USING HYDROCHEMISTRY DATA TO CONSTRAIN THE ROLE OF SNOW AND ICE MELTWATER IN THE LANGTANG VALLEY, NEPAL

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ABSTRACT

The Langtang River Basin of central Nepal is one of the most well-studied valleys of the Himalaya. With an elevation range of 1460m to 7246m and with the Upper Langtang Basin (above 3642m) approximately 40% glacierized, snow and ice melt play a dominant role in the hydrology. Presented here is a synoptic survey of hydrochemistry data from a pre-monsoon field campaign in May 2012. Major chemistry and isotopes are used to conduct hydrograph separations of the Langtang River to quantify the role of meltwater in river discharge. Results using End Member Mixing Analysis (EMMA) show a decline in the contribution of groundwater with increasing elevation - estimated at 24% at 1479m, down to 9% at 3642m. This work isolated contributions of 'high-elevation' water but EMMA did not identify distinct snow and ice contributions. Two versions of EMMA are compared – one including $\delta^{18}O$ in the input tracer set and the second excluding it. EMMA results are compared to a two-component mixing model using $\delta^{18}O$ as the sole tracer to separate groundwater from melt water. Our objective is to distinguish potential source waters through hydrograph separation. We show that using hydrochemistry data for EMMA can be an appropriate tool for this. (KEYWORDS: Hydrologic mixing models, EMMA, glacier and snow melt, hydrochemistry)

INTRODUCTION

In the context of climate change vulnerability, hydrograph separation methods may provide ways to determine how much streamflow comes from snow and glacier melt versus groundwater and direct precipitation in snow and ice dominated catchments. There is a three-decade long legacy of hydrometeorological and cryospheric research in the Langtang Himal of central Nepal. Still not well understood though is the source composition of the Langtang River, particularly how much of the discharge volume is glacier melt, snow melt, and groundwater. The sources of contribution to discharge are referred to here as 'end members'. The Langtang Himal and other mountains play an invaluable role in regulating hydrologic resources that downstream communities depend on, but are susceptible to temporal shifts in the hydrograph due to warming temperatures and changes in precipitation regime. The work presented here adds hydrochemistry-based hydrograph separation results from the Langtang River Basin of Central Nepal to the USAID-funded collaborative project Contributions to High Asian Runoff from Ice and Snow (CHARIS, http://nsidc.org/charis/).

Objectives

1. Using May 2012 synoptic survey samples, determine what fraction of streamwater discharge in the Langtang River comes from different sources at that time using a multiple-component End Member Mixing Analysis (EMMA). Ten sources were identified as potential end members.
2. Compare two-component mixing model results, only separating groundwater and meltwater, with multiple-component EMMA results.
3. Determine the sensitivity of EMMA to the inclusion of δ18O in the tracer set.

METHODS

Hydrochemistry-based hydrologic mixing models mathematically unmix river water based on the measured concentrations of one or more chemical tracers in the end member source waters that contribute to discharge. The simplest approach is a two-component mixing model which uses a single tracer, in our case $\delta^{18}O$, to assign proportions of river discharge to two different end member sources. The $\delta^{18}O$ groundwater value is an average of 2 samples at the Syabrubesi hotspring and the $\delta^{18}O$ meltwater value is from the Late May 'Upper Langtang' river sample. In order to include more than two end members, the use of EMMA allows for consideration of an unlimited

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number of end members and selects for those that best explain streamwater chemistry using principle component analysis (Christopherson et al., 1990 & Hooper et al., 1990). In this study we utilize geochemical and isotopic data from ten potential end members in two multiple-component EMMAs to conduct hydrograph separation and determine which end members are the dominant contributors to discharge in the Langtang River Basin. Methodology for selection of conservative tracers to input into the EMMA is based on Hooper, 2003.
Eight river samples for our analysis were collected at five locations along the Langtang River between 1479m and 3642m. Three of the samples were collected in Early May and five were collected in Late May. Potential end members which were sampled include: groundwater (5 locations between 1400m and 2540m), rain (3880m), snow (5165m), an 'Upper Langtang' river sample (3741m) which is assumed to be an integrated representation of all 'high-elevation' snow and ice melt sources upstream, tributaries (four locations between 1669 & 3168m), Khimsung clean-ice glacier discharge (KYM, 4166m), Lirung debris-covered glacier discharge (LIR, 3784m), Lirung supraglacial streams (4080m), the mixed KYM + LIR water at the Lirung sub-catchment outlet (OUT, 3685m), and a Yala ice sample (5184m). Where multiple samples were collected, median values were used.

Sensitivity of EMMA to isotopic tracer inclusion

This study is carried out as part of the USAID-funded CHARIS project, working with 10 partner institutions across Central and South Asia to examine the role of meltwater in downstream hydrology. A capacity-building end-goal for CHARIS is to have interested partners conduct mixing model work independently. All partners have the capacity to analyze for major chemistry, but only a few have access to facilities that conduct isotopic analysis. Thus we have compared EMMA results with and without the inclusion of δ^{18}O as a tracer to see if comparable results are produced. The long-term potential for hydrochemistry mixing model work by partners is improved if major chemistry data yields similar results to those produced by isotope inclusion.

RESULTS

Using a simple two-component mixing model with δ18O as the sole tracer, the four Late May Langtang River samples were partitioned into groundwater and meltwater (Figure 1). Groundwater was parameterized using a δ^{18}O value of -10.21‰ from the Syabrubesi hotspring and 'melt water' was parameterized using a value of -12.88‰ from the highest elevation Langtang River sample. Estimates of groundwater contribution to discharge were lowest at the 3642m sampling site (15%) and highest at the 1479m site (39%).

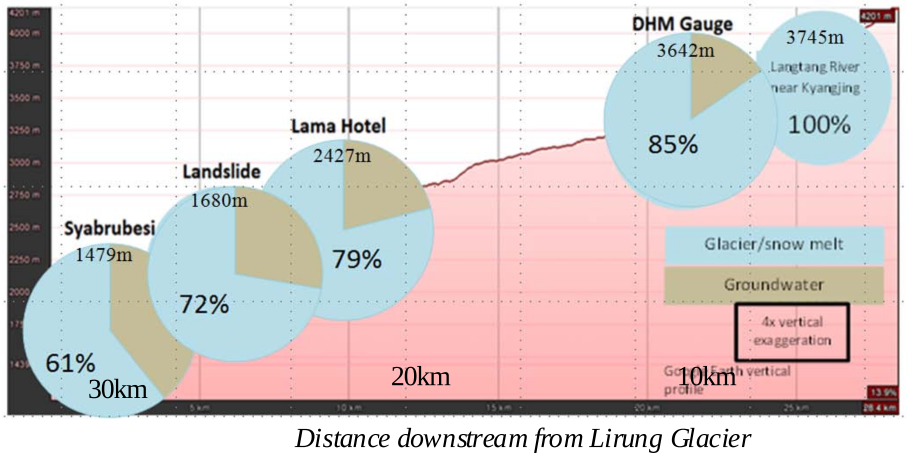


Figure 1. Hydrograph separation for Late May Langtang River samples using δ18O as the sole tracer.

After eliminating tracers that exhibited non-conservative behavior, Ca++, Mg++, Si, SO4=, and δ18O were used as input for an EMMA. A second EMMA was conducted removing δ18O. When plotted in the 2-dimensional U-space created using the principle component analysis, the Langtang River samples are bounded by the projected end members, whether or not δ18O is included as a tracer (Figures 2 & 3). Therefore the potential End Members we have identified are fully sufficient to explain the Langtang River chemistry. While 'tributaries' are plotted as a potential end member, they are not selected as a true End Member since they plot on a line between groundwater and ice and are themselves a combination of different end members. Exclusion of δ18O does not noticeably affect the groundwater or tributary end members, but does shift all ice, snow, and rain related end members. The unique δ18O values for the different end members and its known conservative behavior make it preferred to include the isotopic data, and the EMMA with isotopic data is assumed to be a better representation of the system. The three chosen end members are those that most closely bound the cloud of Langtang River samples: 'Upper Langtang' high-elevation water, groundwater, and KYM clean-ice glacier discharge.

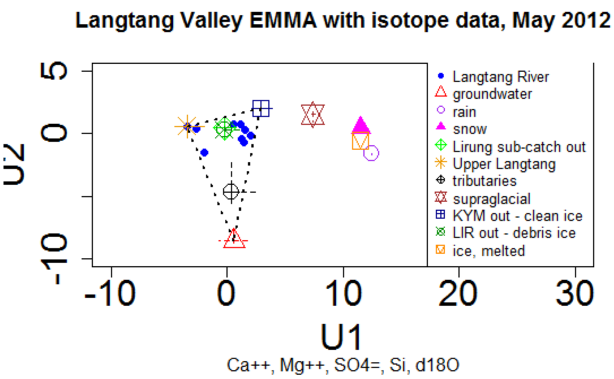


Figure 2. Plot of Langtang River samples and 10 potential End Members in U-space defined by Principal Component Analysis; includes δ18O as a tracer

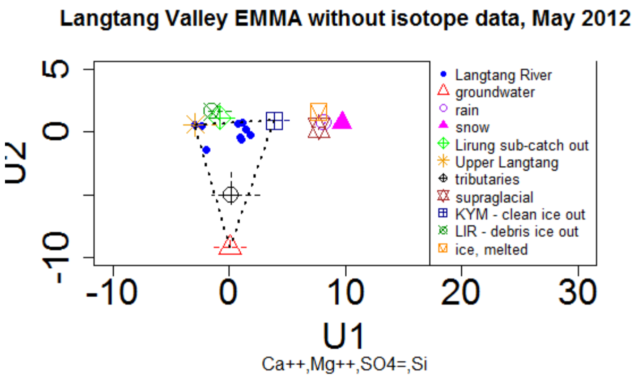
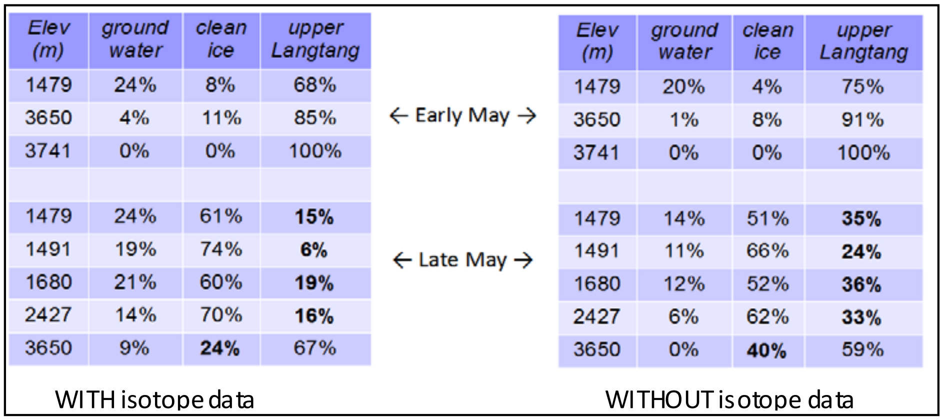


Figure 3. Plot of Langtang River samples and 10 potential End Members in U-space defined by Principal Component Analysis; does not include δ18O as a tracer

Both the EMMAs with and without δ18O as a tracer produced groundwater contribution estimates within 10% of each other (Table 1). The greater discrepancies are in estimates of high-elevation (Upper Langtang) contributions. This could stem from the ambiguity of the high-elevation water composition, given that it is itself a combination of yet-to-be identified end members. It is hypothesized that this discrepancy will be reduced with better constraint on the composition of the Upper Langtang 'end member'.

Table 1. Estimates of end member contributions to discharge using EMMA with δ18O data (left) and without (right).



Elev (m)	ground water	clean ice	upper Langtang		Elev (m)	ground water	clean ice	upper Langtang
1479	24%	8%	68%		1479	20%	4%	75%
3650	4%	11%	85%	← Early May →	3650	1%	8%	91%
3741	0%	0%	100%		3741	0%	0%	100%
1479	24%	61%	**15%**		1479	14%	51%	**35%**
1491	19%	74%	**6%**	← Late May →	1491	11%	66%	**24%**
1680	21%	60%	**19%**		1680	12%	52%	**36%**
2427	14%	70%	**16%**		2427	6%	62%	**33%**
3650	9%	**24%**	67%		3650	0%	**40%**	59%

WITH isotope data | WITHOUT isotope data

DISCUSSION

At the lowest elevation sampling site (1460m), the two-component model using δ18O as a tracer indicates that 61% of river discharge was a combination of snow and ice meltwater in May 2012 and the remaining was assumed to be groundwater. We know the system is more complex than two End Members, so using a three-component EMMA we found a high-end estimate of clean ice glacier melt (using KYM sampling site as a proxy) at Syabrubesi during May 2012 to also be 61%, but with high-elevation water (assumed to be some combination of snow and ice melt) contributing another 15%, there is a total composition of up to 76% meltwater in the spring season. This range of values suggests that the sensitivity of different mixing model methods must be more closely examined before drawing confidant conclusions (Barthold et al., 2010). This EMMA work does not suggest rain or pure snow play a significant role in Langtang River hydrology at this time of year (Figures 2 & 3). We found that the multiple-component EMMA indicates a lower percentage of groundwater in the river water than does a simple two-component mixing model (Figures 4 & 1) and the more robust nature of EMMA suggests this is a more accurate assessment of the catchment.

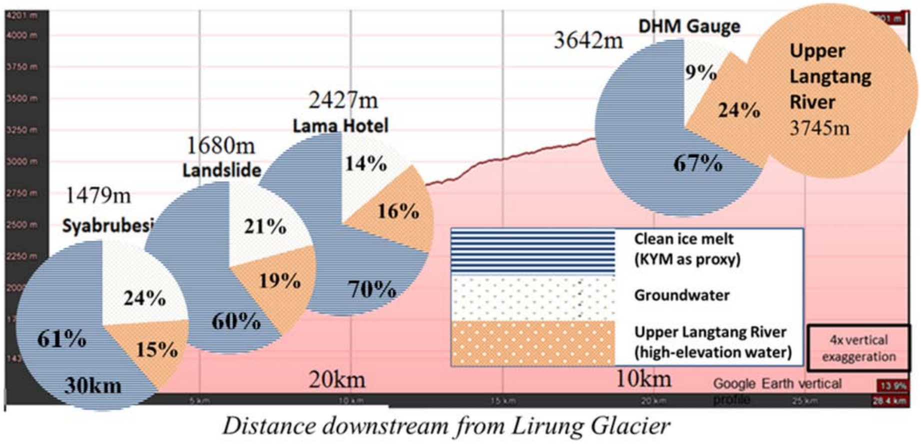


Figure 4. EMMA results for Late May Langtang River water samples, including δ18O as a tracer.

CONCLUSIONS

Using the same data, the 2-component and EMMA (Figures 1 & 4, respectively) give varying estimates of the amount of groundwater in the Langtang River. The EMMA with δ18O suggests that high-elevation water and clean ice glacier meltwater play a significant role in the late spring hydrology, even 30 km downstream from the glacierized portion of the catchment. However the true composition of 'high-elevation water' is unknown and subsequent field work has focused on constraining this end member. Removing δ18O values from the EMMA tracer set gives groundwater estimates within 10%, but additional characterization of the 'Upper Langtang' end member needs to be done before relying on results that don't use isotopic values. The broader suite of chemistry data used in the 3-component EMMA make it a better estimate of hydrograph separation than the 2-component mixing model.

FUTURE DIRECTIONS

Continuing work includes: partition the 'Upper Langtang' EM into its own end members; integrating known isotopic lapse rates for regional precipitation into the EMMA model; facilitate isotopic analysis for regional partners to conduct EMMA work in their local catchments ; and comparing EMMA results with and without isotopic data in these local catchments.

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