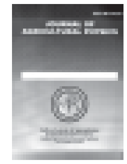
*Vol. 9, pp. 33-37 (2009)*
**Journal of Agricultural Physics**
**http://www.agrophysics.in**



# Delineation of Potential Groundwater Recharge and Productive Aquifer Zones in Delhi Area Based on $^{18}O$ Signatures and GPS

P.S. DATTA* AND S.K. TYAGI

*Nuclear Research Laboratory, Indian Agricultural Research Institute, New Delhi-110012*

**ABSTRACT**

Peri-Urban agriculture in Delhi-NCR area is highly dependent on the availability of groundwater. In view of rapid urbanization of the area, for delineation of potential recharging zones and hydrodynamic zones of the aquifers, integration of dynamic data on $^{18}O$ isotopic composition of groundwater with time independent data such as elevation of recharge sites has been discussed in this paper. Significant $\delta^{18}O$-elevation relationships ($r^2$= 0.808 to 0.982) were found, with a resolution of about 20m (in northwest) and 75m (in southwest) elevation range of recharge sites. The potential recharging zones of the groundwater aquifers are located in different areas, with elevation 210m to 230m (in northwest) and more than 260m (in south). However, variation in the isotopic composition of groundwater with time suggests to relatively small size and low productivity of the corresponding aquifers and possibly the presence of many low permeability zones (having, large isotope gradients) in recharge areas in the northwestern parts.

**Key words:** Groundwater recharge, GPS, $^{18}O$ isotope, Elevation

## Introduction

The Peri-urban agriculture in semi-arid Delhi-NCR area (1485 sq. km.) faces the challenge of sustaining agricultural production in a limited land area, with more and more requirement of water. Groundwater resources are susceptible to over exploitation due to insufficient recharge and ever increasing demand. Therefore, adoption of the safe yield concept of water management faces different problems. Whether an optimal yield or controlled over-exploitation approach of water management is adopted, the development and management of these resources must be based on adequate knowledge of the recharge areas and the extent and amount of replenishable resource. Earlier studies (Datta *et al*, 1996) indicated that in comparison to direct recharge from rainfall, recharge to groundwater in the alluvial plains of the urbanized Delhi area mostly occurs from localized runoff draining high elevation adjacent areas. The characteristics of regional groundwater flow systems create groundwater recharge which is relatively constant with time at any given location, but varies spatially depending on the topographic features. Therefore, time independent data, such as elevation, land use, aquifer permeability etc., is of paramount importance for groundwater monitoring network design. Integration of such information with available dynamic data, such as hydraulic heads, isotopic composition and flow direction, etc., helps in identification and delineation of recharge, recharging and hydrodynamic zones.

It is well established that $^{18}O$ composition of atmospheric water and temperature decreases with increase in altitude (Dansgaard, 1964; Yurtsever and Gat, 1981). Altitude effect is therefore a measure of degree of rainout from any air mass and is essentially a different

*Corresponding author, Email: psdatta@iari.res.in

representation of $\delta^{18}O$-temperature relationship. Earlier studies (Datta *et al*, 1991; Datta, 1995) indicated that the stable isotope ($^{18}O$) composition of rainfall in Delhi-NCR area varies significantly with time due to kinetic isotope and exchange effects produced by evaporation of rainfall during the course of its fall as well as by intensity and distribution of rainfall. This variation is reflected in the isotopic composition of groundwater and provides a detailed and dynamic representation of groundwater source, flow regime, recharge conditions, flow directions and hydrodynamic zones (Datta *et al*, 1994; Datta *et al*, 1996). Therefore, significant differences in elevation of recharge areas are also expected to show significantly different $^{18}O$ composition of the various flow systems, since there is a linear relation between $\delta^{18}O$ and the mean yearly surface air temperature (Datta *et al*, 1991). Depending upon the altitude/elevation effect on the isotopic composition of the rainfall, groundwater isotopic composition -altitude relationship can therefore be used for identification of potential sources and zones of recharge to the groundwater. Against this background, such relationships in Delhi-NCR area have been presented and discussed here.

## Description of the Area

The Delhi-NCR area (Fig.1) occupies a part of the Indo-Gangetic alluvial plain and comprises a quartzite ridge (trending N.N.E. - S.S.W.) which forms the principal watershed and acts as a groundwater divide between the western and eastern parts. The elevation of the crest of the ridge ranges between 213 and 314 meters above mean sea level and about 15m to 121 meters above the surrounding plains (Sett, 1964). In the northern parts of the area, the elevation of the plain from east to west ranges from about 213m to 216m above sea level. The slope of the plain in the northern part of the area, from west to east, is about 0.19 m/km whereas that of the south-western parts from west to north-west is about 0.75 m/km (Sett, 1964). Stable isotopic investigation in the area suggests that the groundwater has a variety of local recharge sources and the system is not laterally

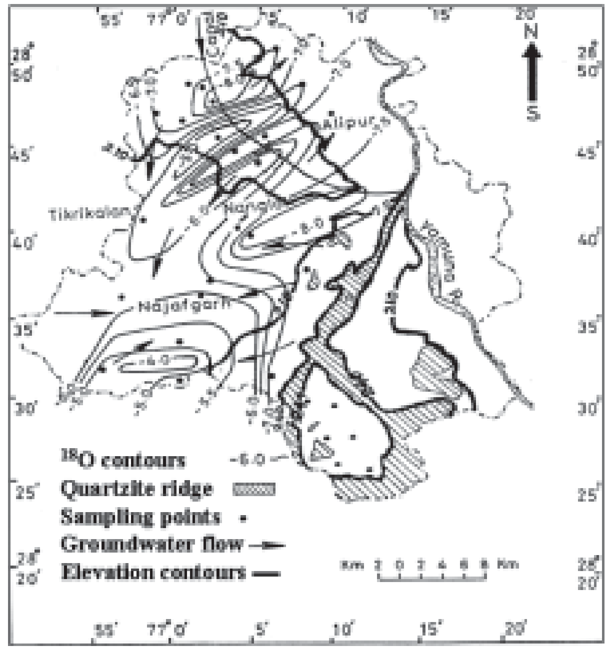



**Fig. 1.** Map of Delhi area showing contours of groundwater $\delta^{18}O$ and elevation. Large isotope gradients indicate the zones of low permeability

homogeneous in its extent (Datta, 1990; Datta *et al*, 1994, 1996). There exists three different flow systems viz, local, intermediate and regional (Datta *et al*, 1994), corresponding to three hydrodynamic zones. Recharge and discharge areas of the local systems (having rapid water circulation) are located on adjacent higher and lower elevation points respectively. Recharge and discharge areas of the intermediate flow system (with relatively slow water circulation) are small compared with the local flow system and are separated by one or more local flow systems (Datta *et al*, 1994). Recharge and discharge areas of the regional 'stagnant' system appear to be located on the main water divide and bottom of the geological formation (Datta *et al*., 1994).

## Materials and Methods

Groundwater samples were collected from thirty four different locations geographically equitably distributed during pre-monsoon (June, 1992) and post-monsoon (January, 1992) period, and stored in air-tight plastic bottles taking precautions to prevent evaporation loss. The elevation (above m.s.l.) of the sampling locations

**Table 1.** Elevation of recharge locations and $\delta^{18}O$ composition in groundwater of Delhi Area

| Sample No. | Location | Elevation (m above msl) | $\delta^{18}O$ (‰) |
|---|---|---|---|
| | **(Pre-Monsoon)** | | |
| **NAJAFGARH BLOCK** | | | |
| DLI-1 | Mitraon (TW) | 212 | -6.5 |
| DLI-4 | Gumman Hera (TW) | 210 | -4.7 |
| DLI-7 | Raghupur (HP) | 218 | -5.2 |
| DLI-9 | Chhawla (TW) | 208 | -5.3 |
| DLI-10 | Najafgarh (HP) | 213 | -6.5 |
| **ALIPUR BLOCK** | | | |
| A-1 | Khera Khurd (HP) | 220 | -7.2 |
| A-2 | Alipur (HP) | 213 | -7.1 |
| A-4 | Singhola (TW) | 212 | -6.5 |
| A-5 | Narela (TW) | 219 | -7.5 |
| A-6 | Bawana (HP) | 225 | -8.5 |
| A-8 | Barwala (TW) | 227 | -8.5 |
| A-9 | Pehlad Pur (HP) | 210 | -5.7 |
| **NANGLOI BLOCK** | | | |
| N-11 | Dariyapur (TW) | 218 | -7.1 |
| N-13 | Punjabkhor (TW) | 220 | -7.6 |
| N-14 | Chandpur (HP) | 217 | -7.2 |
| N-15 | Tikrikalan (TW) | 210 | -5.8 |
| N-17 | Nangloi (HP) | 215 | -7.0 |
| **MEHRAULI BLOCK** | | | |
| MB-2 | Fatehpur (TW) | 261 | -6.8 |
| MB-4 | Dera (TW) | 264 | -6.6 |
| MB-5 | Mandi (TW) | 280 | -7.6 |
| MB-7 | Jonapur (HP) | 260 | -6.5 |
| MB-13 | Ghatorni (TW) | 285 | -7.7 |
| | **(Post-Monsoon)** | | |
| **NAJAFGARH BLOCK** | | | |
| DLI-1 | Mitraon (TW) | 212 | -6.3 |
| DLI-4 | Ghumanhera (TW) | 210 | -4.2 |
| DLI-9 | Chhawla (TW) | 208 | -4.0 |
| DLI-10 | Najafgarh (TW) | 213 | -4.7 |
| **ALIPUR BLOCK** | | | |
| A-2 | Alipur (HP) | 213 | -5.2 |
| A-4 | Singhola (TW) | 212 | -4.9 |
| A-5 | Narela (HP) | 219 | -5.9 |
| A-6 | Bawana (HP) | 225 | -8.7 |
| **NANGLOI BLOCK** | | | |
| N-11 | Dariya pur (TW) | 218 | -6.4 |
| N-14 | Chandpur (HP) | 217 | -6.0 |
| N-15 | TikriKalan (HP) | 210 | -4.9 |
| N-17 | Nangloi (HP) | 215 | -6.2 |

TW - Tube Well, HP - Hand Pump, msl- mean sea level

was measured using Garmin GPS, and checked with the topography maps (scale-1: 50,000). $\delta^{18}O$ composition of the water samples were measured by standard procedure using VG Isogas Mass Spectrometer 602D/E (Datta *et al*, 1996). The analytical reproducibility of the laboratory standard was ± 0.l%o. Data on elevation are given in Table-1 along with the average $^{18}O$ which is expressed as $\delta^{18}O$ (‰) = $\{(R_{sample}/R_{std.}) -1\} \times 10^3$, where R is $^{18}O/^{16}O$ and std. is Standard Mean Ocean Water (SMOW).

## Results and Discussion

In any region, the $\delta^{18}O$-values of rainfall at higher altitude generally are more negative and the magnitude of this altitude effect depends on local climate and topography (Yurtsever and Gat, 1981), with gradients in $\delta^{18}O$ of between 0.15 and 0.50 ‰ per 100m. Since, $\delta^{18}O$ of groundwater in an area is an approximate indicator of the $\delta^{18}O$ of rainfall in that region, this range of gradient is likely to be reflected in the groundwater system also, which is recharged from different altitude/elevation. However, the above gradient will not be applicable in the groundwater of Delhi-NCR area where the rainfall is subjected to evaporation during the course of its fall (Datta *et al*, 1991) and mixing of groundwater of different δ-values also takes place (Datta *et al*, 1996). Moreover, it is also well established that the $^{18}O$ composition of rainfall is depleted with increase in the amount of rainfall (Dansgaard, 1964).

The groundwater recharge characteristics, $\delta^{18}O$-values and GW-irrigated area in Delhi-NCR area has not changed much for last two decades (Datta, 2005, 2009). Based on the amount effect of rainfall in Delhi-NCR area (Datta, 1995), when the groundwater $\delta^{18}O$ in Table-1 are compared with average yearly weighted mean δ-value (-6.09‰) of Delhi rainfall (Datta *et al*, 1991), it is apparent that recharge occurs mostly from more intense and depleted rainfalls. Another study (Bhattacharya *et al*, 1985) also reported a selection in favour of the more depleted rains occurring in the recharge process. Because, the $^{18}O$-composition of rainfall in a recharging zone is reflected in the isotopic composition of groundwater, unless it is subjected to evaporation

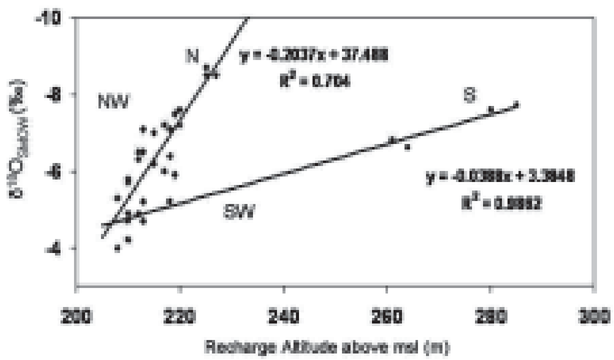



**Fig. 2.** Relationship of land elevation and $\delta^{18}O$ of groundwater in Delhi area. The major source of recharge is from elevation >210m. Southern parts are recharged from elevation (>260m)

or intermixing with another water having different isotopic composition, the $^{18}O$-composition of groundwater from discharge area of a given system should reflect (within a few tenths per thousand) that flow system during the time when most of the recharge occurs.

Combined effect of the aforementioned hydrological characteristics is likely to be determining the $\delta^{18}O$-altitude relationship (Fig.2) in the Delhi area. From Fig.2 it is possible to clearly distinguish between high-land and low-land water sources, with elevation range of recharge sites of about 20m (in north-northwest) and 75m (in south-southwest). The following significant relationships are seen between elevation (H) and $\delta^{18}O$ of groundwater of the area:

(i) North - Northwestern Part

$$\delta^{18}O = -0.2037\ H + 37.4880$$

$r^2 = 0.7040$, n = 27

(ii) South - Southwestern Part

$$\delta^{18}O = -0.0388\ H + 3.3848$$

$r^2 = 0.9868$, n = 7

The data and the Fig.2 indicate that barring a few locations in the northwest and southwest areas, the $\delta^{18}O$-values of groundwater with recharge altitude more than 208m are mostly depleted or enriched within ± 2.0‰ as compared to the rainfall mean δ-value (-6.09‰). Notwithstanding the fact that $\delta^{18}O$ of rainfall decreases with amount of rainfall, apparently groundwater in the northwestern part of Delhi area is recharged mostly from areas having elevation between 208-230 m, while in southern parts major part of recharge takes place from relatively higher elevation (>260m) areas. The recharge area of the groundwater system is not unique in the sense that it comprises different areas, each at a different elevation. The enriched $\delta^{18}O$-values of the ground waters with recharge elevation less than 215m suggest that such water bodies are recharged from evaporated surface runoff water draining adjacent high elevation areas and collected in lower elevation areas. The $\delta^{18}O$-contours (Fig.1) show six plume like features, giving an apparent visualization of the groundwater flow-paths and mixing directions (Datta *et al*, 1994, 1996). In the zones of low permeability, having large isotope gradients, these plumes possibly migrate vertically and laterally through the zones of preferred flow paths and mixing. The scattered distribution of $^{18}O$ in groundwater along the north to south transect as well as east to west transect suggests that local recharge and discharge (with rapid water circulation system) are important. The temporal instability of the $\delta^{18}O$ values for the majority of the samples is indicative of relatively small size of the corresponding reservoirs. This also suggests that the recharge and discharge areas of the intermediate flow system are small compared to the local flow system (Datta *et al*, 1994). Nevertheless, the present analysis indicates that groundwater $\delta^{18}O$ values and elevation relationship can be useful to delineate the potential recharging zones of the groundwater even with relatively small range of elevation differences in recharging areas.

## Conclusions

The study indicates that $\delta^{18}O$ of the groundwater in Delhi area is significantly correlated to elevation of the recharging sites, with relatively small variation in the recharge elevation of about 20m (in northwest) and 75m (in southwest). Most of the recharge takes place from the areas having elevation between 210m to 230m. Groundwater in the southern parts is recharged from relatively higher elevation

(>260m) areas. Apparently small size of the reservoirs and presence of many low permeability zones suggest that the aquifers are less productive, particularly in the northern parts where the potential recharging zones are located. Therefore, from the point of optimal yield or controlled overexploitation approach of groundwater management, it is desirable to put a check on increasing density of tubewells in these parts. Further investigations in relation to land use can help to delineate potential recharge areas and selecting locations of wells with high yield which can be suitable for agricultural irrigation purposes.

## References

Bhattacharya, S.K., Gupta, S.K. and Krishnamurthy, R.V. 1985. Oxygen and hydrogen isotope ratios in groundwater and river waters from India. *Proc. Ind. Acad. Sci.* (Earth Planet Sci.). **94** (4): 283-295.

Dansgaard, W. 1964. Isotopic variation in meteoric waters. *Science*, **133**: 1702-1703.

Datta, P.S. 1990. Deuterium and oxygen-18 studies in groundwater of Delhi area, India- comments. *J. Hydrol*. **113**: 385-389.

Datta, P.S. 1995. Meteorological synoptic situation in relation to $\delta^{18}O$ of New Delhi rainfall. *J. Nuclear Agric. Biol.* **24**(1): 8-12.

Datta, P.S. 2005. Groundwater Ethics for its sustainability, *Current Science*, **89**: 5, 10 September: 1-6.

Datta P.S. 2009. 'Isotopic fingerprinting of groundwater situation in Delhi region'. CGWB Workshop on 'Groundwater Scenario, Water Quality, Information Dissemination and Capacity Building for Delhi State', March 4-5, 2009, New Delhi.

Datta, P.S., Tyagi, S.K. and Chadrasekharan, H. 1991. Factors controlling stable isotope composition of rainfall in New Delhi, *India. J. Hydrol.* **128**: 223-236.

Datta, P.S., Bhattacharya, S.K. and Tyagi, S.K. 1994. Assessment of groundwater flow conditions and hydrodynamic zones in phreatic aquifer of Delhi area using oxygen-18. Proc. Intn. Workshop on "Groundwater Monitoring and Recharge in Semi-Arid Areas", Hyderabad, IAH/UNESCO Publication, S IV, pp. 12-24.

Datta, P.S., Bhattacharya, S.K. and Tyagi, S.K. 1996. $^{18}O$ studies on recharge of phreatic aquifers and groundwater flow-paths of mixing in Delhi area. *J. Hydrol*. 176: 25-36.

Sett, D.N. 1964. Groundwater geology of Delhi region. *Bull. Geol. Survey India. Series B*, **16**: 1-35.

Yurtsever, Y. and Gat, J.R. 1981. Atmospheric waters (In stable Isotope Hydrology, Eds. J.R.Gat and R. Gonfiantini), IAEA Vienna Tech. Rep. Ser. No. 210, pp. 103-139.