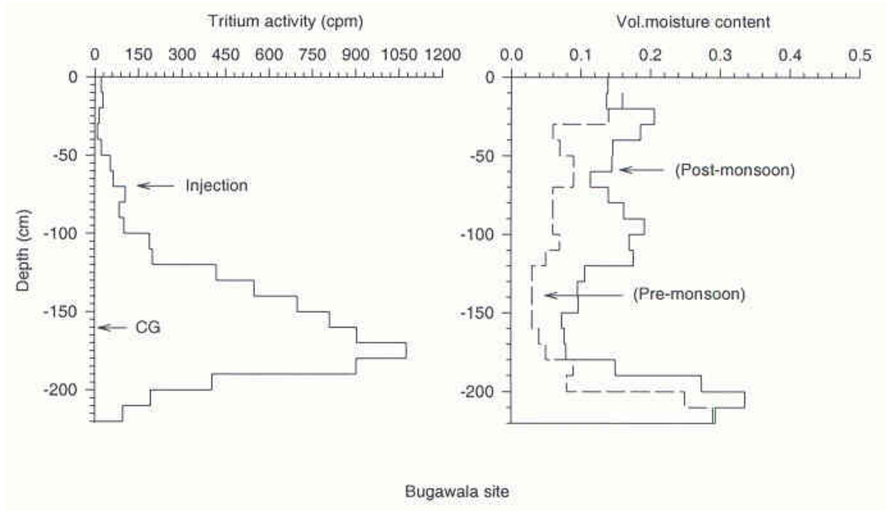


Fig. 6. Movement of injected tritium and soil moisture at representative sites (Bugawala, Bandarjud)

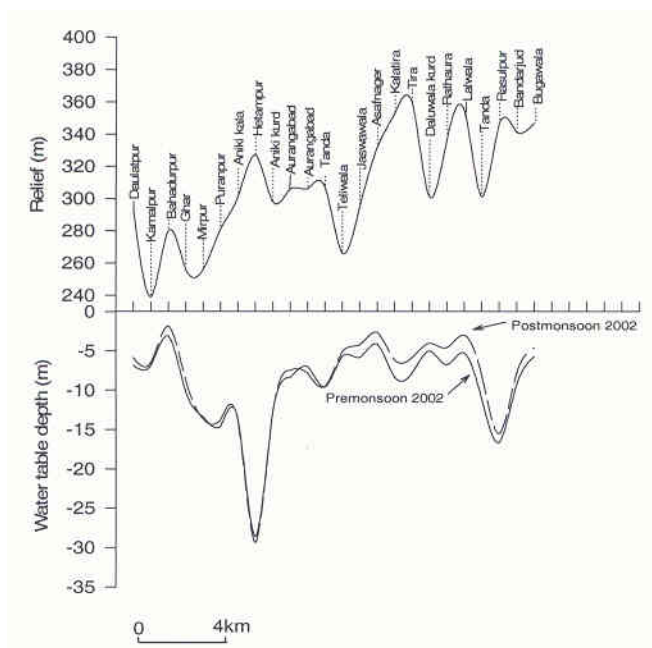


Fig. 7. Surface elevation and water table fluctuation in the study area.

The amount of recharge to ground water due to precipitation between the time interval of Tritium injection (pre-monsoon) and sampling (post-monsoon) can be estimated by multiplying the tritium peak shift and effective average volumetric moisture content in the tritium peak shift region. Mathematically, the equation for the estimation of percentage of recharge to groundwater can be written as (Zimmerman et al. 1967a,b)

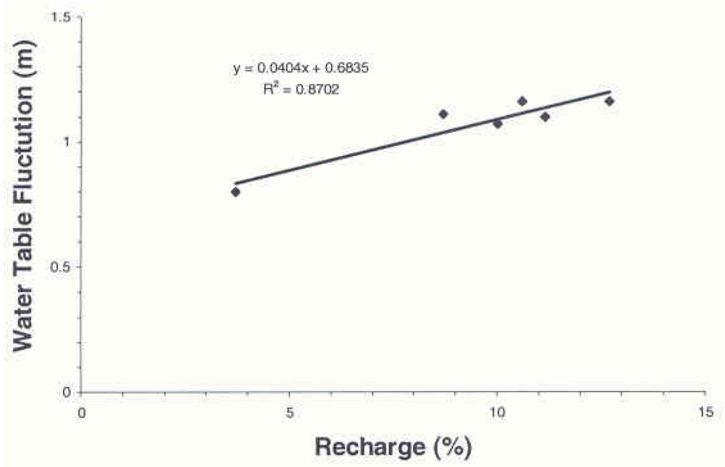


Fig. 8. Relationship between the observed water table fluctuation and the percentage of recharge to groundwater estimated using tritium tagging technique.

$R = \theta_v * d\ (100/p)$ (1)

Where,

'R' is the percentage of recharge to groundwater,

'θ_v' is the effective average volumetric moisture content in the tritium peak shift region,

'd' is the shift of tritium peak in cm and

'p' is precipitation and/ or irrigation in cm.

Volumetric moisture content each soil sample was estimated in the laboratory at National Institute of Hydrology (NIH), Roorkee. The depth of groundwater table was also monitored at these sites at the time of tritium injection (pre-monsoon) and after three months (post-monsoon). Fig. 7 shows the groundwater table fluctuation with surface elevation. The percent of recharge estimated using the tritium tagging technique shows linear relationship between the groundwater table fluctuations. It indicates that the vertical infiltration constitutes the net recharge in the study area (Fig. 8).

Identification of recharges area and flow of groundwater

Environmental isotopes have been used to delineate the recharge areas and mean groundwater flow rate. Twenty-one groundwater samples were collected from shallow and deeper aquifers, from eleven selected sites for the environmental tritium analysis. Tritium activity in groundwater samples was measured at the National Institute of Hydrology, Roorkee using an Ultra Low Level Liquid Scintillation Counter(ULLSC) and calibrating count rate with a standard prepared from standard no 4929E of known activity obtained from the National Institute of Standard and Technology, USA. In order to know the possible influence of the elevation on the recharge characteristics, the data have been analyzed done with respect to the ground elevation of the sampling sites. Finally the environmental tritium contents in the water samples were measured in Tritium Units (TU) as defined in standard literature (IAEA 1983). The tritium content in all samples varies in the range from 0.9 to 12 TU. The plot of tritium activity in TU with the recharge to groundwater in cm (estimated by tritium tagging technique) is shown in Fig 9, that shows a linear relationship.

The Fig. 10 &11 show the plot of tritium concentration in each sample with respect to the ground elevation of sampling site. This indicates that the recharge to groundwater is mainly taking place at higher altitudes (300-400 m AMSL)) in the Bhabhar region, where the shallow and deeper aquifers have good interconnection. On the basis of their topographic elevation, the groundwater sampling sites can be divided into the sites located in north of canal and the sites located in the south of canal. In the north of canal, high concentration of tritium (above 10 TU) is observed and the Siwalik hills act as a water divide line. This indicates the existence of youngest water in the area and act as groundwater recharge area in Siwalik hills which moves downward. One additional recharge area to shallow and deeper aquifer has also been identified close to the Teliwala village, the source for this recharge is probably Kalatira and Ghoina Rao rivers (fig. 1).

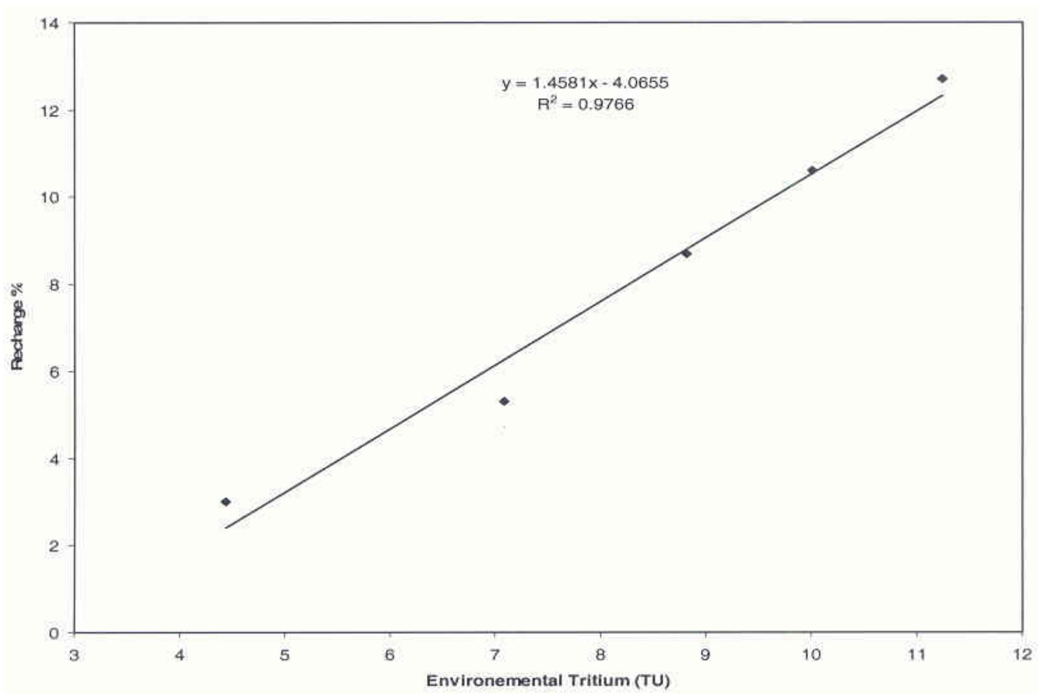


Fig. 9. Relationship between recharge percent estimated by Tritium tagging technique and environmental Tritium

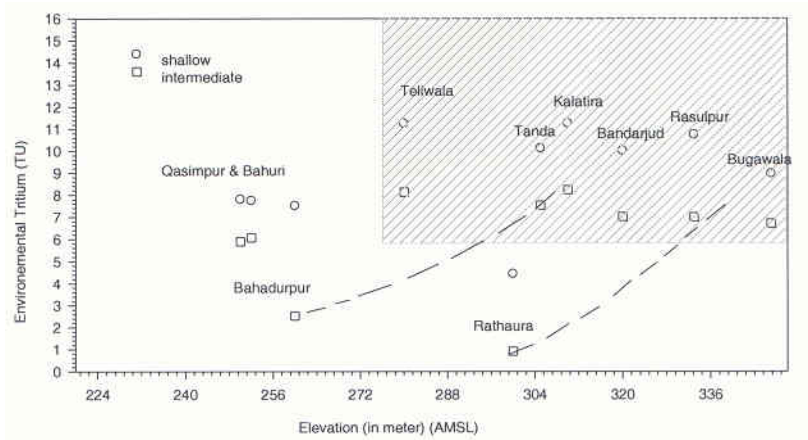


Fig. 10. Plot showing variation of environmental Tritium concentration with elevation in the study area

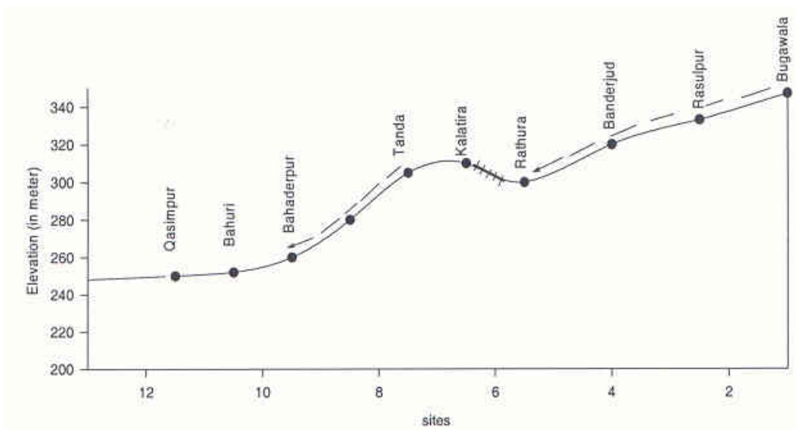


Fig. 11. Topographical variation of sampling sites of the study area

The topographic gradient in this region reduces from 0.005% to 0.001. These sites are therefore, expected to receive substantial recharge from these rivers, which originate in Siwalik Hills. On the basis of tritium contents, two additional recharge locations have also been identified close to the Bahuri and Qasimpur villages (Fig 10).

The mean flow rate of the groundwater in the study area (Ratmau- Pathri Rao watershed) has been estimated by analyzing the environmental tritium content in the water samples collected from the area. The methodology uses the fundamental radioactivity decay equation

$$A_t = A_0 e^{-\lambda t} \quad (1)$$

where, A_0 and A_t are the radioactivity at time t = 0 and t (in years), λ is the decay constant (0.0557 for tritium). The equation (1) can be used to calculate the travel time of the groundwater between the two locations by measuring the Tritium activity at these locations. The variation in the tritium activity measured in the water samples collected from the different locations in the deeper aquifer varies from 7.54 to 2.52 TU. The locations of higher and lower activity correspond to the recharge and discharge zones respectively. The estimated mean groundwater flow rate is 1.2 m/d in the study area. The values estimated by Rao et al (2001), for the Haridwar district in Uttaranchal is 1.1 m/d, which is very close to the present value. The groundwater flow pattern estimated on the basis of TU has been correlated to groundwater flow pattern deduced from the groundwater table elevation data (Fig. 12).

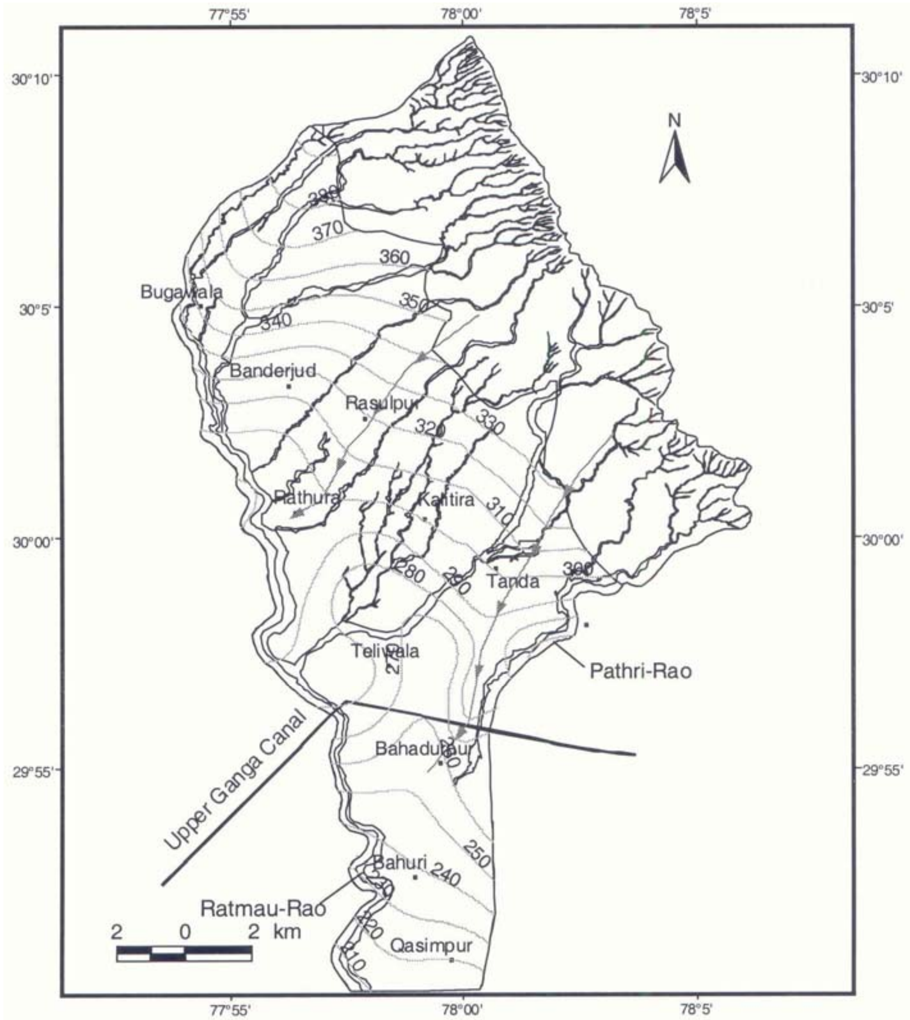


Fig. 12 Groundwater table elevation contour AMSL map indicating flow pattern in the study area

Conclusion

Integrated isotopes, geohydrological and GIS techniques have been used for the groundwater resources evaluation in the piedmont zone of Himalayan foothills region, India. Present study shows that the study area consists of groundwater potential varying from very good to poor zones. The groundwater potential in the northern part of the study area (covering about 135 km² of the area) is poor, due to very steep slopes and very high drainage density, resulting in low infiltration and high runoff. The middle part, covering 172 Km^2, of the study area, has moderate to good potential due to gentle slope and low drainage density. In the southern part of the study area, 60 km² of area, the groundwater potentialis very good due to gentle slope and very low drainage density in the lower piedmont geomorphic unit. Of the remaining study area, about 63 km^2 has moderate to poor groundwater potential. The distribution of groundwater potential has been validated with the yield data of existing tube-wells in the study area.

Isotopic studies using artificial and environmental tritium have been carried out to determine recharge due to monsoon rainfall, recharge sources, recharge zones and average rate of flow of groundwater. The groundwater recharge estimated using Tritium Tagging Technique shows that the recharge in the study area varies between 3 to 13 percent of the rainfall. Environmental tritium activity varies from 1 to 13 TU which shows good linear relationship with the recharge percent estimated using Tritium Tagging Technique. The study indicates that the precipitation is the major source of recharge and groundwater moves is in the direction of decreasing tritium activity (Tarai region) with the flow velocity of 1.2 m/d. Bhabhar zone and Siwalik Hills act as regional recharge zones to the deeper aquifers for the Tarai region. The interconnection between shallow aquifer and deeper aquifer is very good in the study area. The study indicates that the major quantity of groundwater is the result of precipitation infiltration in last 50 years.

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