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Surface Water and Groundwater Interaction along the River Yamuna in NCT, Delhi

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Abstract ; Independently, the surface water and the groundwater systems have fairly been well understood but the interaction between surface water and groundwater is poorly understood. Improvements in understanding the interaction between surface water and groundwater may provide useful information about the impact on the environment and also for the better management of available fresh water resources.

The present study has been carried out in Yamuna flood plain located in northern part of NCT Delhi which occupies an area of about 97 sq km. Number of tube wells has been constructed in the flood plains to withdraw water during non-monsoon months. The two main objectives of the study were (1) to understand impact of large scale pumping of groundwater in the floodplain of river Yamuna and (2) interaction of groundwater and river water in the Yamuna flood plain.

In the present study, the isotope technique has been applied to understand the surface water and groundwater interaction between river Yamuna and adjoining groundwater in the Palla area of National Capital Territory of Delhi. Isotopic analysis (ä^{18}O and äD) of the water samples indicates that the river Yamuna recharges the floodplain during monsoon season. The vertical recharge of the floodplain is more rapid and helps in build up of bank storage. Lateral recharge is slow as the hydraulic conductivity of the floodplain is 1-2 m/day. River water contribution (lateral/vertical) in the pumped groundwater from the Yamuna floodplain varies from 20 to100% depending upon the intensity and duration of flooding in the monsoon season.

Keywords: Surface water, Groundwater, River Yamuna, Isotopes, Water level

INTRODUCTION

Large-scale pumping to meet increasing demand for water from flood plains and bank storage near the river is commonly practiced all over the world. Under typical climate conditions, direct runoff generated by precipitation is confined to a few months (3 months) during the monsoon season in India. The floods during this period recharge the adjacent riverbanks in addition to the direct rainfall recharge in the alluvial flood plains in the vicinity of the river. The low flows during non-monsoon season are mostly from base flow and/or snowmelt runoff. Pumping from production wells along the banks from this naturally replenishing groundwater reservoir helps in meeting the demand during the non-monsoon season on a sustainable basis. But over pumping from these fields may induce recharge to groundwater from river and thus may adversely affect the river flow.

The existing sources of water all over the country are under heavy stress to meet the gross water requirement for all uses of our people. However, there is a scope for improving the situation by optimizing our requirements, ensuring judicious distribution and optimum consumption of appropriate quantity and type of water for a particular use.

The River Yamuna and its canal systems play an important role in the agricultural development of the Haryana (eastern part) and Uttar Pradesh (western part). The river water also forms an integral part of the water supply system of many cities like Delhi and Agra etc. Therefore, it is imperative that the nature of interaction between the River Yamuna and the groundwater must be studied, as it will help in the better management of the both groundwater and river.

In the natural conditions, rivers may be either influent (losing streams) or effluent (gaining streams) or at the most in equilibrium with the groundwater. The natural behavior of the river may be altered by introduction of artificial sources or sinks. It was observed that the river is effluent at most of the locations during non-monsoon season. The study revealed that the groundwater component in the river flow is maximum (60%) during April and negligible during August.

The river enters Delhi near Palla village after traversing a distance of about 224 km from Tajewala. In Palla area, a number of tube wells have been constructed in the floodplains of the river Yamuna to extract water during non-monsoon season from bank storage. These wells are suspected to induce recharge from the river and thereby reduce the flow in the River Yamuna. Before the commissioning of the wells, the regional groundwater flow direction in the area was towards river Yamuna. Thus, a scientific study was initiated to understand the effect of large scale pumping of groundwater in the floodplains of the River Yamuna on the natural interaction of groundwater and surface water in the study area.

STUDY AREA

The study area is a part of Yamuna floodplain and is located in the northern part of the National Capital Territory of Delhi (NCT Delhi). The area is bound by Haryana on the north and Uttar Pradesh on the east (Fig.1). The area is known as Palla area after the name of village Palla in the area. Yamuna Active Flood Plain aquifer of NCT Delhi occupies an area of about 97 km^2 and stretches about 35 km along river Yamuna.

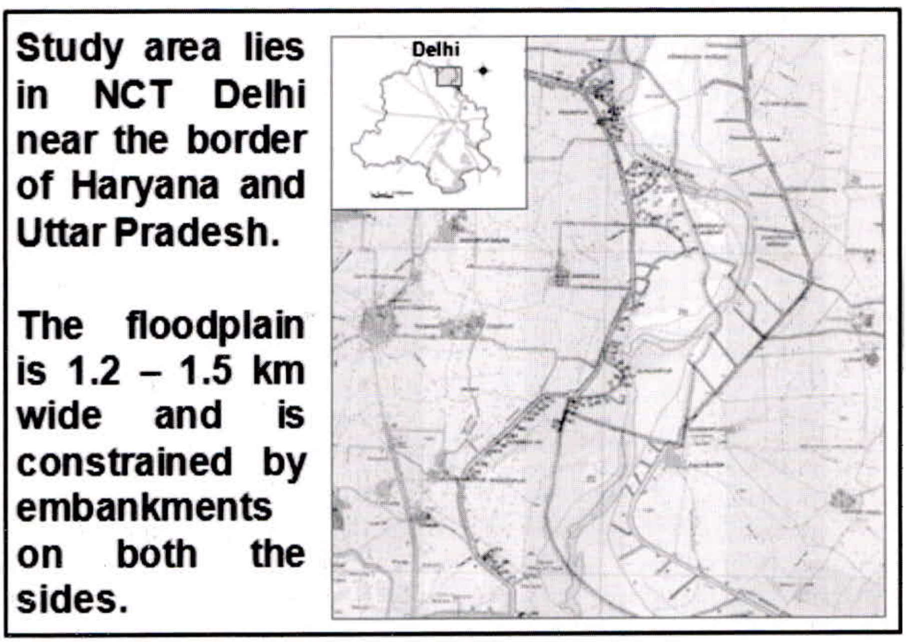


Fig. 1. Location of the Yamuna Flood Plain and Palla Field in NCT, Delhi

The NCT, Delhi has a tropical steppe climate. Monthly mean temperatures range from 14.3°C in January (minimum 3°C) to 34.5°C in June (maximum 47°C). The annual mean temperature is 25.3°C. The normal annual rainfall in NCT, Delhi is 611.8 mm. The rainfall in the Yamuna Flood Plain varies from 600 mm to 700 mm. About 81% of the annual rainfall is received during the monsoon months of July, August and September. Geologically, the entire Yamuna floodplain in NCT Delhi is covered by the unconsolidated sediments of the Quaternary to Recent age on the surface. The Quaternary sediments comprising Older and Newer Alluvium cover most of the flood plain.

METHODOLOGY

The river and groundwater interaction at any location may be studied by groundwater modelling, channel water balance, isotope mass balance and/or by statistical method using the river and groundwater water level fluctuation data. The statistical method based on Darcy's law involves analysis of the river water levels and groundwater levels adjacent to the river.

The isotopic composition of atmospheric moisture, and consequently precipitation, exhibits a broad spectrum of spatial and temporal variation (Dansgaard, 1953, 1954; Epstein and Mayeda, 1953; and Friedman, 1953). Based on characteristics of monthly composite samples of precipitation the latitudinal, continental, seasonal, amount and altitudinal effects can be identified (Dansgaard, 1964; Yurtsever & Gat, 1981; Rozanski et al., 1993).

The present study is carried out using isotope mass balance method. Isotopic tracers provide a mean for identifying the actual mass transport of water in the hydrologic cycle. The spatial and temporal variations in the isotopic composition of river waters are mainly brought about by the number and type of its sources, and to some extent in certain climatic regions by the evaporation from river surface. The variations in the observed δ_R, reflect the variable contributions from isotopically different sources, which can be evaluated if isotopic indexes of the sources are known.

Sample Collection

Ten piezometers were installed (5 each on both side of river Yamuna along a section-1) in June 2007. Water level monitoring and sample collection started from July 2007. Samples from western side were collected at 7 day interval and from eastern side at 15 days interval. Groundwater samples were also collected from existing hand pumps and tube wells along Section-2 near Jhangola village. One ordinary rain gauge was installed in Tiggipur village to collect precipitation samples (Fig. 2).

Approximately 2,000 samples were collected and analysed for isotopic variations (ä^{18}O and äD) from River Yamuna, groundwater from the piezometers / hand pumps installed within and outside the floodplain, Ranney well and precipitation. The samples from the west bank were collected at weekly interval and on the eastern side on biweekly interval during July 2007 to March 2010. The distance of piezometers from the active river channel was 80 m, 180m, 360 m, 570m and 800 m during monsoon and 280m, 380m, 560m, 770m and 1000m during non monsoon period.

RESULTS AND DISCUSSION

Temporal variation of Water level

Water levels were measured along section-1 and section-2 in the piezometers. In both the sections, the water table shows appreciable fluctuation during the year. As is clear from the figure, the depth to water table in floodplain varies from 2 to 8.3 meters on the western side and 0.75 to 4.3 meters on the eastern side of river Yamuna. In addition, water table fluctuation is more on the western side as compared to eastern side.

From Fig. 3, it can be seen that during 2007-08, water table in the floodplain remained below the

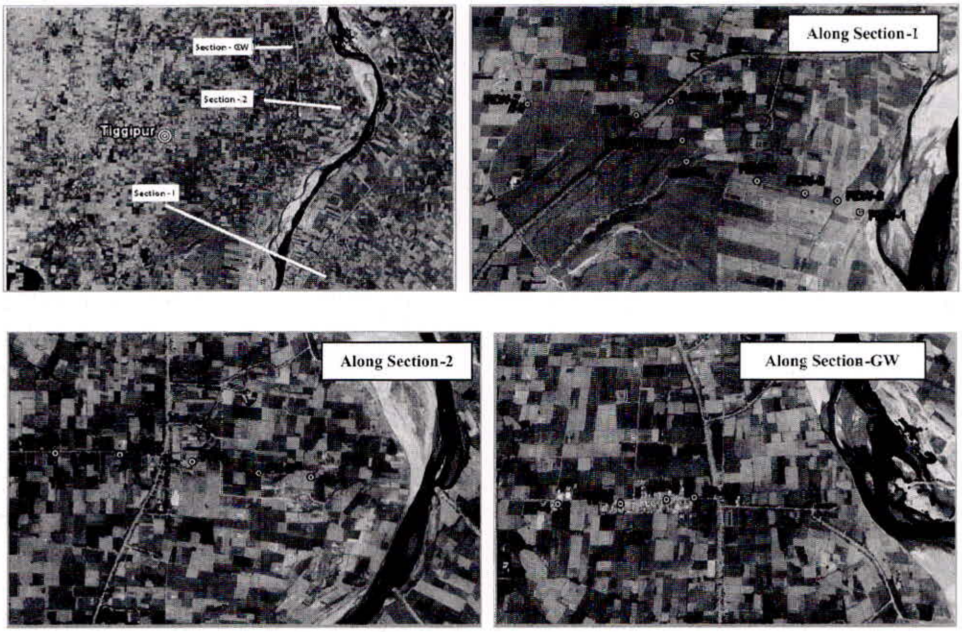


Fig. 2. Location of installed piezometers along Section-1, 2 and GW

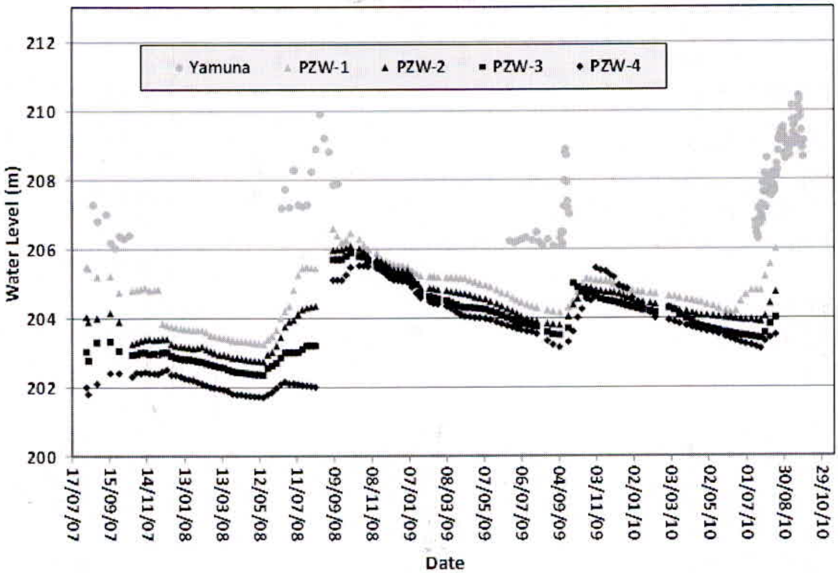
water level in the river Yamuna. This may have caused flow of river water to the floodplain during non-monsoon period of 2007-08. Whereas, during the year 2008-09, after the floods, due to recharging of the floodplain, the water table had risen above the non-monsoon water level in the river (about 205.5 m).

This suggests that river Yamuna should not have recharged the groundwater in the floodplain during October 2008 to March 2009. On the eastern side of the river Yamuna, the water table normally remains above the river level (which declines to below 205.5 meters during most of the period between November and March) and contributes water to the rivers as base flow.

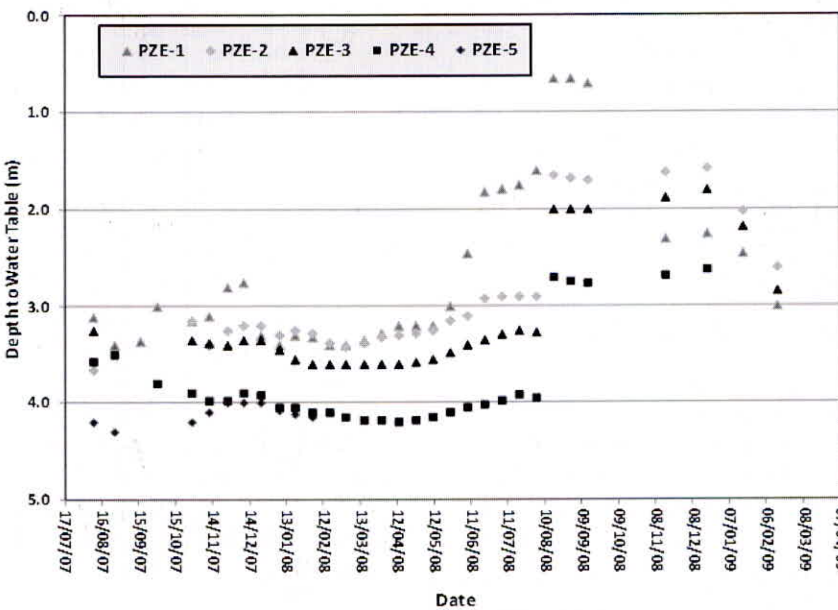
The highest variation in depth to water table is observed in the PZW-1, in which water level rose up to surface (total saturation) during the submergence was observed to be at a depth of 2 meters after the floods of 2008. This rise is due to vertical recharge of the floodplain. After the flood period (monsoon), generally the decline in water table has been observed. The rate of decline has been observed to be higher in the piezometers away from the active channel.

During the monsoon season of the year 2008, most of the piezometers in the floodplain along Section-1 got submerged, which resulted in recharge of the floodplain, and the water level in all the piezometers rose by up to 3.52 meters on the western part of the floodplain. On the eastern side the rise was about 2 m and also the rise was less away from the active channel, as has been observed in PZE-3.

Depth to water table was also monitored after the construction of piezometers along section-3 from



(a)



(b)

Fig. 3. Water Table Variation (A) West (B) East of river Yamuna along Section -1

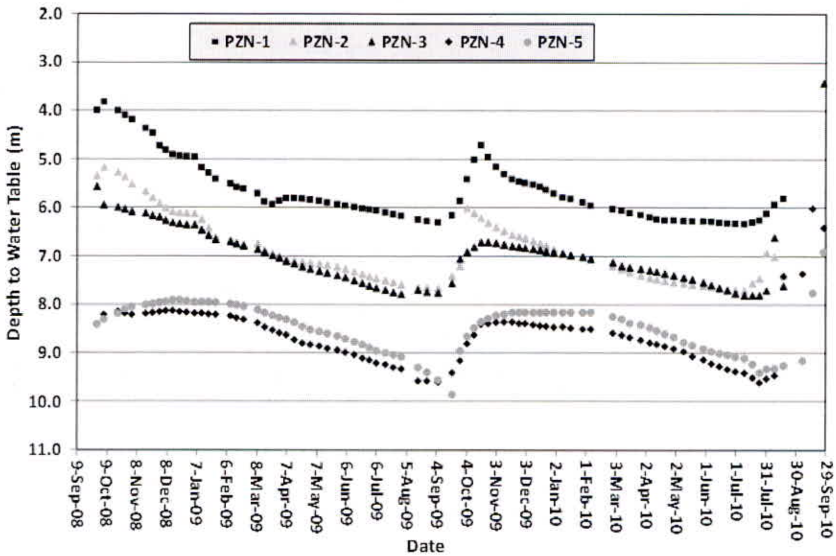


Fig. 4. Water Table Variation along Section-2 of River Yamuna

21st September 2008 onwards. The variation in depth to water table is shown in Fig. 4 The figure indicates that the depth to water table in the piezometers within the floodplain in section-2 (PZN-1, PZN-2 and PZN-3) fluctuates between 3.8 to 7.8 m. The depth to water table is more in the piezometers outside the floodplain, and varies in a narrow band of 7.9 to 8.2 m.

Isotopic Variations in Waters of Palla Area

Isotopic composition of River Yamuna

Water samples collected from River Yamuna show wide variation in isotopic composition during the study period. The d^{18}O and dD values in Yamuna water varied in a narrow range from -6.64‰ to -9.78‰ and -42.73‰ to -65.86‰ respectively (fig. 5.)

Isotopic Composition of Groundwater within the Yamuna Floodplain

Isotopic composition of the groundwater, ranney well and the pumped water are quite stable and vary in a narrow range. This indicates that the waters from these sources are well mixed and are not much affected by temporal variations. On the other hand, the isotopic composition of the waters in the piezometers within the floodplain shows variations with time as well as with space. The isotopic index of the piezometers PZW-1 to PZW-4 is 8.5‰ for ä^{18}O, whereas that of Yamuna River it is -7.5‰ (Fig. 6). This indicates that the floodplain gets recharged by waters of depleted isotopic composition. This happens when floods of depleted isotopic composition inundates the floodplain during monsoon season. But sometimes these depleted signatures in the river water could not be captured in the weekly sampling. But due to the entrapment of this water in the soil, the depleted signatures have been observed in the piezometers.

The PZW-4 piezometer shows, the most depleted signatures, which are not observed in any of the piezometers lying between river and PZW-4. Such depleted signatures have also been observed in

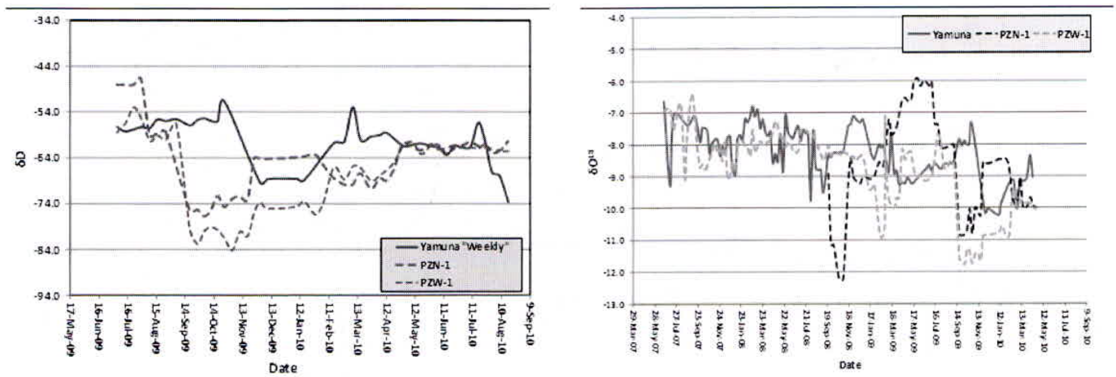


Fig. 5. Variation of $\delta^{18}O$ with time in River Yamuna

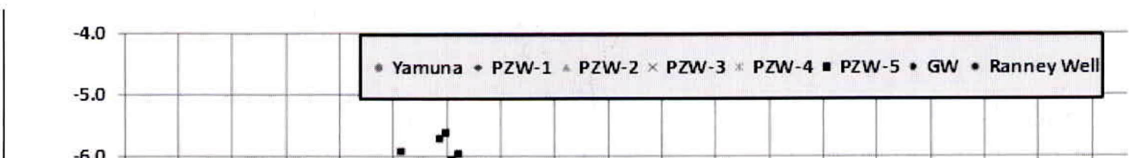


Fig. 6. Variation of $\delta^{18}O$ with time in the floodplain along Section-1 (West of Yamuna)

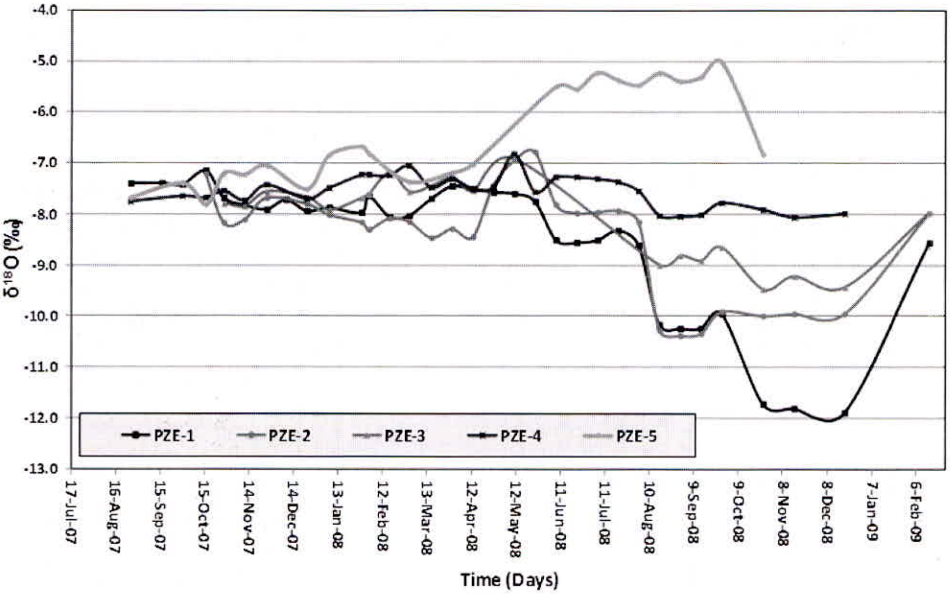


Fig. 7. Variation of $\delta^{18}O$ with time along Section-1 (East of Yamuna)

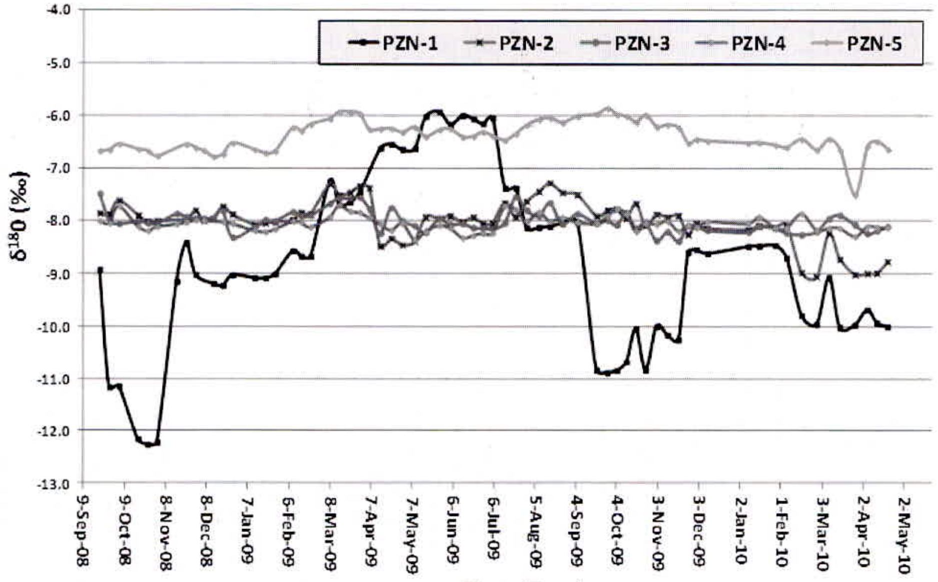


Fig. 8. Variation of $\delta^{18}O$ with time along Section-1 (East of Yamuna)

PZN-1 (Fig.7) and PZE-1 in section-2 and east part of section-1 respectively. This indicates, the direct connection of PZW-4 with the river, may be through paleochannel. This assumption is supported by the presence of surface depression near to PZW-4.

Groundwater and ranney well show very stable isotopic composition during the year 2007-08. The ranney well showed slightly depleted isotopic composition in comparison to groundwater. This may be due to mixing of floodplain water with the groundwater. During the year 2008-09, the groundwater and ranney well water also became slightly depleted and the difference in the isotopic composition was observed to be less than the previous year. This may be due to the recharge of the groundwater (outside the active floodplain) by the high level of water in the active floodplain (constrained by embankments) during the flooding period.

Groundwater generated in the area shows isotopic index -7.5‰ with average value of -7.15‰. This indicates that the groundwater generated in the area is relatively enriched than the water recharged in the floodplain.

Annual analysis of the data indicates that during the period Jul'07-Jun'08, the isotopic values of δ^{18}O and δD are relatively more enriched as compared to the values observed during the year Jul'08-Jun'09 in all the piezometers and also the river Yamuna water. Only the Ranney well indicates same values for both the years.

Groundwater also got depleted in during Jul'08-Jun'09. The depletion was due to recharge of the groundwater due to high floods in the river Yamuna during August and October 2008.

On the eastern side of the river, the piezometers showed a very narrow range of isotopic composition during the year 2007-08 (Fig. 8) indicating no recharge from the river Yamuna on that side during the monsoon of 2007. This indicates that river do not recharge the eastern side during low floods. This is also supported by the water level data which has been observed to be higher than the river level during non-monsoon months.

CONCLUSIONS

The isotopic analysis of the groundwater, river water and pumped wells indicates that percentage of river water in pumped water vary from season to season and from year to year. Isotopic analysis of the water samples indicates that Yamuna recharges groundwater on Delhi side (Palla sector) more than UP side during monsoon season (July to October). The recharge on the UP side takes place only during high floods, but on Delhi side, the recharge occurs even during low floods also. During the years when there is no flood or the floods are of short duration, the contribution of water from the river Yamuna and its floodplain in the pumped water goes upto 50% during monsoon season, which gradually reduces and reaches to the tune of 20% during non monsoon. During the year of major flooding, the contribution from the river Yamuna and its floodplain to the pumped water becomes 100% during monsoon season, which goes on reducing but continues for longer duration depending upon the availability of recharged water in the floodplain. The conclusions drawn on the bases of isotopic signatures of waters are supported by the appreciable decline (4.2 m since 2002) and rise in the groundwater table (3.52 m rise during 2008 floods) in Palla area.

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