A Watershed Approach for the Determination of Groundwater Recharge in Rajasthan, India

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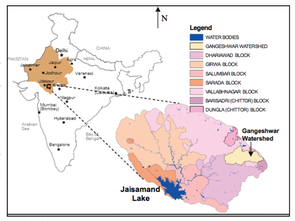
Introduction

Groundwater is a vitally important global resource that is becoming increasingly scarce. Agriculture accounts for more than 70% of global water consumption, much of which is dependent on a finite supply of groundwater. India has one of the fastest growing populations in the world and depends on a reliable supply of water to ensure food security. In order to reduce vulnerability to climate change and promote water conservation, there is a pressing need to monitor groundwater resources so that sustainable water management can ensue.

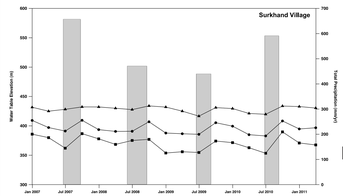
The determination of groundwater recharge is imperative for sustainable water management. Chemical and isotopic methods for quantifying groundwater recharge are considered more advantageous than physically based methods, particularly in semi-arid and arid region where recharge rates will be small and direct measurements are more difficult to obtain [1-3]. Chloride (Cl) is commonly used as a tracer for measuring groundwater recharge due to its capacity to mimic the flow of water. The high solubility and inert nature of Cl in water permits the determination of recharge rates, thereby reflecting the amount of water that has escaped evaporation and infer the quantity of recharge that has occurred in a locale [4-5]. The primary aim of this research is to determine groundwater recharge on a regional level using Cl as a geochemical tracer within the Gangeshwar Watershed in Rajasthan, India to build a conceptual understanding on how a watershed-level monitoring program could best be devised to manage groundwater resources.

Study Site

Figure 1: Study Site Location



The Gangeshwar Watershed (76 km^2) is an upstream sub-watershed within the Jaisamand Lake macro-watershed located in the Aravalli Hills in Rajasthan, India (Fig 1). The geology in this area consists of weathered, fractured hard rock, and characterized as a semi-arid region that depends on 94% of its rain to fall during the monsoon season (June - Sept). Surface water resources are minimal in the region and the drainage network is comprised of ephemeral streams.



Average annual rainfall is ~650 mm within the Jaisamand Basin. Precipitation rates in the Gangeshwar have ranged from 411 to 656 mm/yr. The response of the annual monsoon can be observed in an increase in the water table elevation followed by subsequent drop in water table after the rainy season (Fig 2).

Figure 2: Water Table Elevation (2007-2011) from 3 wells. Total Precipitation is indicated by the bars.

Methodology

Sample Collection & Analysis

A watershed-monitoring program was established in the summer of 2009 in the Gangeshwar with local participation for the collection of rainfall and groundwater samples. Groundwater from open wells was collected in June 2009, January 2010, June 2010, and April 2011. Rainwater was collected from the precipitation gauge after every rain event during the 2010 monsoon. All samples were filtered sterilized on-site using a 0.2 µm Millipore® polycarbonate or cellulose acetate membrane filter. All sample bottles were rinsed with filtered sample water thrice prior to storage.

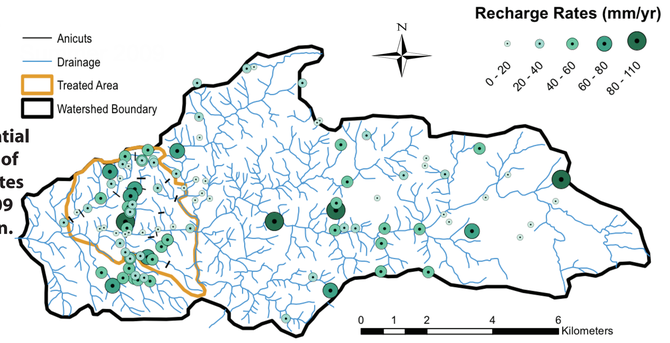
Chloride (Cl^-), nitrate (NO_3), nitrite (NO_2^-), phosphate (PO_4^{-3}), sulphate (SO_4^{-2}) and fluoride (F^-) were determined using Ion Chromatography (Dionex DX-500) at the Centre for the Environment in the University of Oxford, UK. The detection limit was below 1 mg/L, where a standard curve was used to calibrate the samples. Standard concentrations were set at 1, 5, 10 and 15 mg/L. Groundwater samples collected in June 2009 were analyzed at the isotope laboratory in the National Institute for Hydrology in Roorkee.

Chloride Mass Balance Approach

CMB works well as a method for groundwater recharge in semi-arid regions [6], provided that several assumptions are met: 1) the only input of Cl is atmospheric; 2) there is no lateral flow of adjacent groundwater that can enter the sampling point; 3) groundwater recharge moves via piston versus preferential flow (applicable only to the use of CMB in the unsaturated zone). Recharge rates are inferred using mass balance approach [3]: **Recharge Rate = (Cp x Precipitation Rate) / Cr**
where Cp is the solute concentration of precipitation and Cr is the solute concentration of the interstitial water or groundwater sample.

Results

Figure 3: Spatial Distribution of Recharge Rates from the 2009 Pre-monsoon.



Recharge rates ranged between 34.48-36.63 mm/yr (Table 1) for the pre-monsoon datasets collected in the summer of 2009, 2010, and 2011. The recharge rate was slightly lower for the 2010 post-monsoon dataset (29.22 mm/yr). Recharge rate estimates from the Gangeshwar represented ~6.1-8.4% of annual rainfall. Recharge rates spatially varied throughout the Gangeshwar (Fig 3). Recharge rates were highest in the forested region of the watershed, and the lowest recharge rates were associated with wells that are used intensively for irrigation. Higher than expected recharge rates were found along the Gomti River in the western region of the Gangeshwar, where Cl concentrations were found to increase with decreasing elevation in this region.

Isotopic analysis of the 2009 pre-monsoon dataset fell along the Meteoric Line (Fig 4). However, the most oxygen isotopically enriched $\delta^{18}O$ from the 2009 pre-monsoon dataset did not always correlate with higher Cl concentrations (Fig 5).

Table 1: Recharge Rates from 2009-2011

	Pre-monsoon 2009	Post-monsoon 2010	Pre-monsoon 2010	Pre-monsoon 2011
Average Recharge Rate (mm/yr)	34.48	29.22	50.05	36.63
Range (mm/yr)	2.23 - 99.50	3.73 – 68.25	1.54 – 91.35	3.63 – 101.79
Recharge/Precipitation Rate (%)	8.4	6.5	11.4	6.1

Figure 4: δ^2H versus $\delta^{18}O$ of the 2009 Pre-Monsoon groundwater and rain samples with the IAEA meteroric line

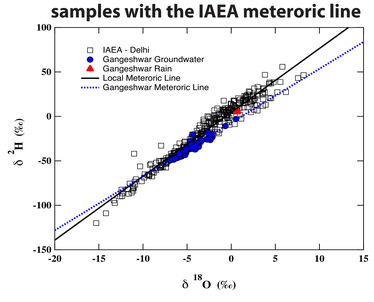
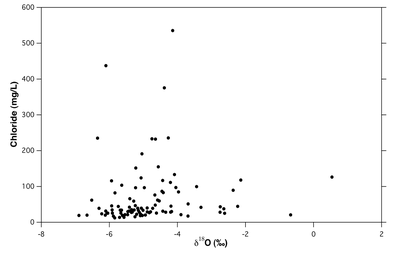


Figure 5: $\delta^{18}O$ versus Chloride from the 2009 Pre-monsoon dataset.



Discussion

The average recharge rates calculated for the Gangeshwar using the CMB approach coincides with previously calculated estimates for recharge rates (~5-12%) in Rajasthan [7]. The lower estimates of recharge are likely to be influenced by irrigation return flow during the winter months. Recharge rates are likely to be slightly under estimated, as 90% of the samples were collected from sites that were susceptible to irrigation return flow. Thereby, highlighting the importance for continuously monitoring irrigation abstraction rates and Cl concentrations of groundwater over time to more accurately constrain recharge rate estimates.

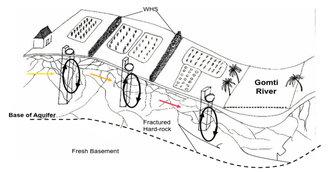


Figure 6: Schematic of Cl transport due to lateral flow

Isotopically enriched groundwater samples reflect higher evapo-transpiration rates, due to a preferential loss of the lighter ^{16}O isotope. The groundwater samples with higher Cl concentration that were not associated with an enriched $\delta^{18}O$ suggest that Cl was not concentrated solely via evapo-transpiration. These samples are likely to be integrated sample points that have experienced lateral flow (Fig 6). Although the CMB approach can estimate reasonable recharge rates on a watershed level, more work is needed to elucidate the recharge rate on a sub-basin localized (well-to-well) level. This is particularly true in regions where there is heterogeneous irrigation return flow.

Next Steps

The development of an end-user tool that will enable rural farmers to predict and monitor groundwater availability are desperately needed to aid strategic planning for their water-related enterprises. In an effort to simplify the estimation of groundwater recharge rates using the CMB approach, total dissolved solute (TDS) measurements will be explored as a substitution for Cl concentrations. The inherent simplicity of a TDS meter would provide a way to continuously monitor groundwater resources and differentiate input sources at each sample site. Preliminary TDS data was collected weekly at a well that was used for irrigation and domestic use (Fig 7). Irrigation periods of ~7-10 hours in duration over the course of 3-4 days are indicated on the graph. More information is needed to refine our interpretation of the site-specific influences (i.e. land-use, crop choice, and irrigation methodology).

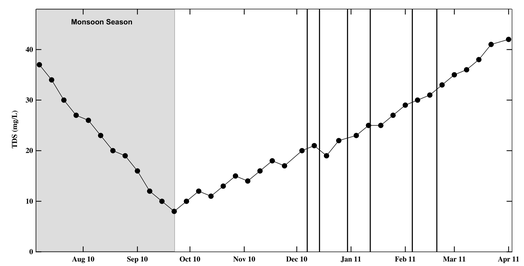


Figure 7: Total Dissolved Solute (TDS) measurements over time. Flood irrigation intervals are indicated by the vertical lines.

References & Acknowledgments

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