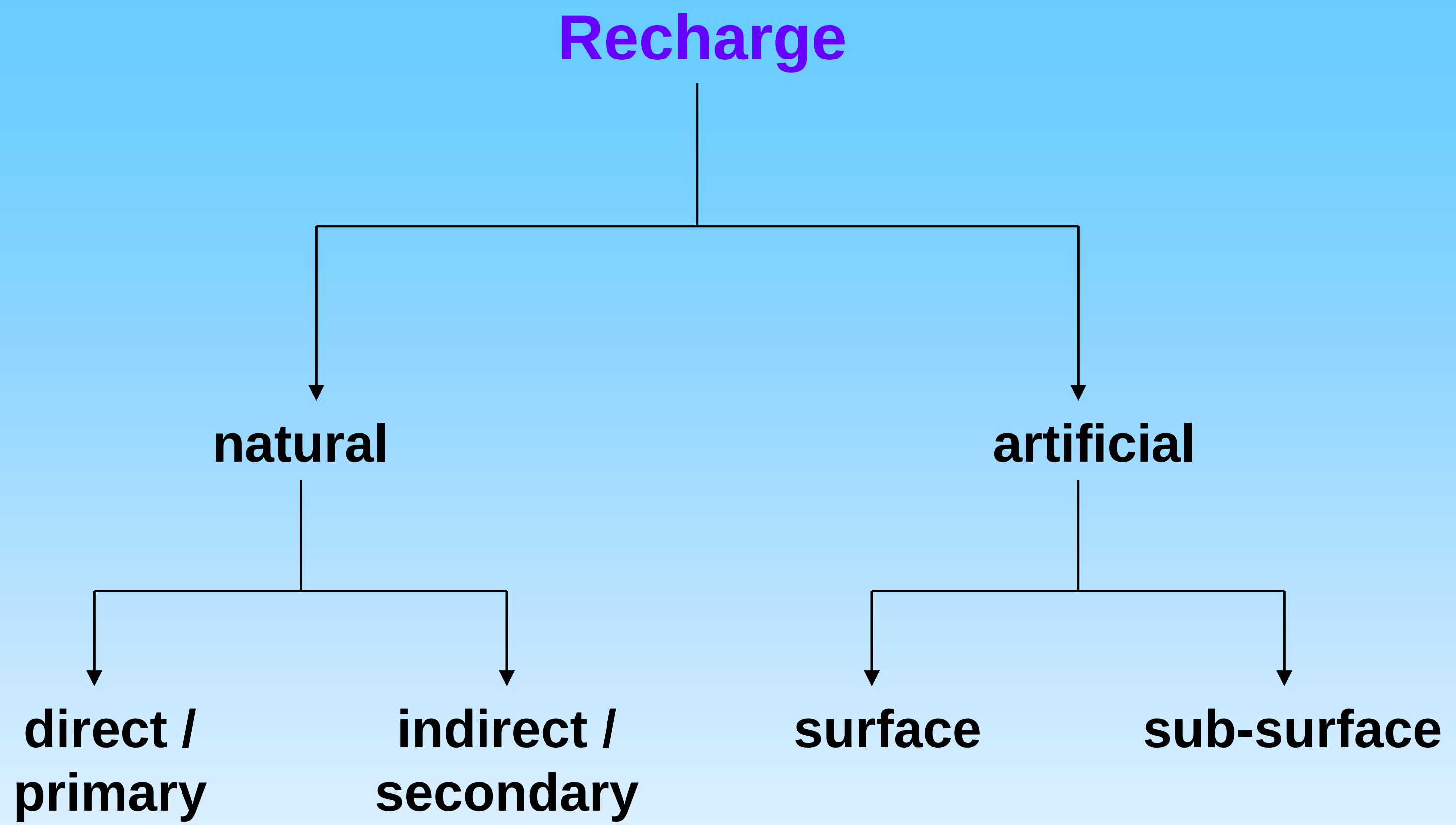
# Applications of Isotope Techniques in Hydrology

- Origin and source of water
- Aquifer – aquifer interaction
- Surface water - Groundwater interconnection
- Efficacy of artificial recharge measures to groundwater
- Source of recharge and estimation of recharge to groundwater
- Sustainability of deep aquifers
- Lake Dynamics & Rate of Sedimentation

- **Origin, source, subsurface temperature etc. of geothermal waters**
- **Origin and mechanism of groundwater salinity and pollution**
- **Groundwater contamination studies**
- **Dating of groundwater**
- **Rate of moisture movement**
- **Discharge of rivers/streams**
- **Estimation of subterranean groundwater discharge**
- **Effluent dispersion in Sea/Ocean**




**Static and dynamic groundwater resources**

**Estimation of annual recharge is important for groundwater development and utilization strategies**

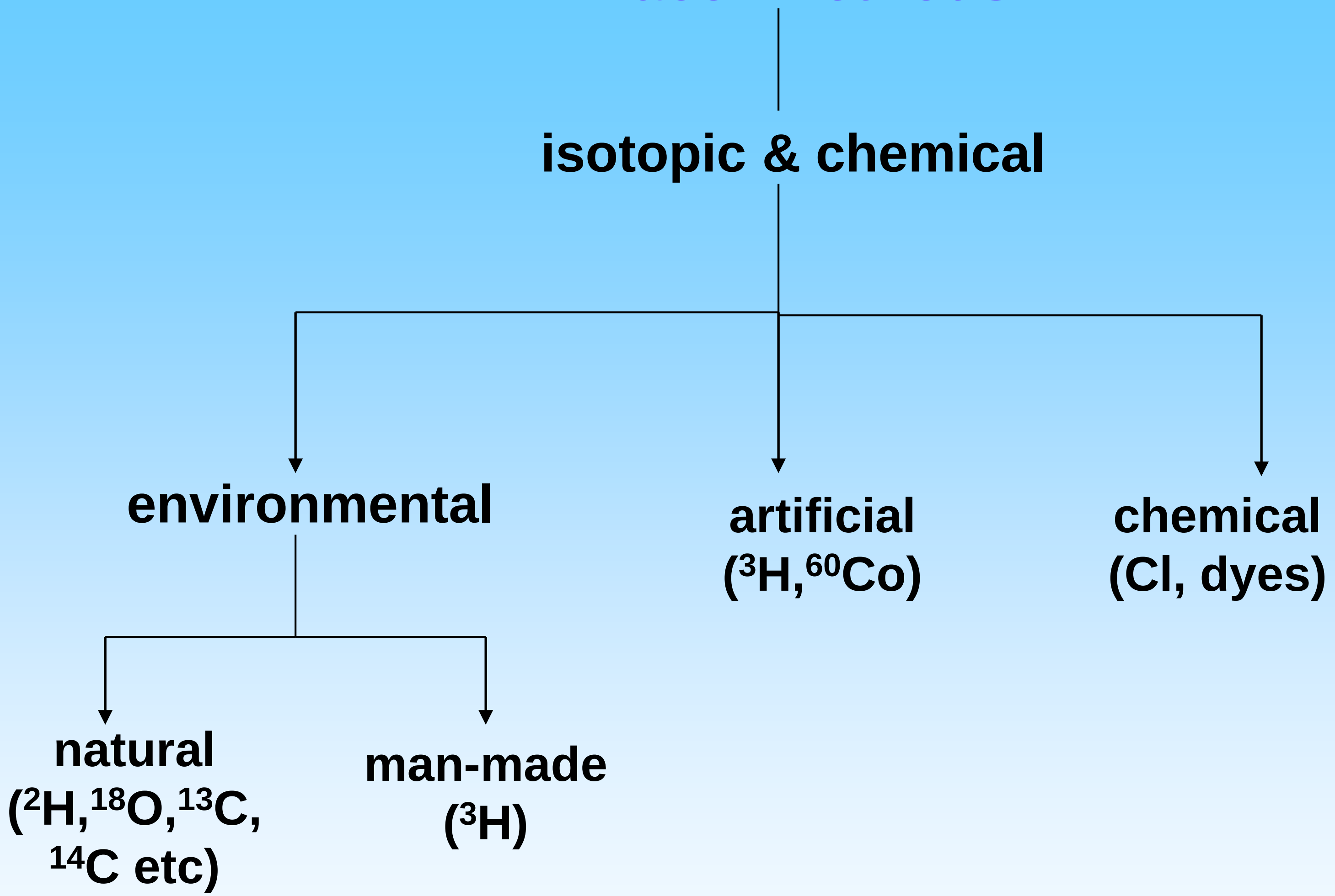
## Relevance of groundwater recharge

- ❑ Sustainable development of aquifers ?
- ❑ Overexploitation in arid and semi arid regions ?
- ❑ Judicious exploitation of coastal aquifers ?

## Factors affecting the groundwater recharge

- ❑ Amount, intensity and gap between rainfall
- ❑ Infiltration capacity & antecedent moisture conditions
- ❑ Evapotranspiration
- ❑ Topography, thickness of unsaturated zone etc.

# Tracer methods



## APPLICATION OF ENV. ISOTOPES FOR RECHARGE STUDIES

**Identifying the source of recharge**

**$^{2}H$ & $^{18}O$ can be used to differentiate local & distant recharge and recharge from surface water bodies**
**$^{3}H$ & $^{14}C$ indicates the time scale of recharge**

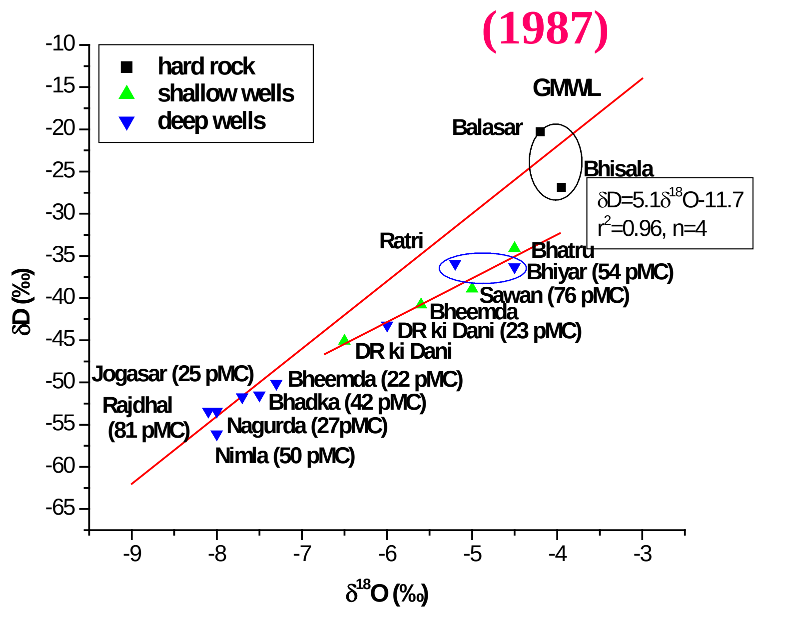
## Investigated area – Barmer Basin, Rajasthan

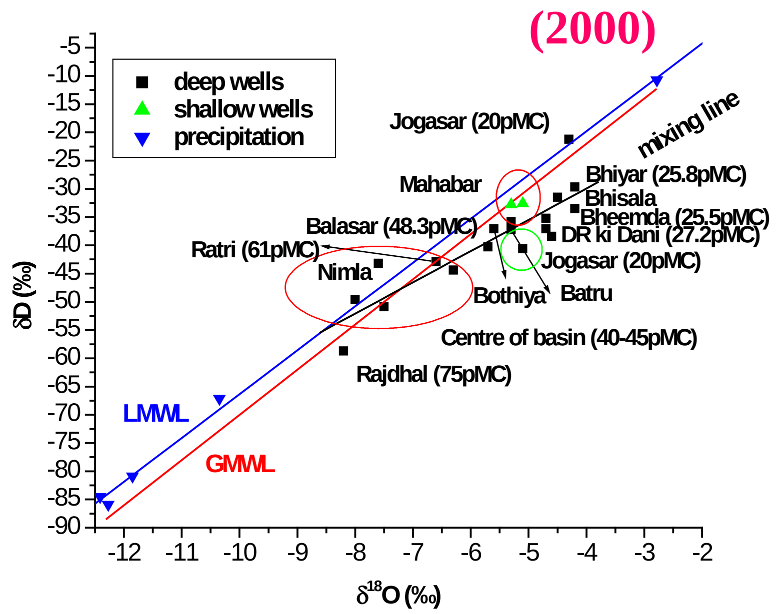
**Problem**

**Any replenishment of groundwater ?**
**Source & mechanism of recharge?**
**When recharge took place?**
**Relationship between deep and shallow groundwaters?**

**Area = 7000 $km^2$**

**Geology: Tertiary sediments**



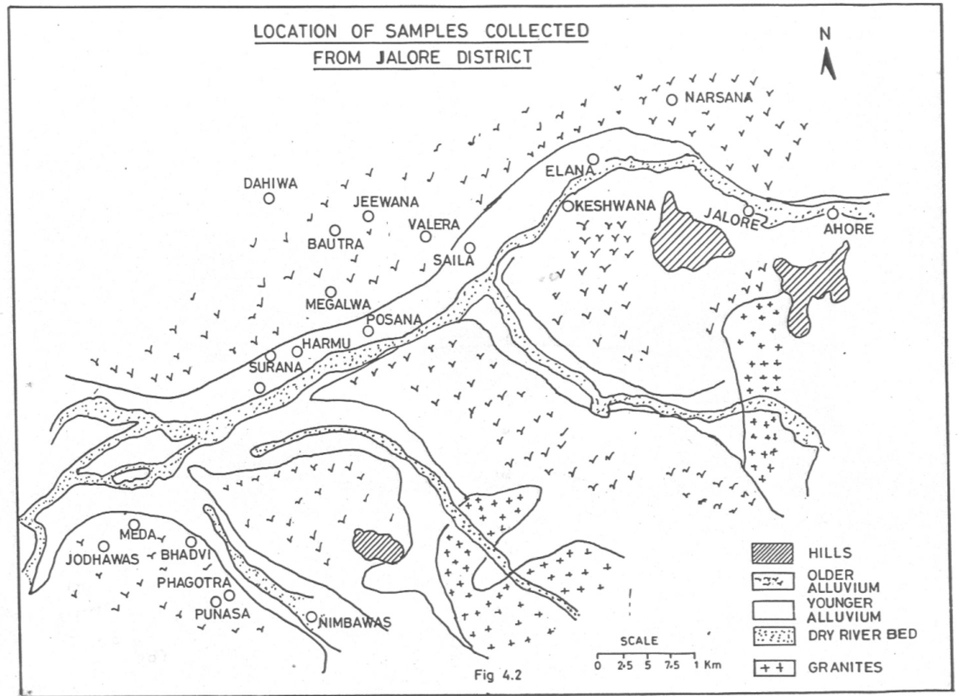



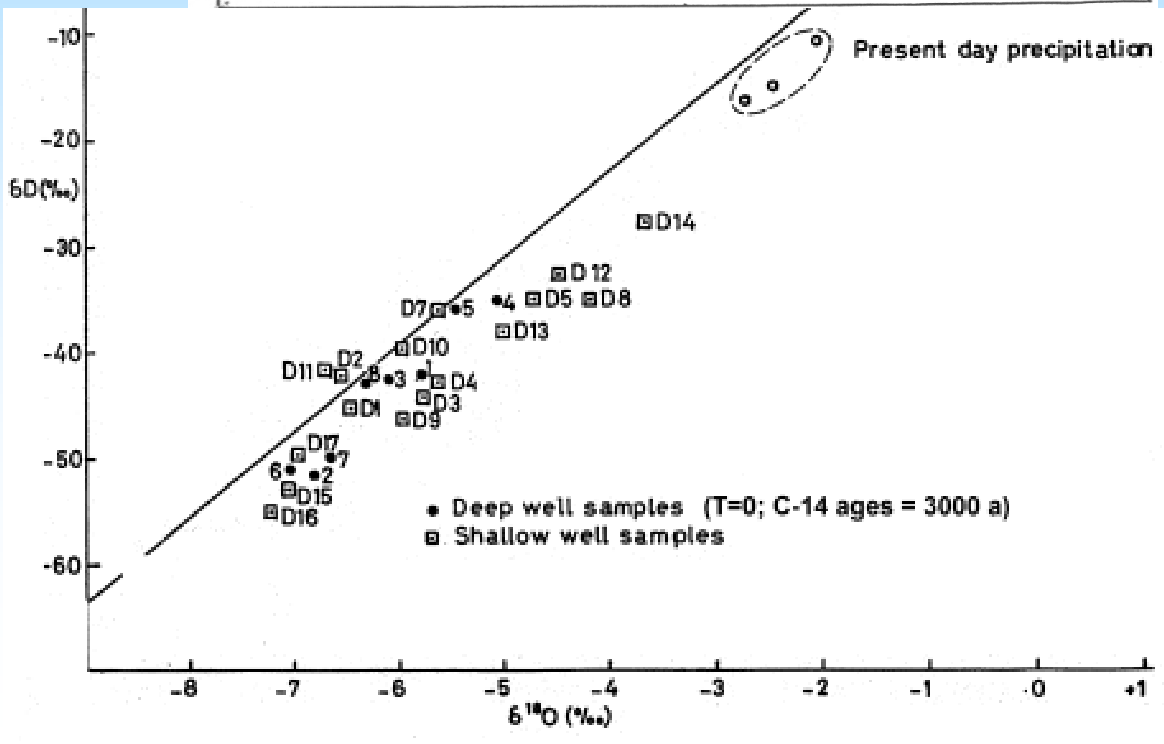

## $\delta D$ - $\delta^{18}O$ diagram for Barmer basin

- shallow GWs are recharged by direct infiltration
- deep groundwaters are devoid of vertical recharge
- Interconnection of shallow and deep aquifer at a few places
- deeper waters in the centre of the basin are fresh and depleted in stable isotopes ($^{14}C$- 40 to 45 pMC), indicating recharged during a humid climate
- deeper waters away from the central portion are brackish and are enriched in stable isotopes ($^{14}C$- 20 to 27 pMC); recharged during an arid climate

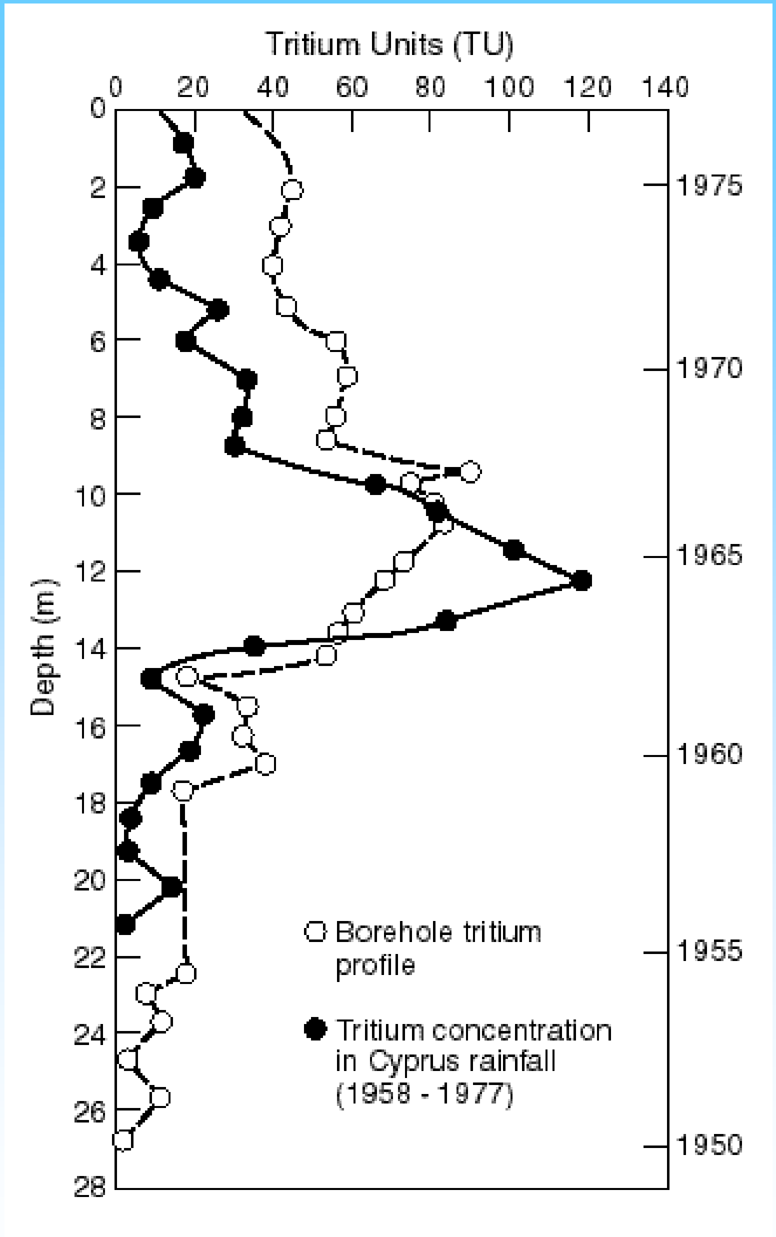
# *Investigated area – Jalore, Rajasthan*

- recharge to shallow aquifer – occurs during episodic floods
- deep groundwaters are 3000 yrs old



# Environmental tritium in soil profile and rainwater

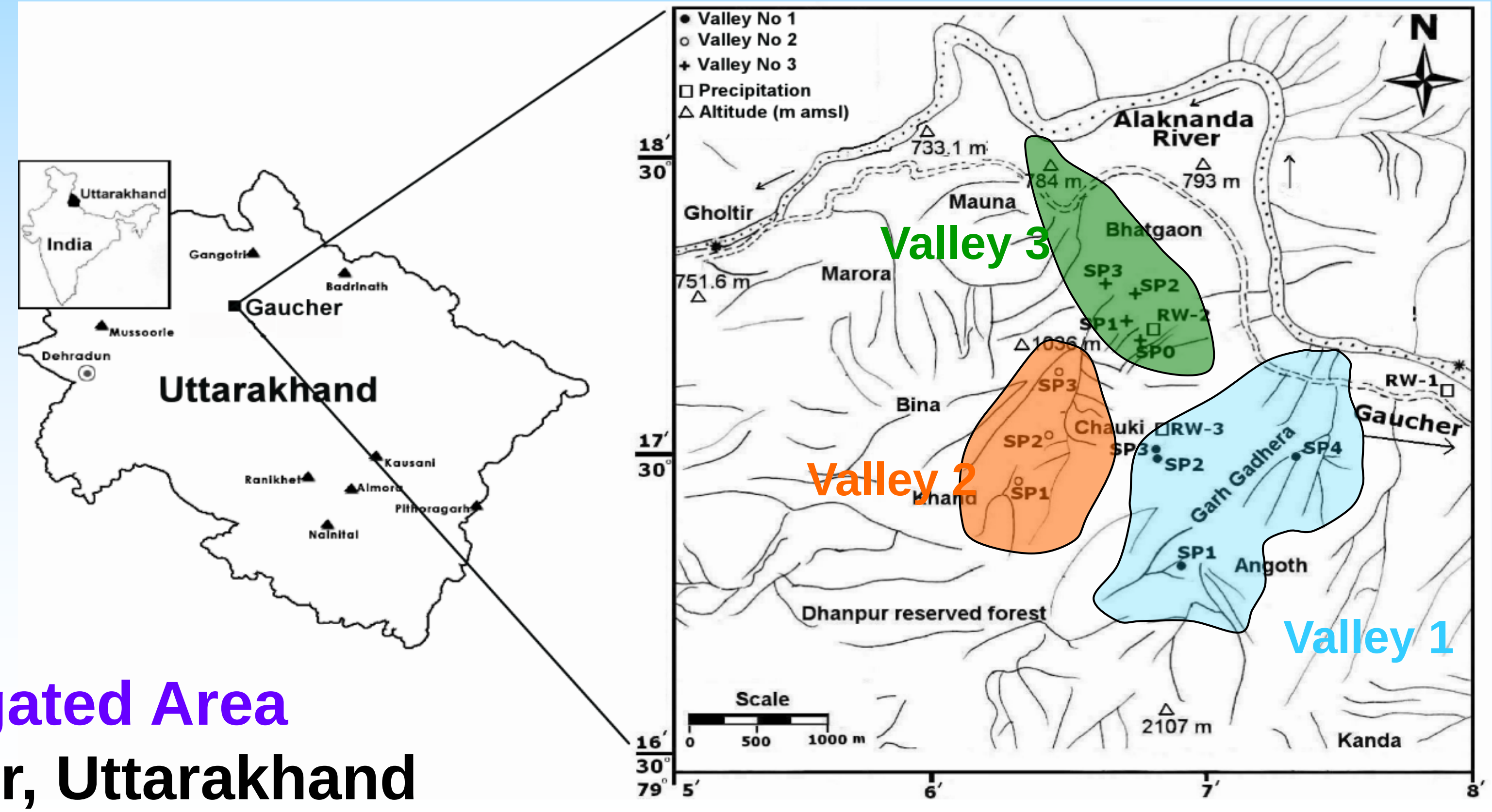


# Identification of recharge area

**Problem**

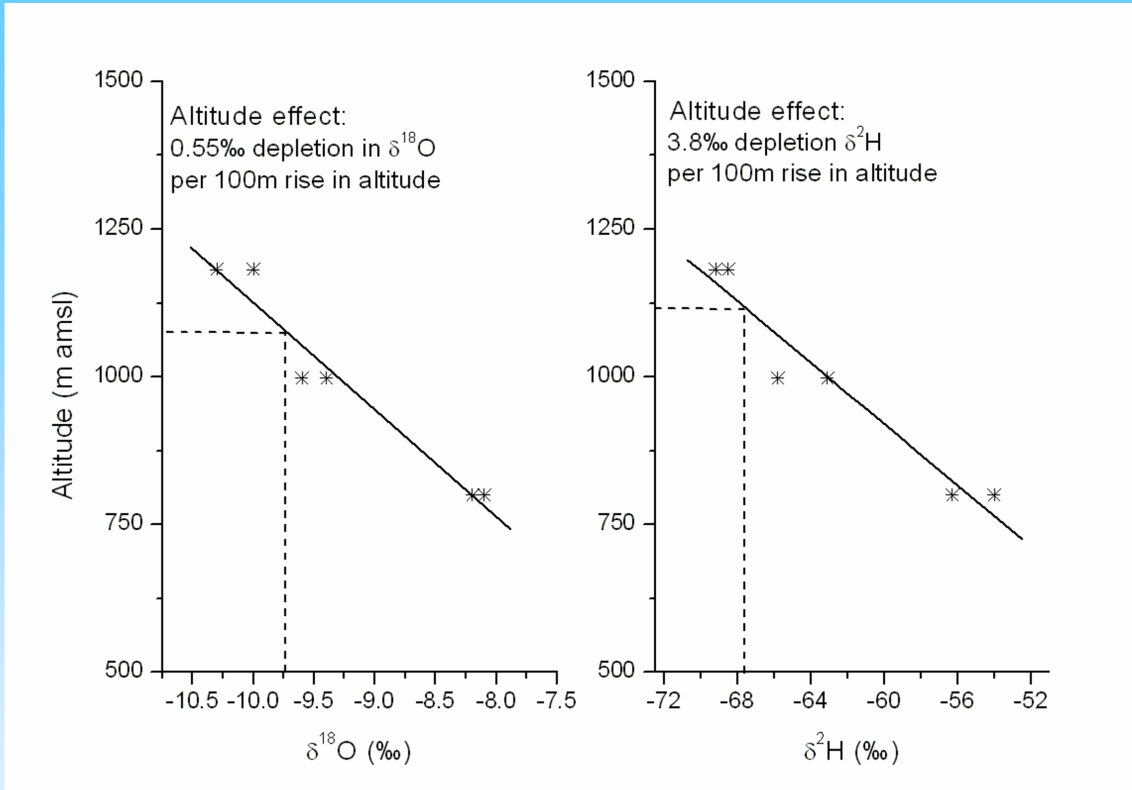
**Drying of springs during summar**

**Probable location for artificial structures**




**Investigated Area**

**Gaucher, Uttarakhand**




# Results

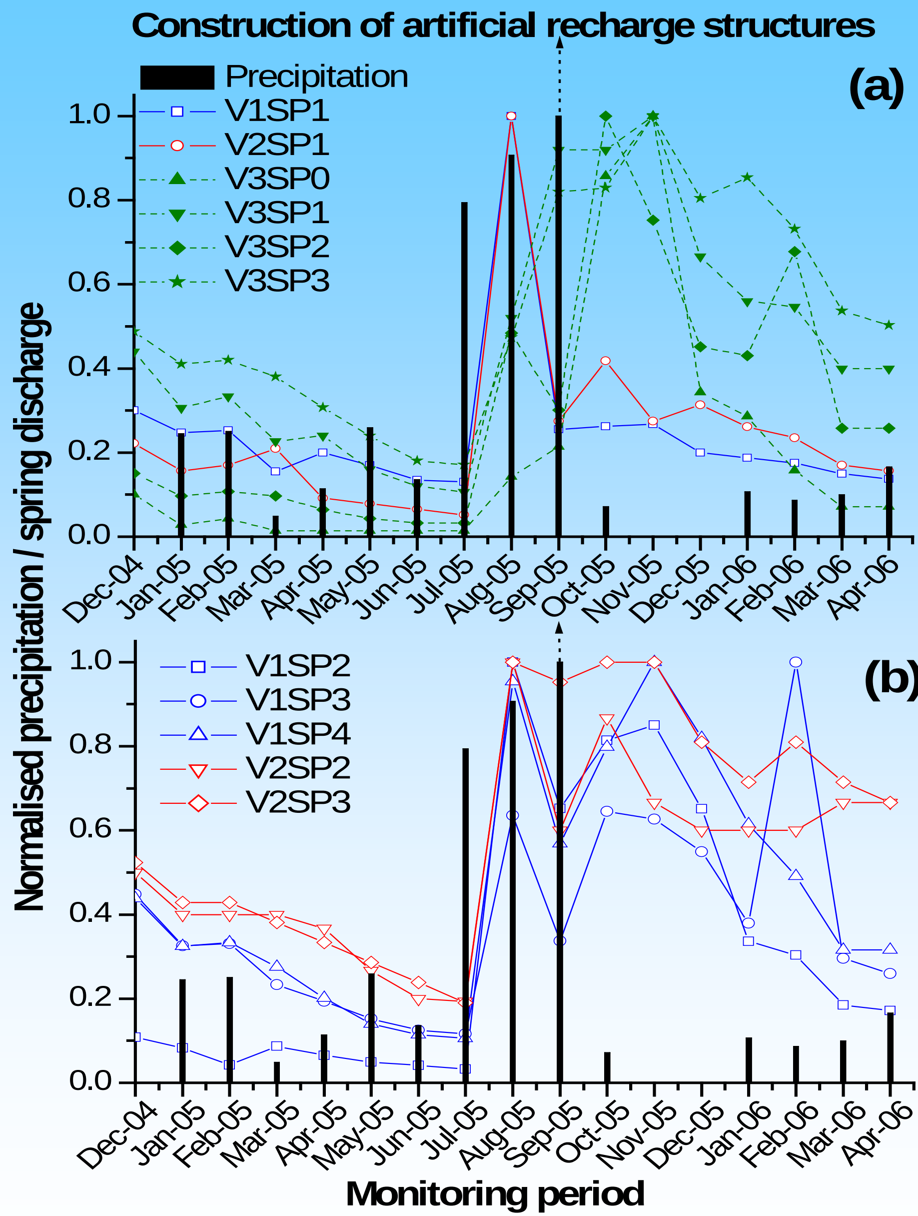
- Established altitude effect - -3.8‰ /100 m for $\delta^2$H and -0.6‰/100 m for $\delta^{18}$O
- Evaporation corrected isotope data was used to locate the recharge area of high altitude springs
- Recharge area of springs at Valleys-1: at +1250 m; Valley-2: at +1330 m; Valley-3: at +1020 m.

# Construction of artificial recharge structures

**Subsurface dykes (5 Nos.) in Valley 1**
**Check bunds (2 Nos.) in Valley 2**
**A few contour trenches in Valley 3**

# Impact

- Discharge rates of most of the springs were nearly doubled
- Two new springs  appeared in valley 1
- No spring dried up during the subsequent summer



Construction of artificial recharge structures
Precipitation
V1SP1
V2SP1
V3SP0
V3SP1
V3SP2
V3SP3
(a)
V1SP2
V1SP3
V1SP4
V2SP2
V2SP3
(b)
Normalised precipitation / spring discharge
0.0
0.2
0.4
0.6
0.8
1.0
Dec-04
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Oct-05
Nov-05
Dec-05
Jan-06
Feb-06
Mar-06
Apr-06
Monitoring period

*The Indian* **EXPRESS**
www.expressindia.com



# A bit of N-tech to recharge Himalayan water sources

S M A KAZMI
RUDRAPRAYAG, OCTOBER 29

BHABHA Atomic Research Centre (BARC), the country's premier nuclear energy research institute, has for the first time used its technology to successfully recharge dry springs and aquifers in Rudraprayag district of Uttaranchal.

The guiding spirit behind the efforts of BARC scientists is none other than their former chief Dr R Chidambaram. The present Principal Scientific Adviser to the Government of India went all the way to Golthir village in Gauchar on October 27 to see for himself the experiment done by BARC scientists in collaboration with Himalayan Environmental Studies and Conservation Organisation (HESCO), a local voluntary group.

In a pioneering effort, BARC scientists, using isotope hydrology technology, were able to recharge nearly 13 water sources that had dried up causing a severe water crisis in the area.

The story starts in 2003, when BARC, on Dr Chidambaram's initiative, went to the area which was facing a severe water crisis as discharge from all water resources had gone down. "Using environmental isotope techniques, we traced the recharge areas of these water sources," said Dr Gursharan, head of the Isotope Application Division.

**Dr R Chidambaram, the guiding spirit behind the project**

Subsequently, 33 rain water tanks were build in the recharge zones. "After monitoring, it was found that water discharge in these sources has increased considerably and even two new water springs had sprung up," claimed Dr Shivanna, the man responsible for the experiment on the ground.

"We should be able to recharge the fresh water sources in the Himalayas as global demand for fresh water will increase in the coming times. Moreover, the local population dependent on these water sources should benefit from latest technology," added Dr Chidambaram.

Using latest isotope hydrogeochemical techniques, the scientists worked tirelessly to track the origin of the dead springs. Once the origin and route were traced, scientists built bunds so that water would start percolating into the earth. Once this happened, the spring got recharged at the village downstream.

Now, water discharge in the springs has risen to 16 litre per minute from two litre with the new techniques. "This is a significant development which would go a long way in not only preserving and recharging water, but also providing water for irrigation and drinking," said Dr Anil P Joshi of HESCO, who won this year's Jamana Lal Bajaj Award for his work in the Himalayan region.

"With technological help from BARC, we would be working at 10 more places in the state to replicate the experiment," said Harshpati Uniyal, chief of Uttaranchal Jal Sansthan, the state government agency responsible for providing drinking water to the state.

In Uttaranchal, drinking water has become scarce forcing women to trek miles to fetch drinking water.

# N-tech for water supply

By **Abhishek Shukla**
in New Delhi

SCIENTISTS, for the first time in India, have used nuclear science to revive dried-up natural springs in of Uttarakhand's hilly regions.

As a result of a unique project — jointly undertaken by the Bhabha Atomic Research Centre and a local environment group in Rudraprayag — water output of springs has gone up three to ten times.

This is helping solve the problem of drinking water scarcity in hilly villages. Now, it i proposed to take up similar projects at 10 locations in Himachal Pradesh and Jammu and Kashmir as well.

Groundwater availability in hilly terrains is limited and residents are forced to depend on natural springs. The forest cover around these springs helps in trapping rain water and helps recharge them. These springs are seasonal with high discharges during monsoon. They tend to dry up during summer.

"Due to continuous deforestation, catchment areas for rain water have been drastically reduced. Eventually, these denuded lands were unable to conserve water, which resulted in drying-up and dying of many mountain springs," said Anil Joshi of the Himalayan Environmental Studies and Conservation Organisation (Hesco).

When residents complained about the water shortage in the area, government agencies, taking a myopic view, developed a water distribution system in which water was diverted from regions with adequate water supply to the deprived ones. The arrangement resulted in local conflicts as residents of the village from where water was diverted were against it. The diversion of water through pipelines resulted in wastage through leakages and posed maintenance problems as well.

Joshi suggested development of catchment areas at strategic locations could help in effective recharge of the natural springs. He conveyed his concerns to R Chidambaram who in turn requested BARC scientists to help in the process.

A team of scientists led by K Shivanna, head of the water resources development section and Gurusharan Singh, chief of the isotope applications division, reached the area in 2003.

They identified 11 springs in three valleys in the Gauchar area for the study. Gauchar is located 300 km away from Dehradun, on the way to Badrinath. It receives an average annual rainfall of about 800 mm from July to September.

**2,500 people in 300 villages have benefitted**

The team used natural isotopes of hydrogen, oxygen and carbon to track percolation of water down the hills. Environmental isotope technique helps in understanding the source and mechanism of recharge, groundwater circulation, recharge areas and transit times of the aquifer and the source source and mechanism of groundwater contamination.

Scientists based their study on a natural phenomenon known as altitude effect. It is common in hilly area that results in lesser concentration of isotopes in water vapours in high altitude, as compared to lower areas. "The data indicates that the chemistry of spring waters of higher altitudes is mainly influenced by water vapours, whereas the chemistry of the lower altitude springs is modified by the interaction with the rocks," pointed out Shivanna. After gathering the data and going through a number of experiments of hydrochemical and isotope analysis, the team concluded that since natural recharge zones were below the spring level, recharging through rains was not possible.

The scientists then suggested building of artificial check dams at strategic locations. "Based on findings, we recommended building five sub-surface dykes, check bunds and few contour trenches at these identified areas to control surface and sub surface flow," Shivanna said.

These measures soon started showing results and water output of springs almost doubled over a period of time.

The springs that were discharging only 70 liters of water every minute started to shower 130 liters in a minute.

The results were evident for all of these 11 springs initially undertaken for the experiment.

A total of 16 springs, serving a community of 2,500 people spread in 300 villages, have been recharged using the same technique.

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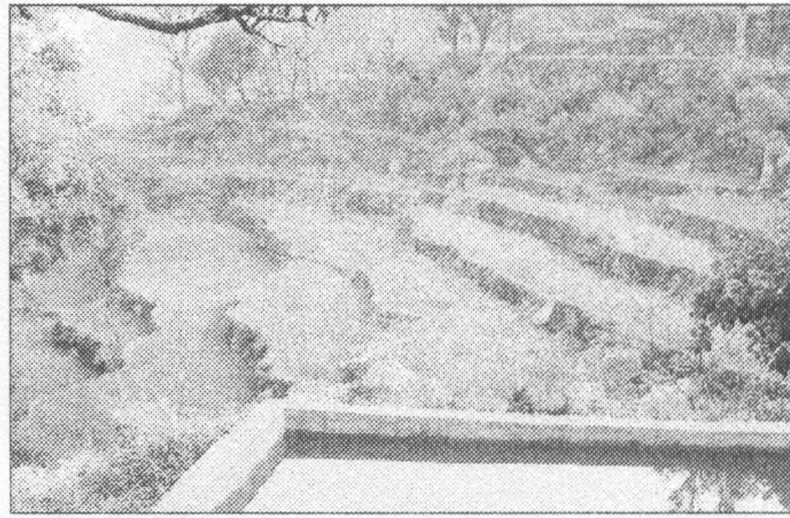
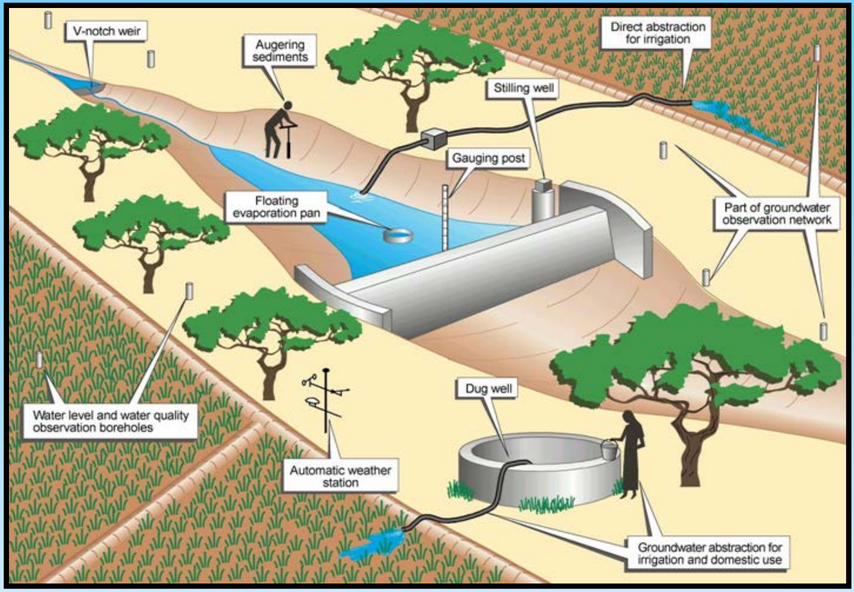


**COMBATING CRISIS:** A water catchment area in a village in Uttarakhand.

# Evaluating the effectiveness of artificial recharge schemes

**Percolation tanks**




## Problem

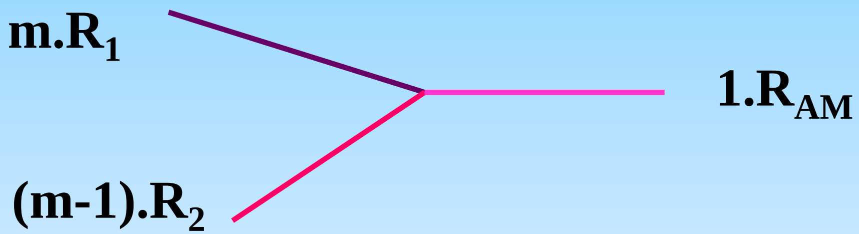
**Effectiveness of artificial recharge ?**

## Investigated area

**Hinganigada tank (Maharashtra)**

- **Location-** **Dhond taluk, Pune district, Maharashtra; in colloboration with Irrigation Dept.**
- **Shallow-** **~ 4 m [Ave. depth];** **Volume-** **~1Mm$^3$ [monsoon]**
- **Dug wells in command area -** **Penetrate soft rock over burden and fissured hard rock, which is exposed in the tank bed**
- **Water samples collected from tank & wells [every 3 months]** **– Analysed for D & $^{18}$O**

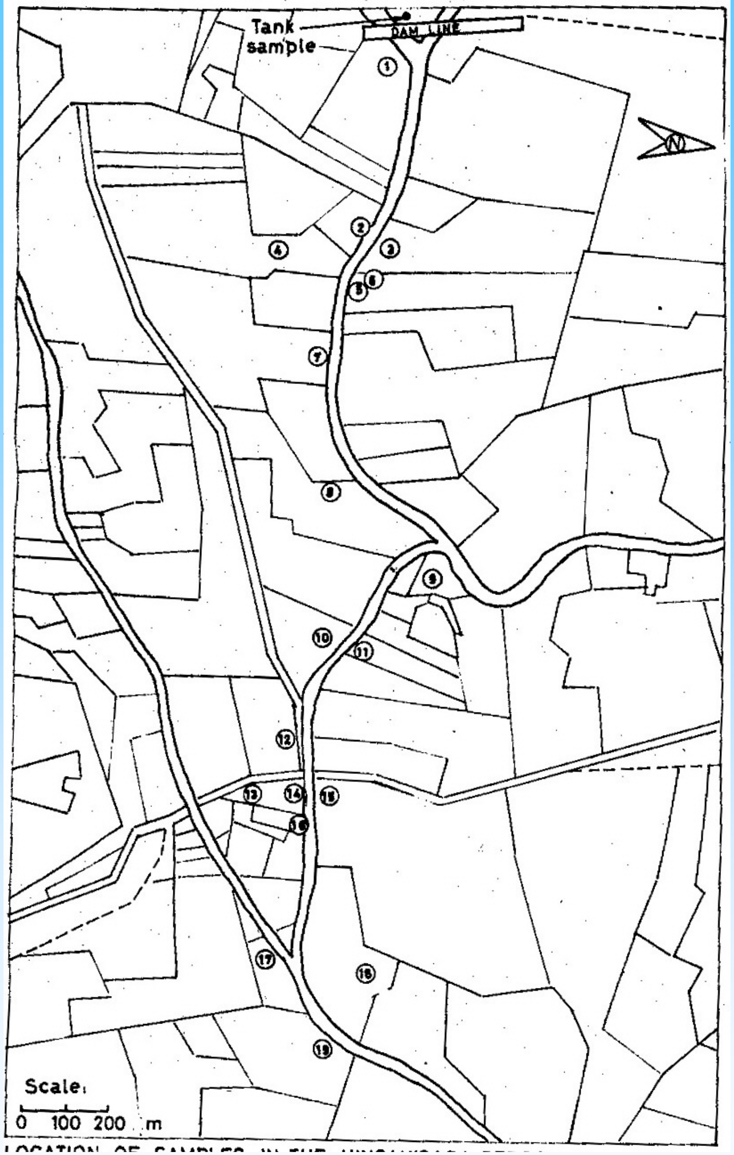
**Tank contribution (m) to groundwater can be estimated using:**

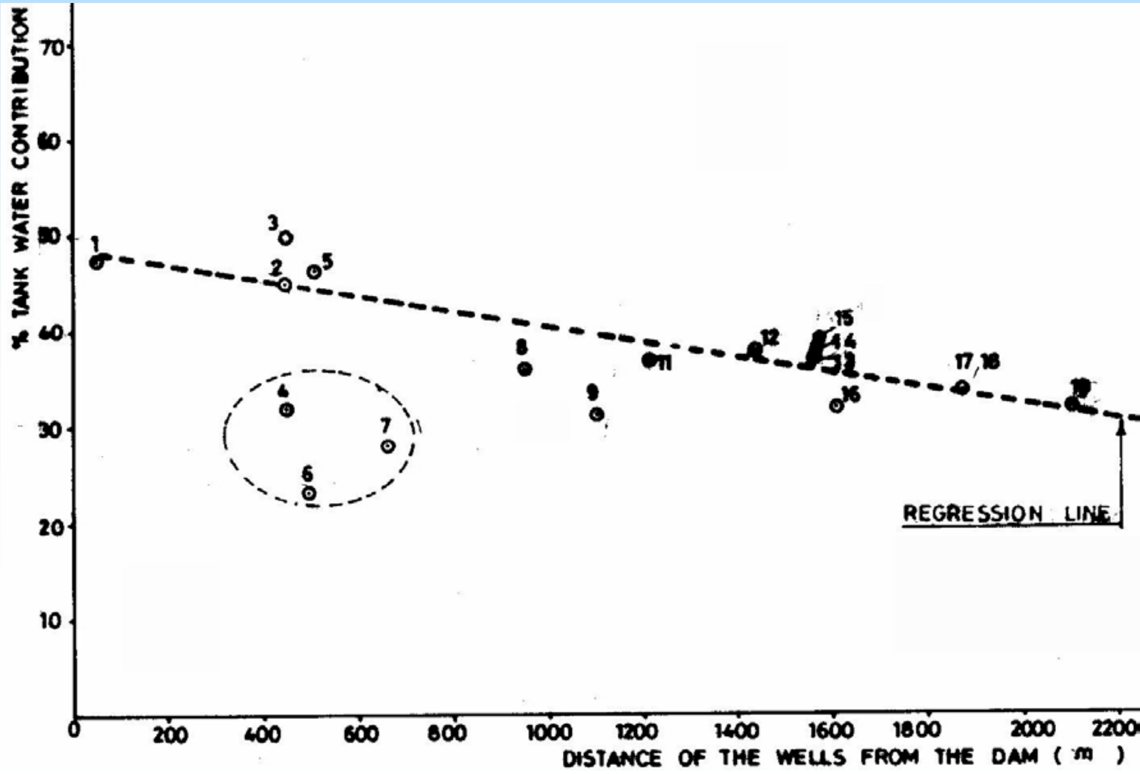



$$R_{AM}=mR_1 + (1-m)\ R_2$$

**$R_1$ - $\delta\ ^{18}O$ of tank water**
**$R_2$ - $\delta\ ^{18}O$ of groundwater**
**$R_{AM}$- $\delta\ ^{18}O$ of admixture (TW+GW)**

# Hinganigada tank, Pune

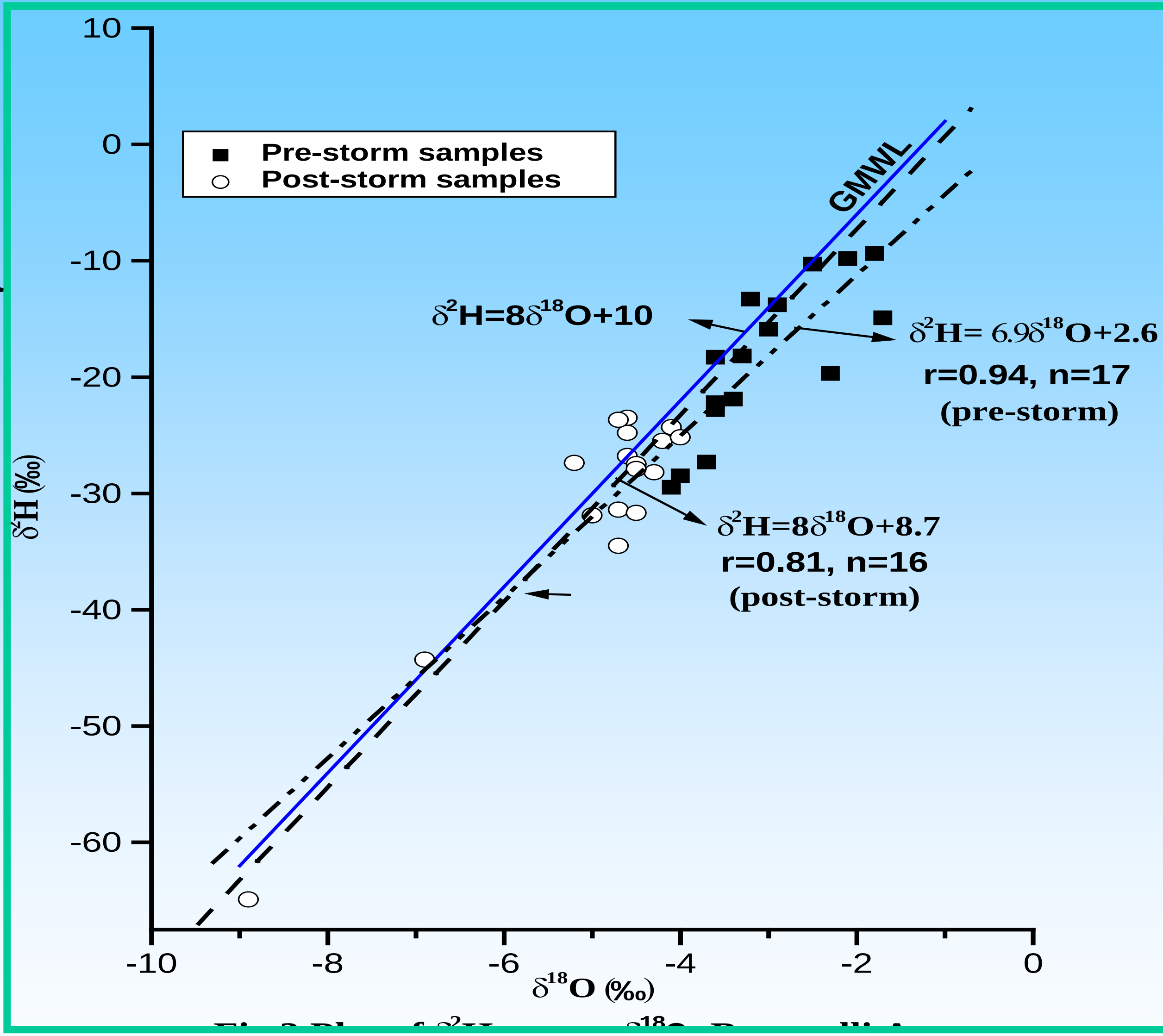


# Effect of storm in recharging groundwater

## Investigated area

**Bagepalli area, Karnataka**




- **The estimated recharge component of single storm event of 600mm to the groundwater is found to be in the range of 117 mm to 165mm.**

# River - aquifer interactions

## Ganga river –groundwater interaction in the Hardwar- Narora sector

- The influent and effluent characteristics of river Ganga was investigated using $^{18}O$.
- $^{18}O$ of the river and groundwater near the river was monitored at 8 stations. River and groundwater levels were also monitored.

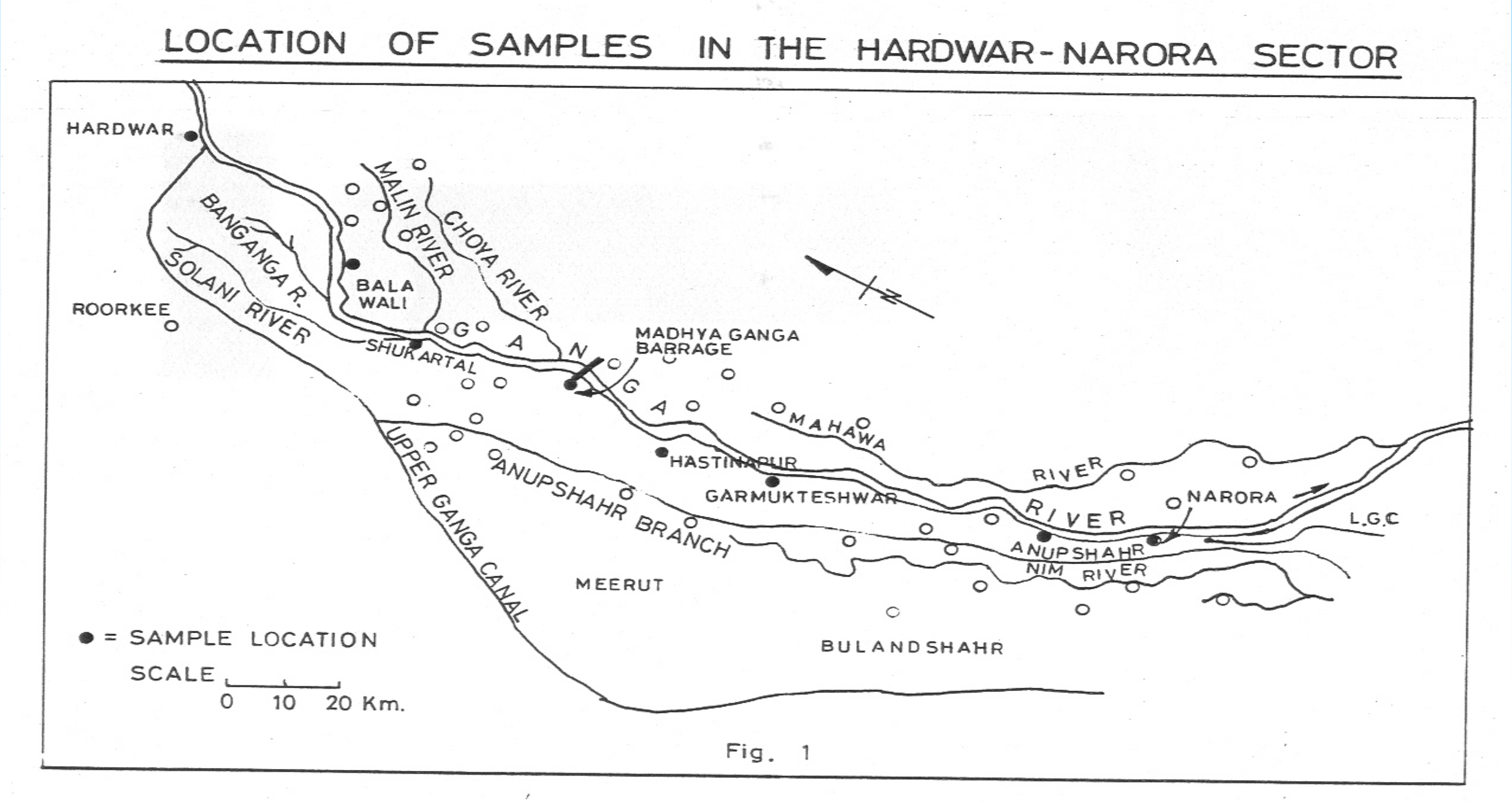
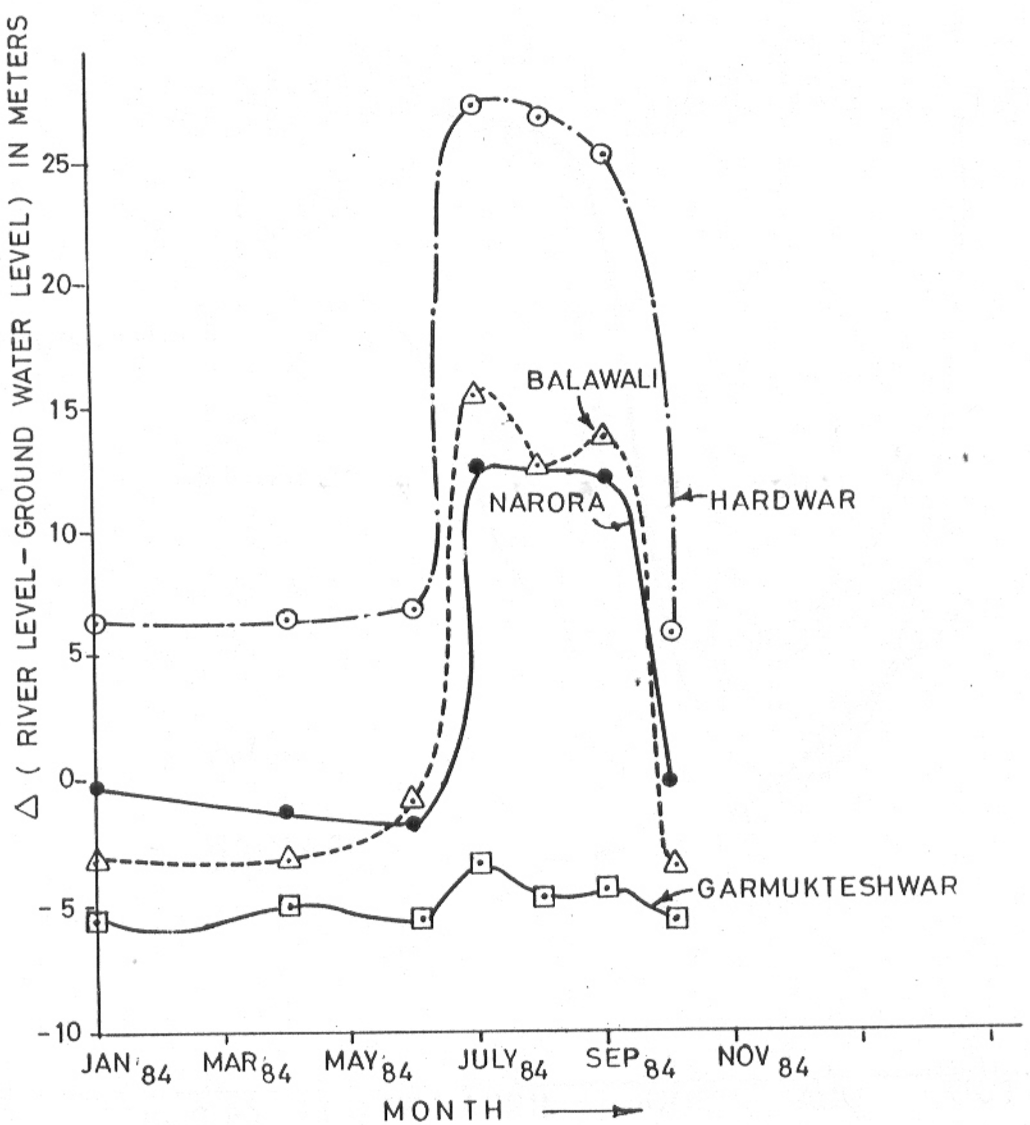
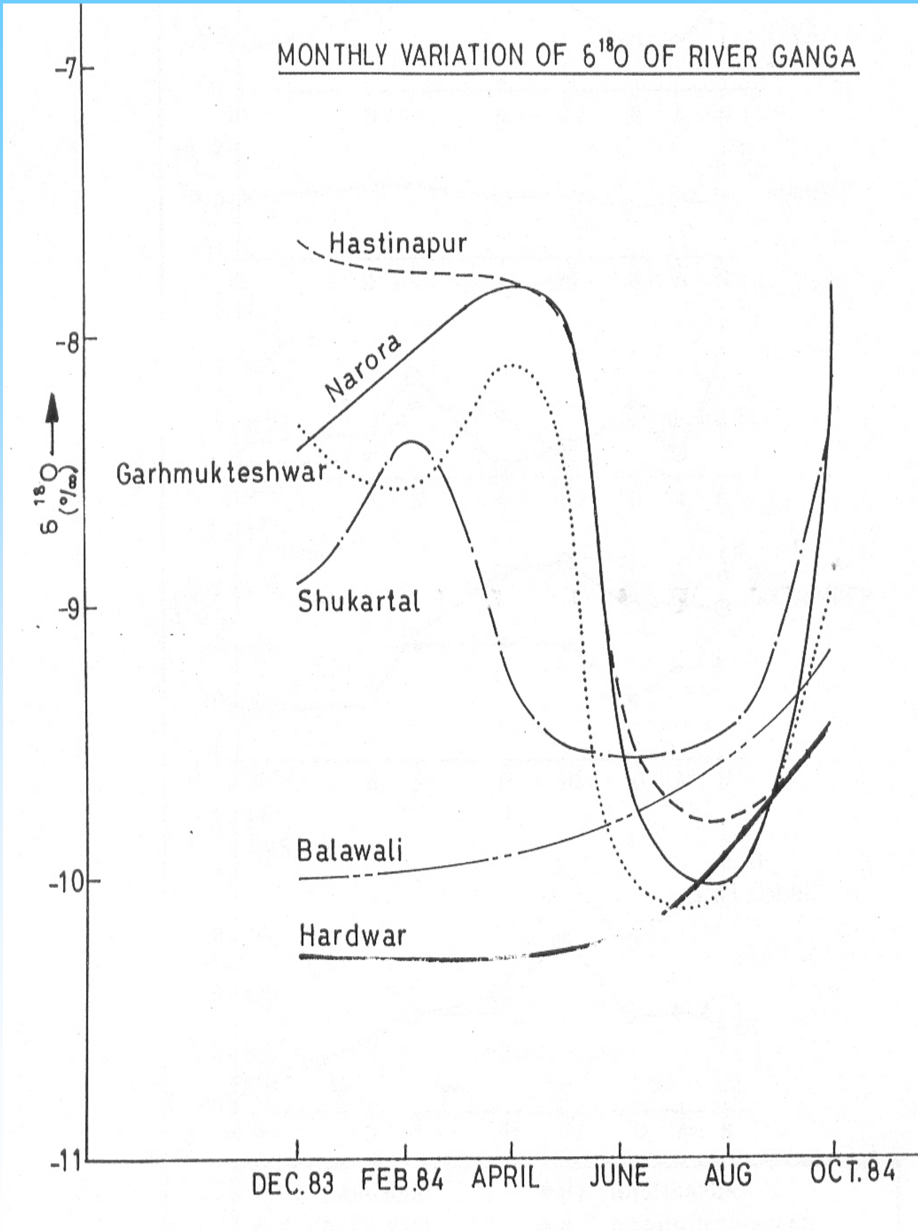


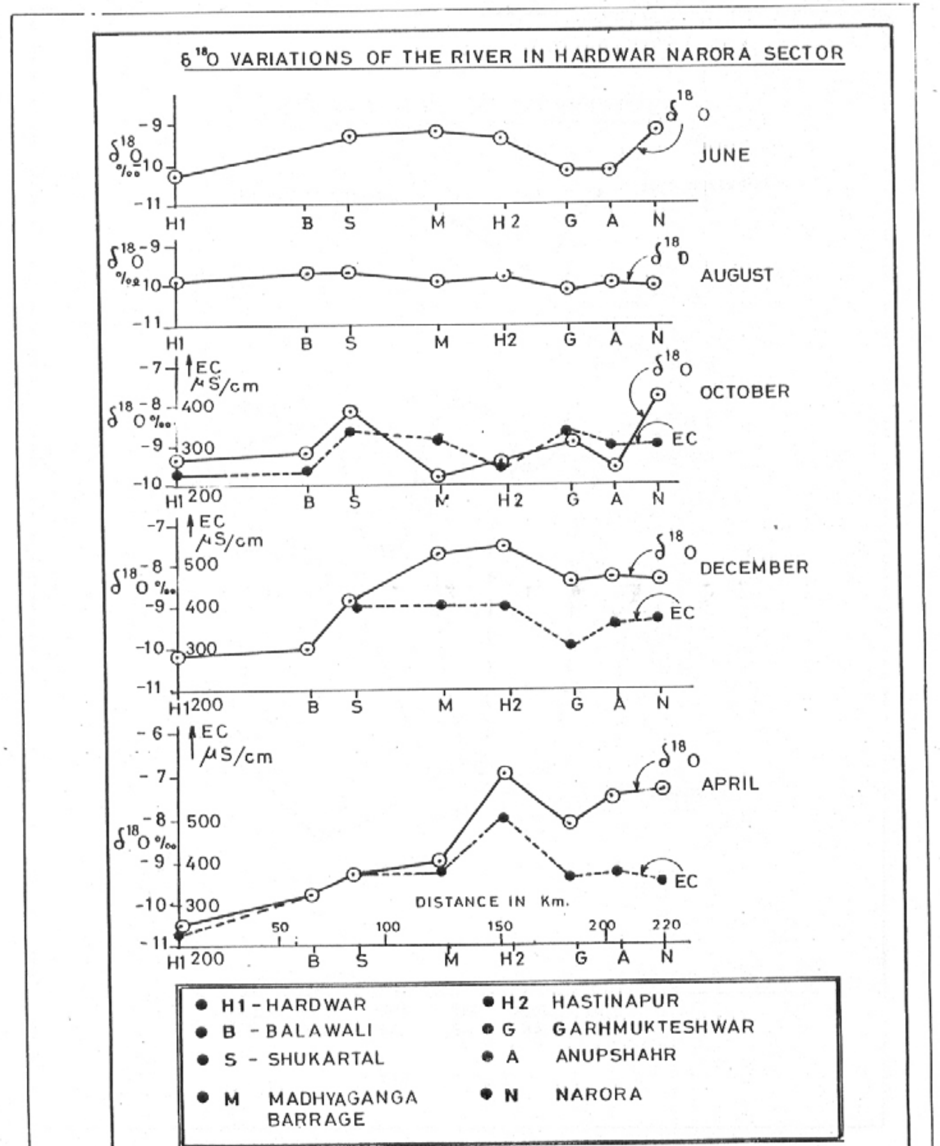
Fig. 1

## Monthly levels of River Ganga and Groundwater Between Hardwar & Narora





MONTHLY VARIATION OF δ18O OF RIVER GANGA
-7
-8
-9
-10
-11
δ 18O (‰)
Hastinapur
Narora
Garhmukteshwar
Shukartal
Balawali
Hardwar
DEC.83
FEB.84
APRIL
JUNE
AUG
OCT.84

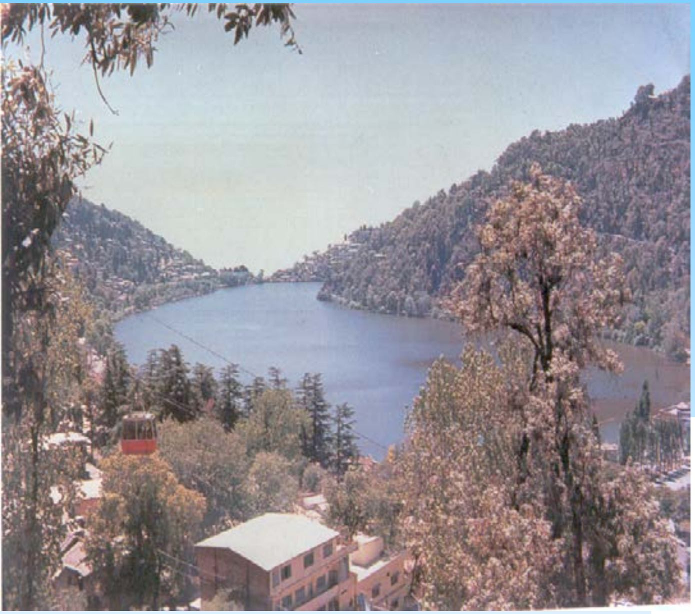



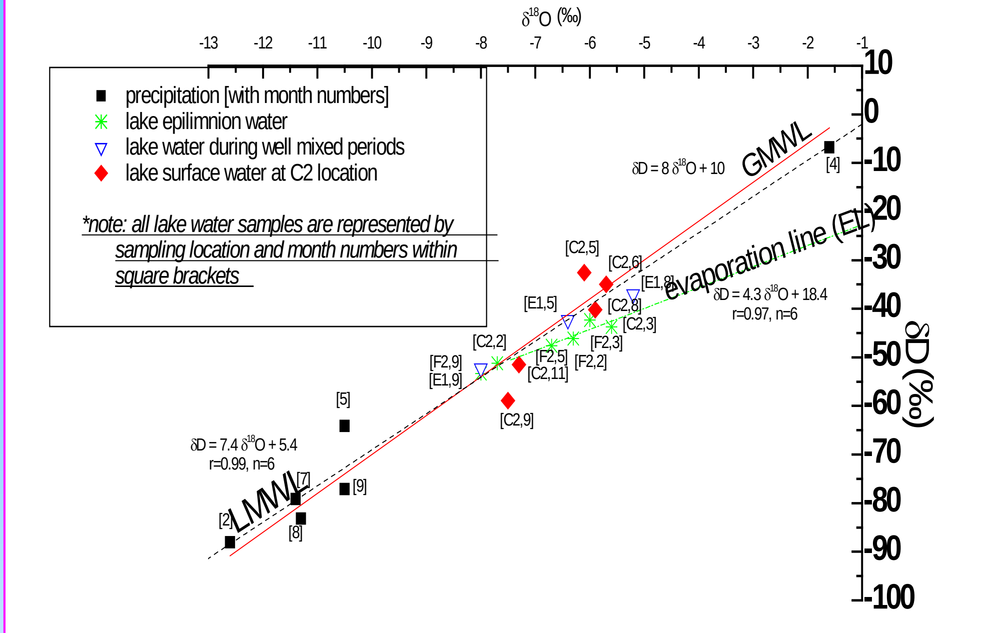
δ18O VARIATIONS OF THE RIVER IN HARDWAR NARORA SECTOR
JUNE
AUGUST
OCTOBER
DECEMBER
APRIL
δ18O ‰
EC μS/cm
H1 B S M H2 G A N
DISTANCE IN Km.
50 100 150 200 220
H1 - HARDWAR
B - BALAWALI
S - SHUKARTAL
M MADHYAGANGA BARRAGE
H2 HASTINAPUR
G GARHMUKTESHWAR
A ANUPSHAHR
N NARORA


Fig. 4

# Lake – groundwater interactions

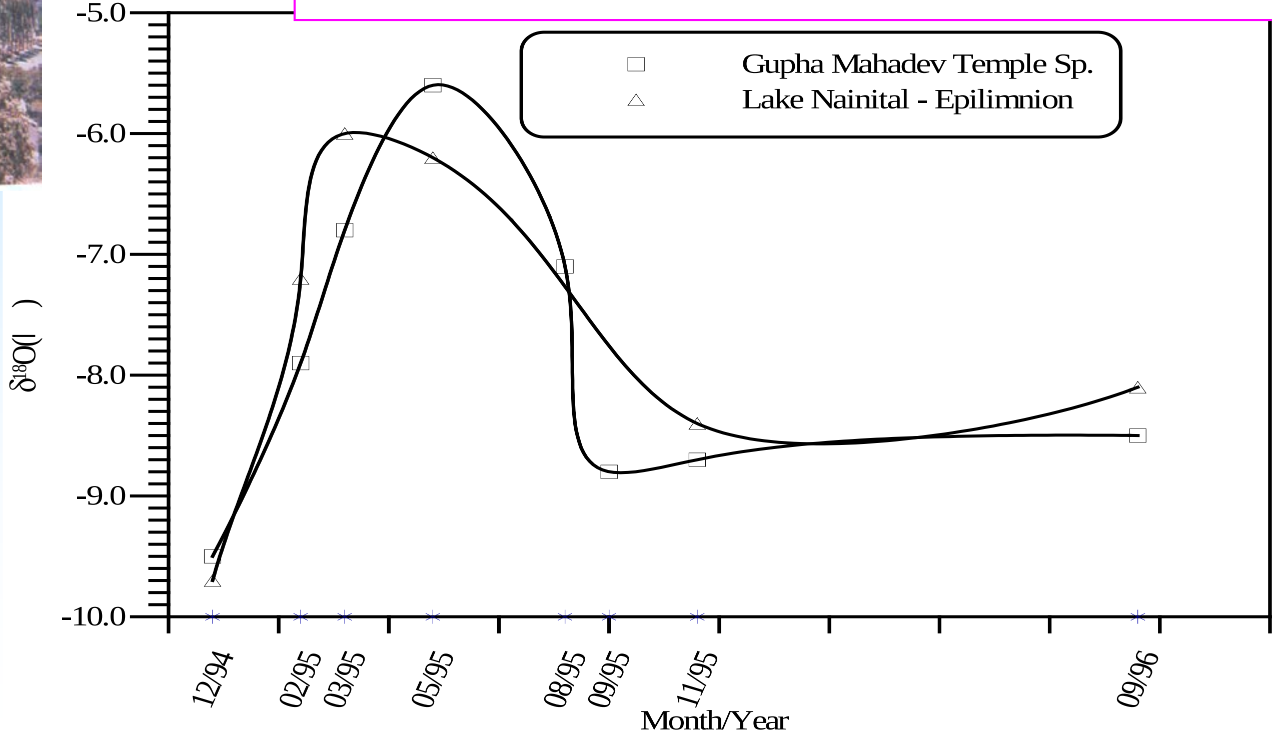
## Investigated area: Lake Naini, Uttarakhand






**Volume: 8.5 Mm$^3$**

**Depth: 18-27 m**



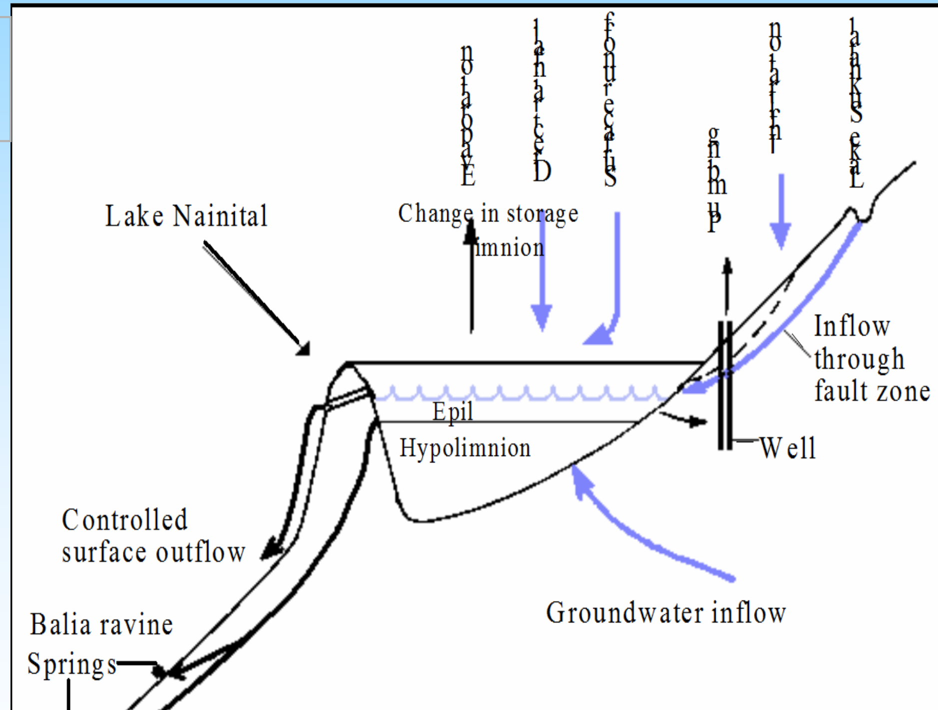
# COMPUTATION OF LAKE WATER BALANCE

- **Volume Balance Equation:** $dV/dt = (I_1+I_2+......)- (O_1+O_2+.....)$
- **Isotope Balance Equation:** $\delta_L(dV/dt) = \delta_1 I_1 + \delta_2 I_2 - (\delta_1 O_1+\delta_2 O_2+....)$

**Using the above equations, the most difficult sub-surface inflow and outflow is estimated**

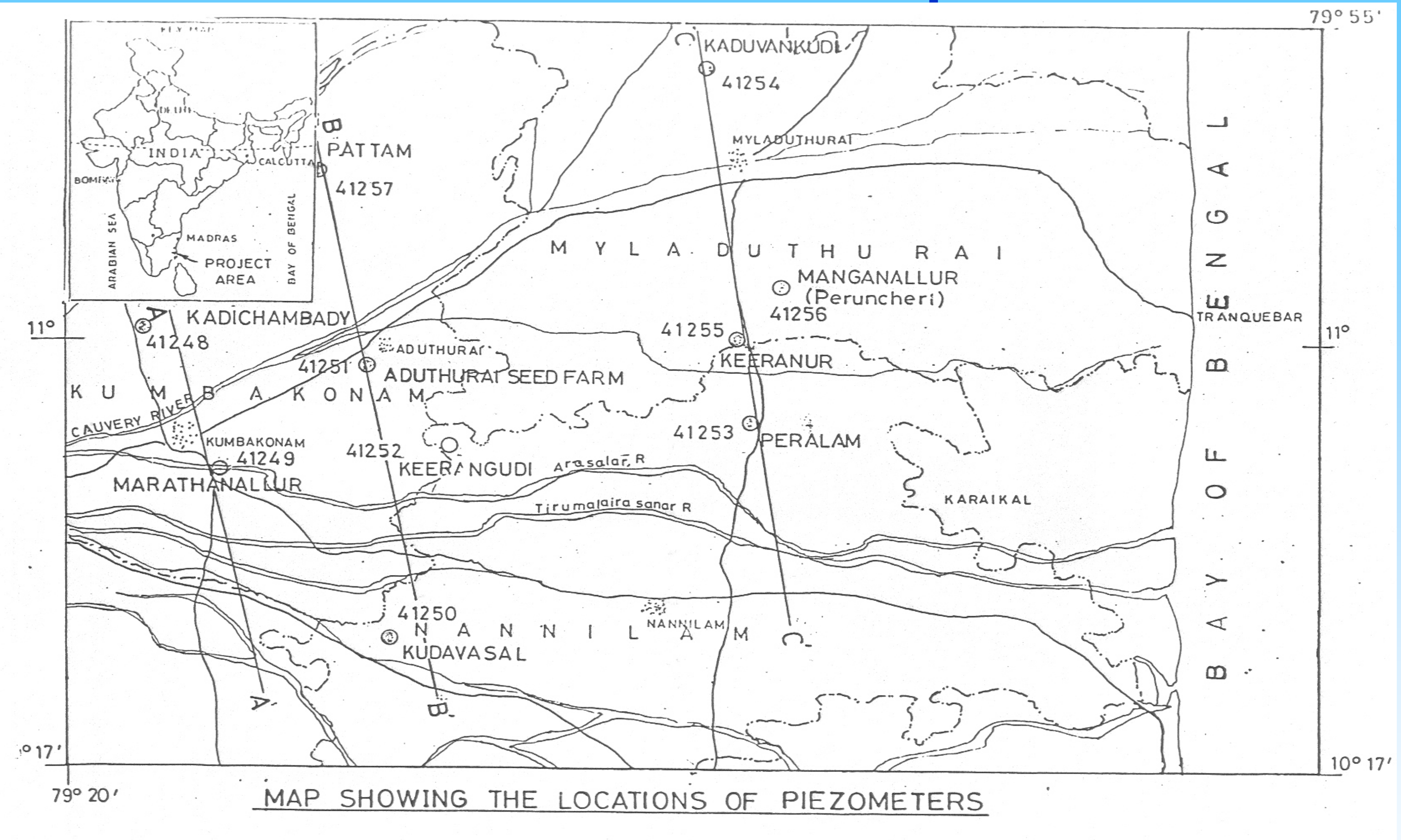
**Estimate on the proportion of lake water in the well water being pumped for domestic water supply**

| Month | $\delta^{18}O$ (per mille) | | | Proportion of the lake water (%) |
|---|---|---|---|---|
| | Lake | Ground Water | Well | |
| Feb. 95 | -7.3 | -8.2 | -8.0 | 25 |
| Mar. 95 | -7.1 | -7.5 | -7.4 | 25 |
| May 95 | -7.1 | -7.5 | -7.4 | 30 |
| Aug. 95 | -6.3 | -8.9 | -6.8 | 80 |
| Nov.95 | -8.2 | -7.9 | -8.0 | 40 |



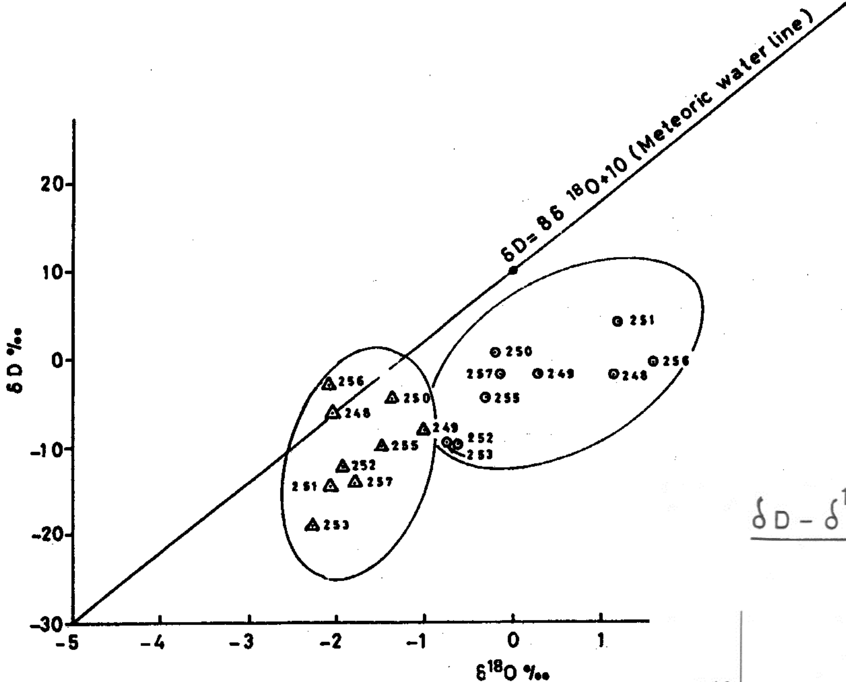

**Conceptual water balance model of lake Nainital obtained with the help of the isotopic findings**

# Interconnection between aquifers




## Investigated area

**Study of interrelation between shallow and deep aquifers in Cauvery Delta, Tanjavur, TN**




δD – δ18O Relationship of samples collected from the Cauvery delta area

(Tanjavur)

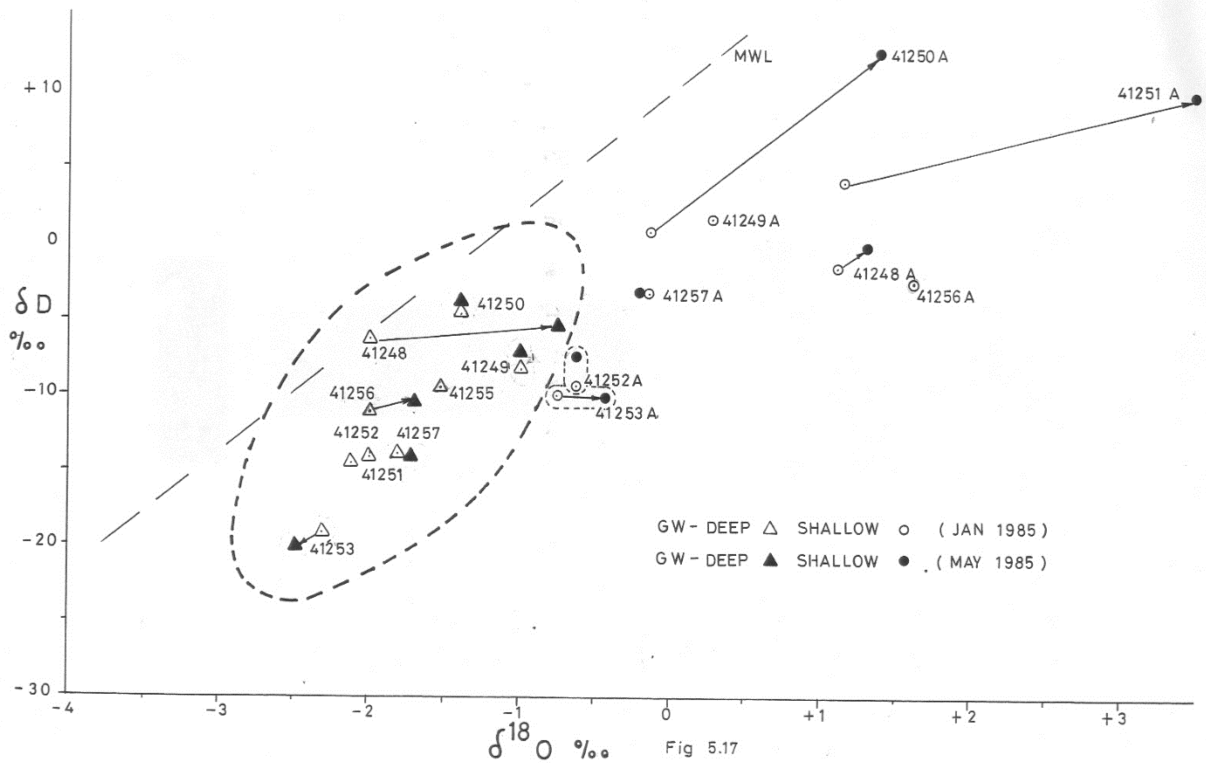
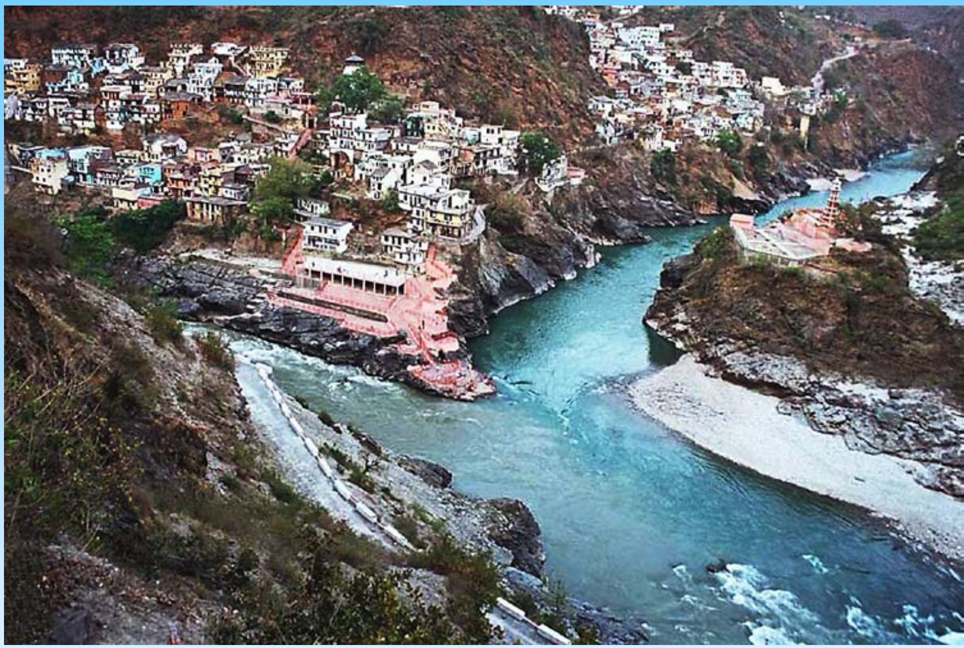
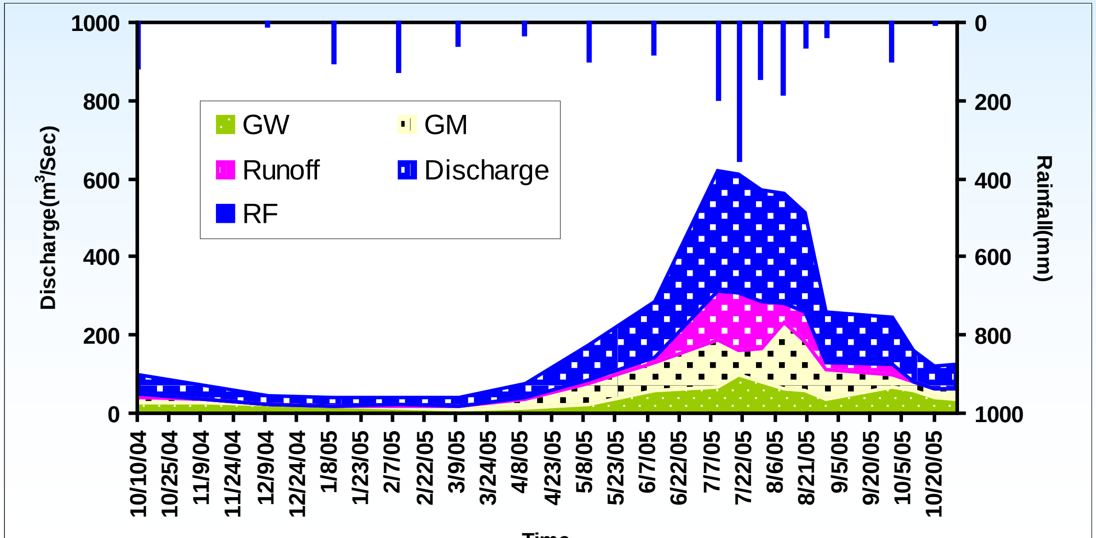



Fig 5.17

# Hydrograph separation of rivers

**total runoff = direct runoff + base flow + glacier/snow melt**

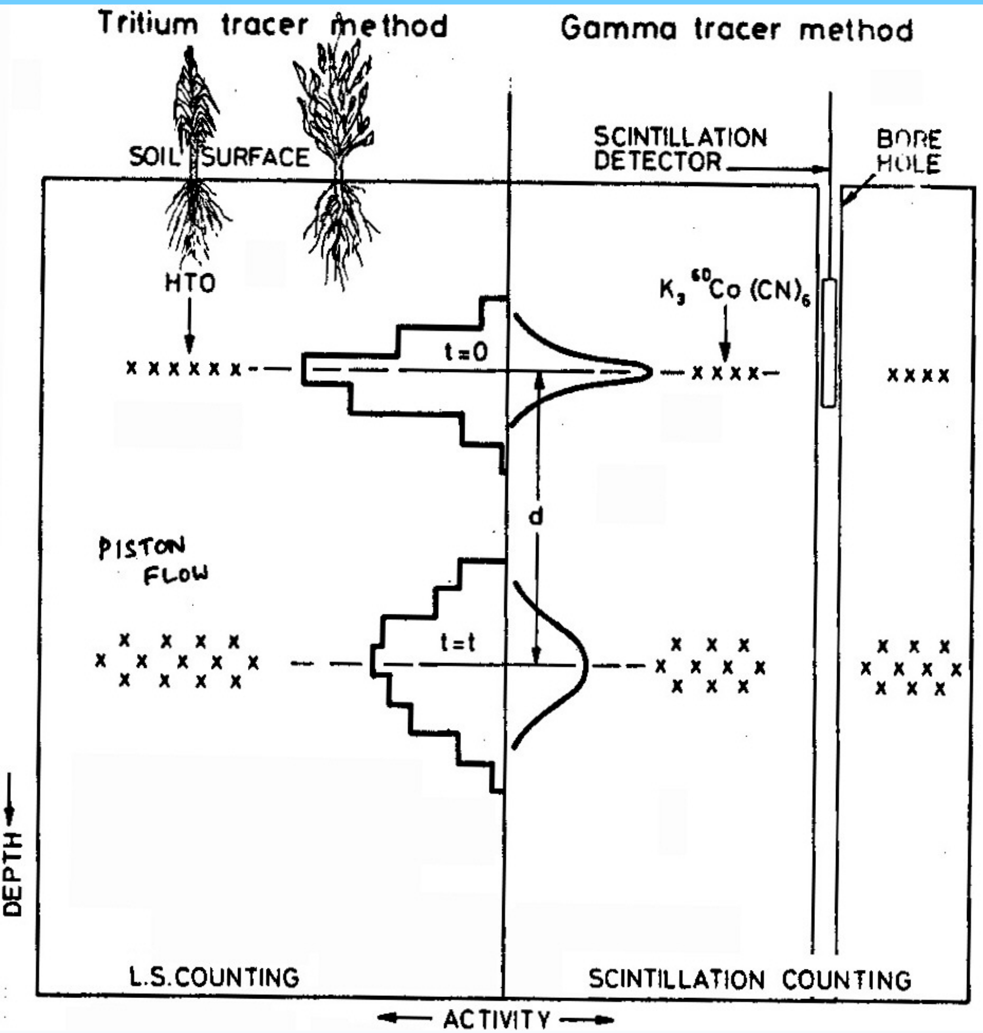





**Investigated area**

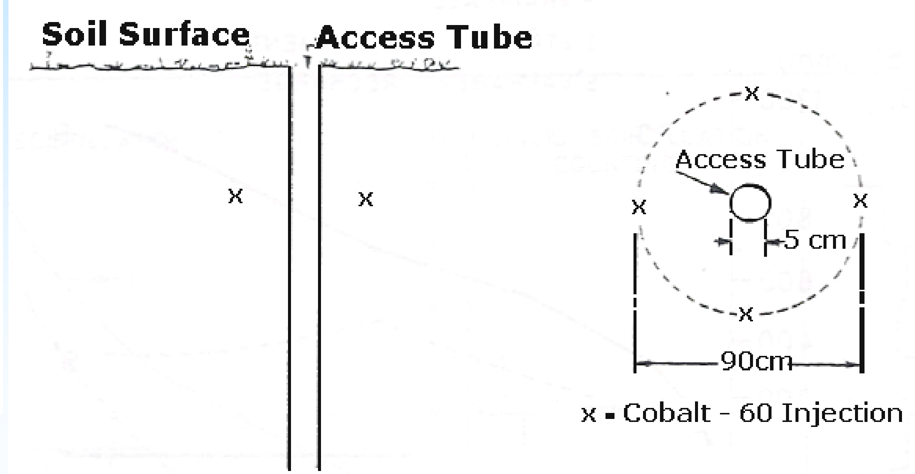
**River Ganga (Gomukh to Devprayag)**

# Quantification of recharge by isotope tagging




**recharge rate,(%)** $R = \frac{d.\theta.D.100}{P}$

**θ = average soil moisture content**
**d = displacement**
**D = bulk density of soil**
**P = precipitation (mm)**



| Location | Rainfall (mm) | Recharge (%) | Recharge (mm) |
|---|---|---|---|
| | | | |
| Chikli (MH) | 740 | 8 | 60 |
| | | | |
| Kamampalli (KR) | 550 | 3 | 16.5 |
| Kottakote (KR) | 550 | 13 | 71.5 |
| Bagepalli (KR) | 550 | 7.5 | 41.2 |
| Neyveli (TN) | 1398 | 12.9 | 181 |
| Vottamalaikarai(TN) | 460 | 13.3 | 61 |
| Noyil basin | 715 | 9.6 | 69 |
| Lower Maner basin (AP) | 125 | 9.4 | |

**Based on the above studies it is concluded that:**

**•Large variation in natural recharge estimates is generally observed.**

**•Recharge rate at a site is decided by parameters such as soil permeability, vegetation, rainfall amount and pattern, local water table, etc.**

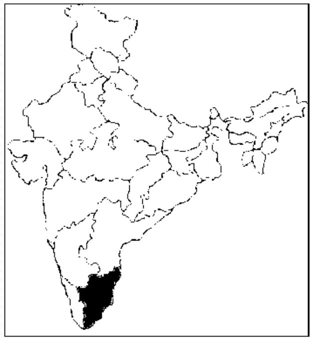
**•A linear relationship generally exists between rainfall and natural recharge. A minimum rainfall requirement exists to initiate rainfall recharge, ~ 355mm in basaltic terrain and ~ 50 mm in alluvial areas.**

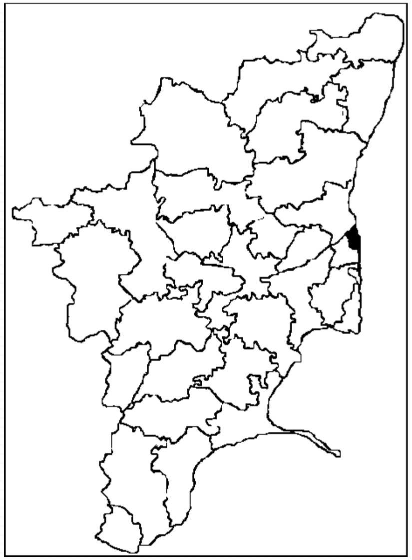
# Isotope Studies on Groundwater of Coastal Tamil Nadu

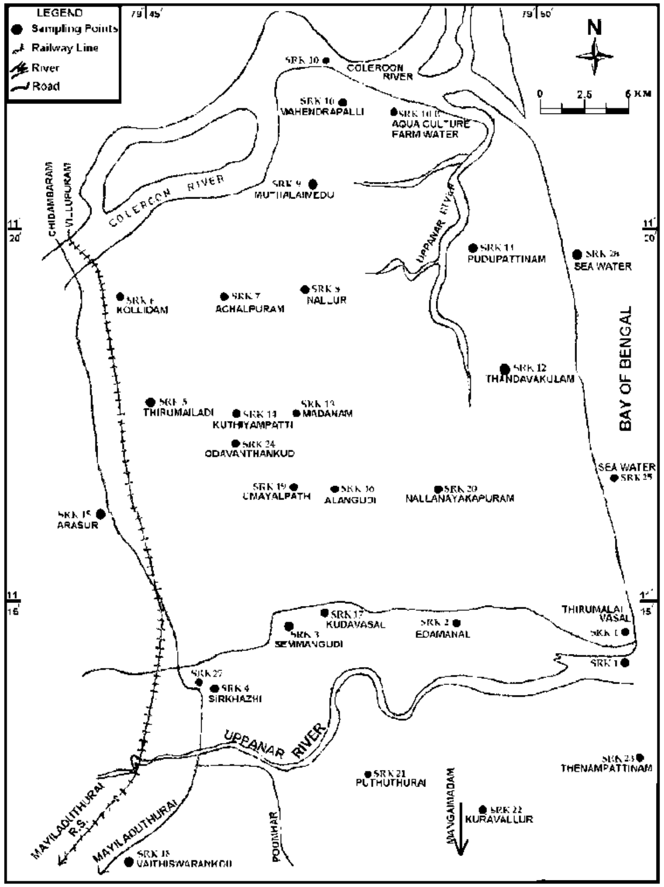
- **Deltaic plains of River Cauvery (very rich and fertile soils)**
- **The socio- economic conditions largely dependent on the agricultural activities**
- **Dam constructed at Mettur is the major source of water supply for the irrigation**
- **Sirkhazhi fall in the tail end of the canals**
- **Poor storage situation at the Mettur dam, erratic water supply**
- **Over exploitation of groundwater resources – GW quality found to be deteriorating**

# Objectives

1. Inter-relation between aquifers
2. Source and origin of groundwater recharge
3. Source of groundwater salinity
4. Dating of groundwater







# Sampling & measurement

Major ions: $Na^+$, $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Cl^-$, $SO_4^{2-}$, $HCO_3^-$ $NO_3^-$

Minor ions: $F^-$, B, $Fe_{total}$ ($Li^+$, $Sr^{2+}$ and $Br^-$ in IHS)

Stable $\delta^2H$, $\delta^{18}O$ and $\delta^{13}C$ (Mass spectrometer)

Radioactive $^3H$ and $^{14}C$ (Liquid Scintillation Counter)

**Purging of the tube wells**

# Measurement of field parameters

$BaCO_3$ precipitation method

Air circulation method

- **Shallow GW**

  Group-A: Fresh & $\delta^{18}O$ similar to Rain

  Group-B: Brackish and evaporated

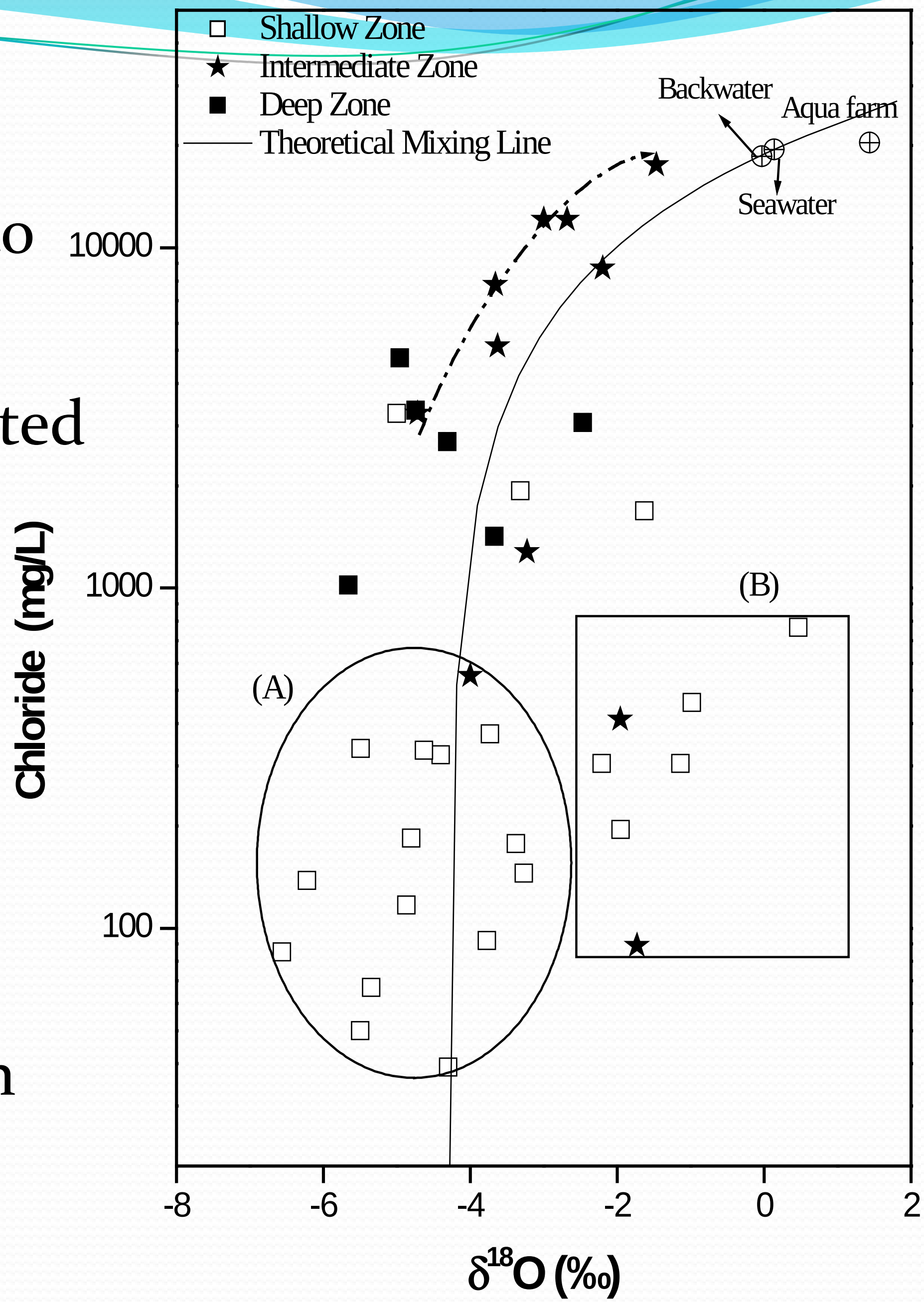
  Saline water – influence of backwater

- **Intermediate GW**

  Mostly fall along mixing line

- **Deep GW**

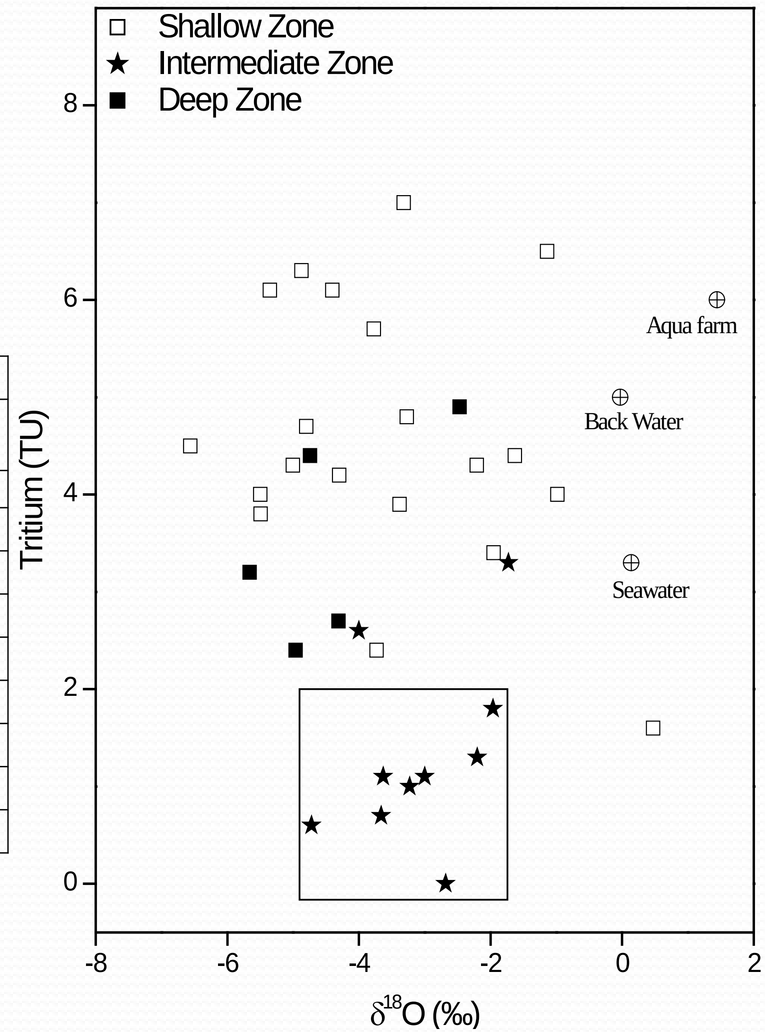
  No systematic trend - scatter on mixing line



# Environmental radio isotopes

- Intermediate GW are old
- Deep GW has some component of modern GW

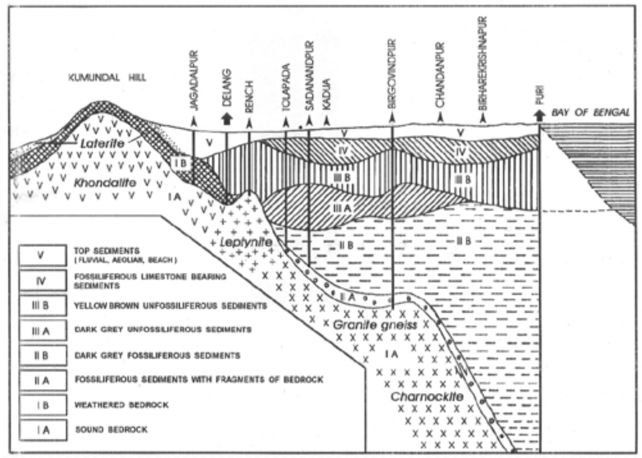
| Sample ID | Location | Depth (m) | E.C. (µS/cm) | $^{3}H$ (± 0.2 TU) | $^{13}C$ | $^{14}C$ (pMC) |
|---|---|---|---|---|---|---|
| SRK 1 | Tubewell | 57 | 35800 | <0.5 | -12.06 | 24.9 |
| SRK 2 | Tubewell | 48 | 36500 | 1.0 | -6.35 | 36.9 |
| SRK 4 | Tubewell | 48 | 6600 | 1.0 | -8.23 | 24.75 |
| SRK 6 | Tubewell | 63 | 16010 | 1.0 | na | 37.6 |
| SRK 7 | Tubewell | 62 | 10330 | 0.6 | na | 30.1 |
| SRK 11 | Tubewell | 51 | 28400 | 1.3 | -15.36 | 29.2 |
| SRK 13 | Deep Tubewell | 152 | 8800 | 2.7 | -10.34 | 44.7 |
| SRK 21 | Tubewell | 84 | 10300 | 4.4 | -17.4 | 1.2 (?) |
| SRK 24 | Tubewell | 81 | 25300 | 1.0 | -14.17 | 21.4 |

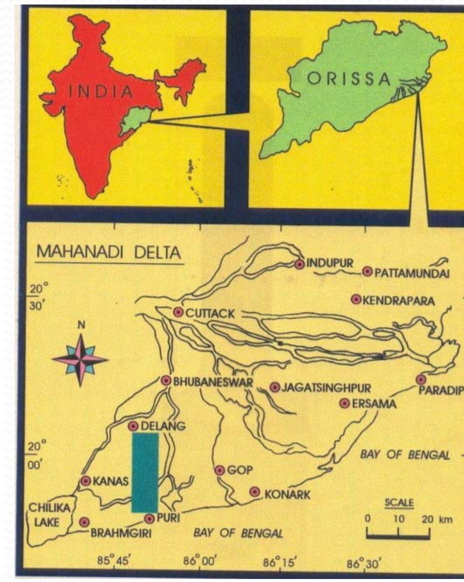


# Important conclusions

- In general these three aquifers are not found to be inter- connected.
- Shallow GW quality is fresh. Backwater influence at a few places.
- Intermediate GW are saline and 8,000 to 11,500 a BP.
- The source of GW salinity in this aquifer is seawater entrapped during Flandrian transgression in Holocene period.
- Deep GW has significant component of modern recharge (2.4 – 6.4 TU) and is mostly brackish.

# Drinking water salinity problem in coastal Orissa, India



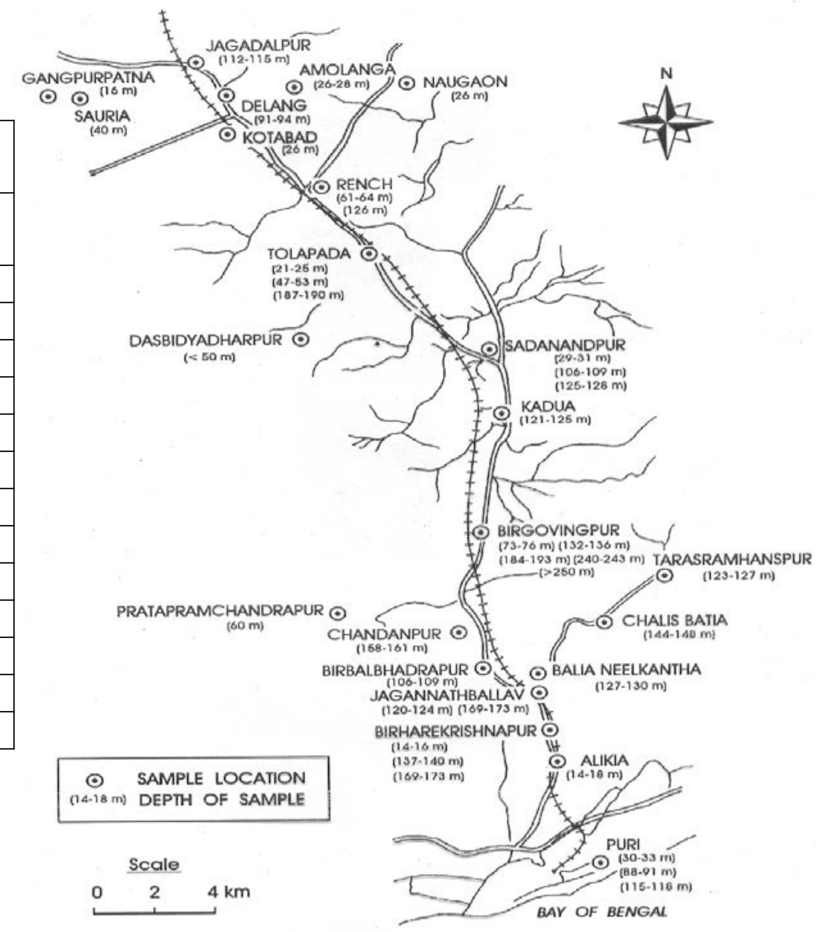

As a part of a drinking water project, thousands of hand pumps were installed in the coastal parts of Orissa.

Many of them were abandoned due to problems of salinity.

Groundwater recharge and palaeohydrological control of the salinisation processes.

# Samples Locations

| | Depth (m, bgl) | EC | C-14 (pMC) | C-13 (PDB) | C-14 (A0 method) | C-14 (Pearson) |
|---|---|---|---|---|---|---|
| Gangapurpatna | 16 | 780 | 65.8 | -14.1 | 160 | modern |
| Sauria | 40 | 540 | 58.5 | -13.6 | 1150 | modern |
| Rench | 31 | 2230 | 36.8 | | 4950 | |
| Rench | 126 | 660 | 67.1 | | modern | |
| Tolapada | 21 | 530 | 62 | | 650 | |
| Tolapada | 47 | 560 | 60.3 | | 880 | |
| Tolapada | 187 | 3580 | 1.2 | | 33300 | |
| P.chandrapur | 60 | 16200 | 20.4 | -12.4 | 9850 | 7350 |
| Sadanandpur | 125 | 2430 | 9.2 | | 16450 | |
| Sadanandpur | flowing | 14000 | 2.7 | -12.6 | 26550 | 24850 |
| Birgovindpur | 185 | 5570 | 3.7 | -9.4 | 24450 | 19650 |
| Birgovindpur | 240 | 21100 | 0.24 | -17 | 46600 | 46350 |
| Birgovindpur | >250 | 29700 | 4.1 | | 23100 | |
| Puri | 118 | 12200 | 14.7 | | 12550 | |



# Important conclusions

- Groundwater salinity in intermediate zone - due to Flandrian transgression during Holocene
- Saline deep waters are entrapped waters during Late Pleistocene
- Fresh and young groundwater in between the above saline aquifers could form the main source of groundwater for exploitation

# Identification of Source and Origin of Groundwater Contaminants and their Flow Path at Indian Rare Earths Ltd., Cochin, Kerala

## Objectives:

1. Identification of contaminants & their concentrations
2. Source and origin of contamination
3. Movement and flow path of contamination

# Techniques Applied

- **Hydrochemical Assay**

  **pH, EC, $F^-$, $Cl^-$, $NO_3^-$, $SO_4^{2-}$ and $PO_4^{3-}$**

- **Environmental Isotopes**

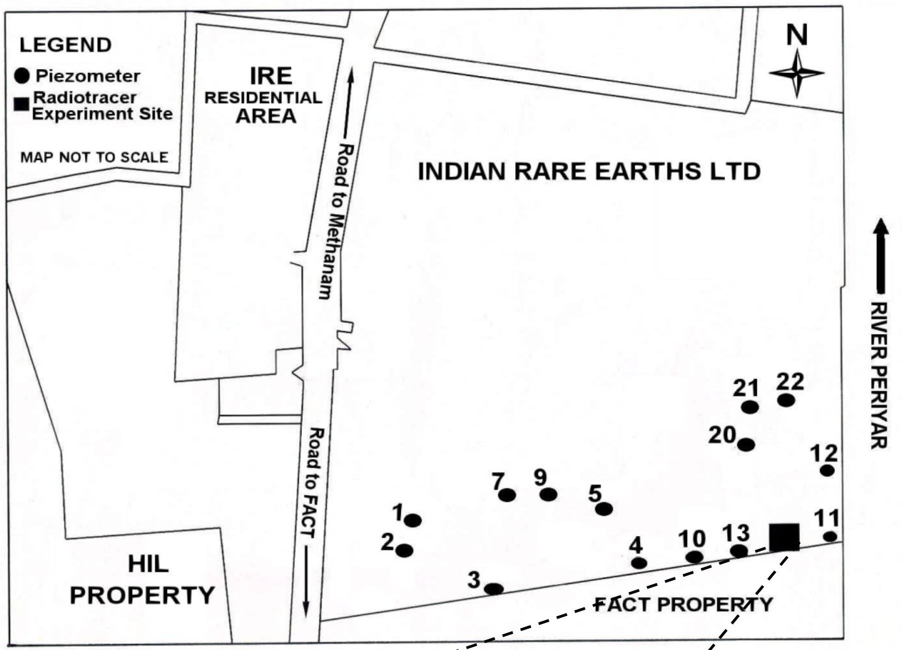
  **$\delta^2H$ and $\delta^{18}O$**

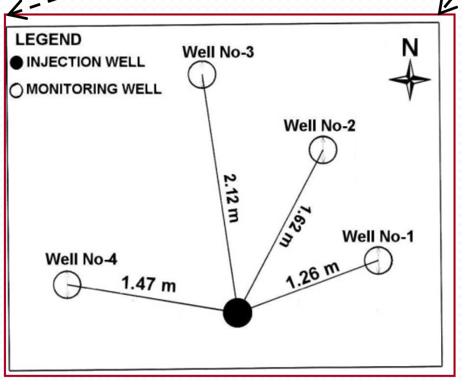
- **Radiotracer Experiments**

  **Single well technique ($^{82}Br$ as $NH_4Br$)**

  **Multiple well technique ($^3H$ as HTO)**

# Location of the IRE site




Tracer Experiment Site

Preparation for radiotracer injection

Radiotracer injection into the borehole

Scintillation detector for logging

# Radiotracer experiments

## Single well method

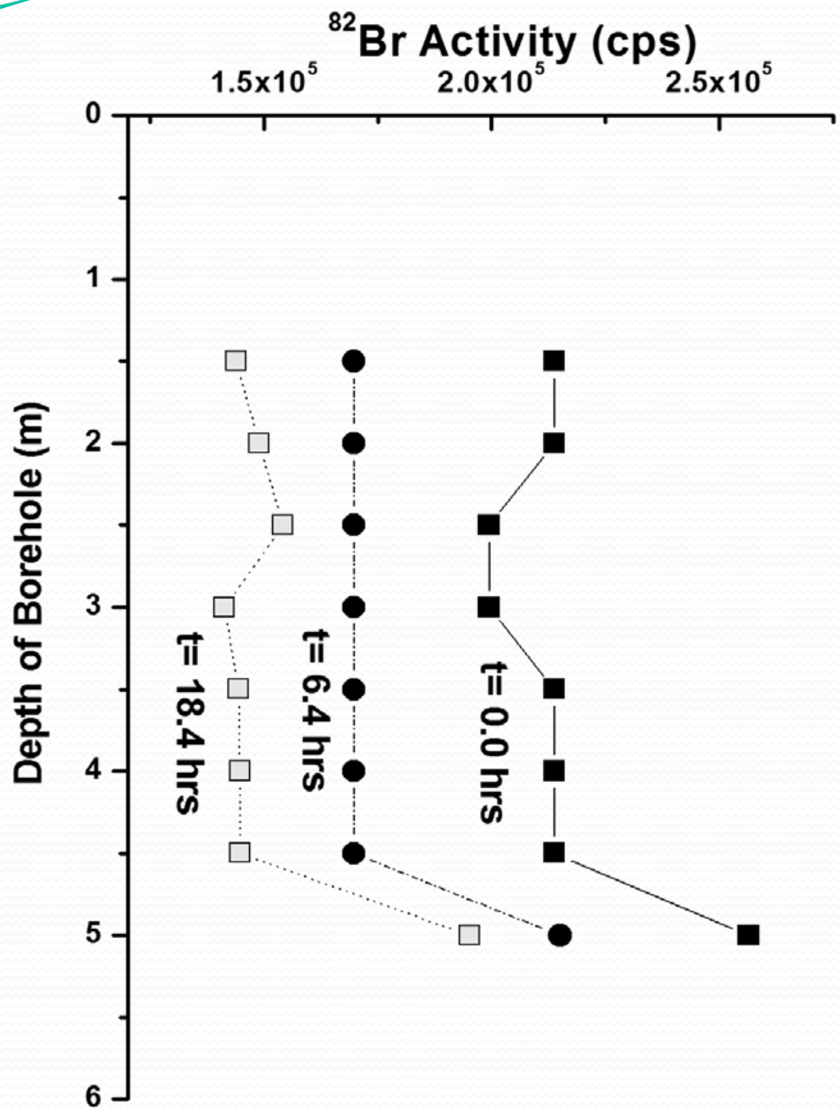
A. Radiotracer: 200µCi $^{82}$Br as $NH_4Br$ ($t_{1/2}$ = 36 hrs)

B. Activity Monitored: 2″ X 2″ NaI (Tl) scintillation detector coupled with a rate meter

## Multi-well Method

A. 1 mCi $^{3}$H as HTO injected & samples were collected from monitoring wells at regular intervals

B. Liquid Scintillation Counting at laboratory




$$Vt = \frac{-V}{\alpha.\mathrm{F.t}}.\ \ln\ \frac{Co}{Ct}$$

$V_t$ filtration velocity

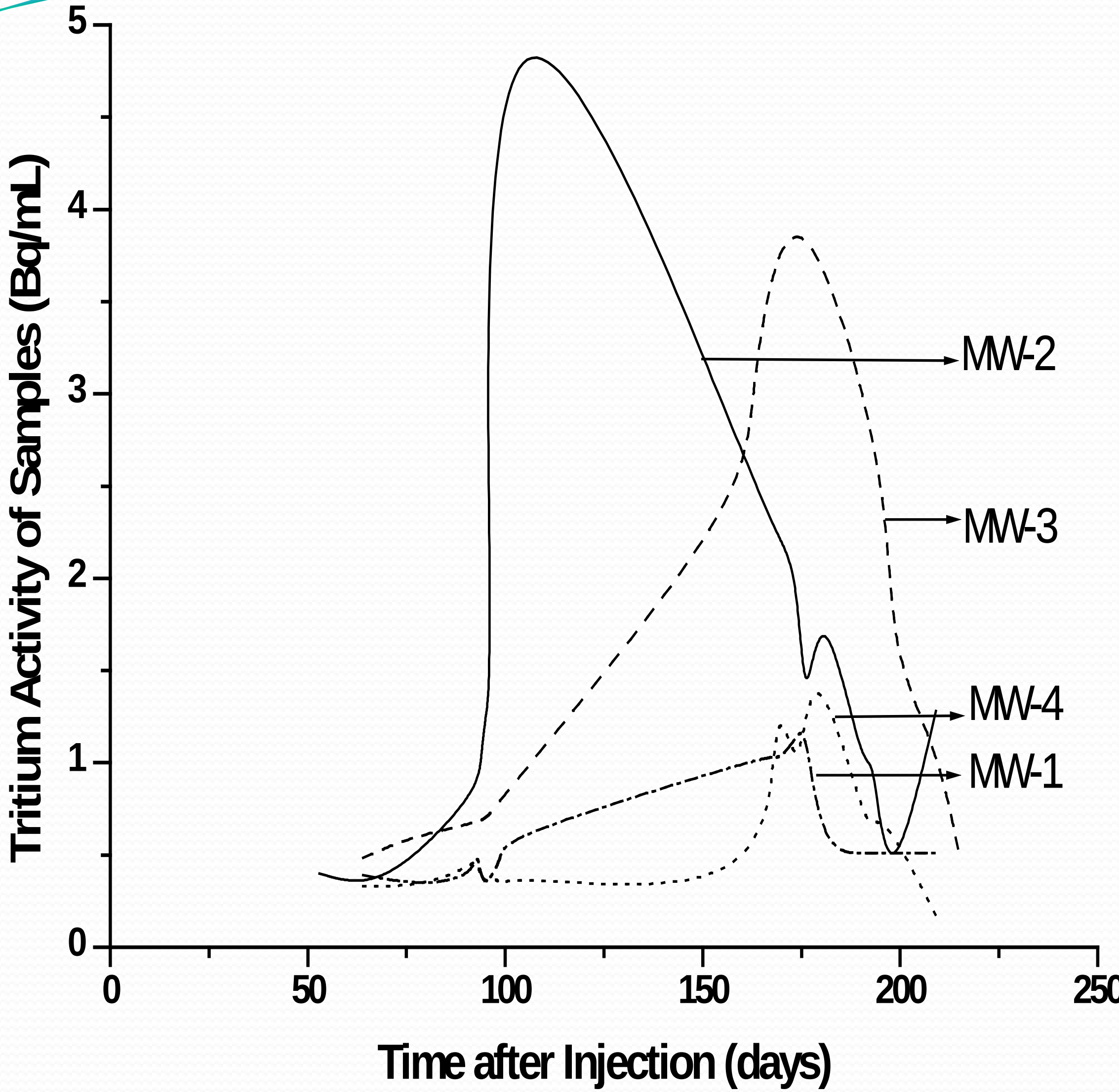
V dilution volume

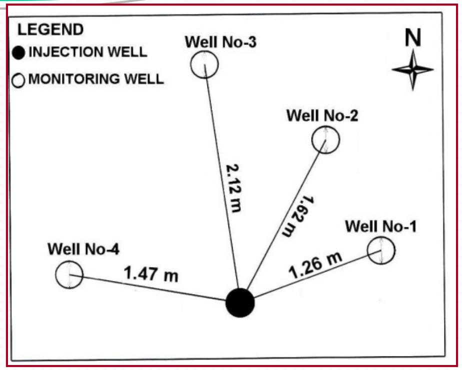
F cross section of borehole

$C_o$ initial tracer concentration

$C_t$ is tracer concentration at time t

α correction factor (taken as 2)




$$Vt = \frac{X}{\tau}$$

X distance between injected & monitoring well

τ transit time of tracer flow.

# Conclusions

1. Contaminated waters are subjected to evaporation.
2. Groundwater filtration velocity is 1.3 cm/day from south to north.
3. The possible source of contamination could be from industry located south of IRE premises.

**_List of books for further reading_**

1. Detection and prevention of leaks from dams,

A. Plata Bedmar

L. Araguas Araguas

A.A. Balkama Publishers, 2002

Lisse / Abingdon / Exton / Tokyo

2. Geochemistry, groundwater and pollution

C.A.J. Appelo

Postma

A.A. Balkema, 1996

Rotterdam / Brookfield

3. Environmental isotopes in hydrogeology

I.D.Clark

P. Fritz

Lewis Publishers, 1997

Boca Raton

4. Tracing techniques in geohydrology
W. Kass
A. Balkema, 1998
Rotterdam /Brookfield

5. Guide Book on Nuclear techniques in Hydrology
Technical Report Series, 91, IAEA, 1983

6. Environmental isotopes in the Hydrological Cycle: Principles
and Applications
W.G.Mook (Ed.)
UNESCO/IAEA Series – 6 Volumes

7. Environmental tracers in Sub Surface Hydrology
P.G.Cook and A.L.Herzeg
Kluwer

# Thank you for your patient attention

Try to answer these questions to yourself

WHAT isotope can be useful to identify source of nitrate in groundwater
HOW can you use isotopes to check if the dam/check dam is helping in recharging the ground water
HOW can you say if rainwater is contributing to groundwater recharge or not?

THINK of a current issue in your neighborhood and develop an isotope strategy to issue the problem