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Stable isotopes of river water and groundwater along altitudinal gradients in the High Himalayas and the Eastern Nyainqentanghla Mountains

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ABSTRACT

Study Region This study considers river water and groundwater in seeps and springs collected from the non-monsoon season in the valleys of the Dudh Koshi River in eastern Nepal and the Niyang River of eastern Tibet, both in the Himalaya Mountains.

Study Focus Data from this study comprise water samples that provide a single season snapshot of $\delta^{18}O$ and δD values that give additional information into the sources of moisture and the altitude lapse rates for the southern flank of the High Himalaya of Nepal and the Eastern Nyainqentanghla Mountains of the Tibetan Plateau.

New Hydrological Insights The local water line for Nepal samples, $\delta D = (7.8 \pm 0.3) \cdot \delta^{18}O + (4.0‰ \pm 4.6‰)$, was moderately lower in slope than for Tibetan Plateau samples, $\delta D = (8.7 \pm 0.1) \cdot \delta^{18}O + (24.3‰ \pm 2.0‰)$; evaporation has a greater influence on the Nepal samples—consistent with warmer temperatures in Nepal versus Tibet within the same altitude range. Mean d-excess values for Tibet samples (13.1‰ ± 2.0‰) implies that recycled continental moisture has more influence than marine moisture observed for the Nepal samples (7.4‰ ± 4.4‰). Altitude lapse rates of $\delta^{18}O$ and δD for Nepal samples (-2.8‰‰ km^{-1} and −24.0‰ km^{-1}) do not significantly differ from Tibet samples (−3.1‰‰ km^{-1} and −27.0‰ km^{-1}) and regional measurements; the lapse rates are reduced above 4500 m and are not influenced by exceptionally high elevations in the Dudh Koshi River watershed.

1. Introduction

Stable isotopes of hydrogen and oxygen are one method used to model hydrological cycles and determine sources of water (Dansgaard, 1964; Gat, 1996; Bowen and Wilkinson, 2002). The isotopic composition is commonly reported in the standard delta notation.

$$\delta = (R_{sample}/R_{standard} - 1) \cdot 1000‰, \quad (1)$$

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where R is the ratio of heavy to light isotope. differences in climate leads to differences in δ^2H and δ^{18}O between geographically separated reservoirs of surface water and groundwater. These isotopes are heavily influenced by regional climate and are used to estimate effects of evaporation on a water body (Dailai et al., 2002; Jeelani et al., 2013) and as an altimeter for orographic uplift—an 'altitude effect' (Clark and Fritz, 1997). The linear relationship between δ^2H and δ^{18}O is one means to assess the cumulative effects of fractionation caused by evaporation and condensation in samples of precipitation (local meteoric water line, LMWL) and surface/ shallow groundwaters (local water line, LWL) as compared to the global equilibrium between evaporation and condensation (global meteoric water line, GMWL) defined by the relation:

$$\delta D = 8\cdot(\delta^{18}O) + 10‰ \quad (2)$$

(Craig, 1961; Ambach, 1968). LWLs may deviate from the GMWL during any non-equilibrium event, such as evaporation, mixing, or additional input of marine moisture. For example, LWLs with slopes less than or greater than 8 can indicate systems dominated by evaporation and recharge/recycled moisture, respectively (Craig, 1961).

During evaporation, δD of the produced moisture decreases less rapidly than δ^{18}O compared to the slope of 8 of the GMWL, leading to samples that lie above the GMWL. In contrast, remaining water in the evaporated source will have values below the GMWL leading to LWL with slopes less than 8. The deuterium excess (Dansgaard, 1964), calculated for each sample as

$$\text{d-excess} = \delta D - 8\cdot(\delta^{18}O), \quad (3)$$

can reveal changes in sources of moisture for precipitation. Values of d-excess greater than 10‰ may indicate recycling of water sources, snow formation, and cooler/dry air masses. In contrast, d-excess values less than 10‰ may indicate secondary evaporation (e.g. from cloud formation or terrestrial waters) and more humid air masses. For example, d-excess in the Tibetan Plateau of China changes per the monsoon (Liu et al., 2008); lower d-excess values from north-migrating moisture from the Indian Ocean during the summer and higher d-excess values derived from drier continental air during the winter months—a 'continental effect' (Clark and Fritz, 1997) produced by multiple cycles of evaporation and precipitation (Gat and Matsui, 1991).

The altitude affect has been studied in Himalayas precipitation and surface waters (Dailai et al., 2002; Wen et al., 2012; Jeelani et al., 2013). Isotopically heavier water falls first during a precipitation event; thus, δ^{18}O and δD values decrease during progressive precipitation from adiabatic cooling along an altitude gradient—an altitude lapse rate (Dansgaard, 1964; Clark and Fritz, 1997). The altitude lapse rate for precipitation in the Kashmir Himalayas measured $-2.3‰\ km^{-1}$ for δ^{18}O and $-12‰\ km^{-1}$ for δD (Jeelani et al., 2013). In the southern Himalayass, the altitude lapse rate for δ^{18}O was lower during the monsoon season (-1.5‰ km^{-1}) compared to the non-monsoon season ($-2.3‰\ km^{-1}$) (Wen et al., 2012). In the Yamuna River in the northwestern Himalayas, the altitude lapse rate for the non-monsoon season was $-1.1‰\ km^{-1}$ for δ^{18}O and $-12‰\ km^{-1}$ for δD (Dailai et al., 2002). In the Boqu River in the southern Himalayas, the altitude lapse rate during the monsoon season was $-3.6‰\cdot km^{-1}$ for δ^{18}O (Wen et al., 2012).

Similarly, LWLs and d-excess have been studied in Himalayas precipitation and surface waters (Pande et al., 2000; Dailai et al., 2002). Rivers sampled spanning the Himalayas have produced LWLs with a slope greater than the GMWL and with d-excess values greater than 10‰ (Pande et al., 2000). Combing precipitation data, Pande et al. (2000) concluded that snowfall contributed to greater slopes and that contributing moisture derived in part from Mediterranean air masses. In the Yamuna River in the north-western Himalayas, tributaries sampled during the monsoon season were depleted in ^{18}O and ^{2}H (Dailai et al., 2002)—a product of the 'amount effect' where increased precipitation leads to lower values of δ^{18}O and δD (Dansgaard, 1964). Further, Dailai et al. (2002) compared LWLs produced from samples collected during the monsoon and non-monsoon season and found that the LWL of the monsoon season correlated well with the predicted effects of the monsoon rains, i.e. the LWL fell above the GMWL. Similarly, the LWL of the non-monsoon season fell below the GMWL, indicating that the river was dominated by evaporation. Values of d-excess from precipitation of the Kashmir Himalayas were low during the monsoon (3.2–12.8‰) from evaporating rainfall derived from moisture sources in the Indian Ocean, and high during the non-monsoon season (20–22‰) from recycled moisture derived from the Mediterranean (Jeelani et al., 2013)

In this study, we present a single-season snapshot of the isotopic composition of river water and groundwater sampled in the Dudh Koshi River watershed in the Himalayas of eastern Nepal and in the Niyang River watershed in the Eastern Nyainqentanghla Mountains of Tibet, China. The isotopic compositions of river water and groundwater in the Dudh Koshi and Niyang River sites have not been evaluated prior to this study, and present an interesting comparison between a tributary of the Ganges River on the south flank of the Himalayas Range in Sagarmantha National Park (Dudh Koshi River) and a tributary of the Brahmaputra River north of the Himalayas crest on the Tibetan Plateau (Niyang River); both are headwater streams that drain to the Indian Ocean.

The present study compares the altitude lapse rates, assess the role of evaporation between these locations, and provide one benchmark for future studies of the hydrological cycle in these portions of the Himalaya Mountains. Aside from questions of strict comparisons between data explored in this manuscript, one motivating purpose is better understand residence times of shallow groundwater to assist with the management of sustainable water supplies in communities with significant tourism demand (Manfredi et al., 2010). Another interesting question is whether the presence of seven mountain peaks exceeding 8,000 ma.s.l. in the region surrounding the Dudh Koshi watershed results in an altitude lapse rate sizably different that elsewhere in the Himalayas Mountains.

2. Physical setting

The Dudh Koshi River watershed in the southern Himalaya spans 3712 km^2 and is located just south of Mount Everest in Nepal, a significant portion within the boundaries of Saragmantha National Park, and includes the towns of Lukla and Namche Bazar (Fig. 1).