Collaboration for Environmental Evidence

Systematic Review No. *CEE10-008*

WHAT IS THE EVIDENCE ABOUT GLACIER MELT ACROSS THE HIMALAYAS?

Protocol

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Cover Sheet

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1. Background

Mountain glaciers are amongst the most sensitive and readily visible indicators of climate change (Kaab, 2007). There is particular concern at the rate of retreat of Himalayan glaciers (Barnett et al., 2005) as they are vital sources of freshwater in one of the world's most populous, economically important and politically sensitive regions.

It has been reported that Himalayan glaciers will disappear by 2035, leading to widespread and catastrophic water shortages (WWF, 2005). Repeated by the IPCC in their 2007 assessment report (IPCC, 2007), these claims were recently exposed (Cogley et al., 2010) as having limited scientific basis, and have forced the vice-chairman of the UN's climate science panel to admit mistakes were made in producing the report. The claims appear to originate from a press interview of an Indian glaciologist in 1999, who, it is thought, misread findings of an earlier study (Kotlyakov, 1996), which suggested glaciers would disappear by 2350! Such a lack of scientific rigour and disregard of proper review procedures, coupled with some journalistic licence has resulted in many sceptics questioning scientific evidence used within such reports. The resulting furore demonstrates the importance of conducting reviews systematically. Only with transparent collation of evidence, based upon objective protocols, will truly critically appraised syntheses be available.

Despite much research, there remains no clear understanding of how glacier retreat varies across the region or how it might impact downstream stakeholders. Clearly this hinders well-informed, evidence based decision and policy making. A rigorous systematic review, to discern *what is the evidence about glacier melt across the Himalayas*, would be a major step to support policy-making in the region and supporting the Department for International Development's (DFID) increasing reliance on systematically derived evidence upon which to base policy decisions (Gasteen, *pers. comms*, 2010).

Existing studies that aim to collate evidence across the region and over the past decades provide a general indication that glaciers in the Himalayas have retreated since records were first kept (Raina, 2009; Rees, 2008). Other studies collating data however show that glaciers are in fact advancing in certain areas (Hewitt, 2005), or exhibiting conflicting behaviours within the same region (Fushimi, 1979). These highlight the potentially significant differences in glacier retreat or advance that may occur across regions, and both also point to localised factors causing differences between glacier fluctuations within the same region. Many such studies, however, do not draw on the primary sources for their conclusion in a systematic manner whereby one can see the relative weight ascribed to certain data in a transparent manner. Systematic reviews apply rigour and objectivity through all stages to provide such transparency in method and provide an independent approach to the available evidence (CEBC, 2010). Applying this objectivity could allow the spatial and temporal patterns to be identified according to the relative accuracy and weight applied to evidence so that as complete a picture as possible is gained of glacier retreat across the region. It may however highlight the lack of quality data and point to deficiencies in monitoring programmes across sparse areas that will not allow any regional synthesis to be possible.

The Himalayan region extends in a broad arc from Afghanistan to Myanmar over a distance of some 3000 km. The region covered within the scope of this review

contains the mountainous regions of the Hindu Kush, Karakoram and Greater Himalaya mountain ranges. These mountainous regions are the source of several major rivers, including the Indus, Ganges, and Brahmaputra. The review will be particularly useful to those responsible for regional water resource planning and natural hazard management, but issues pertaining to water resources and impacts upon human populations downstream of glaciated areas will not be considered within this particular review.

2. Objective of the Review

2.1 Primary question

What is the evidence about glacier melt across the Himalayas?

2.2 Secondary questions

- Are glaciers advancing or retreating, and are there regional differences?
- Is the rate of glacial melt increasing across the region?
- In what areas of research is evidence lacking and how best could future work ensure a more complete evidence base is developed?

Table 1: Definition of components of the primary systematic review question

Subject	Exposure	Outcomes	Comparators
Himalayan Glaciers	Climate and potential climatic changes such as changes in precipitation or temperature	Glacier fluctuation, variable rates of change, change in mass-balance, downstream hydrology, glacial lakes	Baseline data for glaciers, regional characteristics, stability, rate of change, localised factors

3. Methods

An important objective of a systematic review is to ensure the best available evidence has been used to arrive at a conclusion. The objectivity of the search criteria must be established early on. Glacier melt is a topic encompassing many discipline fields and clear search criteria are needed to ensure thorough coverage of all sources of evidence. The design of the search strategy is one that will identify a majority of available literature. The search language has been limited to English, due to time and resource constraints, which should encompass most specific journals and organisations. However it is acknowledged that there exists various research conducted within the region but published in other languages (e.g. Russian, German, Chinese) that could benefit further development of the evidence base on this topic.

3.1 Search strategy

Owing to the subject of this review the primary focus for the search strategy will be on the published peer review articles, elaborated and expanded from evidence sources made available by partners, as well as contributions from other grey literature sources. The grey literature sources will generally include reports from organisations with a history of operating in this study region. The websites of these organisations will be searched in a similar way as the wider literature search. Additionally a general web search will also be conducted.

3.1.1 Database searches

Two of the most widely used computerised journal databases will be searched; ISI Web of Science and Science Direct. The method will utilize a key-word search from a list of selected key words prepared by the review researchers (with input from partners) based on the title question as well as from the list of possible studies to be included in the review that are listed in the project proposal. At CEH we also have access to a federated search engine called Aspire, developed by OCLC, which through one search portal can access the following databases and internet sources;

- Bioone
- CEH Library Catalogue
- DOAJ
- Google Scholar
- Ingenta Connect
- J STOR
- NORA
- Science
- Science Direct
- Springer Link
- Web of Science
- Wiley Interscience
- Zetoc

Test searches using key terms that are contained within many papers upon this subject were conducted to help develop an effective search methodology that would capture as much of the literature as possible. These key words were collated and a search strategy developed that captured the key subject, exposure, outcome and comparator components within the question.

All the below listed key words will be used to search for all relevant papers and the resulting lists will be combined to develop a full list of the relevant literature available from Web of Science and Science Direct. A similar process will be followed using Aspire; however as this access's many of the journal and internet sources listed in the search strategy, it is believed this will return many of the same studies and reports. This will be tested and an applicable search strategy used, perhaps only using Aspire search databases not currently listed within the search strategy. Care will be taking in selecting Boolean operators to maximise the return of relevant literature.

Words reflecting change in Himalayan Glacier Melt

Glaci*	AND	(Himalaya* OR Karakoram OR Hindu Kush)	AND	melt*
				retreat*
				shrink*
				chang*
				differenc*
				fluctuat*
				Variation*
				"mass$balance"
				"mass balance" AND melt*
				"Glacial lake*"

				remote sensing
				surge
				advanc*
				ablation

Words reflecting change in Himalayan Glacier hydrological impacts

Glaci*	AND	(Himalaya*	AND	water resources
		OR Karakoram		climate
		OR Hindu Kush)		"climate change"
				hydrol*
	AND	(Indus	AND	temperature
		OR Ganges		flood*
		OR Brahmaputra)		flow*
				streamflow*
				extreme*
				precipitation
				Jökulhlaup*

Words reflecting impacts and methodology

Glaci*	AND	(Himalaya*	AND	impact*
		OR Karakoram		monitor*
		OR Hindu Kush)		predict*
				evidence
				melt AND evidence
				measur*
				model*
				asses*

Words reflecting measurements and change in Himalayan Glacier ice melt

(Himalaya*	AND	Ice	AND	melt*
OR Karakoram				retreat*
OR Hindu Kush)				shrink*
				advance*
				change
				differenc*
				fluctuat*
				Variation*
				“mass$balance”
				"mass balance" AND melt*
				“Glacial lake*”
				GLOF
				distribut*

Words reflecting change in Himalayan Glacier snow melt

(Himalaya*	AND	Snow	AND	melt*
OR Karakoram				retreat*
OR Hindu Kush)				shrink*

	advanc*
	change
	differenc*
	fluctuat*
	variation*
	“mass$balance”
	"mass balance" AND melt*
	“Glacial lake*”
	distribut*
	ELA
	TSL
	AAR
	snowline

The journals listed below are those that from expert feedback and analysis of existing studies into this subject best capture the types of research conducted. We will ensure that the search engines used retrieve articles from these journals, if not another database or search will be conducted that can access the journal in question.

Selected journal that should be captured in search
Annals of Glaciology
Annals of Association of American Geographers
Arctic, Antarctic & Alpine research
Bulletin of Glaciological Research
Chinese bulletin of science
Climate Variability and Change - Hydrological Impacts
Cryosphere
Current Science
Episodes
Geophysical Research Letters
Global and Planetary Change
Himalayan Geology
Hydrological Processes
Hydrological Sciences Journal
Interactions between the Cryosphere, Climate and Greenhouse Gases
International Journal of Climatology
International Journal of Remote Sensing
Journal of Climate
Journal of Earth System Science
Journal of Geophysical Research
Journal of Glaciology
Journal of Hydrology
Limnology and Oceanography
Microwave Remote Sensing of the Atmosphere and Environment V
Mountain Research and Development
Nature
Nature Geoscience

Photonirvachak-Journal of the Indian Society of Remote Sensing
Progress in Natural Science
Progress in Physical Geography
Remote Sensing of Environment
Water and Urban Development Paradigms
Water Resources Management
Water Resource Research
Water Resources Systems - Water Availability and Global Change

Once a combined list of published sources has been collated and all duplicates removed, a starting list of sources will be available. However this list will most likely result in a large number of papers, with initial indications pointing to over 1000 sources, thus will require an efficient method to remove those spurious hits that have little to do with the subject in question. This will be achieved by applying a simple set of exclusion criteria on journal articles at the title level. These criteria are clearly set out in the following 5 points:

1. Subject not Himalayan glaciers
2. Not contemporary study – the study refers to geo-morphological evidence relating to geological periods, rather than to recent periods when direct measurements of glacial fluctuations have been taken.
3. No reference to any of the outcomes or comparators mentioned
4. Biological or chemical study within the region not related in any way to glacial melt – such as studies of biota within the area
5. Modelling based studies – not suitable evidence for systematic reviews

After this filter selection the total number of publications will be reduced. In essence an assessment of the title will be conducted and only those articles passing the exclusion criteria will be kept. This will be subsequently refined further using a more detailed assessment of evidence sources abstract text using a refined inclusion criteria table that will clearly record which articles have been kept for reading at full text and why. The inclusion criteria developed are listed in section 3.2.

Two researchers will independently apply the inclusion criteria to sections of the evidence sources, recording their results so that it is clear how the list was refined. A Kappa analysis will be undertaken to assess the repeatability of inclusion criteria applied and to check there is agreement upon how to apply the inclusion criteria between researchers. The reference list will then be compared against an existing bibliography of studies upon this subject by Rees (2008) to validate search terminology and illuminate any keywords or evidence sources not uncovered.

3.1.2 Selected organisation search

A number of international organisations with a known history of operating in the subject area have been selected and these will be searched for any reports of projects important to this review.

List of Selected organisations:

- ICIMOD (International Centre for Integrated Mountain Development)

- FRIEND (Flow Regimes from International Experimental and Network Data)
- WWF (World Wildlife Fund)
- UNESCO (UN Educational, Scientific and Cultural Organisation)
- UNEP (United Nations Environment Programme)
- WGMS (world glacier monitoring service)
- IAHS (International Association of Hydrological Sciences)
- GLIMS (Global Land Ice Measurements from Space)
- DFID (Department For International Development)
- World Bank
- INSTARR (Institute of Arctic and Alpine Research)
- NSIDCC (National Snow and Ice Data Centre)
- IGBP (International Geosphere and Biosphere Programme)
- GWSP (Global Water Systems Project)
- IACS (International Association of Cryospheric Research)

Example key word search to be used on the above organisations' website:

Glaci* AND (Himalay* OR Karakoram OR "Hindu Kush") AND melt*
Glaci* AND (Himalay* OR Karakoram OR "Hindu Kush") AND "climate chang*"
Glaci* AND (Himalay* OR Karakoram OR "Hindu Kush") AND evidence

It is anticipated that the search engines on many of the sites will not be very proficient so the search will likely be a process of trial and error using single key terms to uncover sources. Sources that pass the exclusion criteria will be kept on record; however there is too much data to record every source given by such simple search engines. Inclusion criteria will then be applied to the sources main introduction or abstract. Again a clear record will be kept of those sources rejected and why.

3.1.3 General Web search

Two different internet search engines will be used: Google and Bing, along with Google Scholar. The key word search for this section will be more limited and the top 25-50 (dependant on quality of returned material) internet sites will be listed as shown in the example table below.

Key words to be used:

Glaci* AND (Himalay* OR Karakoram OR "Hindu Kush") AND melt*
Glaci* AND (Himalay* OR Karakoram OR "Hindu Kush") AND "climate chang*"
Glaci* AND (Himalay* OR Karakoram OR "Hindu Kush") AND evidence

The key word search has been limited due to the sheer volume of web material on this subject area, and the lack of focus on more scientific terminology that would be used in journal sources. Initial tests showed that the majority of hits were related to blogs and news articles that would not be admissible as evidence sources for this study, and are also subject to journalistic bias and lack of scientific rigour.

Example of table format

Source	Keyword	URL	Date	Include	Source type
search engine: Bing	Glaci* and himalay* and melt*	http://www.huffingtonpost.com/2	09/08/2010	No	News
		http://www.huffingtonpost.com/2	09/08/2010	No	News
		THE EFFECT OF DEBRIS ON GLACIE	09/08/2010	No	Presentation
		http://www.vector1media.com/ne	09/08/2010	No	News

The decision to enter the URL into either column titled “Yes” or “No” will be based on the inclusion criteria. Furthermore at least one of the questions listed below must be fulfilled for the URL to be entered into the Yes column.

- Is it a report?
- Does it show findings?
- Does it mention Data?

This rigorous selection is applied to filter the large amount of results originating from a general search of the World Wide Web. In this manner the relevance of the link will be expressed.

3.1.4 Grey literature sources

Non peer reviewed evidence, often termed ‘grey literature’, such as the studies listed above that would be found on organisation websites, will likely provide a wealth of data. We have access here at CEH to a good library of diverse literature on Himalayan Glaciers due to the involvement of Gwyn Rees on various studies into this particular topic. This library will provide a unique source of ‘grey’ evidence, selected according to our inclusion criteria. Our partners will also be able to provide access to unique libraries of grey literature.

3.1.5 Partner feedback and validation

Our review team comprises various experts from the UK and abroad who each will have particular access to evidence that may not be widely available through the search strategy outlined above, and will be able to assist in developing a more complete and validated bibliography of evidence. We will utilise an iterative feedback process whereby each partner will be provided with an evidence bibliography compiled using the methods discussed. This will have been tested for success by comparing against the reference list of Rees (2008) on the same subject, and attaining at least a 90% match of references relating to Himalayan glacial melt. Each partner will then be able to draw upon their unique knowledge and expertise in helping indicate any missing evidence sources and bringing unique evidence sources to the list that would not have been available to us. This should then provide as complete a bibliography as possible of evidence sources, validated by experts, from which to apply a more thorough selection of evidence according to inclusion criteria.

We will also utilize any other key studies that synthesize evidence from the region on this subject to ascertain if there are any sources that have been missed by the above processes. If such an analysis reveals significant gaps in the evidence base obtained, the above processes will be updated accordingly. Any extra studies will be added to the existing evidence list for application of the inclusion criteria. The initial list of studies to be considered for extra sources are:

Bajracharya, S. R., Mool, P. K., Shrestha, B.R.(2008) GLOBAL CLIMATE CHANGE AND MELTING OF HIMALAYAN GLACIERS. *Melting Glaciers and Rising sea levels: Impacts and implications* edited by Prabha Shastri Ranade. The Icfai's University Press, India.. 28 – 46pp.

Bhambri, R. and T. Bolch (2009). Glacier mapping: a review with special reference to the Indian Himalayas. *Progress in Physical Geography* 33(5): 672-704.

Dyurgerov, M.B. and Meier, M.F., (2005). *Glaciers and the changing earth system: a 2004 snapshot. Occasional Paper No. 58*. INSTAAR/OP-58. Institute of Arctic and Alpine Research, University of Colorado, Boulder, pp. 117.

Haeberli, W., (1996). Fluctuations of mountain glaciers. In: V.M. Kotlyakov (Editor) *Variations of snow and ice in the past and at present on a global and regional scale*. International Hydrological Programme IHP-IV Project H-4.1. UNESCO, Paris, pp. 35-43.

Mayewski, P. A. and P. A. Jeschke (1979). "HIMALAYAN AND TRANS-HIMALAYAN GLACIER FLUCTUATIONS SINCE AD 1812." *Arctic and Alpine Research* 11(3): 267-287.

Vohra, C.P., (1981), Himalayan glaciers, *in* Lall, J.S., and Moddie, A.D., eds., *The Himalaya, aspects of change*. Delhi, Oxford University Press, p. 138–151.

Young, G.J. and Neupane, B., (1996). *Bibliography on the Hydrology of the Himalaya-Karakoram Region. Glaciological Data Report GD-29*. World Data Centre-A for Glaciology (Snow and Ice), Boulder, Colorado.

WWF, (2005). *An overview of glaciers, glacier retreat, and subsequent impacts in Nepal, India and China*. World Wildlife Fund Nepal Program, pp. 70.

An assessment of extra sources identified from these key synthesis papers will guide subsequent development of the search strategy. Each additional source of evidence will be assessed to consider why the search had not captured it. If it is found that there exists a fundamental gap or flaw in the search strategy, such as missing a key journal or search term, then the strategy will be amended accordingly. Where it is found that the source would not be found by any conventional search, such as being a symposium paper or from a much earlier period, then all attempts will be made to access the source and a record will be made.

3.2 Study inclusion criteria

A fundamental element of systematic review evidence is that the data used within the study has been directly analysed or collated by the authors. This is an important statement to make when considering much of the available evidence sources on this subject. Much of the baseline data for glaciers prior to the 1970's is from field mapping. In the early 1970's spaceborne sensors enabled cryospheric studies based on satellite data (Raconviteanu et al., 2008), in addition more comprehensive fieldwork has since been undertaken (Vohra, 1981; Fujita et al, 2006; Dobhal et al, 2008). Where studies use baseline data from such an earlier period as a comparator then this must be available to the study, rather than simply making a comparison to a referenced source.

- **Relevant subject(s):** Studies that focus upon the physical aspects of glacier fluctuation and volumetric change within the geographical scope of the Himalayan mountainous regions of the Karakoram, Himalaya and Hindu Kush. This has been refined so that we only consider evidence on glaciers from these regions that feed ultimately into the Ganges, Indus and Brahmaputra River basins, as shown in Figure 1. We will also consider studies that assess the hydrological impacts of glacial melt, plus studies that assess glacial melt contribution to glacial melt outburst floods. We will not consider studies into the effects of glacier melt on people (society, economy, livelihoods) or the management of water resources.

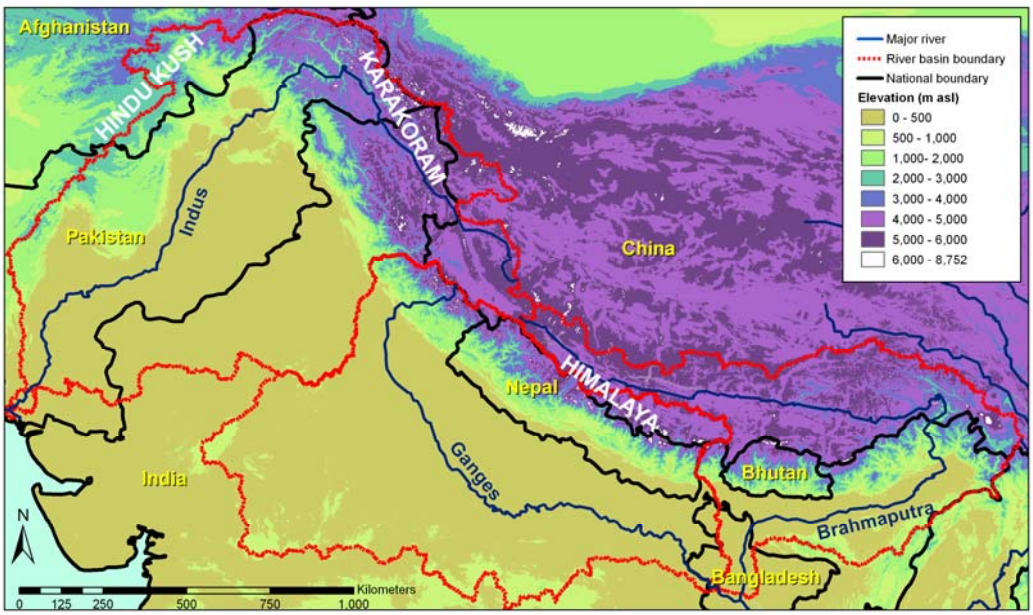

Figure 1. *Geographical extent of the review*

- **Types of exposure:** The key exposure factor causing glacier melt is the climate, and of particular interest will be the effects of climate change. These changes will often be measured as changes in ambient temperature, precipitation and also shifts in monsoon weather systems. Thus studies that explore the potential links between local, regional and global climate and glacier melt in the Himalayan region would be included. These studies must however use primary research data on glacier melt.

- **Types of comparator:** Baseline studies for glacier condition carried out in the recent past will form the core baseline comparator from which to assess the relative change in glacier area and mass, in order to assess the potential changes in melt that may have occurred over that period. This baseline will in most cases take the form of the first available evidence on the glacier obtained by expedition or aerial images. Baseline data must be available to the researcher for comparisons to be made (whether it is the physical map or actual photographs), with studies simply comparing recent data to referenced sources not being admissible. Many modern studies use a series of available aerial images and remote sensing data to determine a picture of glacier

fluctuation. This allows researchers to directly quantify changes in glacier measurements, outlined in outcomes, to determine relative changes in rate of change over time or regional differences.

The recent review of Himalayan glaciers by Raina (2009) is a good example of how baseline evidence and ongoing studies can be collated to form a body of evidence upon which to discuss and explore the relative patterns in glacier retreat/advance using a range of study types. While not providing a direct source of systematically analysed data, such studies provide a solid base from which to identify primary evidence sources from which comparators can be sought, and how data might be synthesized.

- **Types of outcome:** Quantifying glacial melt and identifying regional/temporal trends is the core outcome that this review will aim to achieve through available evidence. Three main study outcomes have been identified that will form the evidence base from which to develop inclusion criteria;
    - Glacier area / snout position
    - Glacier mass-balance / thickness / volume
    - Hydrological data

The difficulty lies in defining and systematically analysing evidence on glacier 'melt' without a clear definition of what is actually meant by melt. A reduction in area over time cannot be taken as a direct indicator that melt has increased, if the glacier as a whole has perhaps gained overall mass through accumulation in the upper areas. Similarly no change in area may not provide an indication that the glacier as a whole has lost mass and become thinner in places. The lack of hydrometric data and the complications in quantifying the downstream river flow component of glacier melt make hydrological studies a complicated source of evidence on glacier melt. Fundamentally each of these outcomes contains potential evidence, yet it will likely be through a combination of evidence type that more rigorous data are obtained. Another key difficulty in accessing data is the classified nature that is applied to such data by various countries, due to the political tensions that exist around national borders.

- **Types of study:** Studies that assess the changes in glacier position and/or mass over time, along with hydrological studies that are deemed of sufficient quality. These variables are assessed using a variety of methods that will be covered;
    - Field observations
    - Remote sensing satellite data
    - Aerial and terrestrial photography
    - Hydrological assessment

Studies must clearly explain the methodological approach, and greater weight will be given to those studies that make some assessment of potential error and bias within the research. Modelling studies will not be included as they are not accepted as concrete evidence upon which to base a systematic review.

- **Potential effect modifiers and reasons for heterogeneity:** The criteria to be taken into account include: slope, aspect, method employed, research group bias, field conditions, incomplete record, discontinuous record. Each of these might affect the measurement taken in the following ways;
    - **Slope –** glaciers on steep slopes will be prone to more sudden surges and delayed retreat
    - **Aspect –** the aspect of the glacier will affect the weather conditions it receives and thus the glacier
    - **Method –** different methods to measure the same thing could involve bias
    - **Research group bias –** different groups may be trained to different levels
    - **Incomplete record –** the distinct lack of continuous records will mean that inferences for glacier melt during intervening periods are made

  We do however foresee that considering such detail in studies, often not taking into account such potential modifiers; will be perhaps beyond the scope of this review. They will be considered further when analysing studies selected for detailed analysis.

Inclusion criteria will be tested by at least two reviewers on a sub-set of evidence to discern potential issues and disagreement. A Kappa analysis will then be undertaken to assess the consistency. Any issues will then be resolved through open discussion from the whole review team.

3.3 Study quality assessment: Initial investigations into potential sources of evidence reveal that early glacier studies in the region only considered the relative position of the glacier terminus over time at specific glaciers. More recent studies have employed techniques to measure mass-balance and have also been able to draw upon remote-sensing data to allow a wide coverage of glaciers across the region. Reviewers will consider evidence sources and assess quality against an agreed set of criteria designed prior to the review. These criteria will be developed with input from all team members and will be developed into a standard format by which to assess study quality.

3.4 Data extraction strategy: Information from evidence sources will be extracted according to a data extraction protocol that will be developed by trial and discussion and recorded in a pre-designed table/form that will allow clear capture of relevant information to the review. This table will be designed according to team input and will be tested against a subset of the studies that covers a range of outcomes, methods and data quality by two reviewers to test its effectiveness in capturing relevant data. This may be subject to amendment after trial data extraction, and will be discussed in detail with the Collaboration for Environmental Evidence (CEE) to ensure the process is as transparent and repeatable as possible.

3.6 Data synthesis and presentation: Existing reviews into glacier retreat across the Himalaya have sought to synthesize data into some kind of central table that conveys the relative advance/retreat of glaciers and to draw together regional patterns. Such studies have not however paid significant attention to the varying quality of

contributing data. Meta-analysis will be carried out in this review by appropriating varying weights to data used as evidence, according to guidelines developed during trial data extraction and synthesis, and subsequent group feedback. How this synthesized data might be statistically analysed will be developed as we become more aware of what our synthesized data might look like.

An aim for the presentation of synthesized data would be to use it to answer, as best possible, the various sub-questions laid out in section 2.2. Data will be analyzed to investigate evidence of trends between regions and, where possible, to identify variation within regions. Additionally recommendations to future researchers could be presented, describing the key exposure criteria that should be include in such studies.

4. Potential Conflicts of Interest and Sources of Support

No potential sources of conflict have been identified.

5. References

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