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# Identification of Recharge Sources Using Environmental Isotopes in Piedmont Zone of Himalaya, Hardwar District, India

Mufid Al-Hadithi[1], Mohammad Israil[2], D. Singhal[3], Bhishm Kumar[4]

[1]*Middle Technical University, Engineering Technical College, Baghdad, Iraq*
[2]*Department of Earth Science, Indian Institute of Technology, Roorkee, India*
[3]*Department of Hydrology, Indian Institute of Technology, Roorkee, India*
[4]*National Institute of Hydrology, Roorkee, India*

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## Abstract

The environmental tritium contents and chemical composition of twenty-one groundwater samples collected from shallow and deeper aquifers were measured in the present study to identify the recharge sources of various aquifers, and aquifer-aquifer interaction in the Piedmont zone of Himalaya, India. Tritium concentrations in the shallow aquifers varied from 4.2 to 11.24 Tritium Units (TU), whereas in the deeper aquifers, tritium varied from 0.9 to 12 Tritium Units (TU). The tritium concentration map in relation to ground elevation shows that high concentrations of tritium (above 10 TU) are observed at higher altitudes (300-400 m AMSL) in the Bhabhar region (Upper Piedmont), which suggests that the existence of youngest water acts as a groundwater recharge area. The chemical composition of the collected groundwater samples indicates the presence of two water types, which suggests the presence of different sources of recharge to the shallow and deeper aquifers in the region. The Electrical Conductivity (EC) values of the shallow aquifers especially in the Bhabhar zone (Upper Piedmont) were high indicating that the shallow aquifers have a recharge source other than that of the deeper aquifers, and that the interconnection between the shallow and deeper aquifers is poor to moderate.

**Keywords:** Groundwater, Environmental Isotope, Recharge Source, India.

## 1. Introduction

Isotope techniques make use of the quality of radioactivity or variations in the isotopic abundance of nuclides in water molecules caused by natural or environmental phenomena as well as monitoring the change in concentration or the movement of artificially-injected isotopes. Stable and radioactive isotopes of different elements in varying concentrations are present in the environment. Several environmental isotopes and tracers can be used to determine the age of groundwater.

Environmental tritium is widely used to differentiate recent from old groundwater by tritium dating as half-life of tritium is 12.43 years. Tritium analysis can be used as a powerful tool to ascertain the groundwater flow rate and its direction in addition to identifying the zones of recharge for deeper aquifers. Tritium analysis may also be used to estimate the time since the recharge to the groundwater system has occurred and the susceptibility of the groundwater system to contamination.

A number of researchers use different applications of environmental isotopes in hydrologic studies, such as the estimation of groundwater quantity, quality and identification of source of recharge. Rao et al. (2000) identified aquifer recharge sources and zones in parts of Ganga- Yamuna Doab using environmental Isotopes. Dassi et al. (2005) identified sources of groundwater recharge in the Merguellil basin (Tunisia) using the isotopic methods of the implication of dam reservoir water accounting. Shivanna et al. (2008) employed environmental isotope techniques to identify the recharge areas of springs in the mountainous region of Gaucher area, Chamoli district, Uttarakhand, India. Choi et al. (2010) evaluated sources and pathways of groundwater recharge for a heterogeneous alluvial aquifer beneath an agricultural field, based on the multi-level monitoring of hydrochemistry and environmental isotopes of a riverside groundwater system in Buyeo, Korea.

## 2. Research Methodology

### *2.1 Study Area*

In the present study, environmental tritium has been used to identify the recharge sources and the influence of elevation on the recharge characteristics in the piedmont zone of Himalaya, India located between latitudes 29° 50' 00" to 30° 11' 21" North and Longitude 77° 54' 19" to 78° 06' 21" East covering an area of approximately 430 km$^2$ (Fig.1).

Geologically, the study area is comprised of Siwalik rocks and alluvial deposits (Pandey et al., 1963). Northwards, the Siwalik sedimentary rocks are composed of indurate to compacted clastic sediments exposed in Haridwar district and represent an over 6000 m thick sequence, consisting of interbedded mudstones, sandstones, conglomerates and subordinate marls (Karanth, 1989).

The formation occurring towards the south of the Siwaliks consists of alluvial fan deposits of a recent age. The alluvial fan deposits are made up of assorted sand and gravel associated with occasional clays (Sharma and Jugran, 1992; Gupta, 1991; and Gupta, 2002). After necessary ground checking and correlation with the existing literature, the

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* Corresponding author e-mail: mufidalhadithi@yahoo.com

geologic units were mapped using ArcGIS 10.1 software to prepare a thematic map for the geology of the area (Fig.2). Based on hydrogeological characteristics, the area is classified into four geomorphic units. The geomorphic boundaries were digitized on the enhanced image through GIS and generated a hydrogeomorphological map as shown in Figure 3.

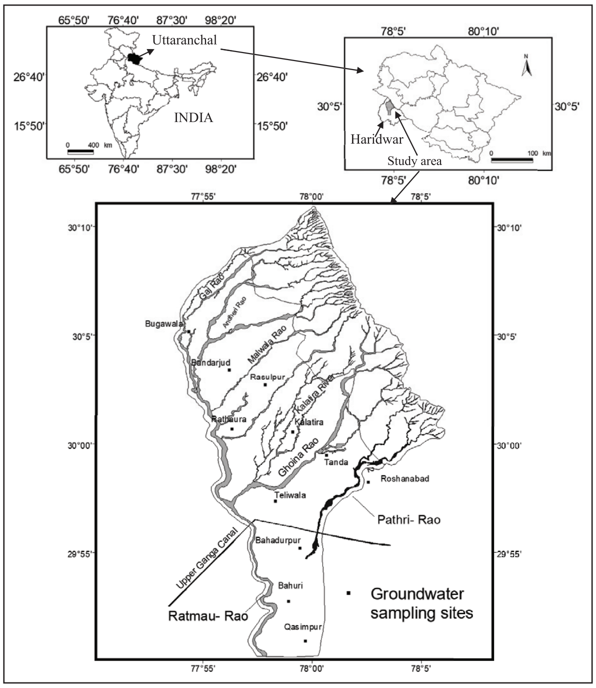

**Figure 1.** Location map of the study area showing the groundwater sampling sites

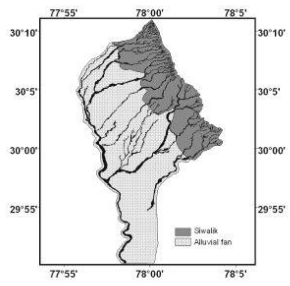

**Figure 2.** Geological map

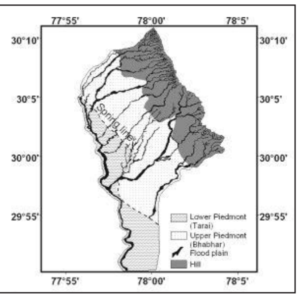

**Figure 3.** Hydrogeomorphological map

**The Upper Piedmont** zone also known as **Bhabhar,** bordering the **Siwalik hill** is comprised of unconsolidated coarse materials. Concerning groundwater, this belt provides an excellent hydrogeological setup for recharge and infiltration. **The Lower Piedmont** (also known as **Tarai**) is separated from the Bhabhar by the spring line along their junction. This zone is composed of coarse-grained sand and clay with gravel. **Flood plains** form the youngest geomorphic unit and include various landforms formed by fluvial action i.e. sandbars, channel bars, and meander scars. These are characterized by a very gentle slope and consist of sub-rounded to rounded fragments of sand, silt and clay.

### *2.2 Sampling and Analysis*

Twenty-one water samples were collected from the shallow and deep aquifers at eleven selected sites during the pre-monsoon season in 2002. These samples represent the geohydrological zones viz., Upper Piedmont (Bhabhar) zone and Lower Piedmont (Tarai) zone. The locations of these samples are shown in Fig.1. The samples were analyzed for the presence of tritium concentration. The measurement of tritium is done by measuring its beta activity through the beta counting using Liquid Scintillation Spectrometer (LSC), 1220 Quantulus model, a complete facility available in Nuclear Hydrology laboratory at the National Institute of Hydrology (NIH). This involves the primary and secondary distillation of water samples, tritium enrichment by electrolytic enrichment of the water samples, subsequent mixing of the water samples with a liquid scintillation cocktail, and Beta counting using a liquid scintillation spectrometer. Commercially available liquid scintillation cocktail viz "Canberra- Packard Pico– flour LLT" (Low Level Tritium) has been used due to its very low background count rate and higher counting efficiency compared to other scintillation solutions. The liquid scintillation counter (LSC) measures the tritium activity in the enriched water samples using the Queue Manager (QM) software. 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 the samples varied ranging from 0.9 to 12 TU as shown in Table 1.

**Table 1.** Sampling sites and tritium concentrations (TU)

| S. No | SiteName | Tritium concentration, EC and error for Shallow aquifers | | | Tritium concentration, EC and error for deep aquifers | | |
|---|---|---|---|---|---|---|---|
| | | TU | Error | Ec (µs/cm) | TU | Error | Ec(µs/cm) |
| 1 | Kalatira | 11.25 | ±1.41 | 788 | 8.82 | ±1.79 | 488 |
| 2 | Bugawala | 8.95 | ±0.78 | 522 | 6.7 | ±6.07 | 575 |
| 3 | Rasulpur | 10.74 | ±1.21 | 995 | 7.0 | ±1.14 | 465 |
| 4 | Bandarjud | 10.01 | ±1.44 | 915 | 7.01 | ±1.79 | 375 |
| 5 | Roshanabad | | | | 12 | ±1.21 | 372 |
| 6 | Tanda | 10.12 | ±0.77 | 868 | 7.54 | ±.98 | 553 |
| 7 | Rathaura | 4.43 | ±0.81 | 1990 | 0.91 | ±0.56 | 353 |
| 8 | Teliwala | 11.24 | ±1.36 | 453 | 8.13 | ±0.91 | 352 |
| 9 | Bahadurpur | 7.08 | ±1.07 | 503 | 2.25 | ±0.23 | 515 |
| 10 | Bhauri | 7.74 | ±0.68 | 693 | 6.07 | ±0.66 | 346 |
| 11 | Qasimpur | 7.8 | ±0.66 | 450 | 5.89 | ±0.89 | 360 |

## 3. Results and Discussion

### *3.1. Identification of Recharge Sources*

The aquifer recharge sources can be identified on the basis of tritium activity observed in the groundwater samples collected from different locations from shallow and deeper aquifers. The measured tritium activity (TU) has been analyzed in the following sections:

#### *3.1.1. Shallow Aquifers*

Ten groundwater samples correspond to the shallow aquifers at depths ranging from 6 m to 11 m. Tritium concentration varies from 4.2 to 11.24 TU and a tritium concentration contour map has been prepared as shown in Fig.4. It is observed that tritium concentration is high in the groundwater samples of wells located in the Bhabhar zone which has a high ground elevation compared with the Tarai Zone. Furthermore, it was noted that tritium concentration is also high (11.24 TU) at the Tialwala site although it has a low elevation of the earth and is located in the Bahabhar region. This can be explained by the possible addition of local recharge from a nearly stream (viz. Ghoina Rao and Kalatira rivers).

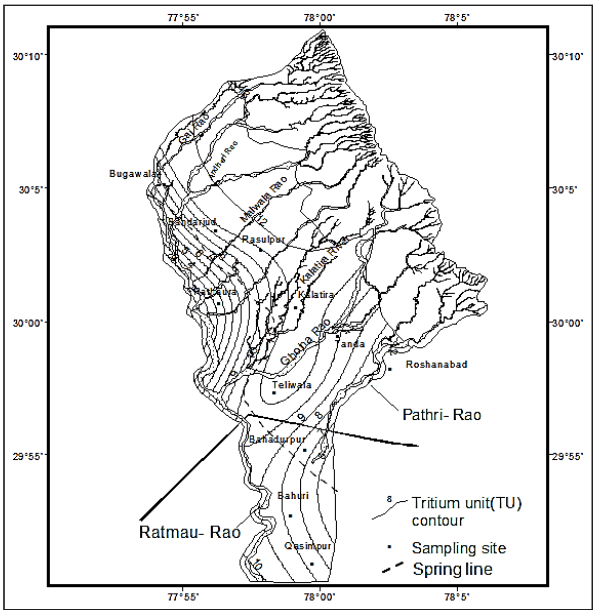

**Figure 4.** Tritium concentration contour map of a shallow aquifer

#### *3.1.2. Deep Aquifers*

Eleven groundwater samples were collected from deep aquifers at depths varying from 50 m to 90 m. Tritium concentration in the deep aquifers varies from 0.9 to 12 TU, and a tritium concentration contour map for the deeper aquifers has been prepared as shown in Fig 5. As in the case of shallow aquifers, it has been observed that tritium concentration is high at high altitudes (Bhabhar zone) gradually declining towards the plain areas (Tarai).

### *3.2. Influence of Elevation*

In order to investigate the possible influence of elevation on the recharge characteristics, the tritium concentration of the samples was plotted with respect to the elevation of sampling sites (Fig. 6). The sampled groundwater sites on the basis of their topographic positioning can be divided into two groups with the Ganga Canal being present in the area separating these two groups:

i- Sites located in the Bhabhar/Tarai region to the north of the Canal: Bugawala, Bandarjud, Rasulpur, Rathaura, Kalatira, Tanda, Teliwala, and Roshanabad villages.

ii- Sites located in the Tarai/Bhabhar region and falling in the south of the Canal: Bahadurpur, Bahuri and Qasimpur.

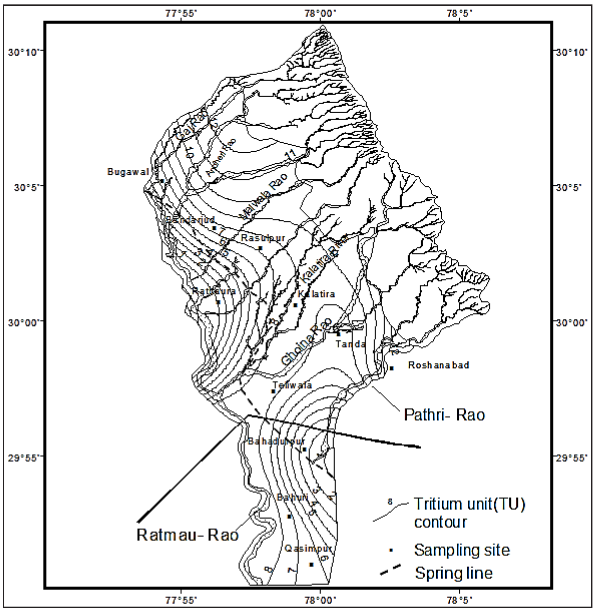

**Figure 5.** Tritium concentration contour map of a deep aquifer

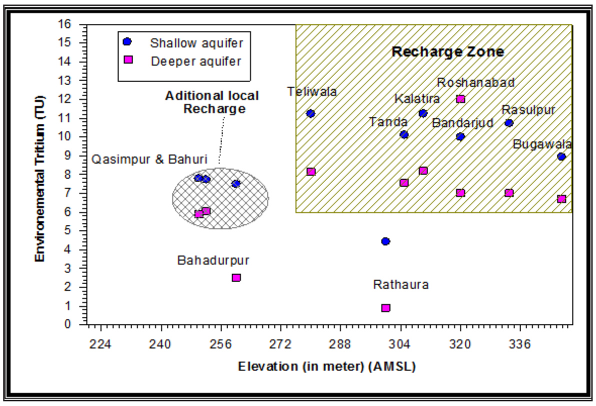

**Figure 6.** Plot showing variation of environmental tritium with elevations.

It has been observed that the highest tritium observed in the deeper aquifer of Roshanabad sites located within a distance of 1.5 km from the Siwalik range indicates that the youngest water or the highest tritium activity in groundwater is expected to be in the groundwater recharge of the Siwalik Hills. Moreover, the groundwater recharged in the Siwalik Hills region moves down to Bhabhar and down to the rest of the area (Tarai zone).

In the Bhabhar zone, the tritium concentration in the deep aquifers is ~7 TU indicating its probable recharge from Siwalik. The tritium concentration being higher than this in the shallow aquifers can, therefore, be ascribed to the local recharge. The tritium values are comparatively lower in the case of deeper aquifers in Bhabhar zone (7 TU) than those of the shallow aquifers (10 TU). This indicates poor interconnection between shallow and deeper aquifers.

Similarly, the EC (Electrical Conductivity) value are higher in the case of shallow aquifers than in the deeper aquifers which also indicates that deeper aquifers have a different recharge source other than that of the shallow aquifers in this region. Therefore, it can be said that the deeper aquifers have recharge zones located in Siwalik region. In the southern part of Bhabhar at the Bahadurpur village, near the spring line the observed tritium value is 7.01 TU in the shallow aquifers and 2.5 in the deeper aquifers. This also indicates that the interconnection between shallow and deeper aquifers is poor. The increase in the tritium values in the shallow aquifers is possibly due to the canal recharge during the passing of shallow aquifers through it. This assumption is supported by the low EC of 900 µs/ cm in the shallow groundwater in the Bahadurpur village, whereas in the Teliwala well located north of canal the EC is much higher (~ 1990 µs/ cm).

In the northern part of Tarai at the site of Rathaura, groundwater appears to be formed by local recharge and the low tritium could be attributed to the low recharge rate. In the southern part of the Tarai zone at the Qasimpur and Bahuri sites, tritium concentration values show an additional local recharge of the shallow and deeper aquifers probably from the Ganga Canal and Ratmau river. These sites also fall in the discharging zone of the river Pathri Rao and in its palaeo river course. Both sites are therefore expected to receive substantial recharge from these rivers. The interconnection between shallow and deeper aquifers is good at these sites. It has also been observed that tritium values at shallow and deeper levels at Qasimpur and Bahuri villages resemble the tritium values in the deep aquifers in the Bhabhar zone though located away from Bhabhar zone. The EC values are lower than those at the shallow aquifers. This indicates that the aquifers in the Tarai zone receive recharge from the Bhabhar region.

The nearly constant tritium activity about 10 TU obtained above 300m indicates that precipitation is the major source of recharge to the shallow aquifers; the groundwater movement occurs in the direction of the decreasing tritium values in the water samples towards the Tarai zone. It has also been observed that the tritium values of the deep aquifers at Roshanabad located very near to the Siwalik region resemble the tritium values of the shallow aquifers in the Bhabhar zone and the EC values are lower than those at the shallow aquifers. Moreover, its EC values are slightly lower than the other deeper aquifers because the other deeper aquifers are located quite away from the Siwalik region. This observation is in support of the present paper's conclusion that deeper aquifers in the Bhabhar zone receive recharge from the Siwalik region.

## 4. Groundwater Quality

In the present work, water chemistry is used as supportive evidence in the study of recharge rather than to make a detailed investigation. Cations and anions in addition to the other physical parameters such as pH, TDS and EC have been measured in all the collected water samples. Cations ($Ca^{++}$, $Na^+$, and $K^+$) have been analyzed by flame photometer, $Mg^{++}$ in EDTA titration method, $HCO_3^{--}$ and $Cl^-$ analyzed by $H_2SO_4$ and $AgNO_3$ titration method, respectively. The measured values are summarized in table 2.

**Table 2.** Major cation, anion concentrations and Physical parameters. [S-Shallow, D- Deeper aquifer]

| S. No | Depth | pH | EC | TDS | $Ca^{++}$ | $Mg^{++}$ | $Na^+$ | $K^+$ | $Cl^-$ | $SO_4^{--}$ | $CO_3^-$ | $HCO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | D | 8.3 | 488 | 320 | 40.05 | 31.58 | 17.10 | 1.60 | 5.00 | 67.90 | 33.00 | 192.17 |
| 2 | S | 9.1 | 788 | 520 | 67.08 | 37.66 | 41.70 | 9.80 | 24.99 | 69.95 | 63.01 | 268.42 |
| 3 | D | 8.7 | 575 | 380 | 28.03 | 38.87 | 35.60 | 3.40 | 3.75 | 67.90 | 39.01 | 256.22 |
| 4 | S | 8.2 | 522 | 346 | 55.07 | 21.87 | 10.50 | 3.20 | 12.50 | 74.07 | 24.00 | 170.81 |
| 5 | D | 8.5 | 465 | 350 | 40.05 | 28.55 | 13.50 | 2.00 | 5.00 | 67.90 | 24.00 | 179.96 |
| 6 | S | 8.2 | 995 | 658 | 100.12 | 18.83 | 45.10 | 3.30 | 81.22 | 189.29 | 36.00 | 125.06 |
| 7 | D | 8.3 | 915 | 602 | 96.12 | 27.33 | 19.80 | 2.00 | 106.22 | 205.75 | 12.00 | 164.71 |
| 8 | S | 8.8 | 375 | 248 | 29.03 | 12.76 | 9.90 | 22.70 | 12.50 | 65.84 | 18.00 | 94.56 |
| 9 | D | 8.5 | 372 | 245 | 47.06 | 11.54 | 6.90 | 1.30 | 3.75 | 43.21 | 39.01 | 100.66 |
| 10 | S | 8.2 | 868 | 573 | 85.00 | 27.33 | 35.40 | 1.80 | 44.99 | 96.70 | 18.00 | 280.62 |
| 11 | D | 9.1 | 553 | 365 | 33.04 | 25.51 | 33.00 | 2.90 | 29.99 | 88.47 | 27.00 | 161.66 |
| 12 | S | 8.3 | 1990 | 1320 | 137.16 | 35.23 | 86.90 | 78.50 | 231.18 | 316.85 | 9.00 | 103.71 |
| 13 | D | 8.8 | 453 | 298 | 53.06 | 12.76 | 10.20 | 1.10 | 16.24 | 63.78 | 33.00 | 137.26 |
| 14 | S | 9.4 | 353 | 233 | 29.03 | 15.18 | 17.70 | 3.00 | 10.00 | 61.73 | 30.00 | 125.06 |
| 15 | D | 9.3 | 352 | 232 | 25.03 | 17.61 | 15.30 | 2.90 | 6.25 | 69.95 | 27.00 | 149.46 |
| 16 | S | 8.8 | 503 | 335 | 62.07 | 9.72 | 4.40 | 1.50 | 6.25 | 98.76 | 33.00 | 167.76 |
| 17 | D | 8.7 | 418 | 276 | 46.06 | 14.58 | 6.10 | 1.20 | 8.75 | 57.61 | 21.00 | 134.21 |
| 18 | S | 8.6 | 515 | 339 | 36.04 | 10.93 | 10.70 | 48.80 | 21.24 | 49.38 | 18.00 | 118.11 |
| 19 | D | 9.3 | 693 | 458 | 71.09 | 19.44 | 10.70 | 12.90 | 37.49 | 67.90 | 36.00 | 128.11 |
| 20 | D | 8.7 | 346 | 227 | 40.07 | 8.50 | 11.00 | 1.10 | 7.50 | 59.67 | 15.00 | 152.51 |
| 21 | D | 8.8 | 450 | 299 | 53.16 | 12.78 | 10.28 | 1.11 | 16.25 | 63.79 | 33.01 | 137.27 |

Hydrochemical facies or hydrochemicla zoneation for the present investigation has been carried out by plotting the percentage of reacting values of major ions in Pipers (1944) trillnear diagrams (Fig. 7). This diagram shows that 90 % of groundwater in the study area belongs to $Ca^{2+}$ – $HCO_3^-$ type with a significant portion of $Mg^{2+}$. At few places which receive additional recharge, the groundwater belongs to $SO_4^{-2}$- $Cl^-$. The expected EC in the resultant groundwater can be estimated from the EC data of the recharge sources and the present recharge from these sources. Any differences between the estimated and the observed EC of groundwater at the same site provides information on salt concentrations separated or added to the groundwater during the infiltration or flow processes and also on errors in the estimated recharge percentages.

As observed from the data of the environmental tritium, the deep aquifers of Bhabhar zone receive recharge from high altitude regions (Siwalik region); therefore, as expected, these aquifers show EC in the range of 370-420 µS/ cm as shown in Figures 8 and 9. The increase in EC of the shallow aquifers at the Bhabhar zone provides a measure of the EC of the local recharge groundwater in this zone and shows that the interconnection between the shallow and deeper aquifers is poor.

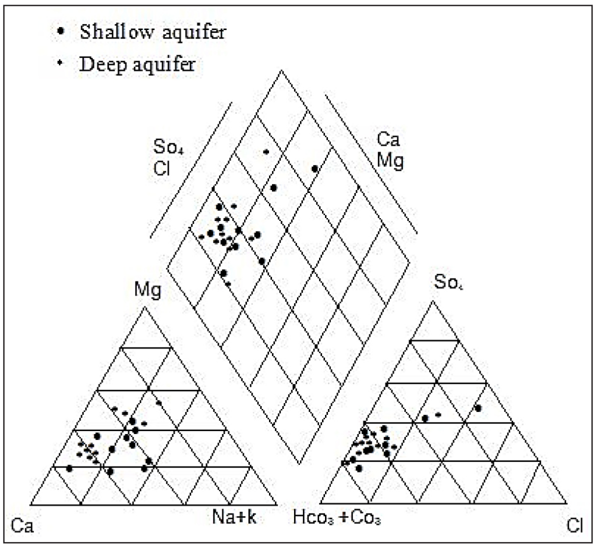

**Figure 7.** Pieper diagram showing the chemical composition of Groundwater from shallow and deeper aquifers in the study area

In the northern part of the Tarai zone, the local recharge and the marginal evaporation enrichment of the salt content increased the EC of its shallow aquifers above the background 600 µS/ cm (788 µS/ cm); the value is close to this (575 µS/ cm) in its deep aquifers . In the southern part of the Bhabhar/ Tarai zone when passing through the Canal Zone, the recharge is expected to reduce the EC at these sites. This is close to the observed value of 995 µS/ cm at the Bahadurpur village. Similarly, a respective recharge from the rivers Ratmau and Pathri Rao refreshes the shallow and deeper aquifers as observed at the Bhauri and Qasimpur sites. This indicates that the interconnection between the shallow and deeper aquifers in this region is moderate to good. The close resemblance between water chemistry and tritium data explains the source and recharge from these sources to the groundwater system of the study area.

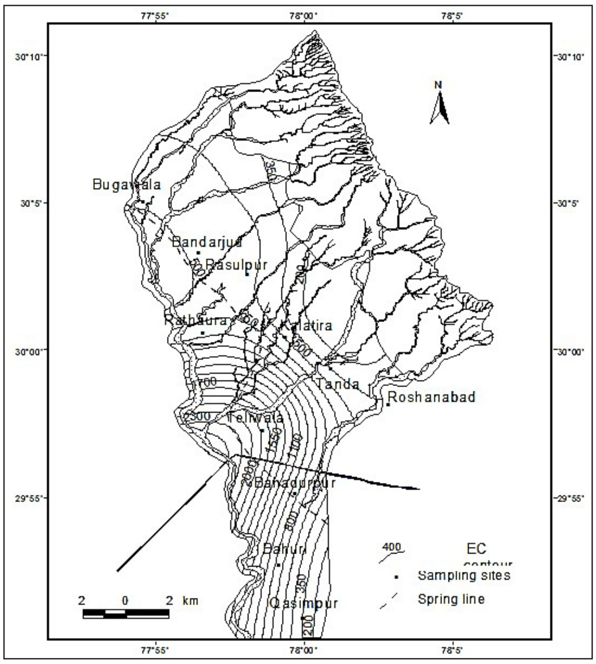

**Figure 8.** contour map of a shallow aquifer

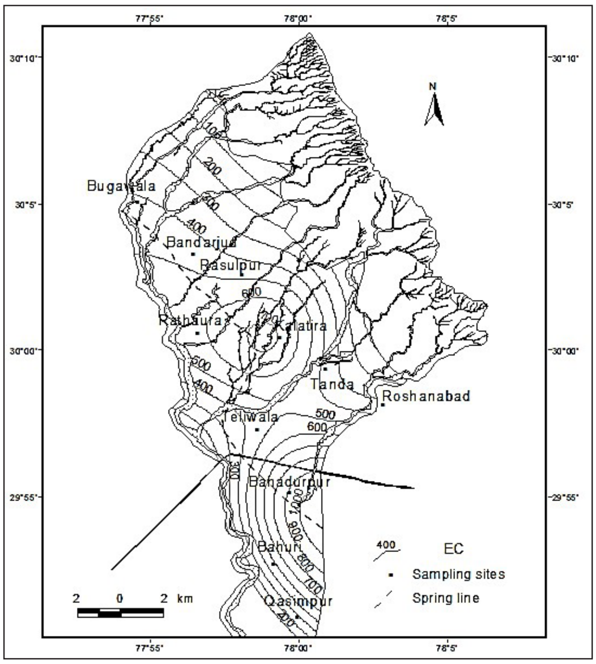

**Figure 9.** EC contour map of the deeper aquifer

## 5. Conclusions

The evaluation of groundwater quality has been carried out to explain the recharge sources of various aquifers, and aquifer-aquifer interaction in the Piedmont zones of the Haridwar District, India. The current study shows that precipitation is the major source of recharge and that groundwater recharge takes place mainly at higher altitudes (300-400 m AMSL) in the Bhabhar region where the shallow and deeper aquifers have good interconnections. The piper diagram shows that there are different water types in the study area which indicate that there are different recharge sources. These findings are supported by the Electrical Conductivity (EC) data of groundwater which show an increase in the shallow aquifers. The increase in the EC indicates that the shallow aquifers have different recharge sources from those of the deeper aquifers, and that the interconnection between the shallow and deeper aquifers is poor to moderate in this region.

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