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**Application of environmental tracers in managed aquifer recharge:  
case studies from Punjab**

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**Abstract:** In Punjab, groundwater (GW) levels are rapidly declining due to its uncontrolled use mainly for irrigation and also for drinking. The investigation of environmental tracers is useful for understanding hydrological processes and pollution sources. In this study, a suite of environmental tracers, namely stable isotopes of oxygen ( $\delta^{18}\text{O}$ ), hydrogen ( $\delta^2\text{H}$ ), tritium ( $^3\text{H}$ ), CFCs and  $\text{SF}_6$  were used to investigate the aquifer-aquifer interaction, characterizing surface water – GW interaction; identification of sources of GW recharge; component separation and seasonal changes in multi aquifer systems of Punjab. These tracers helped in identifying the GW flow directions and calculating mean residence times of GW. The measurements for these isotopes were conducted at Nuclear Hydrology Laboratory at the National Institute of Hydrology (NIH), Roorkee and for CFCs and  $\text{SF}_6$  at British Geological Survey, UK. As a result, the recharge zones were identified and could potentially be considered for managed artificial recharge (MAR) measures. At some sites the component of river water in GW was found more than 50% for about 500 m distance from the river, thus indicating potential sites for MAR by riverbank infiltration. Furthermore, where surface water significantly contributes to GW, there is an immediate need to maintain the surface water quality to use it as source-water for MAR. Regular water level and quality monitoring should be conducted and vulnerable locations should be identified where there is a risk of pollution to source water. The management of MAR measures at suitable locations along rivers in Punjab may help to mitigate GW over-abstraction.

**Keywords:** Environmental tracers, groundwater, irrigation, drinking, Punjab