Expedition Report- Water Sampling in the Khumbu Valley

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Project Name: Assessing the meltwater runoff of the Khumbu Glacier, Nepal, through stable isotope analysis

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Location: Khumbu Valley, Nepal

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Abstract

This report details an expedition undertaken in October 2024 to collect water samples from the Khumbu Valley, Nepal for the purpose of using stable isotope analysis to assess the contribution of glacial meltwater to the flow of the Dudh Koshi river. I (with the aid of field guide Shiva Bhantana), collected river, stream, snow, and glacial ice samples while trekking through the Khumbu Valley between Lukla and Gorakshep. 45 samples were successfully recovered and returned to the UK, whereupon the samples were analysed for the proportions of oxygen-18 and deuterium isotopes. This data fills a gap in previous sampling efforts in this region and can be used alongside previous data to assess seasonal fluctuations in the importance of glacial meltwater to water resources and risks throughout the Khumbu Valley, which will be crucial information over the coming decades given the accelerated melting of the Khumbu Glacier in response to anthropogenic climate change. Preliminary results indicate that glacial meltwater is a strong contributor to water resources in the upper valley, particularly during the weeks immediately following the monsoon.

1. Introduction

Glaciers are important stores of fresh water which can make a crucial contribution to the water security of communities, particularly in high mountain areas. Meltwater produced by a glacier during melt periods will flow downhill and eventually join rivers and streams, which may serve as an important source of water for a variety of human purposes, as well as sustaining ecological populations. However, glaciers worldwide are shrinking, which brings into question how the flow of glacier-fed rivers will change over decadal timescales. As such, it is important to quantify the contribution currently made by glaciers to water resources in order to identify regions vulnerable to drought or flooding as a result of accelerated glacier wastage.

The contribution made by glacial meltwater to river flow is difficult to gauge. Measurements of water discharge at a glacier terminus stream do not constitute measurements of meltwater output, partly because there may be other contributors to glacial streams, such as rain incident on the glacier surface, and partly because there may be multiple routes by which meltwater leaves the glacier, some of which may be hidden. Attempts to recover the meltwater contribution via glacio-hydrological modelling are necessary, but modelling studies must be calibrated against in-situ observations. One way to indirectly measure the contribution of meltwater to river flow is to use isotopic analysis. Samples of river water, as well as samples of contributing sources of river water such as glacial meltwater, precipitation, and groundwater are collected in the field, and then measured for the proportions of oxygen-18 and deuterium in each sample. Once an isotopic profile is assigned to each contributing source, a simple set of simultaneous equations can be used to 'un-mix' the river into the fractional contribution made by each source.

This project addresses that aim for the Dudh Koshi river, located within the Khumbu Valley in north-eastern Nepal. This glacierised region is subject to strongly seasonal weather patterns, and as such the contribution of glacial meltwater to the Dudh Koshi is also likely to have a seasonal dependence as precipitation and glacial melt rates fluctuate. Therefore, samples collected at any one time will not be representative year-round. While many samples have previously been collected during the winter (December-February) and pre-monsoon (March-May) seasons, the monsoon (June-September) and post-monsoon (October-November) seasons are under-sampled, which prevents an understanding of the year-round importance of glacial meltwater to water resources from being established. The under-sampling during the monsoon is difficult to address due to practical difficulties- the very high volume of monsoon rain swells the river, making the collection of river samples dangerous, and the saturated ground is subject to landslides. However, sample collection during the post-monsoon season is more feasible, and as such was identified as a research opportunity for this project to address. Samples collected during the post-monsoon will be synthesised with pre-existing samples to create a year-round database of isotopic data from the Khumbu Valley, enabling a more comprehensive assessment of the hydrological risks associated with glacier wastage.

1.1. Study Area

The Khumbu Valley is located in eastern Nepal, approximately 140 km ENE of Kathmandu. The valley ascends along a south-north axis. The gateway to the lower valley at Chhirdi is approximately 1500 m above sea level, and the upper valley extends to the summit of Mount Everest at 8849 m. The lower and upper reaches of the valley are separated by a steep ascent between the towns of Phakding (2610 m) and Namche (3440 m). The Dudh Koshi river, which flows through the valley, is fed by streams originating at the termini of several glaciers in the upper valley, including the Ngozumpa, Imja, and Khumbu glaciers (the latter extending over the southern slopes of Everest). The upper valley constitutes Sagarmatha National Park (SNP), which is supplemented by a buffer zone to the south extending into the lower valley.

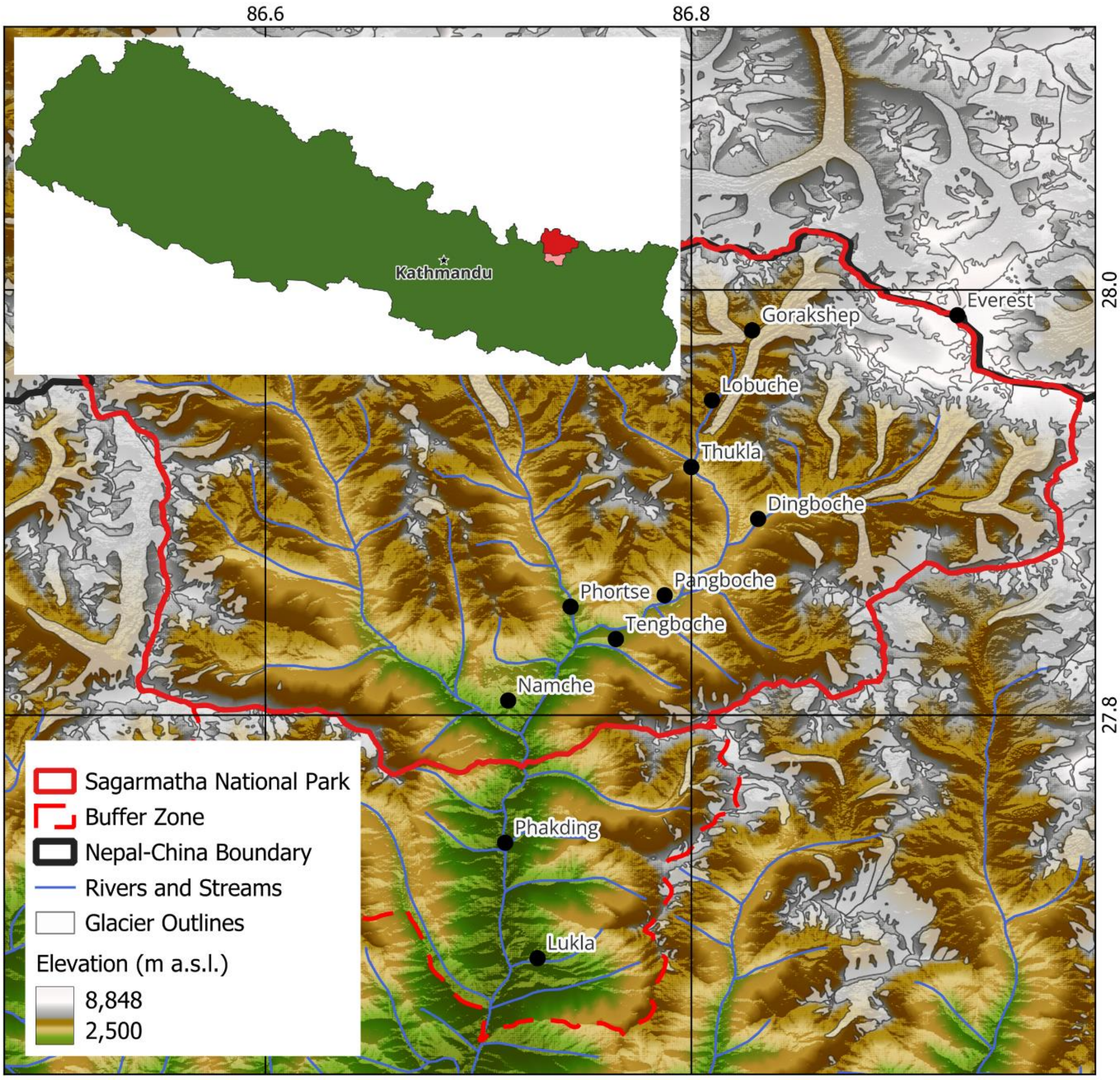

Figure 1: Map of Sagarmatha National Park (SNP) and buffer zone. Towns along Everest Base Camp trail are highlighted. Inset highlights SNP and buffer zone location within Nepal.

For the purposes of this report, the Dudh Koshi river is defined with an origin at the terminus of the Khumbu Glacier. While this is not conventional (it is more commonly considered to originate at the Ngozumpa Glacier outlet, meeting the Imja Khola below Phortse), here 'Dudh Koshi' is simply used as a convenient name for the continuous flow of surface water from the Khumbu Glacier down through the valley, so that glacial melt contribution can be assessed along a coherent transect of flowing water.

1.2. Scientific Rationale

Melting glaciers are one contributing element of hydrological regimes at the catchment scale. Precipitation is the ultimate source of all river water, but it is stored over periods ranging from minutes to millennia by various buffers such as vegetation, wetlands, aquifers, reservoirs, and seasonal snowpacks, in addition to glaciers. All of these components of the hydrological system are affected by human behaviour, either directly (deforestation, dam construction) or indirectly (anthropogenic climate change). Each component fluctuates seasonally, and the way in which these seasonal cycles compound determines the local hydrological regime. The glacier meltwater fractional contribution therefore depends not only on glacier melt rates, but on the timing of other contributing sources of river flow.

As the world warms, glaciers everywhere are losing mass. Higher air temperatures lead to accelerated melting of glacier ice, which in turn entails higher rates of glacial meltwater runoff. On short timescales, this creates an increase in the contribution glaciers make to local hydrological regimes. However, over longer timescales, mass loss results in glacier shrinkage. The increased output of water cannot be sustainable, because eventually the glacier shrinks to a sufficient extent that the surface area available for melting is restricted and the total rate of meltwater production reduces, even if the melt rate per unit area continues to increase. Thus, the concept of 'peak water' has been developed to refer to the pattern of meltwater output from a given glacier over decadal timescales, wherein an initial increase in output due to higher melt rates reaches a peak, then declines as the glacier area shrinks.

This changing pattern of glacier meltwater output is important for communities downstream of glaciers. In general, large population centres close to glacier-fed rivers but far downstream of the headwaters are unlikely to feel much of an effect, as the glacial contribution as a fraction of river discharge is in almost all cases very small in downstream regions (the Indus, Amu Darya, and Rio Santo rivers are notable exceptions). However, for mountain communities the contribution of glaciers to river flow can be crucial, and fluctuations felt keenly.

Changes to glacier meltwater output can represent both opportunities and risks. An increase in river flow can provide resources for irrigation and power generation via hydroelectric dams, but could also present a flood hazard. A decline in river flow after glacier peak water has passed could lead to seasonal drought. In any given region, mitigation of (and adaptation to) changes in future river flow requires knowledge of the current balance of contributing water sources, and how they vary seasonally.

My research addresses this need for the Khumbu Valley. Precipitation is strongly seasonal in this region, as the South Asian Monsoon over the months June-September provides up to 76% of the annual precipitation. Seasonal snow mostly melts in the spring, and while the lower valley is forested, there are communities above the tree line in the upper valley, so vegetation will have a limited effect as a seasonal water store. There are no reservoirs or wetlands in the Khumbu Valley, so in the post-monsoon and winter it could be anticipated that glacial meltwater and groundwater will likely be important contributors to the flow of the Dudh Koshi river, particularly in the upper valley.

A more quantitative assessment of the glacial meltwater contribution is required for meaningful conclusions to be reached concerning future changes in Dudh Koshi river flow in the context of glacier shrinkage. My research uses stable isotope analysis to assess the relative contributions that precipitation, glacier melt, and groundwater make to the Dudh Koshi river. The fieldwork described in this report concerned the collection of water samples throughout the Khumbu Valley during the post-monsoon period for that purpose.

1.3. Previous Similar Work

Stable isotope analysis has previously been conducted for water samples from the Khumbu Valley. The earliest such published data is from Wushiki (1977), who analysed samples of precipitation collected between 1973-76 at Lhajung, near Dingboche. That study only measured the deuterium ratio of the samples and not the oxygen-18, which makes it of limited use for my purpose (but perhaps a useful marker in how deuterium content has changed over the last 50 years, which may reveal insights into changing sources of seasonal precipitation).

More recently, Balestrini et al. (2014) collected samples of precipitation and surface water (river, stream, and lake) between Pheriche and Gorakshep in 2007-08. While detailed isotopic data in full were not published, this publication demonstrated that surface waters, particularly the Dudh Koshi river, demonstrate much lower seasonal variation in both deuterium and oxygen-18 than does precipitation. This indicates that precipitation is not a dominant source of river flow in the upper valley.

Chevallier et al. (2017) conducted several field collections in March, May and November 2014-17, sampling the river, streams, groundwater, and precipitation between Kharikhola in the lower valley and Lobuche. The published data are mean values, which can make them difficult to interpret when the same location was sampled in multiple seasons, but this study provides the only previous dataset of surface water collected during the post-monsoon and will be a crucial comparison with my samples. Florea et al. (2017) collected river, stream, and spring samples between Phakding and Pheriche in March 2013. The isotopic results were published in full, and include easily the highest volume of groundwater samples from this region.

Acharya et al. (2020) made public the isotopic data from a long-term precipitation collection project, with collection points located at Lukla, Khunde (nr. Namche), and Lobuche. Precipitation was collected at each site on a daily timescale, throughout 2014-17. Dr Sunil Acharya is a collaborator of mine, and his sample collection has also continued over more recent years. The precipitation samples are extensive and year-round, and will be well suited for creating a seasonally varying pattern of precipitation isotopic profiles, which will be crucial for identifying precipitation input to the river samples. Wood et al. (2020) collected river and precipitation samples, as well as one glacier melt sample, in April and May 2016-17. This study sought to quantify glacier melt contribution to river flow in much the same way as I will and will be a useful check on my results in the pre-monsoon season.

Dasgupta et al. (2021) collected river, stream and snow samples throughout December 2018-January 2019. Hundreds of samples were collected between Lukla and Lobuche and constitute the only surface water samples collected in winter, revealing another crucial part of the seasonal cycle. Clifford et al. (2021) collected some stream samples near Pheriche, an ice core from the Khumbu Glacier, and many snow samples from the Western Cwm in April-May 2019. This study provides the highest altitude samples available, and the most focus on glacier ice isotopic profiles.

In addition to the above, there are several studies which may be of value as a point of comparison, or for wider context. Racoviteanu et al. (2013) performed similar sampling and analysis work to that described above, but for the Hinku Valley, the eastern (and parallel-inclined) neighbour of the Khumbu Valley, which may reveal the rate of spatial variation of the isotopic profiles. Takeuchi et al. (2020) presents isotopic data from two ice cores collected from the Western Cwm in 1980, which will help to reveal the temporal variability in the isotopic profiles, particularly when compared to the Clifford et al. (2021) samples from the Western Cwm. Lastly, Yang et al. (2023) presents data from a large collection of samples throughout the Khumbu Valley over several field collections, extending to the Everest summit. The data were not presented in full, but were provided by the author on request. Unfortunately, the metadata were not clear enough to enable the isotopic data to be matched to the sample location, and no further clarification was provided on request, which makes the provided data not usable for my analysis. The findings presented in their publication my be a useful comparison with my findings.

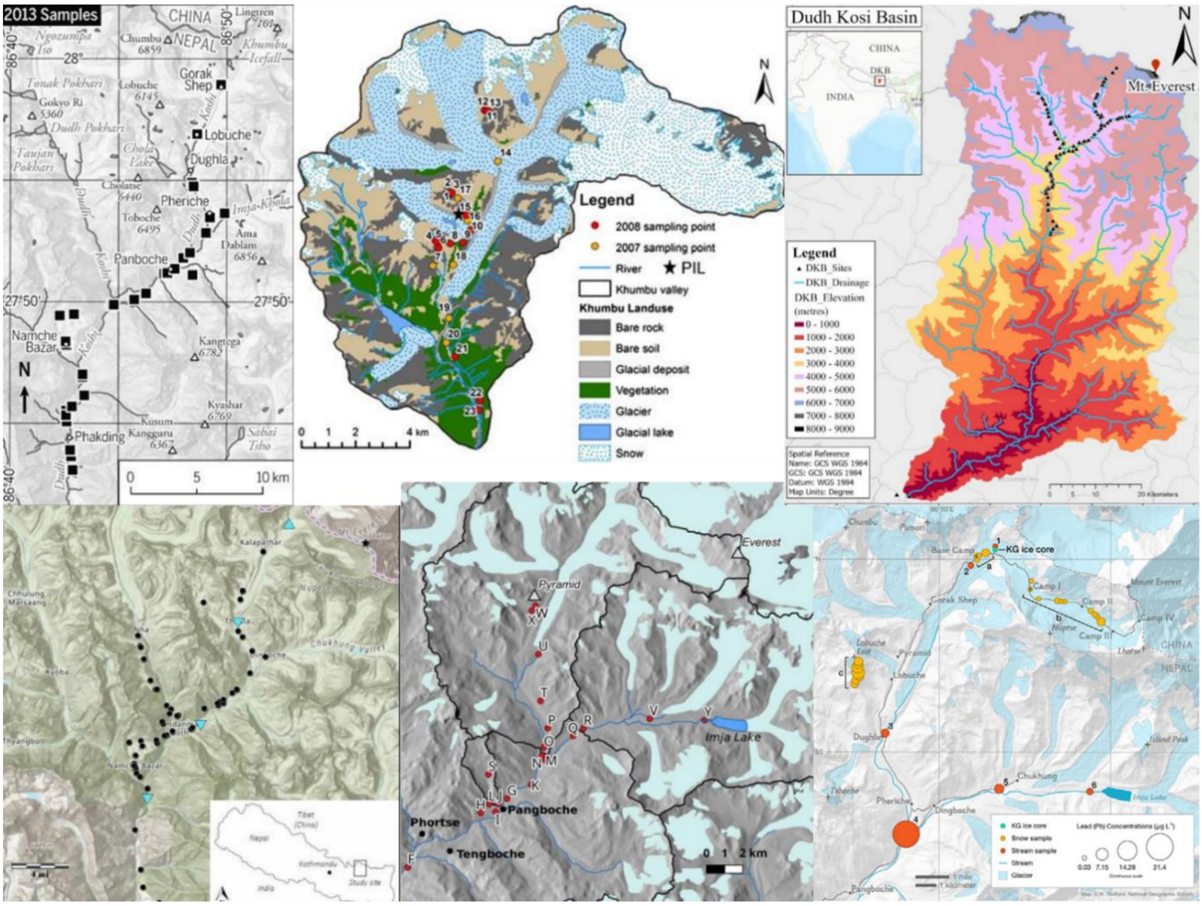

Figure 2: Maps of samples collected in previous studies. From left to right, top to bottom: Florea et al. (2017), Balestrini et al. (2016), Dasgupta et al. (2021), Wood et al. (2020), Chevallier et al. (2017), and Clifford et al. (2021).

2. **Planning**

Having decided on October as the optimal period in which to collect samples to complement the existing available data described above, I set about planning the expedition. The main areas to address were:

1. Funding
2. Collaborators
3. Trekking Logistics
4. Travel
5. Equipment
6. Scientific Procedure
7. Admin

The order of this list is arbitrary as the planning across all these components had to be done concurrently, but to provide structure I will describe the planning for each component in turn.

2.1. Funding

I attended the RGS Explore Symposium in 2023, in part to better understand the funding landscape for early-career and student geography fieldwork in the UK. In the week preceding the symposium, I had attended a workshop at the RGS on planning mountaineering expeditions, which was followed the same evening by the MEF annual lecture. These events in October-November 2023 helped me to identify the MEF and the RGS Postgraduate Research Award as the most appropriate sources of funding for my fieldwork (as well as providing a wealth of advice on fieldwork planning and execution). Other potential grants I identified for the project were a National Geographic Level 1 Explorer Grant, or a GEO Mountains Small Grant. However, I felt that the MEF and RGS were the most appropriate sources, given the scope of the project and my student status, and resolved to prioritise making the best application possible to those organisations. I have some discretionary research funds for my PhD expenses, which would not be enough to fund the fieldwork, but which I was confident could bridge a partial shortfall in funding. Making the best application possible was a process of seeking advice where possible, drafting the application multiple times with help from my supervisors, and working proactively to get the planning done well in advance to be able to make a detailed case for the project.

2.2. Collaborators

Working with Nepali collaborators was always a priority, not only for this fieldwork but for my PhD in general. My supervisors Dr Tom Matthews and Dr Baker Perry had a network of contacts they could direct me towards from their previous fieldwork in Nepal. I contacted Dr Deepak Aryal at the Central Department of Hydrology and Meteorology, Tribhuvan University, Kathmandu, to ask if he knew of any appropriate candidates. He passed me on to Sunil Acharya of the same department, who specialises in the isotopic analysis of water samples. I already knew of Sunil's published work (some described in section 1.3), and he will be a key scientific collaborator when analysing my sample data.

At the same time, my supervisor Baker put me in touch with Navaraj Pokhrel as a potential early career collaborator to be actively involved in the sample collection. When I contacted Navaraj, he suggested Sandesh Tamang, a master's student at Tribhuvan, as the most appropriate candidate. After contacting Sandesh, it was clear from his field experience in the Khumbu Valley and his scientific background in collecting hydrological and meteorological data that he was an excellent candidate for this project, and he became involved as a collaborator for the field sample collection.

2.3. Trekking Logistics

I had received many recommendations for various trekking agencies to contact about my plans. I set about contacting all of them, describing the proposed fieldwork and my specific needs, and asking for an estimated quote to facilitate the accommodation, in-country travel, food, guide, and permits. I received a wide range of responses. From the many discussions I had with different agencies, I selected Desire Adventures Nepal, run by Navaraj Thapa, as my preferred option. I chose this agency because of the care and attention that Nava gave to my messages, and the changes that he made to the itinerary and quote in response to my requests. Some agencies clearly did not fully read my messages, and only sent a stock Base Camp Trek itinerary without making the alterations I had requested to facilitate the fieldwork. Nava provided a reasonable quote, and did not attempt to upsell me any unnecessary additions, so I felt I was in good hands. Desire were honest about not having previous experience facilitating scientific fieldwork, and I felt this was not a necessity as the sample collection is a simple procedure not requiring unwieldy or sensitive equipment, and the main requirement was a flexibility on behalf of the agency and guide to adapt the itinerary based on my requests.

2.4. Travel

Travel from London to Kathmandu was a straightforward planning procedure. Having looked at flights on the selected dates, the main options were to fly with Air India via Delhi, Qatar Airways via Doha, or Emirates via Dubai. Air India via Delhi was the cheapest option, so I booked that.

I decided early on that I wanted to avoid flying within Nepal. The most common way for visitors to reach the Khumbu Valley is to fly from Kathmandu to Lukla Airport (a.k.a. Tenzing-Hilary Airport) and trek from there, but I wanted to avoid this for several reasons:

- Travelling overland via 4x4 would be more environmentally friendly
- Taking the road would allow me to begin the sample collection lower down the valley, thus increasing the altitudinal range of my samples
- Beginning the trek from a lower elevation would allow for a more gradual altitude acclimatisation process

Accordingly, I arranged with Desire Adventures to take a jeep from Kathmandu to Phaplu, and begin the trek from there, and the same on the way back.

2.5. Equipment

I consulted with my supervisor Prof Richard Taylor about the sampling equipment I would need, drawing on his extensive experience collecting water samples for isotopic analysis. He recommended 2 ml glass vials with septum caps, which are appropriate for the Picarro isotopic analyser we would be using. As these 2 ml vials are very difficult to fill in the field due to their small aperture, he also recommended 30 ml HDPE bottles for the initial field sample collection, and pipettes to decant the collected samples into the vials. Richard was able to loan me a syringe and filter papers, to filter any dirty water samples, which could otherwise clog the analyser.

In terms of trekking equipment, I felt I already had everything I needed from previous trekking and fieldwork experience. The equipment I took was:

- Waterproof jacket, trousers, gaiters, and cap
- Trainer-type walking shoes with waterproof uppers
- Two pairs of walking trousers (one very light, one thicker)
- Fleece
- Down jacket
- Sun hoody
- Photochromic wraparound sunglasses
- Down sleeping bag, plus a silk liner
- Beanie hat
- Buff
- One pair of waterproof warm gloves, plus a thinner, more tactile pair
- Wool tshirts, underwear, walking socks, and base layer top and bottom
- 50 l backpack with rain cover
- 22 l waterproof daysack

- Variety of drybags
- Waterproof notebook and pens
- Trekking poles
- Power bank
- Sunblock
- First Aid kit
- Head torch plus spare batteries
- Reusable zip ties, tenacious tape, multitool
- Basic toiletries
- Small microfibre towel plus face towel
- Small trowel
- One water bottle with filter, one without
- Hut slippers
- Handheld GPS device and communicator (borrowed from my supervisor Tom)
- Phone, charging cables, etc
- Inflatable camping pillow

This kit served me very well, and I was prepared for all circumstances I encountered. I would recommend a similar kit list for anyone planning an expedition in this region. The only things I would change if I were to go again would be finding a lighter-coloured and more breathable sun hoody, as the solar radiation is very intense and I found myself overheating, and sturdier shoes, as the upper separated from the lower during some scrambling, and I was lucky not to subsequently encounter rain as my shoes would definitely have let in water.

Items I would highlight for others planning travel in the same region are the sun hoody (enormously useful for protection from the intense sunlight, as sunblock and a tshirt are not protective enough), filter water bottle (I met other trekkers who struggled to get enough clean water), hut slippers (it is a relief to take shoes off in the lodge after a long walk), and wraparound sunglasses (important on the glacier, where sunlight reflects up from the ice and snow). The sleeping bag liner was a useful item, as I could use it by itself lower down where it was warm at night, and it provided extra insulation inside the sleeping bag in the higher altitude lodges where nights were cold. I purchased a Nepali SIM card in Tribhuvan Airport, which ensured I could access the internet along most of the trail (this saved me from paying high fees for WiFi in lodges). A good capacity power bank is very useful (mine was 10 000 mAh), as otherwise you pay a lot in lodges to charge devices. The inflatable pillow was a welcome luxury as many beds in lodges don't have pillows, and a bad back is best avoided when trekking. I supplemented my first aid kit with acetazolamide (brand name Diamox), which can be bought cheaply at pharmacies in Kathmandu, and took one per day on the trail to help ward off altitude sickness.

2.6. Scientific Procedure

The sampling procedure was straightforward for this fieldwork. The 30 ml bottle used to collect the sample should be washed through several times when taking a sample, to eliminate any traces of a previous sample. The same goes for the pipette or syringe when decanting into the 2 ml vial. The 2 ml sample vials are best not being reused, I took 200 to ensure I would have more than enough. All bottles and vials were labelled with unique numbers in advance (this is best not done in the field). I set out tables for the metadata in the waterproof notebook in advance, again not something you'd want to do on site. I would collect a sample in a bottle then immediately fill in the metadata (time, place, sample bottle number, type of sample, notes). I got the latitude, longitude, and altitude of each sample location using the handheld GPS. In the lodge each evening I would then decant the day's samples into the glass vials, filtering any dirty samples, and adding the vial number(s) to the metadata. One in every five samples would be decanted into two vials, as duplicates are useful to check that the analyser is working correctly. I would then copy the metadata into two additional places: paper kept in my daysack, and an app on my phone. This ensured that the metadata would not be lost if anything had happened to either of those, or the notebook. In hindsight, a cloud-based document would have been even safer than an app stored locally on my phone. Taking photos of the notebook pages would also have worked. I showed my guide Shiva how to collect samples when we first started trekking, so that he would be able to collect some if for any reason I was temporarily unable to (though this did not end up being necessary). Potential sample locations were identified in advance using a trekking map, and maps from previous sample collections (those in Figure 2), though in practice identifying sample locations was much easier on the ground.

2.7. Admin

Being based in a university, there were many resources to help me with fieldwork planning. I drafted a risk assessment (with input from Tom, based on his experiences in the Khumbu Valley), and it was approved by my department health and safety coordinator. Similarly, my university was able to provide very comprehensive travel insurance (including helicopter medevac) at no cost to myself, a privilege for which many trekkers have to pay considerable sums. I attempted to complete an ethical assessment, but my proposed fieldwork did not meet my university's criteria to complete one, as it did not involve human data collection.

I was able to get travel vaccines for Nepal (Hepatitus A, Typhoid, and a Diptheria, Tetanus & Polio booster) provided at no cost to me through my NHS GP.

I sourced a 30-day tourist visa for Nepal at a cost of £40, which I got in-person at the Nepali Embassy in Kensington. This can also be done on arrival, but the embassy is convenient for me in London anyway, and it saved a very long queue in the airport.

I calculated the CO_2 emissions of my air travel (3.0 t) using the website myclimate.org, and through the same website paid to offset these emissions at a cost of £64. Myclimate support renewable energy, reforestation, and moorland renaturing projects in Africa, South America, and Asia, and meet the strictest offsetting standards.

I was able to secure assurance in advance from my colleagues at Tribhuvan University that I was allowed to collect the field samples, and that they would secure for me any required permissions to export my samples to the UK. We did discuss the possibility of me performing the sample analysis at their institution, but their department was moving into a new building, and the isotopic facility would not be ready in time, so I stuck to the original plan of processing the samples in London.

3. Fieldwork

3.1. Travel

My arrival in Kathmandu coincided with devastating floods in the Kathmandu Valley. The rate of rainfall was the highest recorded since 1970, and tragically over 200 people lost their lives. The extreme precipitation caused river levels to rise rapidly, and in addition the ground became saturated, which resulted in landslides on sloping ground. These landslides destroyed roads and bridges, buried cars, and damaged electricity and water supplies.

I arrived just after the rain had slackened off, and the worst of the damage had been done. While keenly aware of the bigger picture of a national tragedy, it was imperative that I respond quickly to change my fieldwork plans. I immediately met with Navaraj from Desire Adventures to discuss the situation.

The main road I had intended to take towards Phaplu had been damaged by landslides and would not be passable again for several weeks. We discussed alternative options for road travel, but it was unclear immediately which roads were closed, when they would open again, and how long it would take to reach Phaplu by road. We agreed to meet again the following day when things might be clearer, and to postpone the outward travel by an extra day in the hopes that more roads would have been cleared.

Shortly after meeting Nava, I was able to talk to my collaborator Sandesh. I had been worried after several days of not hearing from him while seeing the news coming in. I was very pleased to get an email response from Sandesh, and to hear that he was in Kathmandu and available to meet me. When we met, Sandesh informed me that he was OK, his family and home were safe, but sadly his village had been very badly affected by the floods. He was understandably not in a position to participate in the fieldwork. He tried to find among his degree cohort an alternative candidate to take his place, but between the flooding and the upcoming Dashain festival in Kathmandu, unsurprisingly no one was able to substitute in for a month's fieldwork at such late notice. I was disappointed not to be able to collaborate with Sandesh or have any early-career Nepali scientist involved in the data collection as planned, but such extreme circumstances could not be helped.

The next day's meeting with Nava helped to clarify our plans. So many roads were closed that travelling overland to Phaplu was not feasible, and flying was the only option other than delaying the travel by over a week. A delay that long would not have left enough time for the trek, so I reluctantly agreed to fly to Lukla. We quickly drew up a new itinerary for the fieldwork as a whole, retaining the original plan to travel back to Kathmandu overland, hoping the roads would have re-opened by then. The new arrangements were considerably more expensive, but after informing Nava that Sandesh was not longer able to participate, Nava generously agreed to use the money I had already paid up front for Sandesh's expenses to cover all the new additional transport and accommodation costs. I am grateful for his tireless work and adaptability during a very stressful time.

Internal flights within Nepal had been cancelled for several days during the heavy rain, so there was a huge backlog of travellers in Kathmandu waiting for flights to Lukla, and it would take me at least a week to get on a flight if I joined the back of that queue. We decided instead that my guide Shiva Bhantana and I would travel by jeep to Manthali near Ramechhap Airport and fly to Lukla from there. The backlog of delayed travellers was smaller there, so we were optimistic of getting a flight within a few days. The main road to Manthali had been taken out by a landslide, but a smaller mountain road was still open.

The next day saw Shiva and I getting a jeep in the early morning. The smaller mountain road had also been affected by landslides, but our driver was a brave and capable off-roader, and he managed to traverse the terrain. The usual four hour journey took nine fairly hair-raising hours, and I arrived in Manthali grateful to stretch my legs, and feeling sorry for our driver who was turning around and driving back home to Kathmandu.

Shiva and I set off as early as possible walking to Ramechhap Airport the next morning. Not having made earlier arrangements to fly, we were relying on making ourselves available for any flight with two empty seats. The airport was in quite a chaotic state, as many planes from Kathmandu had been unable to land at Lukla due to adverse conditions, and had been diverted to land at Ramechhap instead. The scene was one of all the guides surrounding the booths, trying to talk themselves and their clients on to the next plane, and the trekkers lounging on the concrete, trying to keep out of the sun, and attempting to fend off boredom. Shiva and I were there all day, but didn't manage to get on a plane, and walked back to Manthali thoroughly frustrated.

We set off again even earlier the next morning, but the day mostly progressed in much the same fashion. The situation became increasingly tense, because wind speeds were picking up at Lukla, and it was predicted that flights would be unable to land over the next few days. I started to think through the impact this would have on the fieldwork, fearing we might not be able to reach the glacier and collect ice samples. Finally, at 3pm Shiva informed me that the last flight of the day was leaving in less than an hour and that he had secured for us the last two seats, assuming that conditions in Lukla remained OK. A hurried dash through security saw us onto a tiny Sita Air plane, and 20 minutes later we landed bumpily but safely in Lukla.

Figure 3: Our plane after landing at Lukla.

3.2. Trekking

The trekking began immediately, as we decided to push on to Phakding that evening, rather than stay in Lukla. I collected the first sample from a stream on the way, and we reached our lodge about an hour after sundown.

I won't describe the trekking day-by-day. It was far from monotonous, as the views were spectacular, each Sherpa village had its own charm, and the relatively rapid altitudinal ascent brought new conditions each day. The walk from Phakding up to Namche was the hardest part as it was long, steep, and hot. The lodges became more spartan the further up the valley we went, but given that almost everything is transported by porters, yaks, and mules I was generally astonished by the facilities available. The company from trekkers, guides, and locals was welcoming, and the food hearty. I was pleased not to suffer from altitude sickness, though the walking became more arduous with decreasing oxygen levels.

The days followed a familiar pattern: a good breakfast in the lodge at 5.15, set off walking by 6. Collect samples wherever we could spot an opportunity. Find somewhere for lunch around noon. Continue walking and sampling, and we would usually reach our next lodge and finish the day's walking around 3 pm. I would then decant the samples, copy out the metadata, and chat to other trekkers while attempting to stay awake until dinner at around 6, lest I make it difficult to sleep at night. I would generally crash into my sleeping bag, exhausted, no later than 7.30.

The long walks and low oxygen levels make 10 hours of sleep per night feel like just about enough.

Figure 4: 'Fixing' the Phortse weather station

At Phortse, I met up with Kunsal Sherpa, who works at the Khumbu Climbing Centre. Together, we looked at the automatic weather station situated near Phortse village. It had stopped transmitting data the previous month, and we wanted to fix it if we could. The problem became apparent quickly. The transmitter, which was supposed to turn on once a day, transmit data, then turn off again, had got stuck 'on' permanently, which drained the battery faster than the solar panel could charge it, which ran the battery flat and stopped the whole station from functioning. Neither of us knew how to fix the transmitter, so we turned it off. We replaced the flat battery so the station could record data again, and I showed Kunsal how to download the data directly from the station. We decided this was the best option for the time being, as the station could continue to record data, and Kunsal could download the data and send them via email as and when required to get around the transmitter being out of action. The station has subsequently been fixed properly.

The trek up to Gorakshep was quick and uneventful. We moved on to the glacier to look for sites to collect samples, and I was both pleased and in a wider sense disheartened to find myself surrounded by melting ice. There were multiple exposed ice faces where I could sample melting glacier ice directly, and I also sampled running water in supraglacial streams. Moving on the glacier was easy as the lower reaches are mostly covered with rock debris, and as long as we avoided exposed ice, crampons were not needed. Downstream from the Khumbu Icefall, the surface is level (albeit hummocky), and there are no crevasses.

At Gorakshep I finally succumbed to the dreaded 'Khumbu cough', essentially the common cold which is very prevalent on the trail. The system of lodges, where trekkers mix between different company each night, mostly in poorly-ventilated open spaces, is perfect for transmitting viruses, so if one person on the trail is ill, it spreads to everyone. I was prepared for the possibility of catching it from having read trekking blogs, though it definitely felt more severe than a usual cold, because the body is already under stress from the reduced oxygen. The best way to expedite recovery is to move to lower altitudes and more oxygen, which unfortunately


Figure 5: On top of Kala Patthar, near Gorakshep. The Everest summit dominates the background, and the Khumbu Glacier surface is visible below, plus glacial lakes

means having to press on with walking even when feeling rough. I fully recovered after a few days once I got back down to the lower valley.

On reaching Phakding on the way down, we got confirmation that the road from Phaplu was now passable again, so we decided to stick with our original plan of walking to Phaplu and getting a jeep, rather than flying back from Lukla. This was convenient, because conditions at Lukla had been foggy, and there had been several days without flights, and no signs of the fog letting up.

On trekking down past Lukla, we reached the part of the trail which is being turned into a road. Once complete, this will make things much easier for trekkers, as there will be an alternative to flying from Lukla (particularly useful given how often Lukla Airport is out of action due to wind or fog) which won't require extra days of trekking.

Unfortunately, on the trail between Surke and Paiya, I suffered a fall. The road development had left some surfaces unstable, and a rock gave way underfoot. I fell into a drainage ditch at the side of the road, and stopped myself by putting my arms out. I could tell immediately that my wrist felt 'off'. We kept walking, but I became uncertain whether I had suffered a fracture or a sprain, as the symptoms are similar at first. I decided that the best course of action was safety first, and we should get back to Kathmandu as soon as possible for a medical examination. Rather than walking down to Phaplu as planned, we decided instead to get a jeep from Bupsa, the furthest point along the trail that jeeps could reach at that time, which would save a couple of days.

The jeep from Bupsa to Phaplu took a full day, and was very slow and rough going. I imagine that spending nine hours in a tumble dryer would provide a comparable experience. We stayed in Phaplu, and got another jeep in the early hours back to Kathmandu. Though the road had been made passable, the devastation was still apparent. In many places, vehicles were diverted to drive along the riverbed, now mostly dry after the end of the monsoon. The journey was much slower than when the road was complete, and the full journey from Phaplu took 14 hours.

3.3. Samples

The sampling was a success, and 45 samples were recovered. The breakdown of sample types was 8 from streams, 28 from the Dudh Koshi, 3 from snowpacks, and 6 glacier melt samples. Unfortunately, the entire time I was in the Khumbu region, there was no precipitation whatsoever, so I was unable to collect precipitation samples. This is not a catastrophe, as precipitation samples are the kind most often collected in the Khumbu Valley anyway, largely due to Sunil's daily sample collection program. A good spread of river samples throughout the valley transect was recovered, which will allow for a thorough analysis of changes in river water constitution with altitude.

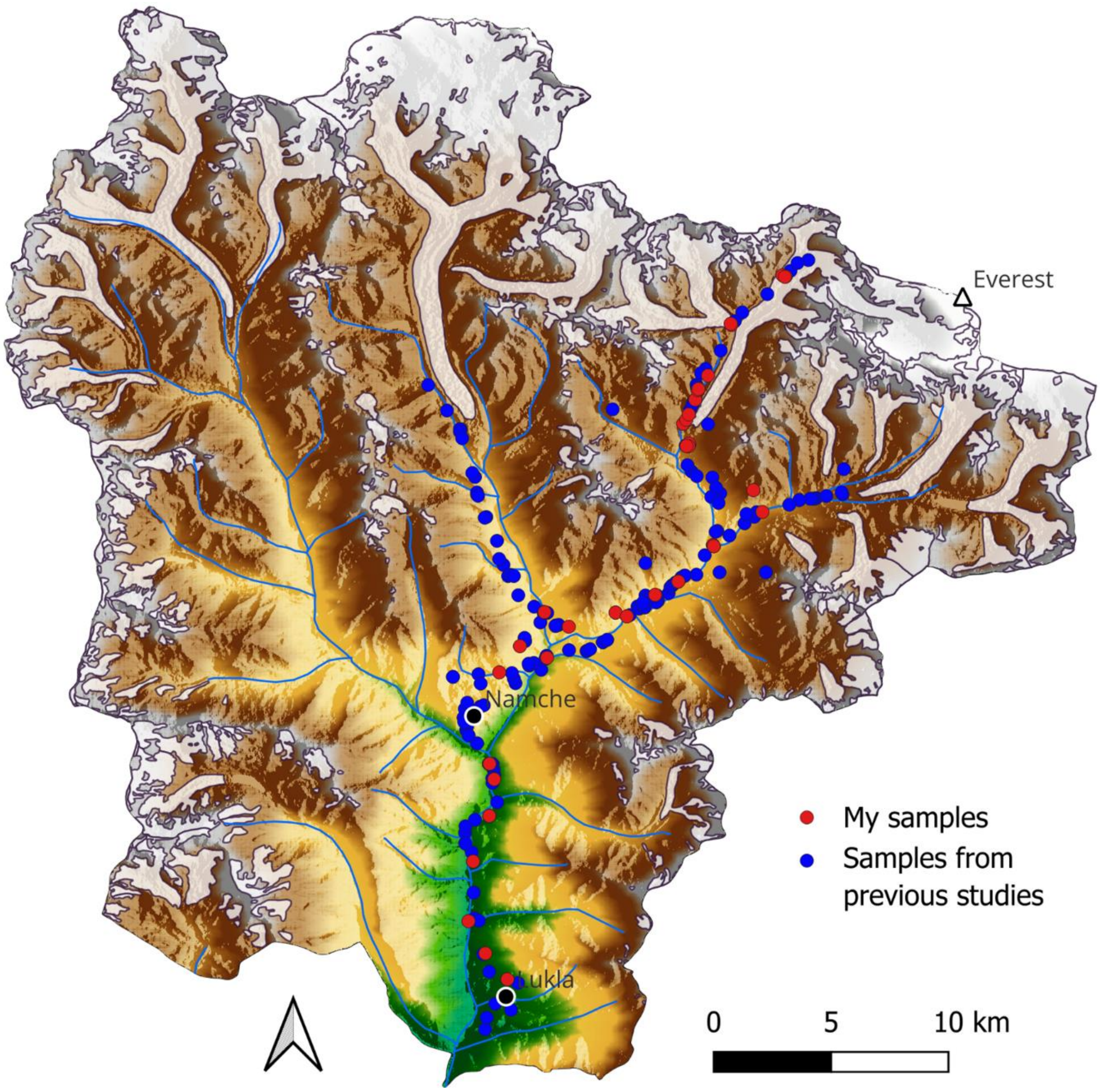

Figure 6: Map of samples recovered (red). They overlap well with samples from previous collections (blue)

3.4. Wrapping Up

Getting back to Kathmandu a few days early due to getting the jeep from Bupsa to Phaplu allowed me to visit my collaborators at the Central Department of Hydrology and Meteorology, Tribhuvan University. It was good to meet in person Sunil and Deepak, with whom I had exchanged many emails over the previous year, as well as Dr Dibas Shrestha, an eminent hydrometeorologist and glaciologist who has since been a co-author of mine. Those wrote a letter on TU headed paper, which I could show at the airport if my samples were queried. Sunil also showed me their new isotopic facility, which was not yet up and running but will be impressive. I was fortunate that my visit coincided with a course being taught to environmental science students from south and east Asia, facilitated collaboratively between TU and Institut des Géosciences de l'Environnement, Université Grenoble-Alpes. I was able to catch up with several glaciologists I had met on a previous visit to Grenoble, including Dr Arbindra Khadka, who I have also since co-authored with.

Figure 7: With Dr Sunil Acharya outside the new CDHM TU building, the all-important sample export permission letter in my hand

The day after visiting TU I unfortunately got a bad bout of food poisoning. I was almost entirely restricted to my hotel room for three days, and luckily recovered just in time for my flight home.

My wrist had already started to feel better by the time I reached Kathmandu, which made it very unlikely to be fractured. Since little can be done for wrist sprains other than rest, and a hospital visit would have been privately funded, I decided it wasn't worth the trouble and expense of getting a scan.

4. <u>Post-Return</u>

4.1. Scientific Analysis

After getting the samples home safely, I took them along to the Bloomsbury Environmental Isotope Facility at UCL. Richard helped me to prepare the samples ahead of using the Picarro L2130-i spectrometer. After the samples had been processed, I calibrated the resulting data using the FLIIMP package for MATLAB, aided by Jon Holmes and Trista Chang. The results so far look sensible, and suggest that the glacial melt contribution to Dudh Koshi river flow is higher than seen from previous sample collections. I hypothesise that this results from the high air temperatures on the lower glacier in October ensuring a good supply of glacier melt, coupled with the very low precipitation (none at all while I was there) reducing the rainfall contribution to only late monsoon rain re-routed through the subglacial hydrological network.

I have since made the calibrated isotopic data publicly available via the online repository Zenodo (https://zenodo.org/records/15799459). It was always a key aim of the project to share the data, along with comprehensive metadata, so it can be used freely. Contributors, including funding contributors, are acknowledged in the data description.

More in-depth analysis of the isotopic data will continue over the next 6 months. Un-mixing the river samples into the fractional contribution made from each source will require identifying an isotopic profile for each source, which may have to be seasonally-varying (especially for precipitation). One nuance which must first be addressed is whether to separate rain from snow as separate contributors with separate isotopic profiles, and likewise fresh snow from ground snowpacks. This will take some careful consideration from myself and Richard. Once fractional contributions have been assessed, these can be combined with existing observations of Dudh Koshi flow rates to estimate the volume of glacial meltwater being produced in total, and how it varies seasonally. This will be crucial for constraining hydro-glaciological modelling studies and projections of future Khumbu Glacier mass changes over coming decades.

Figure 8: The sample vials ready for analysis

4.2. Communication

I have given talks about the fieldwork, and the resulting data, in London at the Ocean and Atmosphere Climate Dynamics group, and at a King's College London Geography Departmental Seminar, as well as more informal presentations to several lab groups I'm involved with. I aim to give further presentations to the Centre for Polar Observation and Modelling this September, and at the Climate and Cryosphere Open Science Conference in Wellington, February 2026, and the European Geosciences Union General Assembly in Vienna, April 2026.

Both the fieldwork and the results have generated a high level of interest so far. Finishing off the data analysis and writing up a paper will go hand-in-hand. I will aim for a publication in a high-impact hydrology journal. The paper will not only present my new data, but synthesise them with the existing dataset, which has not previously been collected together, to provide a year-round picture of Dudh Koshi contributing sources. This will dovetail with other chapters of my PhD thesis, focussing on modelling Khumbu Glacier accumulation and ablation.

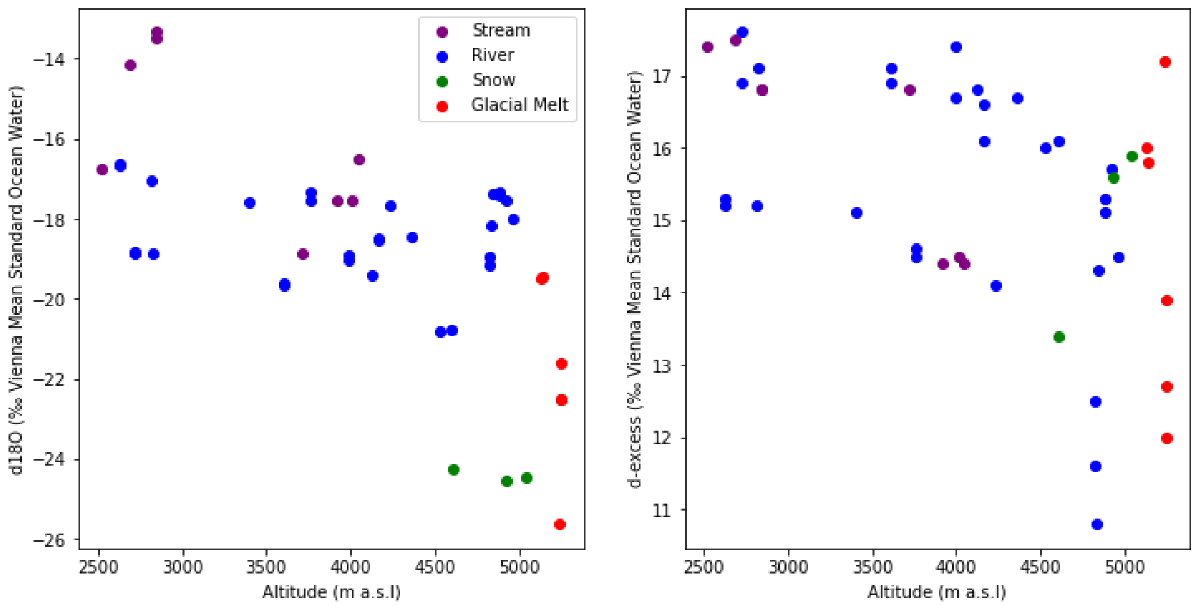

Figure 9: Preliminary results, showing river values becoming more similar to glacier melt profiles at higher elevations

Financial Report

Money In		£	Notes
	Mount Everest Foundation	4000	
	Royal Geographical Society	1000	
	Total	**5000**	
Money Out			
	Flights	1129.66	
	Trekking Agency	2724	Includes accommodation, travel in Nepal, guide wages, guide insurance, trekking permits, and food on trail
	Sample analysis	270	A very reasonable in-house rate of £6 per sample at UCL
	Equipment	59.50	For bottles, vials, and pipettes
	Tourist visa	40	See section 2.7 for details
	Carbon offsetting	64	
	Expenses in Nepal	454.47	This mostly consists of the extra few nights in a Kathmandu hotel, due to arriving back earlier than planned. Small purchases and guide tips are also included
	Total	**4741.63**	
	Remainder	**258.37**	
Returned			
	Mount Everest Foundation	206.70	Split in the ratio 4:1, the same as the initial input
	Royal Geographical Society	51.67	

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