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Identification of aquifer recharge sources and zones in parts of Ganga-Yamuna Doab using environmental isotopes

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Abstract
Environmental tritium has been used to identify the recharge zones and sources to groundwater, in parts of Ganga - Yamuna Doab, western Utter Pradesh, India. The study area is characterized by thick alluvial deposits and has been a challenging area due to the complex hydrogeologic setting. In spite of several studies in the past, by several investigators who used conventional techniques, information on the groundwater flow regime is very less. The study reveals that rainfall actively recharges the local aquifers (extended over an area about 800 km^2) in the Saharanpur district where, the aquifers upto a depth of around 100m are well interconnected to form a single unit. This is in stark contrast to the conditions in Hardwar district (mainly the area falling in the river Solani - river Ganga interfluve) where, the recharge is mainly taking place at higher altitudes, and the unconfined aquifer is poorly or not connected to the deep seated aquifers in the multi-aquifer system. In addition, the mean transport rate for the deep-seated aquifer has been evaluated as about 1.1 m/d, which is marginally lower than the values considered by other investigators. In general, it is found that the area characterized by sand-bars developed in the paleo-channels act as local recharge zone in the plains, while the Bhabhar and Siwalik Hills (above an altitude of 400 m above m.s.l.) act as regional recharge zones. The area close to the major rivers viz., river Ganga and river Yamuna act as discharge zones for the regional groundwater system. Further studies to correlate the water chemistry will help to identify those recharge zones that are to be preserved, in order to protect the groundwater from being polluted.

INTRODUCTION

Groundwater forms the most important resource of potable water as it is believed to be safe, free from pathogenic bacteria and from suspended matter. The withdrawal rate of groundwater is increasing continuously due to faster pace of population growth, agricultural/industrial development. This has increased the concern on groundwater resource mapping and its management that require identification of groundwater recharge areas and its subsurface flow pattern.

Environmental isotopes are useful in identifying the recharge areas and also in estimating the mean flow velocities (Bradbury, 1991; Rose, 1992). However, it may not be entirely feasible to use the geochemical and isotope data to understand the groundwater flow regime, due to the complexities introduced by mixing of different sources of water such as rainfall, seepage from surface water bodies, irrigation return flow etc. Such conditions require collating information on the topography, geological structures, land use, and conventional hydrogeology. This approach is particularly more useful when the area being investigated is of large extent or complex drainage settings. In the present study, an attempt has been made to identify the recharge areas, major recharge sources to the groundwater and to map the subsurface flow pattern in the Western Uttar Pradesh using environmental isotope techniques

The earlier work in the present study area were concentrated mainly on mapping of water-table (Taylor and Mackenzied 1936; Dwivedi and Gupta 1961); groundwater quality(Seth and Singhal, 1994; NIH, 1999); estimation of aquifer parameters using pump test and grains size analysis (Agrawal, 1994; Nautiyal, 1991); subsurface details using lithologs and electrical resistivity data (Mithal et. al., 1973; Musampa, 1994, 1988; Singhal et al., 1998); and on groundwater balance (UPGWD, 1999). These studies, however, do not yield information on the recharge zones of various aquifers, rate of recharge to different aquifers and aquifer-aquifer interconnection.

BACKGROUND

Tritium is a radioactive isotope of hydrogen with a half-life of 12.43 years. It occurs in the environment as a result of both natural and man made processes. As part of the water molecule, tritium is one of the better tracers in hydrological studies. It undergoes radioactive decay by beta emission (a low energy beta radiation of 18.3 keV). Continuous record of the tritium concentration in rainfall is available for many stations worldwide since 1960, most of which are under the initiative of the International Atomic Energy Agency. In India, the longest tritium input record is available for the New Delhi station.

STUDY AREA

The study area that is a part of Indo-Gangetic alluvium, lies in Saharanpur and Hardwar districts of Uttar Pradesh (77°10’- 78°15’E and 29°30’ - 30°15’N) (Figure 1a). The total area of the present study is about 5400sq km. Rivers Ganga and Yamuna mark the eastern and western hydrological boundaries and Siwalik range with its surface water divide forms the northern boundary of the study area. The area experiences moderate type of sub-tropical monsoon climate. The mean annual rainfall in the area is about 1000mm of which around 85% is received during monsoon season (July-September). Apart from the major rivers Ganga and Yamuna, the area is drained by two smaller river systems viz., Solani and Hindon. The study area is part of a rich agricultural belt and the irrigation demand is met through the water supply from canal system, state tube wells, private tube wells and by other minor irrigation works.

Geological framework

The study area is tectonically active (Rajal and Madhawal, 1999; Prakash et. al., 2000). It is underlain by Delhi Hardwar Ridge (Rao, 1973). The important tectonic features in the study area are (i) Himalayan Frontal Fault that separates Siwalik Hills and Gangetic plains (Nakata, 1972); (ii) NE-SW trending Meerut-Hardwar Fault that coincides with the eastern boundary of Delhi Hardwar Ridge; (iii) Solani fault along whose dissected fault scrap, the river Solani flows (Meijreink, 1974); (iv) Ratmau fault along which the river Ratmau flows and (v) Behat fault that is aligned parallel to the river Hindon and its north end it coincides with the Yamuna tear fault (Sudhir Kumar, 1991).

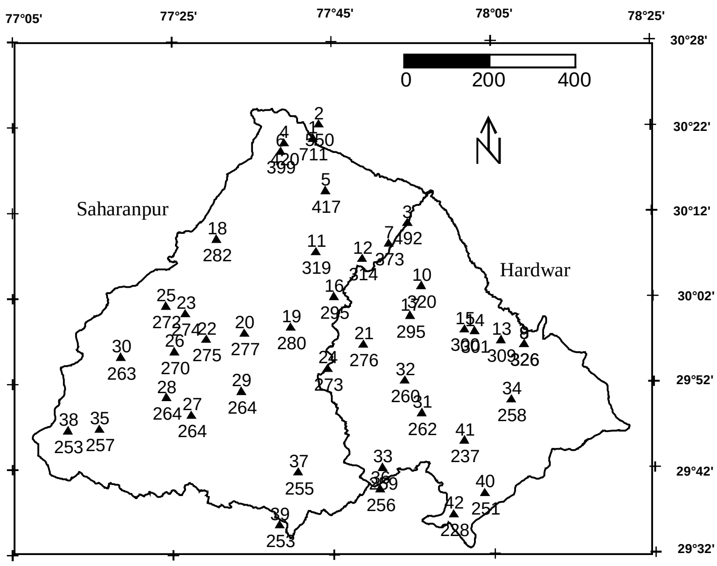

Figure 1a. Map showing the location of sampling sites. The number above and below the solid symbols indicate the sampling site codes and altitude of sampling site (m amsl) respectively.

Paleochannels are prominent features in the study area. These are considered to be of neotectonic origin. These paleochannels are presently occupied by underfit streams like Hindon or by sand ridges in the plains (Sudhir Kumar, 1991).

Hydrogeological Setting

Hydrogeologically, the study area can be divided into three zones (Figure 1b) viz. Bhabhar, Tarai and Plains (Taylor, 1956). The Bhabhar zone, characterized by piedmont deposits and dendritic drainage pattern, lies along the foot of Siwaliks with its northern boundary coinciding with the Himalayan Frontal Fault. The topographic slope of Bhabhar is 1-2%. The Bhabhar formation comprises of coarse grade material generally forming a single aquifer. The high permeability and steep water table gradients cause fast draining and large water level fluctuations in this zone. Groundwater levels in Bhabhar zone vary from 0.6 to 32.4 m in post-monsoon season and 1.5 to 33.8 m in pre-monsoon. From north to south, down along the Bhabhar, sediment texture become fine grained and split up amidst clay and silt layers that act as aquitards and confines groundwater in the lower aquifers. This zone is known as Tarai and has a gradient of about 0.3%. The groundwater level in this zone varies from 1.8 to 7.1 m during post monsoon and 2.8 m to 9.5 m during pre-monsoon. Artesian wells, springs and perennial streams also mark the Tarai, as the shallow water table is cut by the land surface. The southern limit of Tarai extends upto plains. The plains have gradient less than 0.08% and show comparatively stable landform compared to Bhabhar and Tarai. The streams that flow east of Solani fault discharges into the river Ganga where as rivers flowing west of this fault discharges into the river Yamuna.

MATERIALS AND METHOD

For the present study, about 130 ground water samples were collected from shallow (SHP - Shallow Hand Pumps), intermediate (MII – India Mark II Hand pumps), and deep-seated aquifers (TW - Tube wells), from 40 selected sites (Figure 1a) during the pre-monsoon season of 1998. Sampling was made from all the geohydrological regions viz., Bhabhar, Tarai and plains.

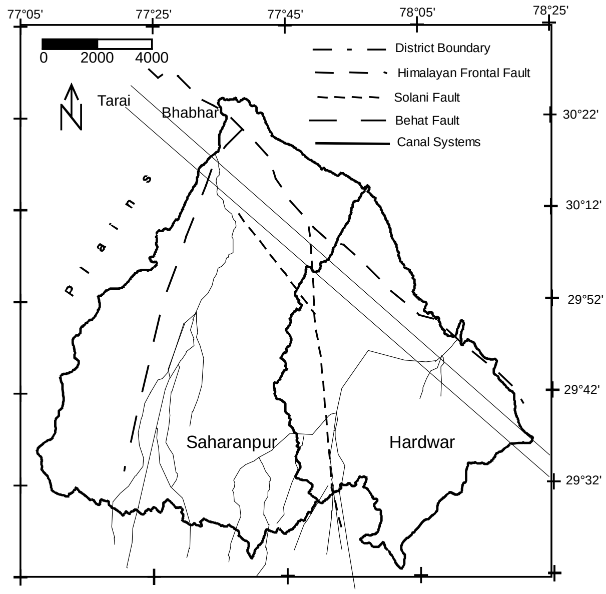

Figure 1b. Location map of the area showing the geological structures along with canal systems and geomorphologic zones.

The data on depth and thickness of different aquifer suggest that the area is characterized by multi-aquifer system with depth of shallow aquifer extending up to about 15 m below ground level. The depth ranges of intermediate and deep-seated aquifers are 25 - 45 m and 100 - 150 m below ground level respectively. Samples were also collected from a few sites along the rivers Ganga and Yamuna and near the canal systems in the area, to investigate surface water contribution to groundwater.

For environmental tritium analysis, samples were electrolytically enriched under IAEA type enrichment unit followed by activity measurement in ultra low level liquid scintillation counter (Quantulus®) using Picoflour LLT® cocktail. The background count rate measured using tritium free water samples were typically about 0.8 cpm. Activity of groundwater samples was computed by calibrating their count rate with the count rates of standards prepared from NIST standard **(**No 49279E) of known activity. Altitude of sampling sites above the mean sea level was evaluated by interpolating the digital contour and spot height data using ILWIS® software (V.2.2). Paleochannels in the study area were identified from LISS-II imagery (May 1989).

RESULTS AND DISCUSSION

As isotopic characteristics of groundwater are greatly influenced by precipitation, information on the precipitation isotopic characteristics are required for proper interpretation of isotope data in groundwater studies. The tritium input (to the area) from the precipitation is determined from the precipitation and tritium data available at IAEA/WMO Global Network for Isotopes in Precipitation station at New Delhi (Figure 2). This station is about 160 km south of the study area and experiences the similar rainfall characteristics. It is seen from Figure 2 that the tritium input function show a most recent peak during 1984-1986. Following this minor peak the activity has decreased gradually and at present is around 12 - 16TU.

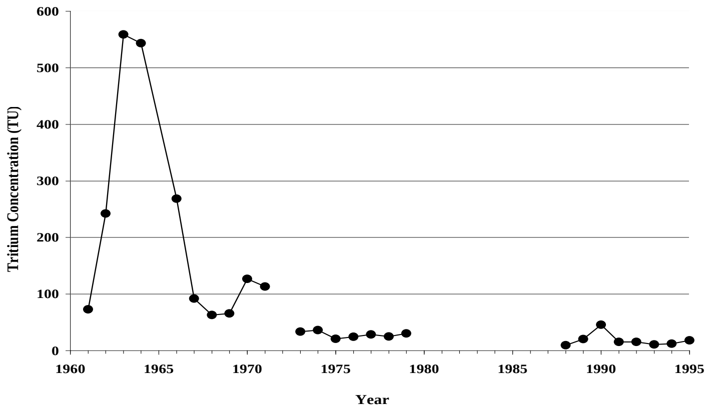

Figure 2. Tritium Concentration in New Delhi precipitation (Source - IAEA).

The results of environmental tritium, oxygen isotope data of ground water samples are presented in Table 1 along with the altitude of the sampling site. From the data it is observed that the higher tritium concentration (12-15TU) in groundwater in the study area is due to the recent precipitation.

In order to investigate the possible influence of elevation on the recharge characteristics, the analysis of the data is carried out with respect to the ground level of the sampling sites. As the drainage pattern in the study region indicate different flow directions on either side of the Solani fault, the study area is divided into two categories as (i) Solani-Yamuna Interfluve and (ii) Solani- Ganga Interfluve.

Solani-Yamuna Interfluve

The plot of tritium concentration of samples with respect to elevation of sampling sites in the Solani-Yamuna interfluve is shown in Figure 3. It is seen from the figure that the data cluster into three different categories viz.

Type1- region with altitude higher than about 400 m above m.s.l. showing tritium concentration characteristic of recent precipitation,

Table 1. Sampling site in the study area with altitude, site index and Tritium Concentration.

(TU) [S – Shallow, I – Intermediate, D – Deep aquifers] [ND-less than 0.5TU]

Interfluve Type	S. No.	Site	MSL (m)	Site Index			TU		
				S	I	D	S	I	D
Solani-Yamuna Interfluve	1	Timli Pass	711	2	*	*	8.8	*	*
	2	Timli	550	*	*	1	*	*	10.4
	3	Mohand	492	6	*	*	8.5	*	*
	4	Badsahibag	420	8	*	*	9.9	*	*
	5	Nagal Kothari	417	*	*	7	*	*	7.0
	6	Rupur Dummwala	399	*	*	17	*	*	8.2
	7	Ganeshpur	373	*	*	15	*	*	10.9
	10	Bandarjud	320	11	12	*	4.8	ND	*
	11	Muzafarabad	319	42	43	*	2.7	1.2	*
	12	Ismailpur	314	*	*	141	*	*	5.5
	16	Chhutmalpur	295	*	39	40	*	17.8	1.8
	18	Todarpur	282	32	*	*	12.1	*	*
	19	Gagalhedi	280	53	54	*	7.2	3.4	*
	20	Saharanpur	277	*	*	55	*	*	10.4
	21	Bhagwanpur	276	*	51	52	*	6.9	0.8
	22	Unali	275	*	75	*	*	ND	*
	23	Surana	274	*	*	56	*	*	ND
	24	Chudiala	273	70	71	*	7.6	1.8	*
	25	Sarsawa	272	*	57	58	*	2.2	0.7
	26	Phandpuri	270	*	77	*	*	7.6	*
	27	Rampur	264	98	99	*	9.7	*	*
	28	Islam Nagar	264	100	101	*	8.7	8.6	*
	29	Sadholi Horiya	264	88	89	*	11.7	7.1	*
	30	Nakud	263	87	90	91	11.7	4.8	0.9
	31	Landhora	262	*	65	*	*	9.1	*
	32	Roorkee	260	0	*	0	7.5	*	2.5
	33	Gurukul	259	*	*	96	*	*	14.1
	35	Gangoh	257	*	104	*	*	ND	*
	36	Purkaji	256	*	*	110	*	*	10.7
	37	Deoband	255	111	*	113	1.7	*	3.8
	38	Lakhnauti	253	106	*	*	2.2	*	*
	39	Pauti Kutesara	253	135	136	*	7.6	ND	*
Solani-Ganga Interfluve	9	Devpura	309	*	*	4	*	*	12.4
	13	BHEL	309	*	*	5	*	*	16.1
	14	Roshanabad	301	*	*	9	*	*	9.0
	15	Aniki	300	10	*	*	8.8	*	*
	17	Manubas	295	25	24	*	4.3	4.3	*
	34	Dhanpura	258	34	34A	*	2.5	0.8	*
	40	Kalsia	251	*	93	*	*	0.7	*
	41	Laksar	237	*	62	63	*	1.9	ND
	42	Chandpuri Kalan	228	108	109	*	3.0	2.0	*

- Sample not analyzed.

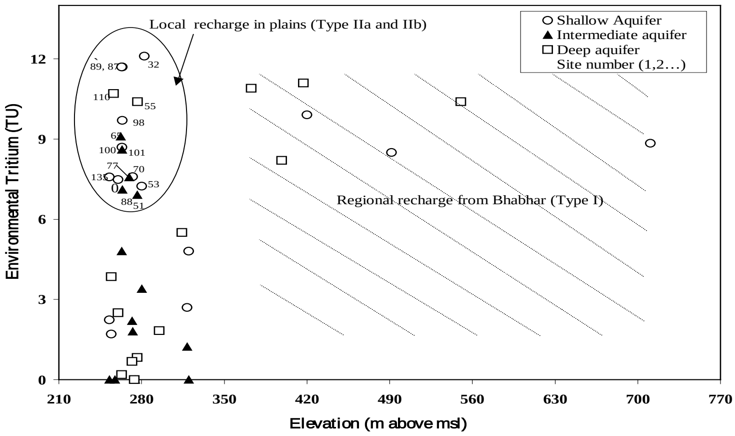

Figure 3. Groundwater recharge area identification based on variation of environmental tritium values with elevation in Solani-Yamuna interfluve.

Type IIa and IIb - region in the altitude range of 250 to 290 m above m.s.l. indicating local recharge region in plains, and

Type III – ground-water in the plains at altitudes below 320 m above m.s.l. and showing longer residential time i.e. the region that is not actively getting recharged (un-shaded portion of the Solani-Yamuna interfluve in Figure 3).

Perusal of Figure 3 raises two important questions 1) Why the samples from shallow depths in Type III region show a lower value of tritium and 2) why the samples from greater depths show higher tritium values in Type II regions. The answer requires some additional information on the specific geo-morphological settings of these regions in particular, that are discussed below:

The type I region comprises of Bhabhar zone and Siwalik Hills (Figure 4). The high recharge rate in this region could be due to high porosity and permeability of its matrix. The steep gradient of this region makes the groundwater flow down-gradient with relatively higher velocity. Its vast areal extent forming the northern boundary of the alluvial plains makes this region the largest recharging zone in the study area.

As seen from Figure 4, the type IIa region falls in the region between the rivers Hindon and Yamuna. The region is bounded in its north by braided tributaries of the river Yamuna (Budhi Yamuna and Maskara Rao) that drains from Siwalik Hills. The southern stretch extends up to Rampur (Site #99). The type IIa region is aligned along the Behat fault and covers an area of approximately 900 km^2. The high recharge in this region is probably due to the higher permeability as it is a part of sand bar plains formed in the paleochannels.

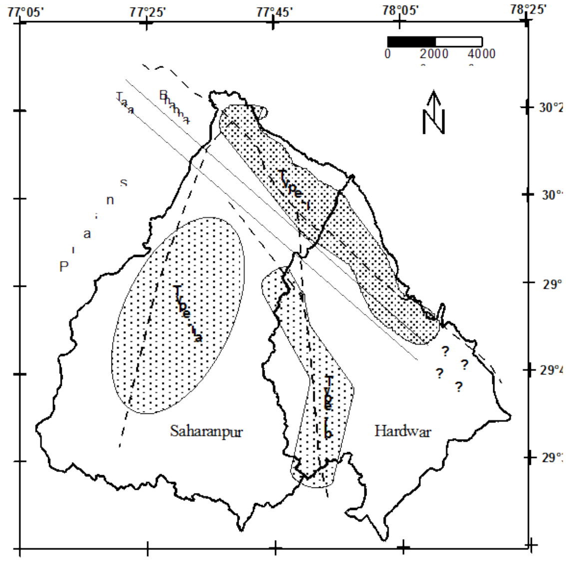

Figure 4. Map showing different recharge zones, identified on the basis of tritium concentration. Area marked with ? symbol indicated absence of data.

The type IIa region is also a local topographic high. As one moves away from this area towards the river Yamuna, tritium indicates higher groundwater ages suggesting the river Yamuna as its discharge zone.

The type IIb region is a part of Solani Fault bounded in the north by Tarai zone and in the east by river Solani. The region is sandy in nature and forms ravenous structure near Landhora (Site #65). The southern half of this region between Roorkee and Purkaji, is aligned along the Upper Ganga canal which could be the recharging source to this region. The lower retention time of groundwater in this region is probably due to its discharge into river Solani. However, this has to be verified by additional investigations.

The type-III region is more of a sag type structure between the two highlands (Type I and Type II regions). Very low slope in this region could be the possible cause for the high retention time of the groundwater in this region.

From the above discussion, it is apparent that the recharge characteristics are controlled mainly by the geo-morphological settings, fault zones and grain size distribution and sorting. Regions of Type I, IIa and IIb facilitate higher permeability in comparison to regions of Type III. This also evident from a lower density of drainage network in the Type IIa and IIb regions as compared to the Type III region.

Solani-Ganga Interfluve

Figure 5 shows variation of environmental tritium in ground water samples of Solani-Ganga interfluve. The data points show exponential decay in tritium activity along the regional slope suggesting a single recharge zone in this region, unlike in the Solani-

Yamuna Interfluve where multiple recharge zones were identified. The nearly constant tritium activity of about 13 TU obtained at altitudes above 310 m indicates that the regional recharge zone is situated in the Bhabhar zone. The sample from deep-seated aquifer at Laksar (Site #62) shows very low value (nil or not detectable). If the tritium data for groundwater samples from all the three aquifers are analyzed, an exponential best-fit curve is obtained (r = 0.997). This suggests little or no mixing with modern water along the flow path. However, samples from shallow aquifers have a tritium activity of about 3 TU in plains at altitude below 260m above m.s.l. This suggests fractional contribution from rainfall recharge. The samples (#62 and #109) from inter-mediate aquifers show tritium values of about 2.0 TU. Since, the sites are characterized by water logging the marginal increase in the tritium values comp-red to deeper aquifers may be linked to slower percolation rates. These also show that the connectivity of shallow and intermediate or deeper aquifers is very poor.

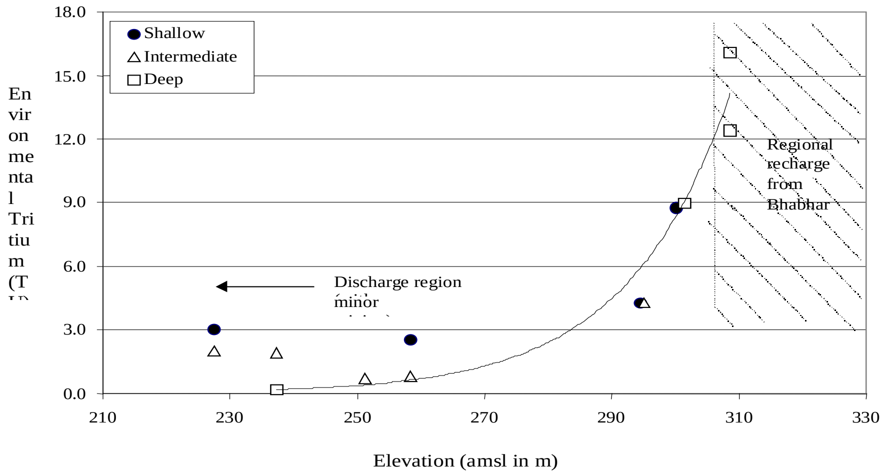

Figure 5. Plot showing variation of environmental tritium concentration with elevation in the Solani-Ganga interfluve.

Transportation rates

The mean transportation rate of the groundwater in the Solani-Ganga interfluve has been estimated from the basic radioactive decay equation:

$$A_t = A_0 e^{-\lambda t} \tag{1}$$

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 above equation may be rewritten to calculate the time taken for the tritium to decay from 13 TU to 0.2 TU (that correspond to tritium content at recharge and discharge zones in the Solani-Ganga interfluve).

The time taken for travelling a distance of approximately 30 km is about 75 years. The mean transportation rate then, is about 1.1 m/d or $1.3*10^{-5}$ m/s. This value is marginally lower than that considered in earlier studies (Rao, 1965). However, this is the first time that the mean transportation rate has been estimated for the regional groundwater system in the study area. The above estimation has been made on the assumption that the groundwater flow follows a piston-flow model.

CONCLUSIONS

The following conclusions are drawn from the present investigations:

Bhabhar zone and Siwalik Hills act as regional recharge area to the intermediate and deeper aquifers in the plains region of Solani-Ganga and Solani-Yamuna interfluves. In the Solani-Yamuna interfluve, two additional recharge regions have been identified, that are closer to the Behat and Solani faults. In the Solani-Ganga interfluve the local recharge due to rainfall infiltration in the plains region is very low. Both Ganga and Yamuna rivers act as regional discharge zones of the groundwater.

The mean transportation rate of groundwater in the Solani – Ganga interfluve is about 1.1 m/d. As seen from the environmental tritium data the interconnection between shallow, intermediate and deeper aquifers in the plains region between Behat and Solani faults and also in the Solani –Ganga interfluve is poor.

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