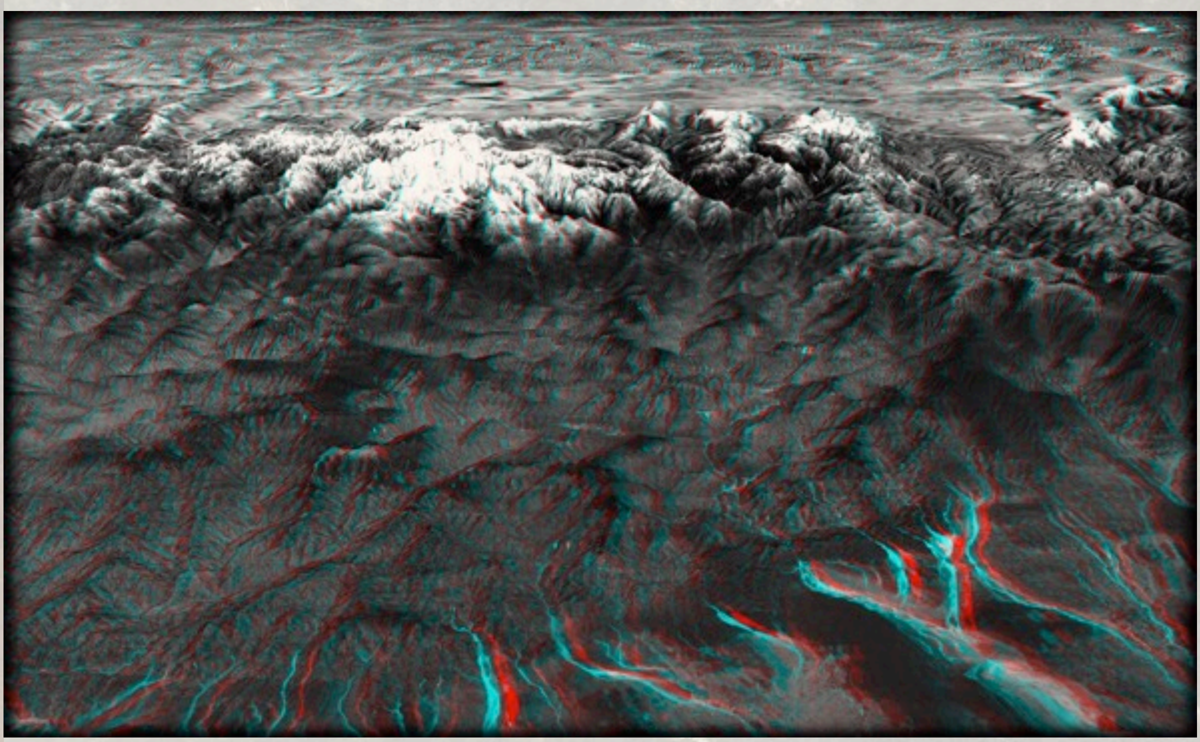
Sikkim Landscape

Water Resources

and

Climate Change Sensitivity

Analysis



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By Nikolai Sindorf

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Find updates on: http://thirdpolegeolab.org/#snowy

About the author:

This work has mainly been produced and compiled by Nikolai Sindorf as a consultant on spatial freshwater analysis under the Asia High Mountains Inititiative. This is one of the six landscape analyses under that project.

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Specialties: water resources development, conservation hydrology, freshwater climate change sensitivities, environmental flows, sustainable hydropower planning, irrigation, land-water management and geographic information systems

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w a t e r , *d e v e l o p m e n t* , n a t u r e
---~~~--~------~~~~------~~------~~~~------~~~----~~-~-----
"A person cannot step in the same river twice,
for it will neither be with the same flow,
nor be with same character."
after Herakleitos

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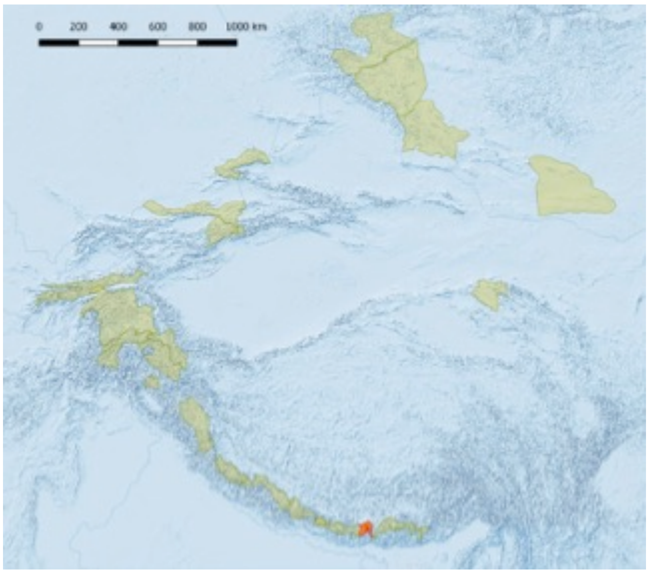
Sikkim Landscape

Country: India
Size: ~3,570 km^2
Population: ~~~270,000~~ (WorldPop 2010, has some glitches inside the landscape)
Highest elevation: ~8,560 MSL
Lowest elevation: ~1000 MSL

Connections:
East: Bhutan Landscape
West: Eastern Nepal landscape



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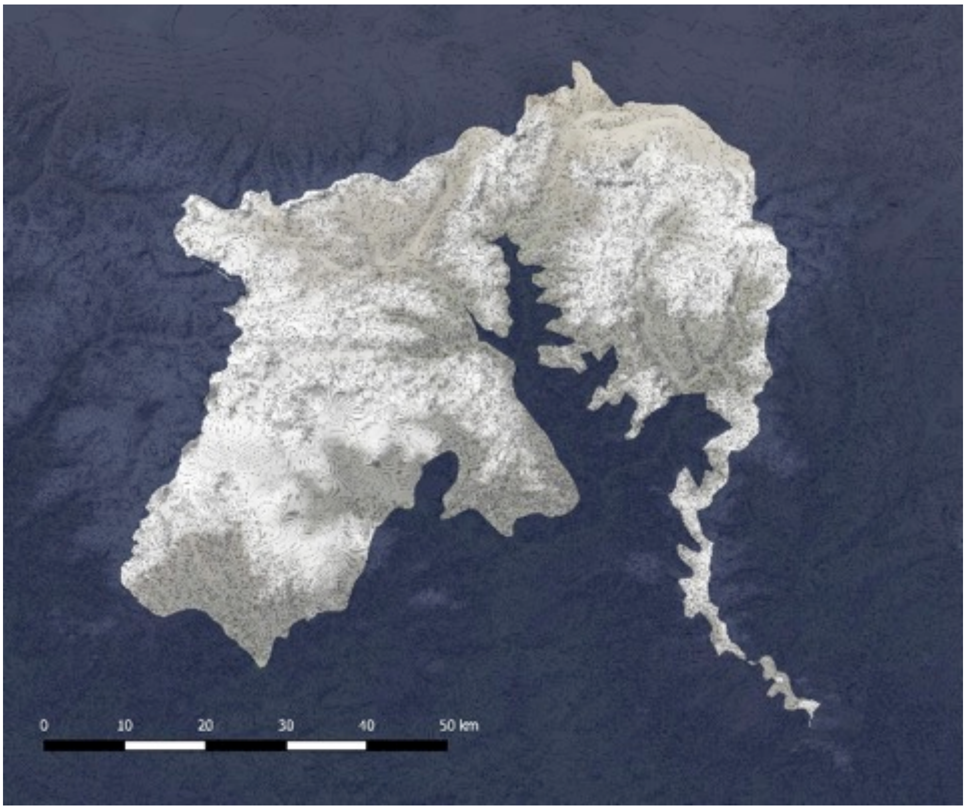
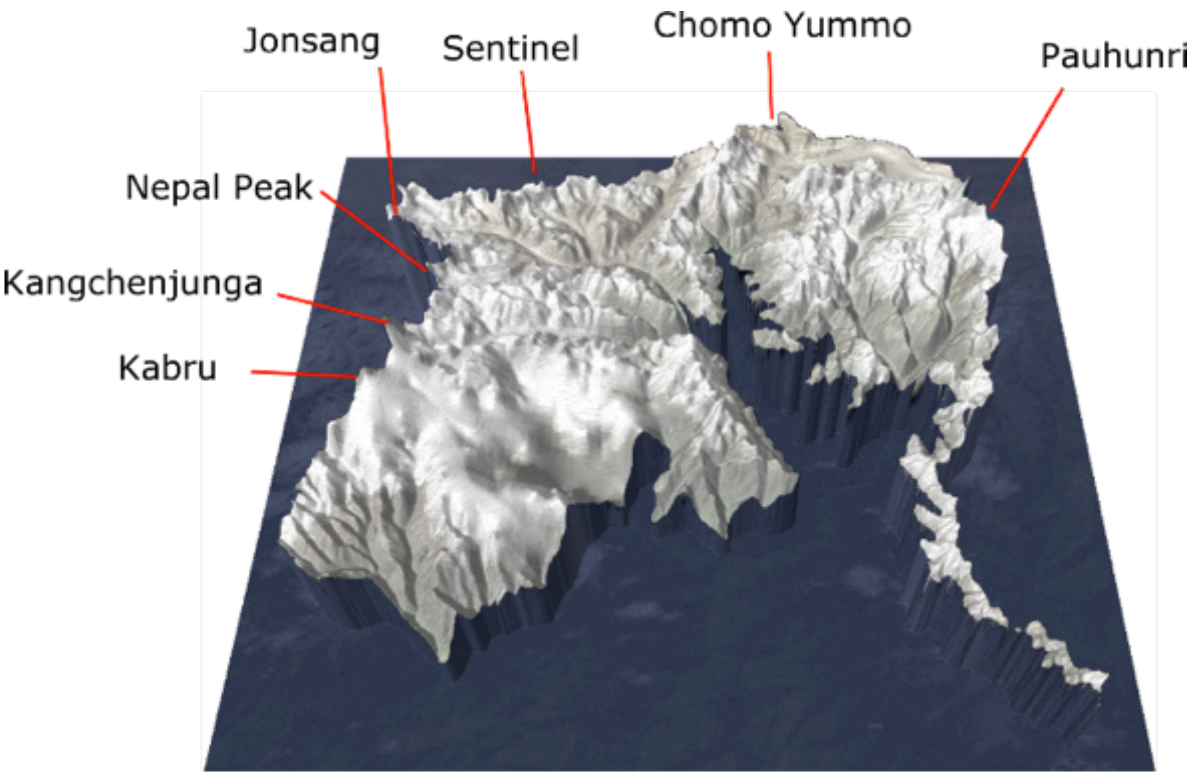
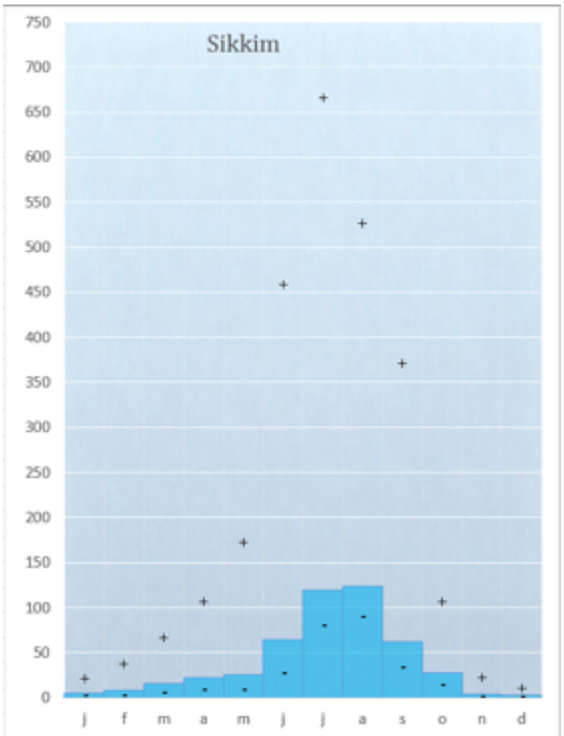
Overview

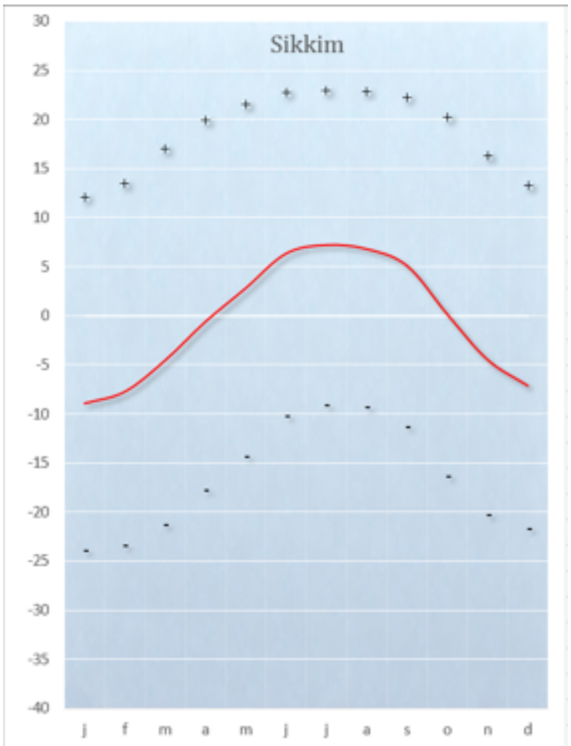

0
10
20
30
40
50 km


Jonsang
Sentinel
Chomo Yummo
Pauhunri
Nepal Peak
Kangchenjunga
Kabru

Basic climate



Historic monthly mean precipitation
in millimeters (WorldClim, 1950 -2000)
+ = highest mean of the landscape
- = lowest mean of the landscape



Historic monthly mean temperature
in centigrades (WorldClim, 1950-2000)
+ = highest mean of the landscape
- = lowest mean of the landscape

The rainfall distribution illustrates that the Sikkim landscape is dominated by the monsoon; rainfall in the months of June to September amounts to over 75 percent of annual rainfall.

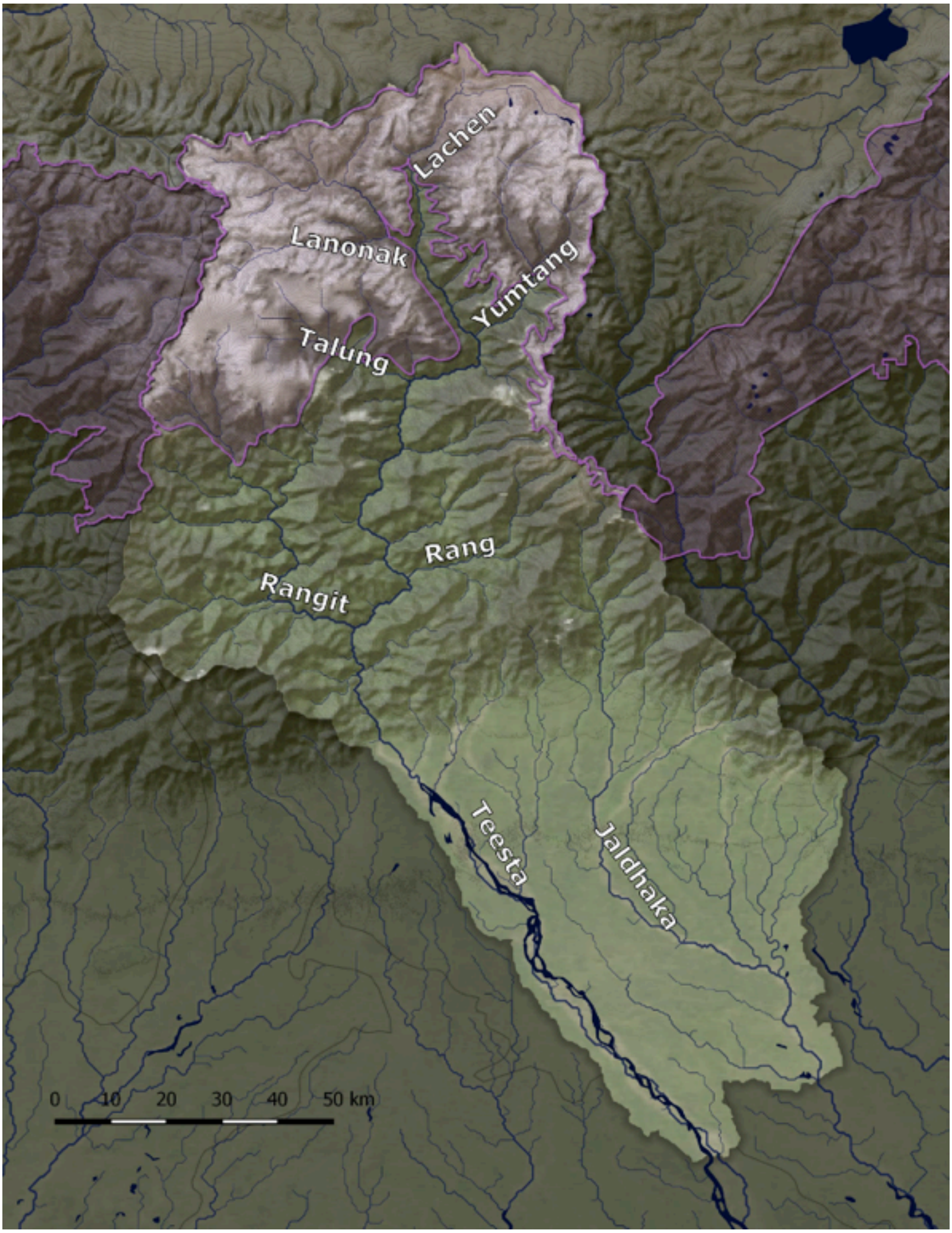
Both of the above graph shows that historically, the temperature and precipitation range inside the Sikkim landscape is very broad;

- E.g. in July the difference between the wettest and driest location inside the landscape is about 600 mm
- For temperature, for every month there seems to be locations inside the landscape that have a temperature difference between 30 - 35^{o} C

Though the graphs do not show how these extreme differences are distributed over the landscape – they might be isolated extremes -like mountain tops- while they do illustrate that for the size of the landscape, the Sikkim landscape must be one of the world's most climate diverse contexts.

This high density of micro climates might have historically played an important role in the survival and evolution of the landscape's species. Though movement through the landscape might be a challenge to most of its species, to a certain degree they will be able to find a suitable climate to survive, or move on. This is an important realization when considering species-climate interactions under climate change.

Subbasin context; hydrography

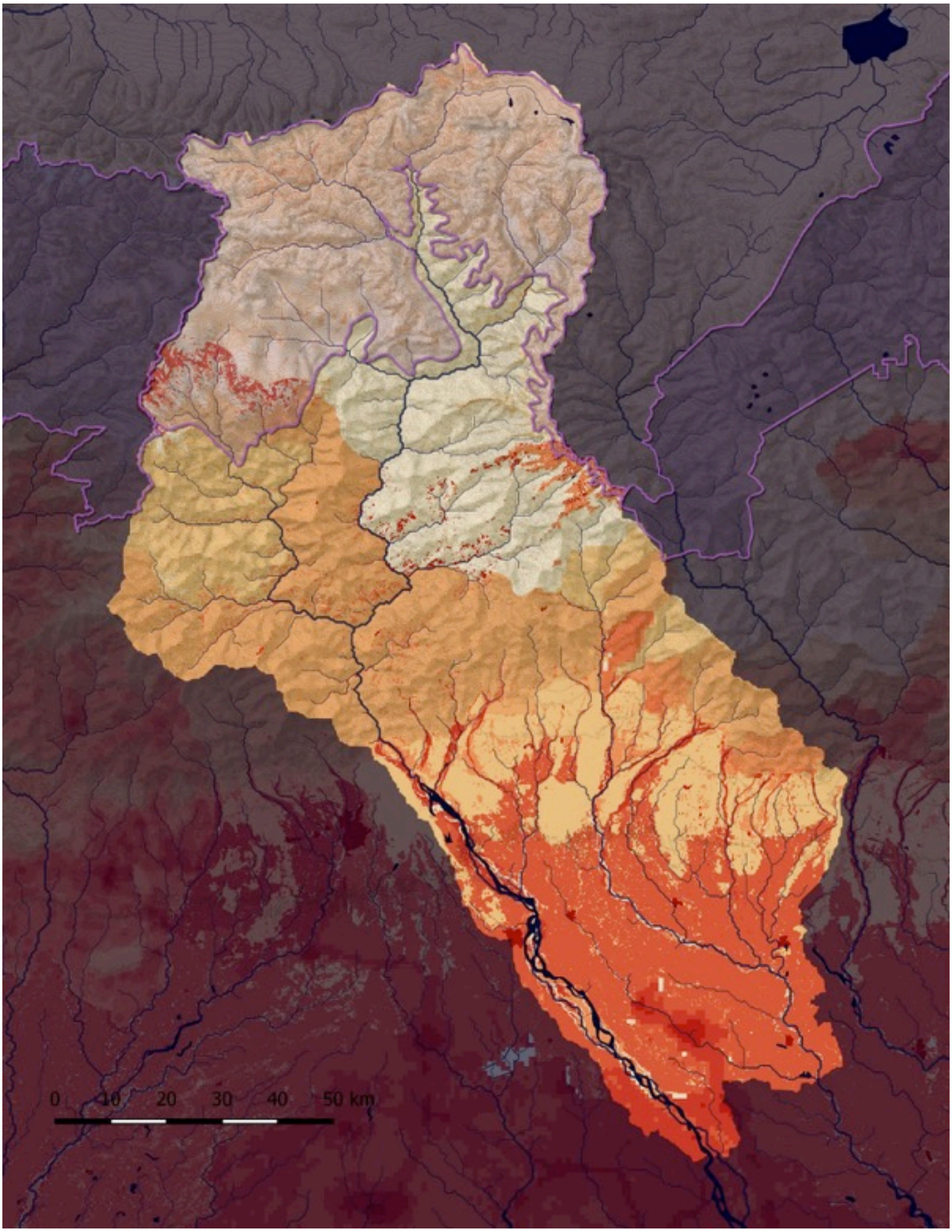


In order to determine the importance of water provision by snowleopard landscapes, it is of importance to consider the landscape's role in its larger subbasin context. For the Sikkim landscape this would include the Teesta river basin both flowing through Sikkim and West Bengal states. The most downstream influence of the landscape's downstream importance coincides with where the

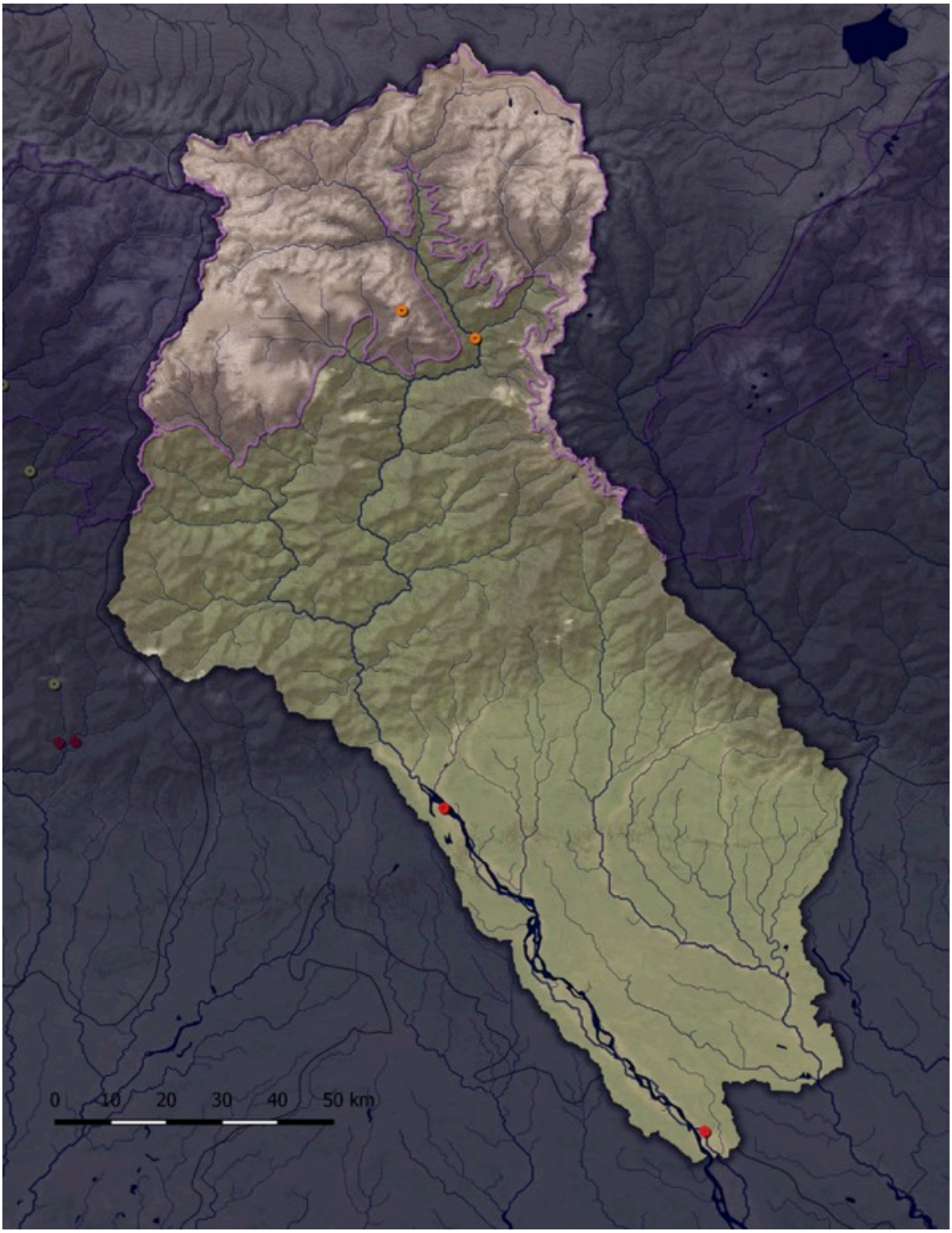
Teesta river enters Bangladesh. The Teesta river is considered to be the life line of Sikkim state (https://www.internationalrivers.org/campaigns/teesta-river).

The Sikkim snow leopard landscape covers all of the headwaters of Teesta river.

Subbasin context; population densities (2010, WorldPop)



Dams, exisiting and planned (GRAND, 2011)



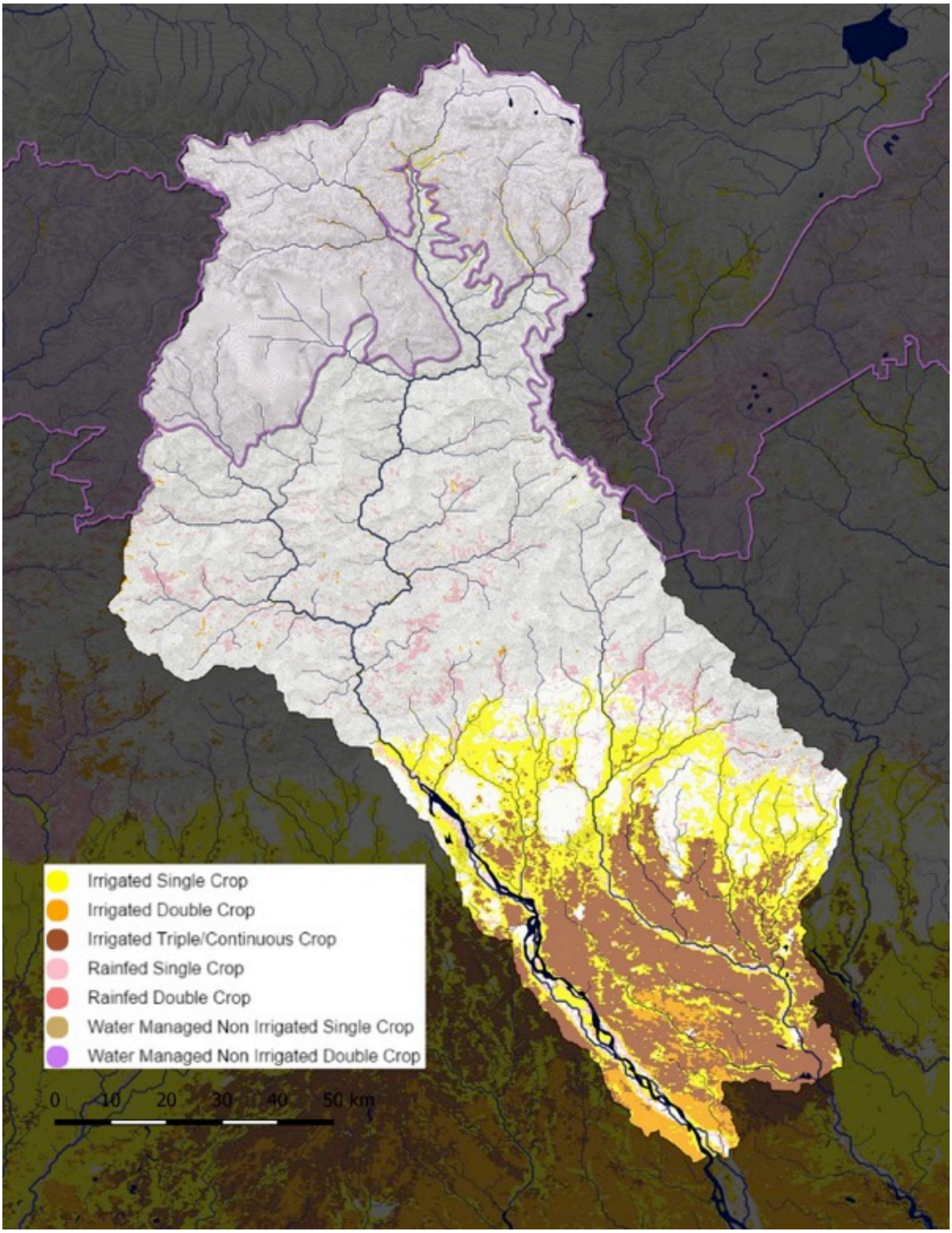
"*…Over the past decade, the Sikkim government has signed letters of intent or MoUs with the government-owned and private power production companies for the construction of 27 small and large power projects, with a total capacity of 5,494MW on the River Teesta and its tributaries. Four of these projects have been scrapped following sustained protests from the Lepcha community*."

From:

https://www.thethirdpole.net/2017/01/25/locals-step-up-protests-against-large-sikkim-dam/

last accessed February 2017

Irrigation Area Map Asia (IWMI, 2010)



Analysis

Some irrigated and rainfed agriculture takes place inside the landscape, but most of the irrigated agriculture takes place directly downstream of the landscape, which indicates that the landscape does provide an important role to water provision downstream; this connectivity might mainly be through groundwater.

Towards the more downstream, in the plains, irrigation intensifies both in extent and intensity.

Methodology

From the Irrigated map website:

"*The natural vegetation and croplands exhibit different patterns of seasonal changes. A procedure was developed to utilize the seasonal variations captured in multi-seasonal satellite images to classify the landscape and identifying the irrigated croplands. The mapping was done using 16-day MODIS 250m NDVI composites images (MOD13Q1). A hierarchical classification procedure involving classification techniques and time-series analysis of the NDVI data was followed. Initially, an unsupervised classification using ISODATA algorithm was performed and subsequently, the seasonal patterns of NDVI for each output cluster was analyzed to differentiate various land cover types.*

The developed methodology based on the phenological changes in agriculture areas to map the irrigated and rainfed areas. An image time series created using the MOD13Q1 product of MODIS at 250m spatial resolution has been used to map the phenological stages of crops using advance image processing techniques such as Fourier and Wavelet transformation Analysis of NDVI. The analysis focus was on the quantity of green biomass, annual and semi-annual cycles of vegetation change, and its dependence on the annual rainfall cycle using Canonical Correlation Analysis (CCA) and time lagged regression to separate irrigated and rainfed areas etc.

The agricultural areas were then further categorized into irrigated and rainfed by analyzing the seasonal vegetation trends. Agricultural areas with multiple cropping cycles were identified by analyzing the cyclic nature of vegetation change in agricultural systems. Based on the cropping intensity, agriculture areas were categorized into single, double and continuous crops."

Data

IWMI, http://waterdata.iwmi.org/applications/irri_area/

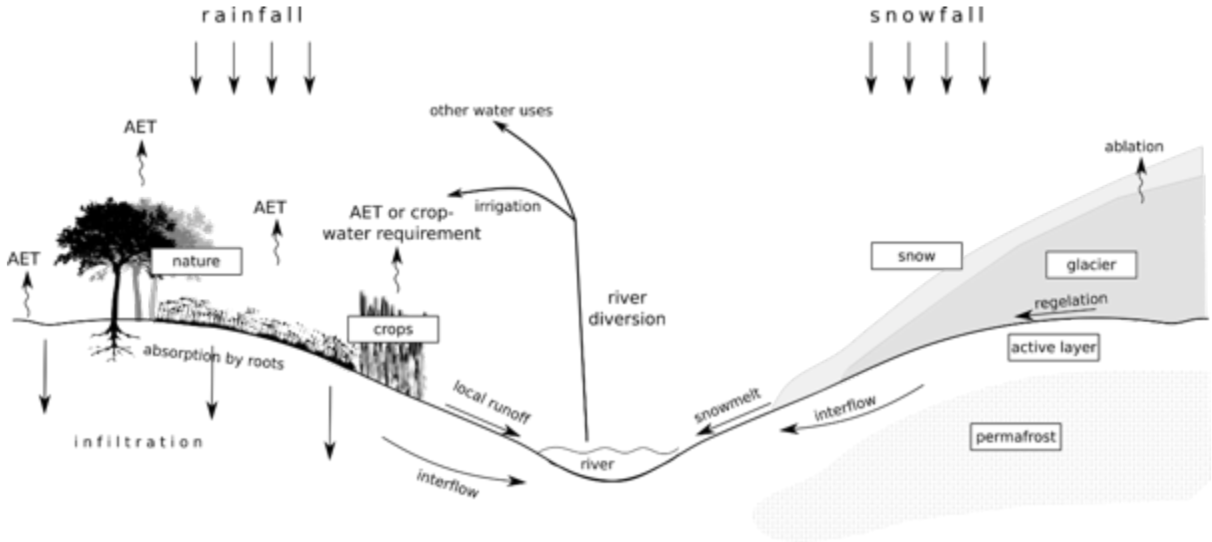
Water provision functions

For the Eastern Nepal landscape four different primary functions are selected that represent different aspects of water provision. These functions are mapped out for the subbasin context, in such a way that it can be assessed what role the snow leopard landscape plays in providing water as an ecosystem service.

- **Local runoff**; is often regarded as the only water provision function. Local runoff is the amount of water in the landscape that ends up in a river or stream and then flows downstream. This is often called “water towers”, since local runoff often starts on the upstream mountain slopes. It can be modelled by looking at rainfall and then taking off the component that is “consumed” by vegetation and soils (actual evapotranspiration). On itself, local runoff has to be considered in monthly timing over a year, and in spatial patterns throughout the landscape. In the larger regional contexts, water provision arguments should not only show positive associations with larger quantities of water, since floods are severe and abundant.
- **Snowmelt**; downstream of mountainous regions, the seasonality of water provision is under direct influence of the annual snowmelt cycles. In many locations, the snowmelt cycle has a different timing than timing of rainfall (or local runoff), often providing essential amounts of water just before, or at the end of the dry season. Under changing temperatures and changing amounts of snow, the change in timing and distribution of snowmelt is essential to be understood; it might lengthen the downstream dry season, but timing might also shift in such a way that it exuberates any flood season. For example when precipitation that historically would have been stored as snowfall in the landscape over the winter, might now runoff and coincide with the flood season.
- **Aridity**; aridity concerns the extent to which water is the limiting factor in vegetation development. Often -in a landscape- local water balances range can from being humid to different levels of aridity; where a chronic level of aridity indicates a trend of desertification. In terms of water provision, it helps to see where in the landscape -or its larger subbasin – there is enough water to sustain vegetation or provide water downstream, and where in the landscape there is a demand for extra water. Aridity is calculated as the amount of precipitation compared to the amount of potential evapotranspiration.
- **River system layout**; through river system layout it can be determined to which extent a location has the capacity to provide water to its downstream. As much as a wet location at the very downstream does not hold much capacity to provide water to the rest of the subbasin, an arid area in the upstream does not hold much capacity to receive water from its upstream.
- **Lakes, wetlands, floodplains**; lakes, wetlands and floodplain are freshwater entities that form a relevant part of the river system layout and the overall water provision context. Recent publications of publically shared databases on surface water and lakes allow more advancedanalysis of a landscape’s surface waters over time.

The water provision functions that are listed below are acknowledged to be of certain importance to water provision and can be mapped out, but at the moment lack essential scientific insights to be incorporated as water provision functions for any of the landscapes.

- **Presence of glaciers**; as much as snowmelt, glaciers provide essential water provision outside of the seasonal precipitation. An important process that lies at the basis of this, is the amount of water that melts off a glacier under pressure (regardless of surface temperature) of the thick ice layers, so-called regelation. Yet modelling quantities of glacial melt has been a challenge; each single glacier act as a reservoir where water melts, or snowfall accumulates, according to many micro factors that underlie the existence of each glacier. In general terms glaciers cannot be considered to be renewable water resources without taking into account at which they accumulate new snowfall, or considering the overall temperature-melt balance through which they have existed for centuries. Under a changing climate, these balances shift, though there is no real rule of thumb for each specific glacier whether it is growing or shrinking.
- **Permafrost coverage**; the presence of permafrost is of direct influence on local hydrology. Season shifts in depths of permafrost are at the base of local hydrology, for example in determining the seasonal water levels in wetlands. Often the permafrost layer is impermeable, and soil-water interaction take place on top of the permafrost layer; the so-called active layer. Naturally the thickness of the active layers is a very local soil characteristic, where issues of soil temperature, aspect, and vegetation cover are all of influence. Any change to this, as well as changes in temperature will all trigger a chain of event, which often leads to permafrost degradation. There is a high correlation between the presence of permafrost, and the larger snow leopard landscape. At the moment there are not enough scientific insights on how locally and region-wide permafrost degradation will be taking place, and whether this would be of influence of snow leopard habitat.
- **Snow cover and freeze line**; the seasonal presence of snow and temperatures below zero centrigrades are an important landscape characteristic that guide seasonality of most of the landscape processes, including hydrology. Under changing temperatures, it is real important how much the freeze line would shift, when and where. Seasonality will change when the freeze line changes, though this change might not always happen linear; a shorter winter will result in earlier spring snowmelt, or maybe also in an extended flood season at the start of winter.
- **Groundwater interactions**; such as recharge, infiltration, interflow or baseflow. Though there is monthly information available on soil-water-balances and recharge flows, this is often too general, too coarse and simplistic to predict the complexity of groundwater interactions inside the landscape, for example in relation with permafrost depths. This study takes an “upstream” approach, any signal in the surface water component will evidentally lead to a change in groundwater interactions, but is is beyond the scope of this study to look further into this subject.



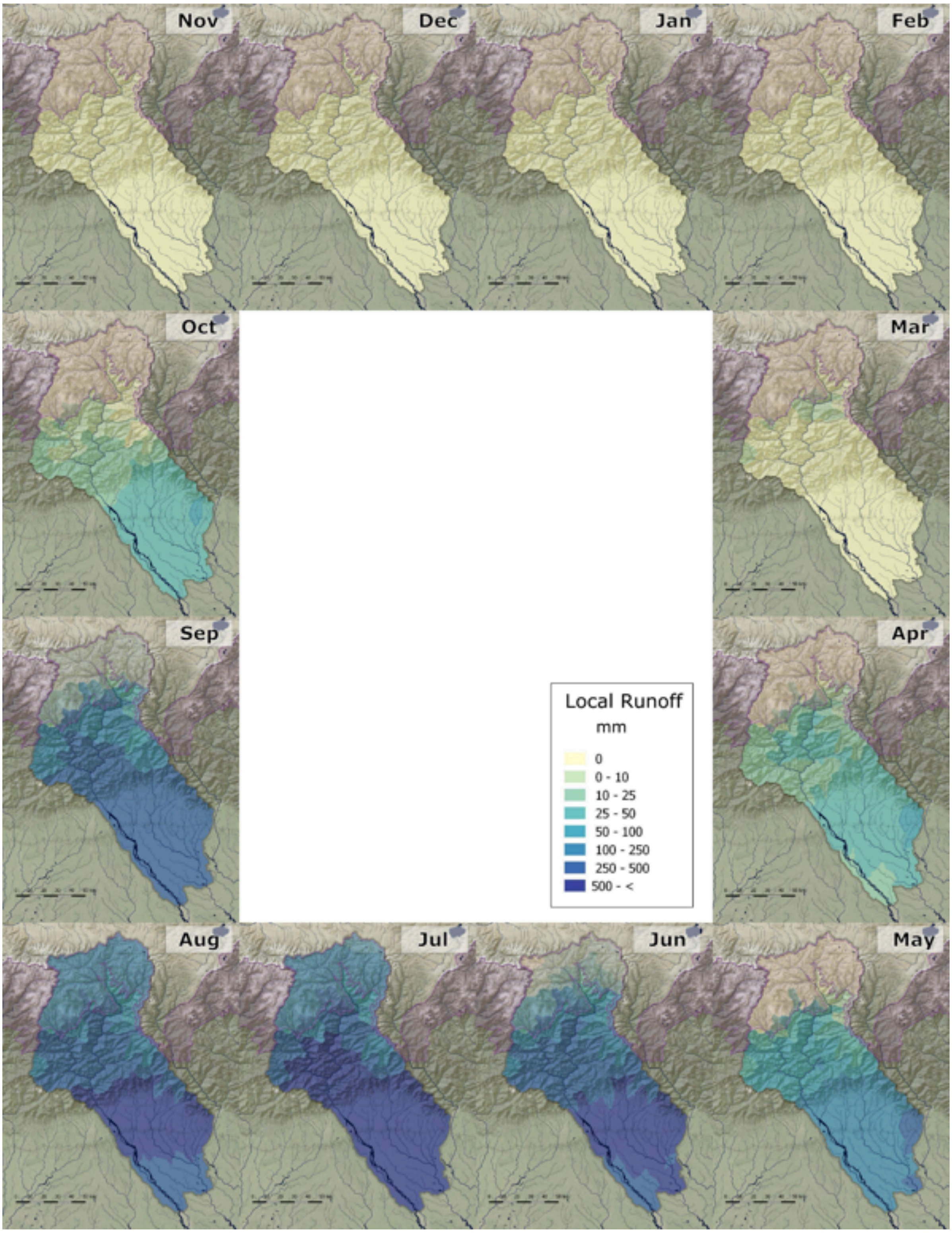
A simplified water balance including the components of rainfall, actual evapotranspiration, and local runoff. To the right: a simplified water balance of the cryosphere, including the components of snowfall, snowmelt, glaciers and permafrost.

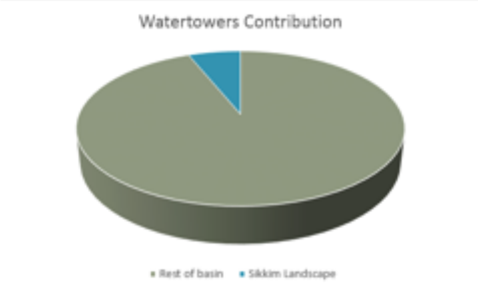
Summarized findings for the Eastern Nepal landscape

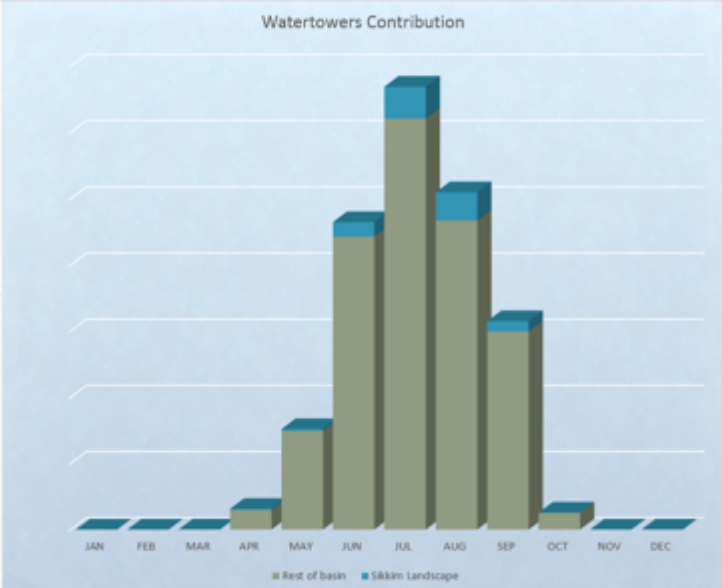
Water Towers/ Local Runoff	
Water provision	In general, the downstream areas receive much more water throughout the year, and the upstream areas are much drier. In this setup it would be difficult to justify a water provision argument. The landscape itself is the driest part of the basin.
Projected Climate change	The low-end estimate of future runoff is more closely related to the baseline than the high-end estimate. This indicates that any change will be skewed towards the high-end estimate. The high-end estimate would create a more extreme peak around the monsoon season, which would indefinitely result in in extra floods towards the immediate downstream.
Snowmelt	
Water provision	Given the distribution of flow and snowmelt over the months it can be concluded that snowmelt does play a significant role in streamflow at the end of the dry season. The early spring snowmelt (February and March) are considered to be of most importance for water provision; the timing coincides with the end of the dry season on the downstream, when water would be in relative high demand. This is until the earliest monsoon rains start at the downstream areas in April.
Projected Climate change	The shift in freeze line will specifically affect the timing of snowmelt on the (upstream) plateau in spring (March-May) and the accumulation of snow and timing of snowmelt at mountainpeaks later in the monsoon. There will be extra snowmelt occuring earlier in the year, which would coincide more with monsoon runoff and most probably exuberate downstream floods.
Aridity	
Water provision	The landscape occupies the most arid parts of the subbasin. Again, there is a strong North-South, upstream-downstream, elevation component in the landscape's aridity. The largest part of the landscape experiences a prolonged eight-month dry season from October to June.
Projected Climate change	Though for the timing and duration of the monsoon will always result in humid condition, regaless of the projection; for the rest of the year there is a high level of uncertainty on how dry and wet seasons will change. Under the high-end estimate most of the landscape would be one class more humid than under the low-end estimate.
River system layout	
Water provision	The landscape covers the entire headwaters of Teesta river, which runs through the heart of Sikkim state.
Projected Climate change	The headwaters inside the landscape coincide with a wide range of cyrospheric components: seasonal snow, glaciers, permafrosts. Under projected climate change, the timing and extent of the cryosphric process will change, leaving dramatic impacts not only inside the landscape, but also to its downstream and will threfore have direct impact on Sikkim.
Glaciers	
Water provision	The glaciers are exposed to 4-5 months of above-zero temperatures over summer. So every winter, these glaciers must historically have

	accumulated enough snow to last through the summer months; most of the seasonal snow melts off, but the perennial glaciers remain.
Projected Climate change	This would imply a very precarious balance: • under decreased snowfall, the glaciers would be exposed during the summer months, • under increased temperatures, the seasonal snow will melt off earlier and start melting off the glaciers. The projections are skewed towards more precipitation, but also towards shorter freeze periods; so extra precipitation might falls as rain, and no longer as snow.
Permafrost	
Water provision	For the Teesta basin, the only permafrost is located inside the snowleopard landscape, but covers the entire upstream area. Historically, the permafrosts have survived there, despite the summer surface temperatures being about zero for 4-5 months.
Projected Climate change	A decrease in duration of sub-zero temperatures will have direct impact on the presence of permafrosts. Such changes will become more dramatic at the frontier between permafrost and none-permafrost lands. This frontier runs throughout all the headwaters of this subbasin –inside the landscape- and any climate change impacts on permafrosts will likely trigger unprecedented change at the entire Teesta subbasin level.
Snow cover and freeze line	
Water provision	The Sikkim landscape encompasses the entire subbasin's freeze area throughout the year. Hence, the landscape covers the seasonal fluctuation of minimum and maximum freeze/snow extent, and therefore provides an essential role in the generation of snowmelt and cryosphere interactions
Projected Climate change	The cryosphere here is historically exposed to a 4-5 month summer period. Despite this summer, many important cryospheric characteristics do occur in the headwaters (glaciers, permafrosts). It is likely that any decrease in freeze duration under rising temperatures will have direct and immediate impacts on the cryspheric characteristics.
Lakes, wetlands and floodplains	
Water provision	There are around 50 glacial lakes detected in the landscape (Worni, 2012), these may play a role in local water management, but eight of them also pose a risk for glacial lake outburst floods (GLOFS). Compared to other Indian Himalaya landscapes, Sikkim's glacial lakes are relatively large. Floodplains exist directly downstream of the landscape, there, floods are recurring and devastating.
Projected Climate change	It is likely that the observed melting of the glaciers would result in increased sizes of glacial lakes. Yet, a global assessment on changing water surfaces (2016) shows that the surface water areas in the Sikkim landscape have been relatively stable for the period 1984-2015. This might be because of the sloping geography; any possible increase in lake water would result in a relatively low spatial footprint, but a certain degree in water storage. It would therefore be recommended to get records of any change in lake depths as well.

Water provision functions; water towers (local runoff)







Analysis

Subbasin context

There is a distinctive South-North gradient in the subbasin runoff generation, which is entirely driven by the monsoon (June-September). In general, the downstream areas receive much more water throughout the year, and the upstream areas are much drier. In this setup it would be difficult to justify a water provision argument. The landscape itself is the driest part of the basin.

When comparing the annual local runoff that is 'generated' inside the Sikkim snow leopard landscape with the rest of the subbasin, it becomes evident that the landscape is located entirely upstream of the so-called "water towers", the landscape cover 30% of the entire subbasin, but only contributes to 6 % of it runoff.

Throughout the dry season (October-May), when water demand is highest, there is a clear mismatch between the landscape location and water provision areas in the subbasin.

Landscape context

Throughout the landscape, and in every month, there is a gradient in local runoff that decreases from;

- south to north,
- lower to higher elevations, and
- downstream to upstream.

Methodology

Local runoff is the difference between monthly precipitation (P) and actual evapotranspiration (AET). Monthly precipitation and AET are downloaded and, through a simple GIS command, summarized by their watershed 'mean', using HydroBASINS level 12 watersheds. The mean values are multiplied by each of the watershed area in order to convert from millimetres to cubic meters. Then these values are subtracted (P – AET); local runoff values that are less than zero are displayed and flagged as being zero. Inside the subbasin, those watersheds that drain the snow leopard landscape are flagged. See download links below.

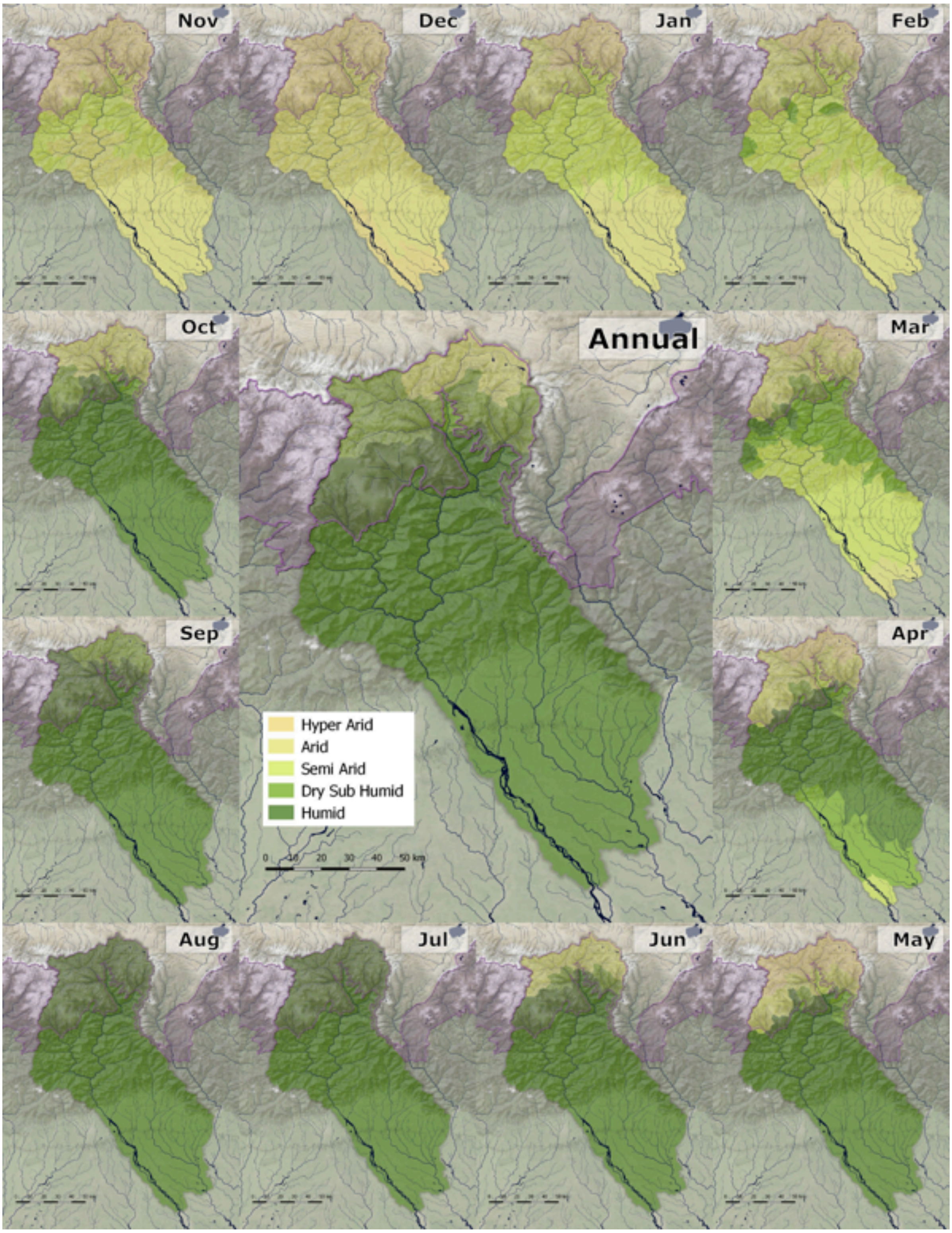
Data

Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution; Trabucco, A., and Zomer, R.J. 2010. Global Soil Water Balance Geospatial Database. CGIAR Consortium for Spatial Information. Published online, available from the CGIAR-CSI GeoPortal at: http://www.cgiar-csi.org

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Water provision functions; aridity



Nov
Dec
Jan
Feb
Oct
Annual
Mar
Sep
Apr
Hyper Arid
Arid
Semi Arid
Dry Sub Humid
Humid
0 10 20 30 40 50 km
Aug
Jul
Jun
May

Analysis

Subbasin context

In the subbasin, the upstream areas are much more arid than the downstream areas at any time of the year. In terms of water provision this implies that downstream water demand does not coincide with upstream water surpluses.

Landscape context

The landscape occupies the most arid parts of the subbasin. Again, there is a strong North-South, upstream-downstream, elevation component in the landscape's aridity.

The largest part of the landscape experiences a prolonged eight-month dry season from October to June, while some of the more downstream part of the landscape this dry season last from November to March.

Methodology

Aridity measures to which extent precipitation (P) is the limiting factor in water demands for vegetation growth (potential evapotranspiration, PET). Monthly precipitation and PET are downloaded and, through a simple GIS command, summarized by their watershed 'mean', using HydroBASINS level 12 watersheds. Then these values are divided (P/PET) and classified according to the following aridity classes:

Aridity (P/PET)	
< 0.03	Hyper arid
0.03 – 0.2	Arid
0.2 – 0.5	Semi arid
0.5 – 0.65	Dry sub humid
0.65 <	Humid

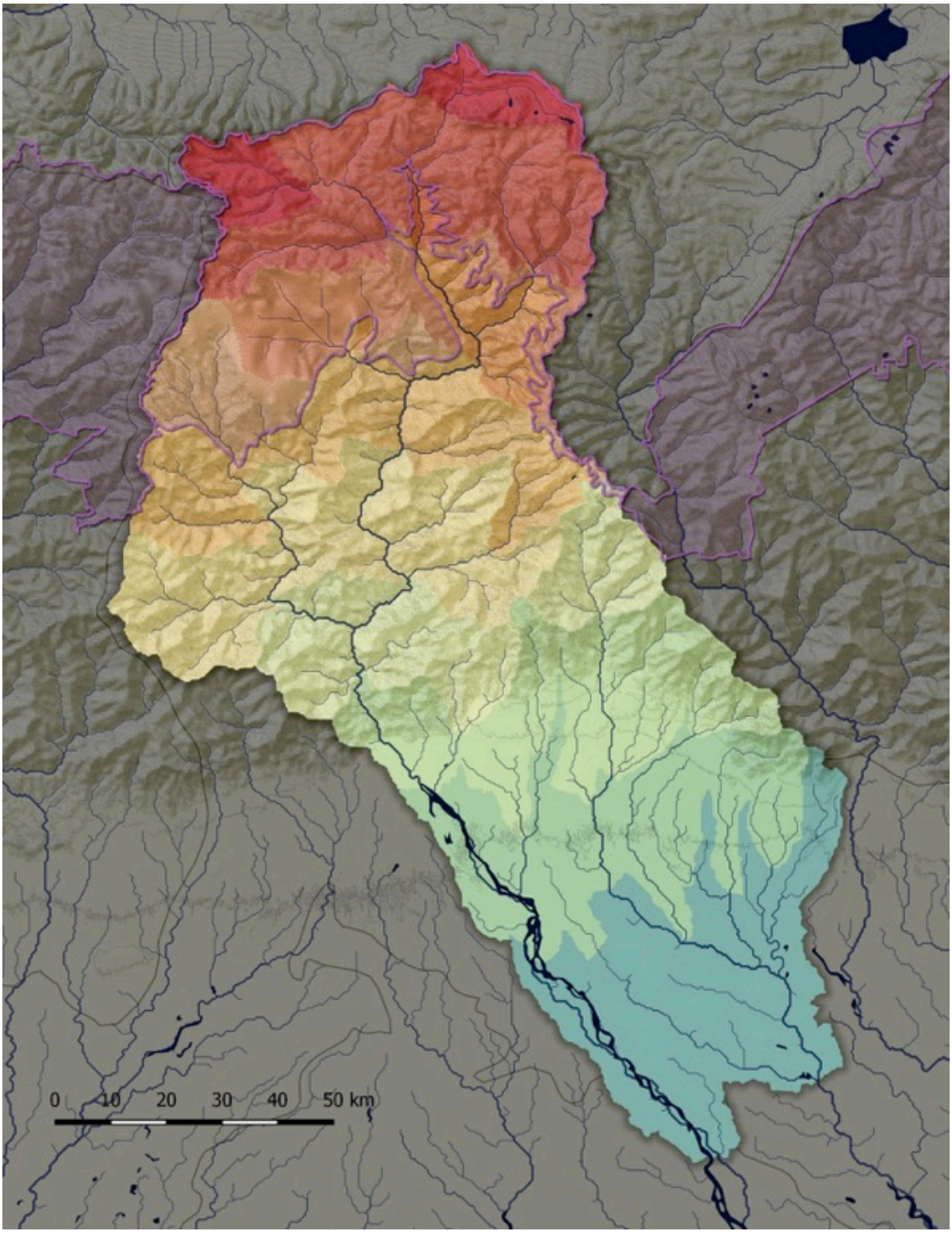
Data

Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution; Zomer RJ, Trabucco A, Bossio DA, van Straaten O, Verchot LV, 2008. Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. Agric. Ecosystems and Envir. 126: 67-80.

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Water provision functions; river system layout



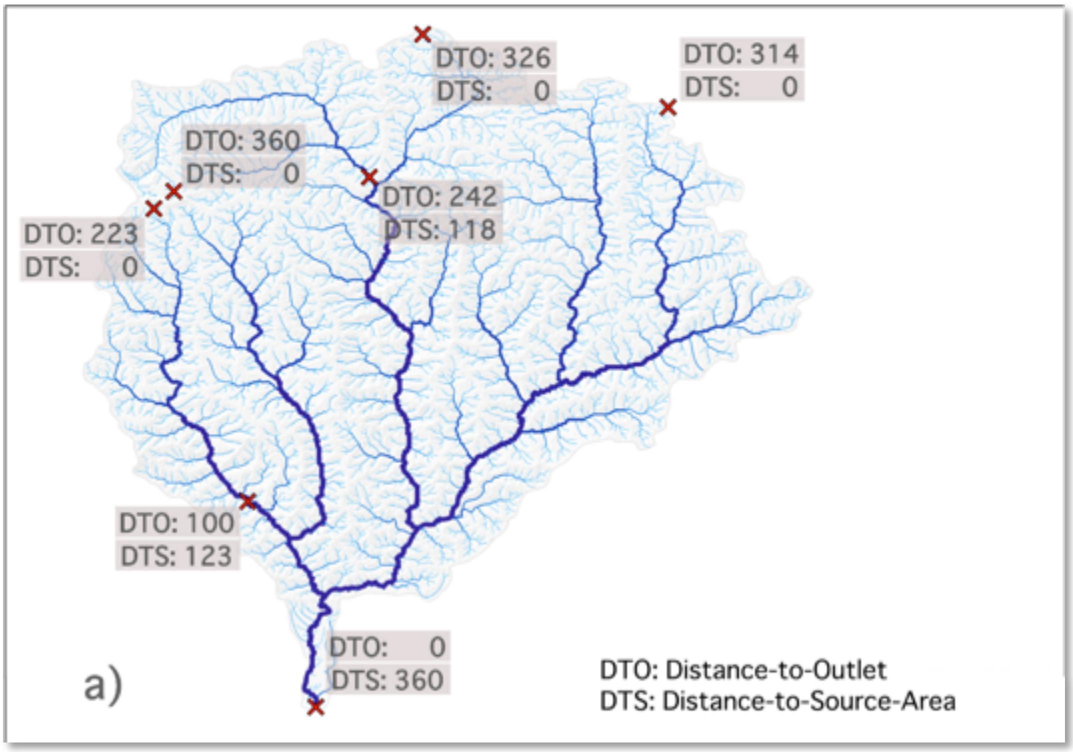
Analysis

This is a straightforward river system layout where the snow leopard landscape occupies all of the most upstream areas.

Methodology

HydroSHEDS 15 drainage directions are used to calculate flow distances; first local flow distances (the distance that a virtual stream flows over each individual cells) and then calculating the distance to source area and distance to outlet. These functions work as follows:

- ***distance to source*** (DTS) areas measures for any location inside a river basin, along the stream, the distance to the most upstream source,
- ***distance to outlet*** (DTO) measures for any location inside a predefined river basin, the point furthest downstream, i.e. the point where the entire basin drains to,
- ***longest stream***, the maximum values DTS and DTO of a river basin are identical and measure the longest stream in the basin.



These three variable are calculated into a single function, and summarized (mean) for each level-12 watershed:

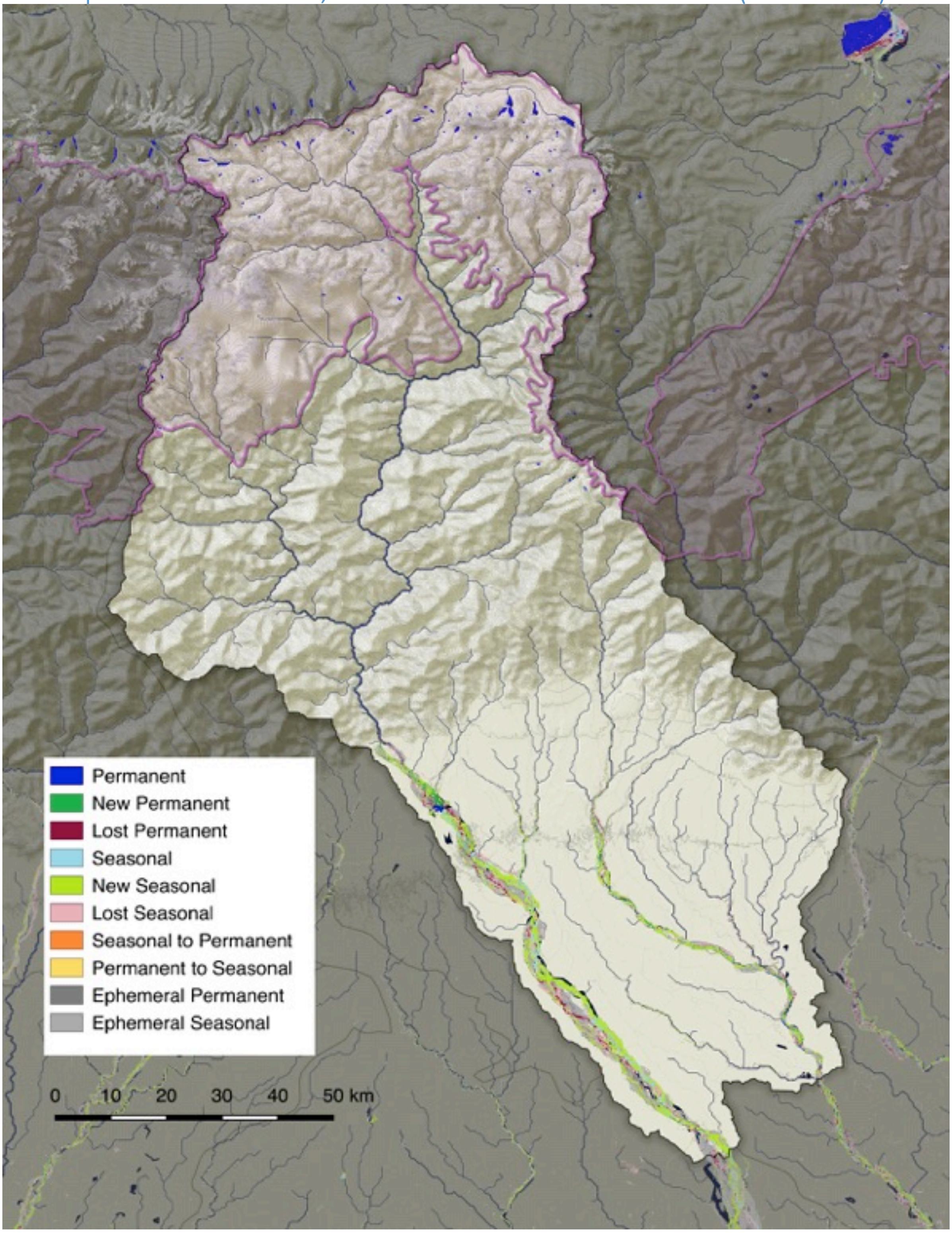
$$headwater\ function\ = \frac{DTO}{longest\ stream} \times \frac{DTO}{DTO + DTS}$$

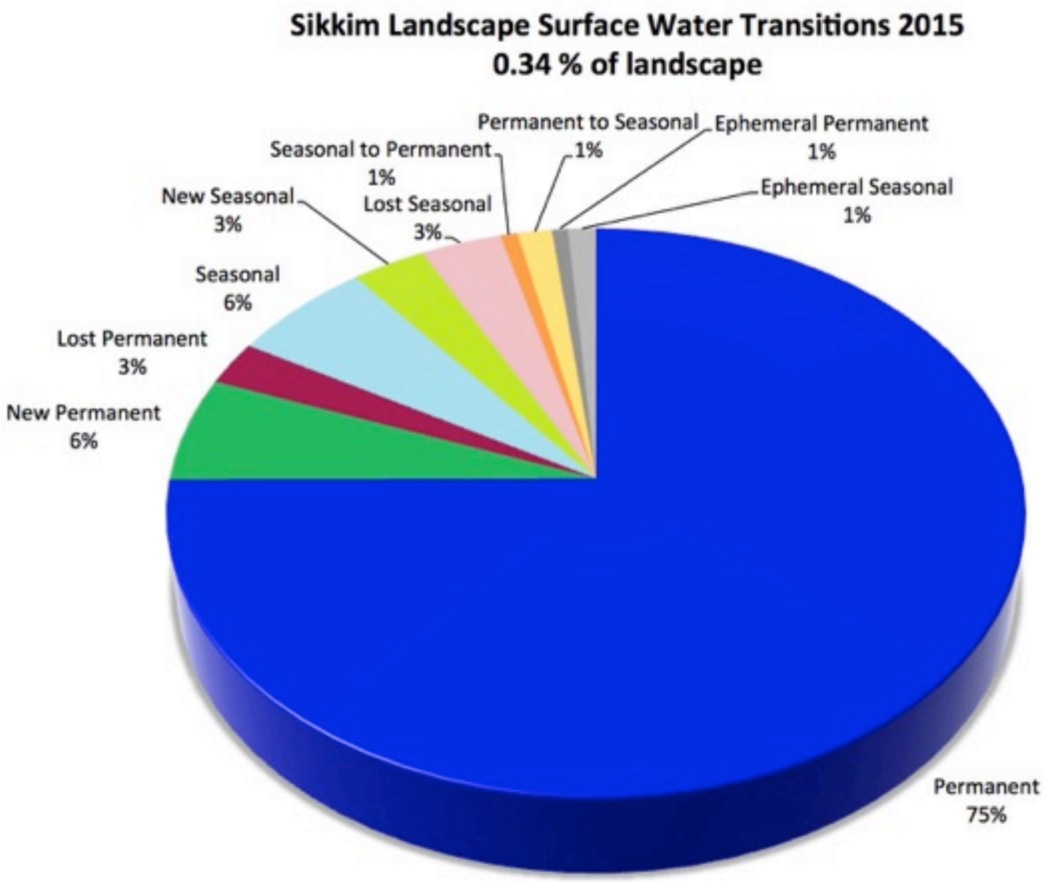
Data

HydroSHEDS 15s drainage directions; Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94. Data is available at www.hydrosheds.org

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Water provision functions; Global surface water transitions (1984-2015)



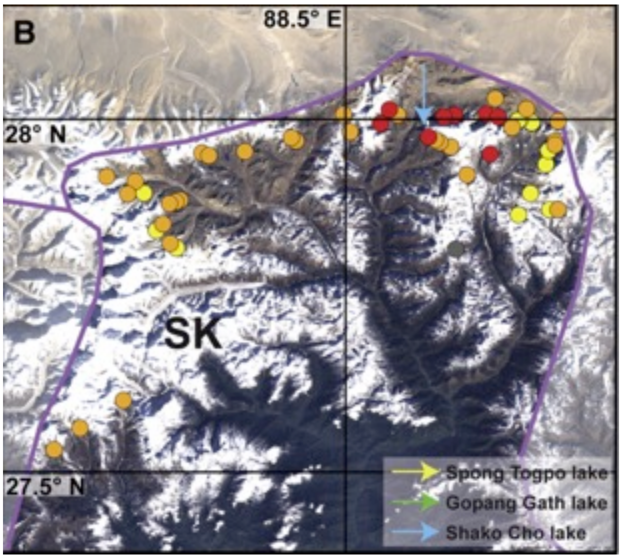


Overview

Inside the landscape; according to the most recent map of global surface water (Pekel, 2016) only 0.34% is classified as open surface water; it can therefore hardly be identified in the above map. The following transitions occurred between 1984 and 2015:

- 83% of the open water surface was *stable* (permanent 75 %, seasonal 6 %, ephemeral 2 %)
- 6 % of the open water surface *disappeared* (permanent 3 %, seasonal 3 %)
- 9 % classified as *new* surface water (permanent 6 %, seasonal 3 %)
- while 2 % of all open water surface *changed from permanent to seasonal and vice versa*.

Worni et al (2012) from their assessment on glacial lakes in the Indian Himalayas, detect around 50 glacial lakes in Sikkim, of which 8 are classified as critically at risk for an outburst flood. Compared to other Indian Himalaya landscapes, Sikkim's glacial lakes are relatively large.



Worni et al, 2012 (source of geodata is not available)

It is likely that the observed melting of the glaciers would result in increased sizes of glacial lakes. Yet, a global assessment on changing water surfaces (2016) shows that the surface water areas in the Sikkim landscape have been relatively stable for the period 1984-2015. This might be because of the sloping geography; any possible increase in lake water would result in a relatively low spatial footprint, but a certain increase in overall water storage through rising water levels. It would therefore be recommended to get records of any change in lake depths as well.

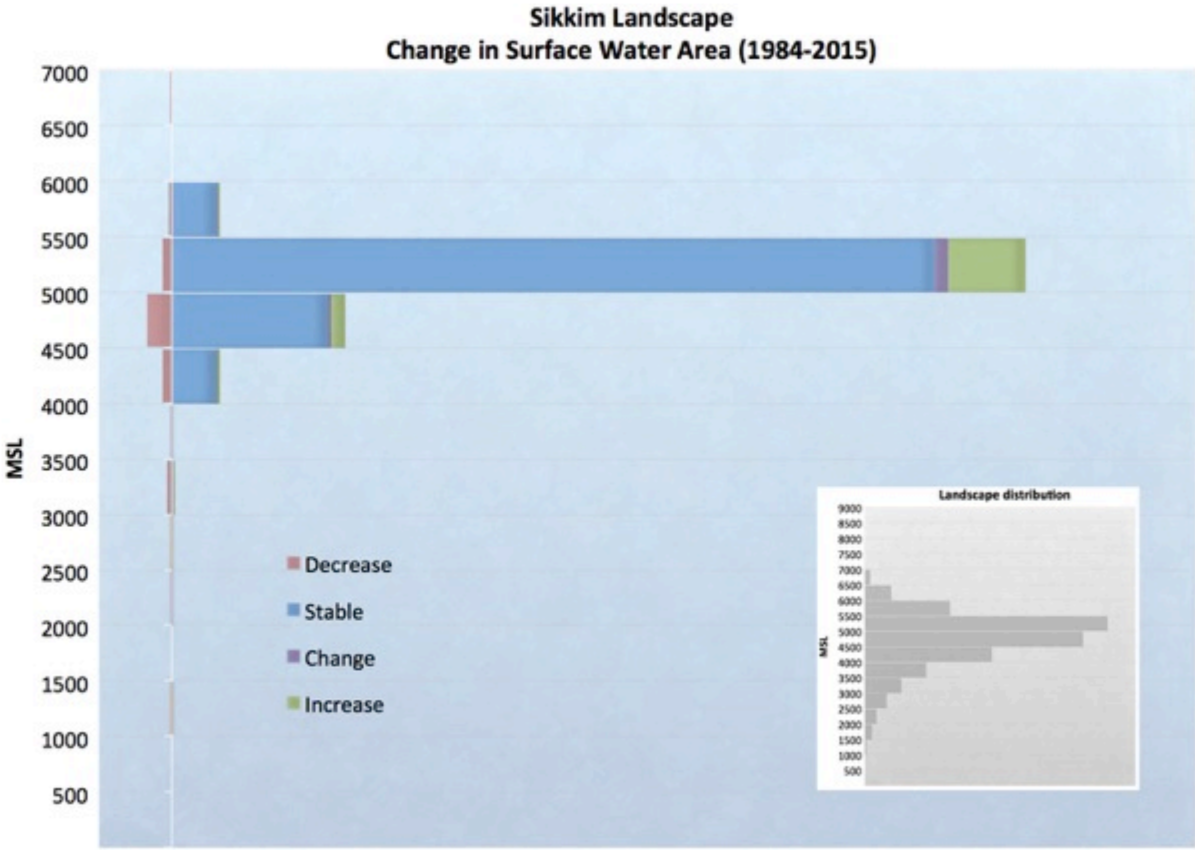
Methodology

The the map of global surface water and its long-term changes, is a recent high-resolution product (Pekel, 2016). It contains at least 6 different datasets, and allows time-lapse analysis from 1984-2015, which coincides with Landsat coverage. From the https://global-surface-water.appspot.com/ website:

"The Water Transitions map documents changes in water state between the first year and the last year of observation. It documents:

- *New permanent water surfaces (i.e. conversion of a no water place into a permanent water place.)*
- *Unchanging permanent water surfaces*
- *Lost permanent water surfaces (i.e. conversion of a permanent water place into a no water place)*
- *New seasonal water surfaces (i.e. conversion of a no water place into a seasonal water place)*
- *Unchanging seasonal water surfaces*
- *Lost seasonal water surfaces (i.e. conversion of a seasonal water place into a no water place)*
- *Conversion of permanent water into seasonal water*
- *Conversion of seasonal water into permanent water*
- *Ephemeral permanent water (i.e. no water places replaced by permanent water that subsequently disappeared within the observation period)*
- *Ephemeral seasonal water (i.e. no water places replaced by seasonal water that subsequently disappeared within the observation period)*

Temporal profiles recording the full history of each pixel are provided. These allow us to define on a monthly basis the water presence or absence (and also the absence of observation) throughout the archive. Using the profiles it is possible to identify specific months/years in which conditions changed, e.g. the date of filing of a new dam, or the month/year in which a lake disappeared. In addition, profiles documenting the seasonality (and possible transition of seasonality) are provided. These profiles allows to discriminate between occurrence changes resulting from intra and inter-annual variability or resulting from appearance or disappearance of seasonal or permanent water surfaces."



When the surface water change is plotted against elevation, it becomes evident that a single belt (5,000-5,500 msl) contains most of the surface water entitities in the Sikkim landscape. This is closley reltated to the presence of the glacial lakes, directly downstream of the glaciers. In the period 1984-2015, there is an increase in open water surface area, which might indicate the melting off of glaciers. It is important to emphasize that the plot depict *areas*, and *not volumes* of water.

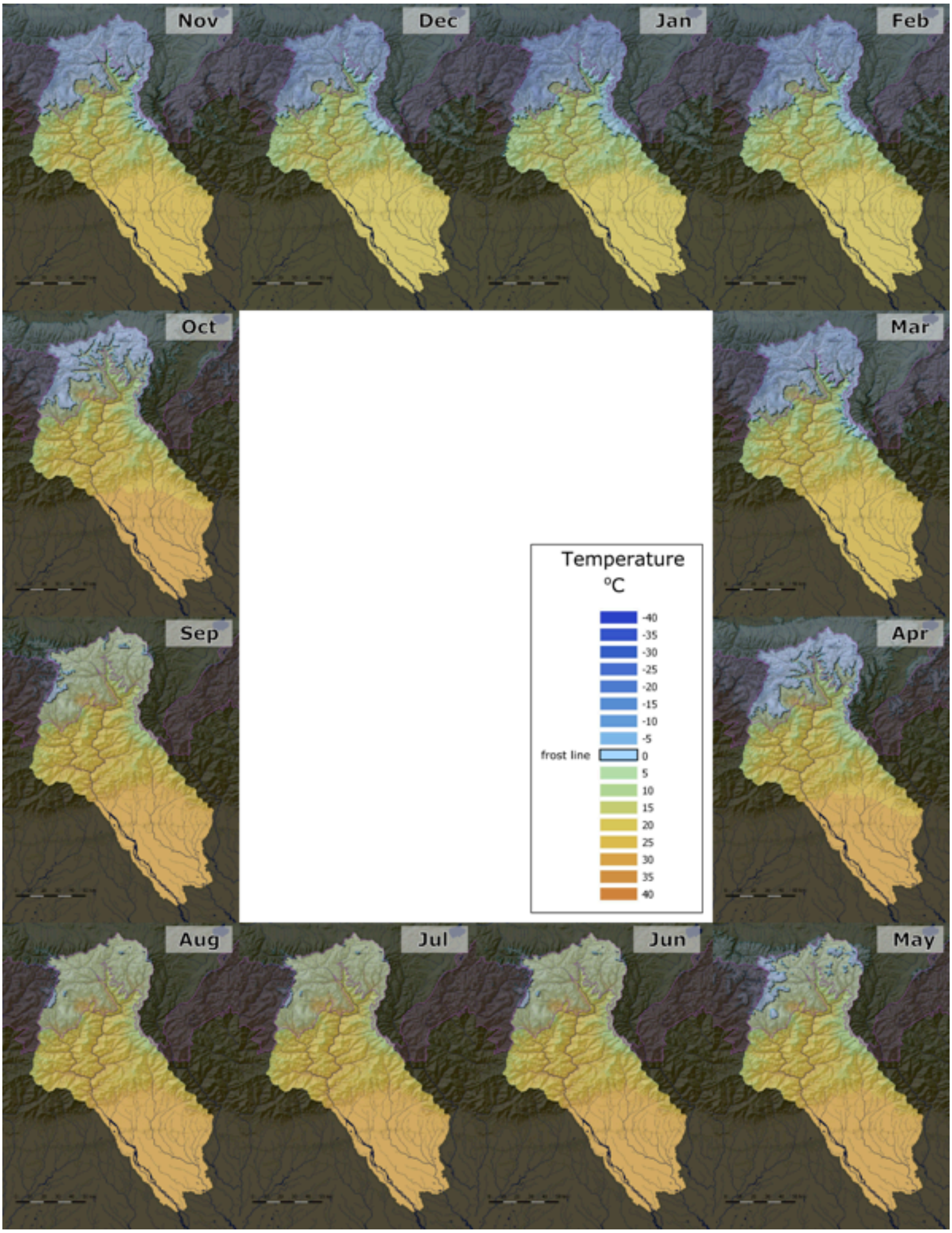
Data

Pekel, J.-F., Cottam, A., Gorelick, N. & Belward, A. S, *High-resolution mapping of global surface water and its long-term changes,* Nature **540**, 418–422 (2016). https://global-surface-water.appspot.com/

Messager, M.L., Lehner, B., Grill, G., Nedeva, I., Schmitt, O. (2016): *Estimating the volume and age of water stored in global lakes using a geo-statistical approach.* Nature Communications: 13603. doi: 10.1038/ncomms13603. Data is available at www.hydrosheds.org.

Worni R, et al, *Glacial lakes in the Indian Himalayas — From an area-wide glacial lake inventory to on-site and modeling based risk assessment of critical glacial lakes*, Sci Total Environ (2012), http://dx.doi.org/10.1016/j.scitotenv.2012.11.043

Water provision functions; freeze line



Analysis

Subbasin context

The freeze line here coincides with seasonal fluctuations and subbasin elevations. At its peak –in January- about a quarter of the subbasin is in sub-zero temperatures. The northern boundaries of the basin follows the mountain ridges and does not reach into the Tibetan plateau; this means the temperature gradient is quite steep; any increase in temperature would not leave a large footprint on the freeze line, because higher up the mountain, up the slopes, temperatures drop very quickly over short distances.

In the summer months, the sub-zero area is very minimal, concentrated around the Kangchenjunga mountaintop; this is an important observation in relation to the location of glaciers, and permafrosts. It raises the question of how these have continued to exist, if for most of the subbasin, including glaciated- and permafrost areas, there is a thaw period of at least 4 months. *Maybe there are such amounts of seasonal snowfall, that it blankets these areas and melts off entirely only after the summer season. If this is the case, the entire subbasin is very sensitive to changes in winter precipitation and increased summer temperatures.*

Landscape context

The Sikkim landscape encompasses the entire subbasin's freeze area throughout the year. Only on the eastern slopes of the subbasin, on the small sliver of the landscape that follows the Tibetan border, the freeze line exceeds the landscape, from November till March.

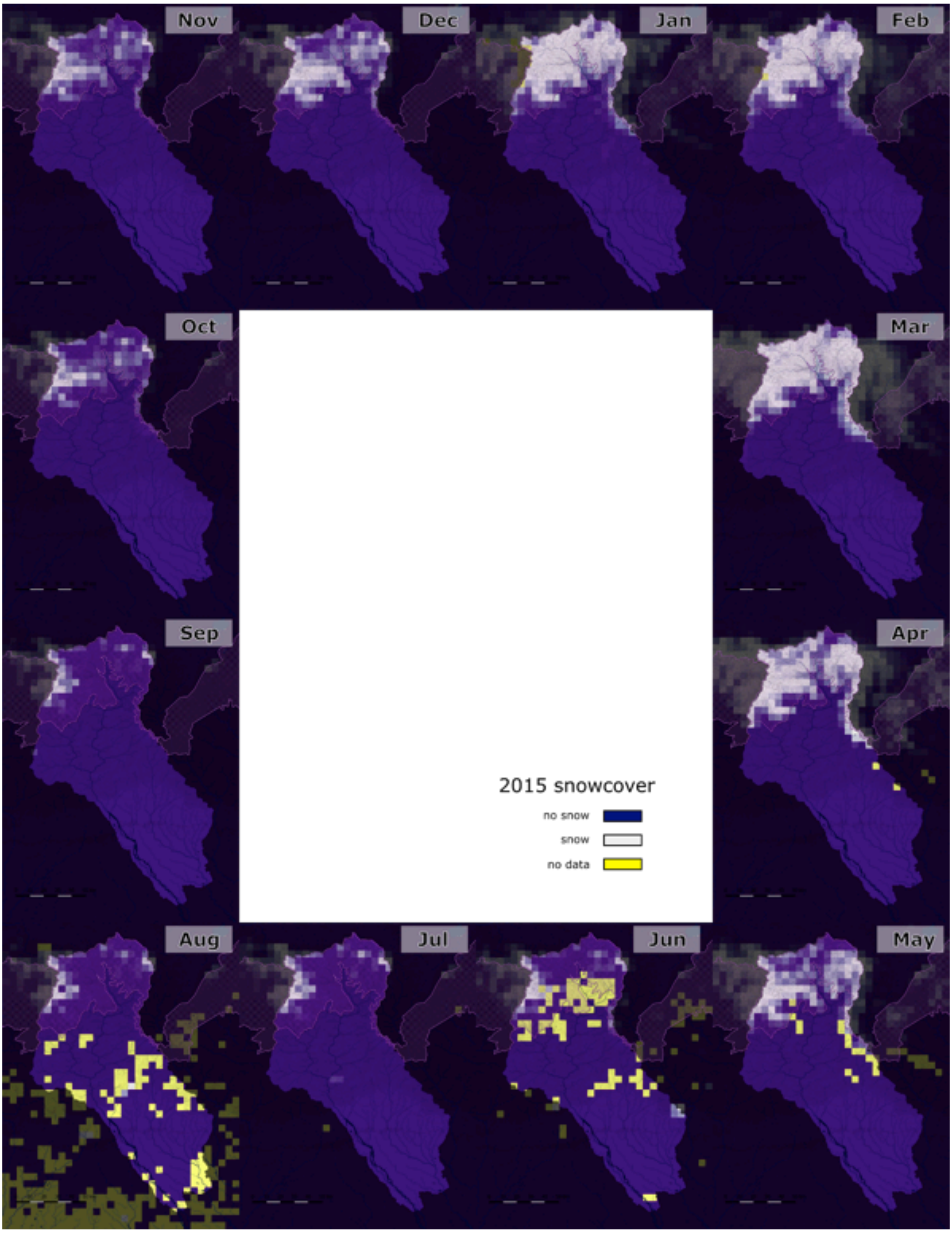
Methodology

This is a map of WorlClim mean monthly temperatures at 30s resolution with the freeze line highlighted.

Data

Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.
www.worldclim.org

Water provision functions; snow cover 2015



Analysis

Subbasin context

This snowcover database is a product of satellite image interpretation, part of the MODIS library. It is therefore based on observation and not on modelling. For each 0.05 x 0.05 degree cell, the percentage of monthly snow cover is reported. Due to some of the data artefacts (no data, e.g. through cloud cover), it is difficult to calculate inter-annual means, hence only the snow cover for the year 2015 is mapped out.

The monthly snow cover in winter follows the freeze line, and largely coincides with the snow leopard landscape. Not much snow falls outside the landscape.

In the monsoon months (June to September), there is snow cover remaining, even on locations where temperature are currently/historically above freezing points largely; these locations also contains the subbasin's glaciers (on another map).

The map shows snow cover as a landscape attribute, it does not provide information on the amounts of snow, snow depth, or timing of snowmelt. The next map goes into more detail on snowmelt amounts and timing.

Landscape context

Just like with the freeze line over the different months, the snow covers the entire landscape at its maximum extent in winter. In summer it retreats mainly around to the Kangchenjunga mountaintop. At any given month in the year, the landscape contains (or directly connects to) the majority of snow cover locations inside the wider subbasin.

Snowcover coincides with the arid areas in the landscape; this implies that -to most of this area- snowfall and snowmelt is the main source of water, except for the months of July, August and September, when some of the monsoon rains also reach the very headwaters of Teesta basin.

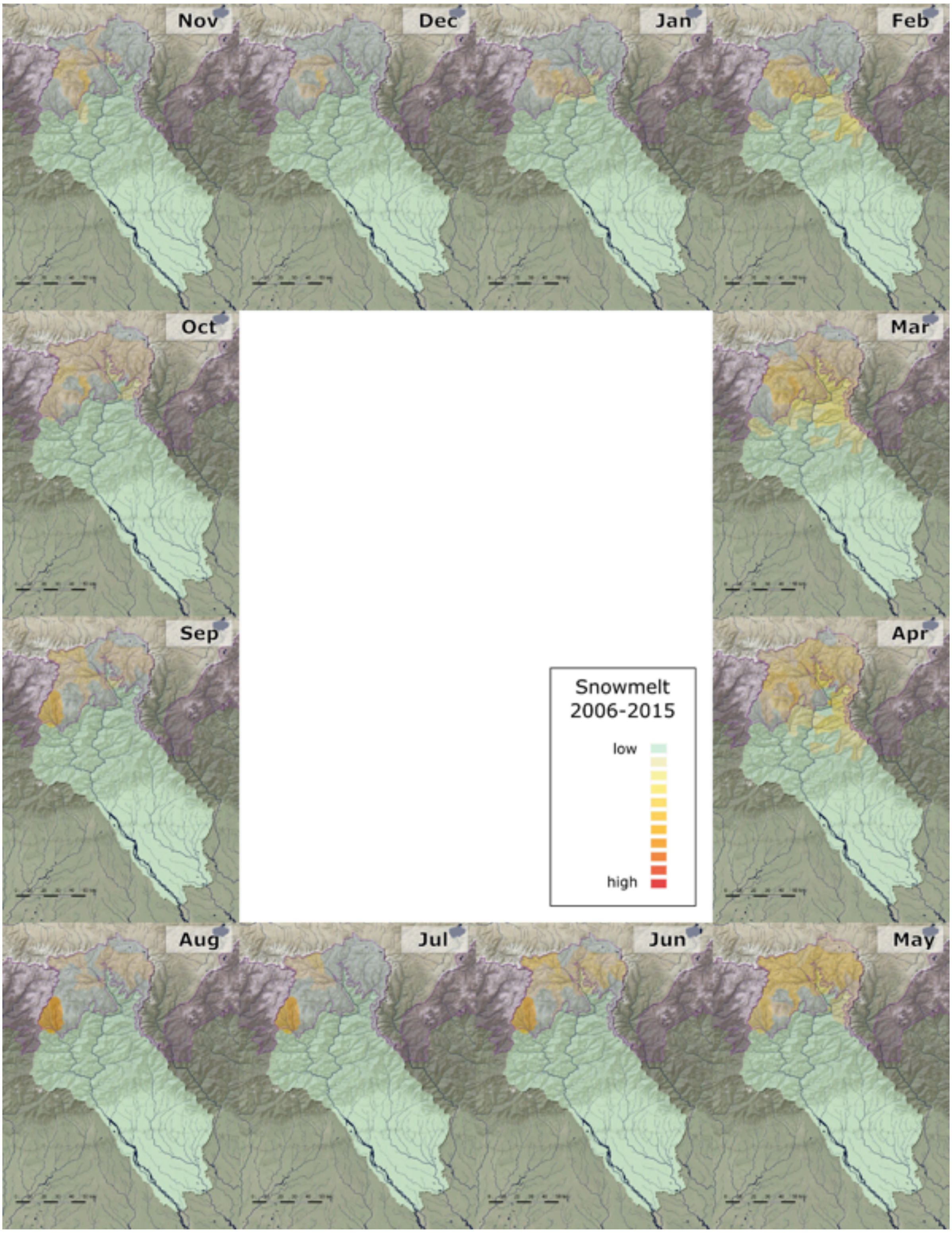
Methodology

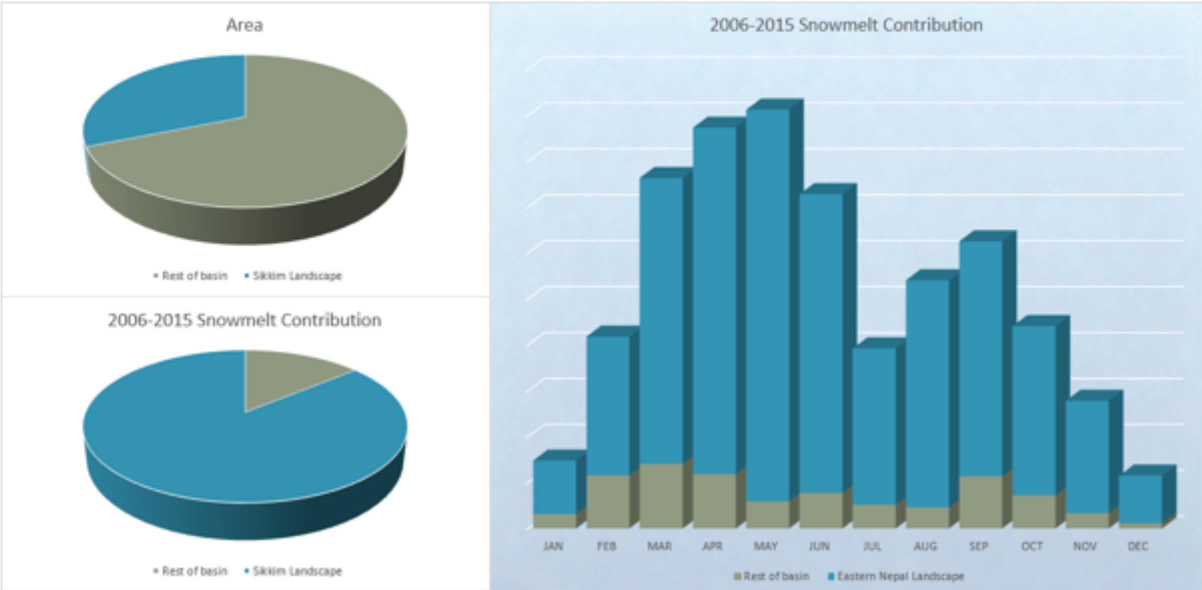
This is a map of MODIS/TERRA snow cover at 0.05 degree resolution with no additional processing required.

Data

MODIS/TERRA Montly Snowcover L3 at 5km (0.05 degree) resolution; Hall, Dorothy K., George A. Riggs, and Vincent V. Salomonson. 2006, updated monthly. *MODIS/Terra Snow Cover Monthly L3 Global 0.05Deg CMG V005*, [Year 2015, downloaded April 2016]. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Water provision functions; snowmelt





Analysis

Subbasin and landscape context

There are two peaks in the snowmelt season;

- during spring (March-April) when winter snow cover melts off in the headwaters
- another one at the end of the monsoon (August-September) that is concentrated around the Kangchenjunga complex.

The melt-off concentrated around Kangchenjunga actually can be seen from June onward, but is not in those amounts to continue the spring peak of snowmelt. It is likely that due to the high elevation and low temperatures of Kangchenjunga, its snowmelt amounts only peak late summer, after the onset of the monsoon.

Over the year, the landscape provides 86% of all snowmelt in the subbasin. Bookhagen et al (2010) calculate that 9.1% of total annual flow from the Teesta river originates from snowmelt. Given the distribution of flow and snowmelt over the months it can be concluded that snowmelt does play a significant role in streamflow at the end of the dry season. Though this provides a valid indication, since the snowmelt data here comes from a different model (GLDAS-NOAH) than the water towers and aridity calculations (WorldClim); these cannot be linked into a single model.

For the analysis here, the early spring snowmelt (February and March) are considered to be of most importance for water provision; the timing coincides with the end of the dry season on the downstream, when water would be in relative high demand. This is until the earliest monsoon rains start at the downstream areas in April.

Methodology

NOAH-GLDAS monthly data 2006-2015 is downloaded, it contains 28 bands of data; snowmelt is band 11 in this dataset. For every month, the 2006-2015 mean snowmelt component is calculated in a GIS, through adding all individual months.

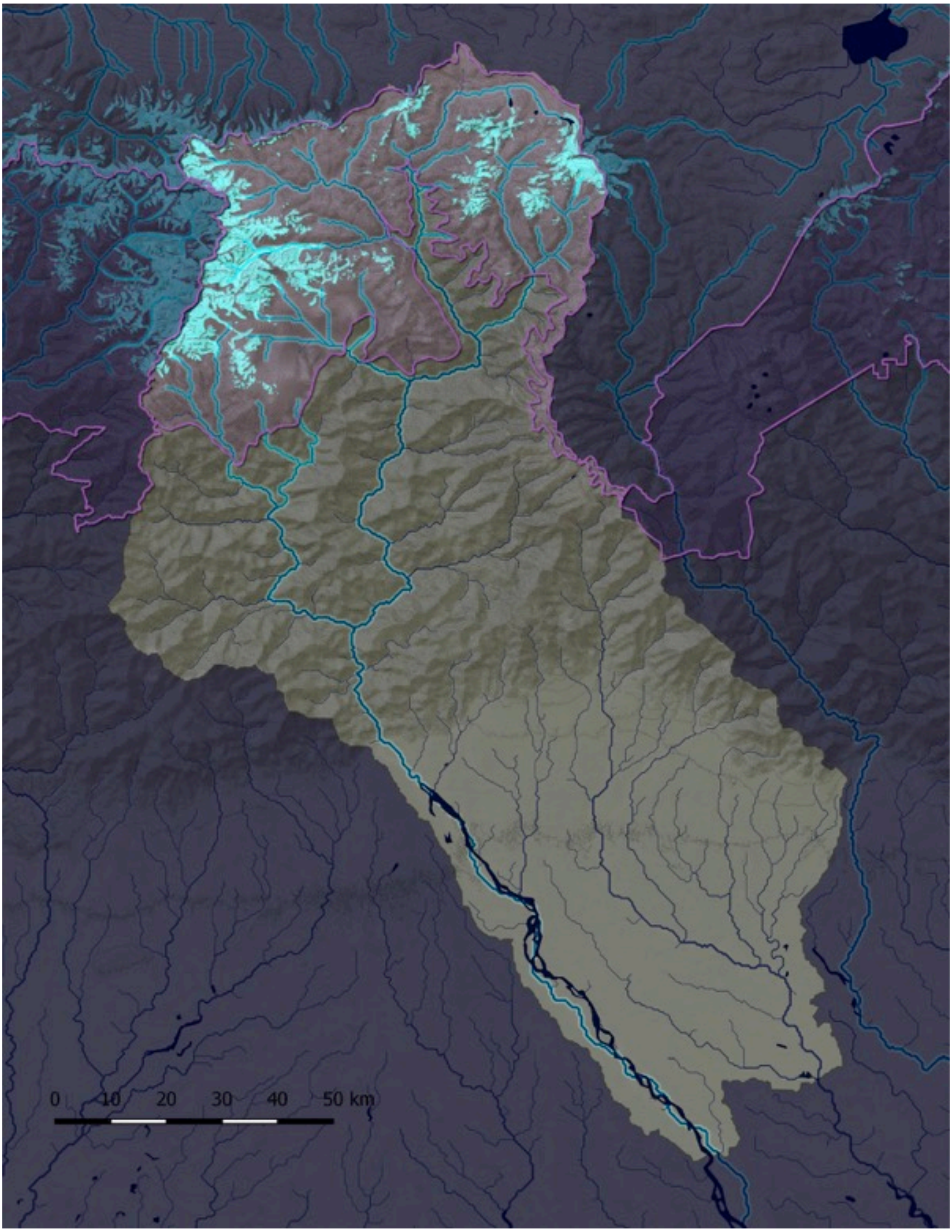
The mean snowmelt is then summarized in a GIS for each month by the selected HydroBASIN level 12 watersheds, and multiplied by each watershed area (in order to calculate quantities), both for the entire basin and the snow leopard landscape.

Data

NOAH-GLDAS V2.0, Monthly data on snowmelt from 2006-2015 at 0.25 degrees resolution
http://disc.sci.gsfc.nasa.gov/datareleases/gldas-version-2.0-data-sets

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Water provision functions; glaciers and glacial streams



Analysis

Subbasin context

Glaciers are important water sources because they can provide water to downstream throughout the year. Through regelation –pressure built up under thick layers of ice cause melting of the ice under the glacier- water keeps flowing from glaciers, regardless of the season. Therefore streams with glaciers in the headwaters do have different runoff pattern –as well as water chemistry- than streams with seasonal snowmelt in the headwaters.

Glaciers can continue to exist due to the imbalance between snowfall and snowmelt; where there is more snowfall than snowmelt, snow accumulates over the years and the layers get pressed into ice. This is a process that takes hundreds of years; that is how long it could take from initial snowfall to melt-off at the foot of a glacier. Ice melts off under high pressure under each glaciers, which makes glaciers slowly slide down, until it reaches elevations with seasonal thaw that melts-off the foot of the glacier. Under rising temperatures, this elevation gets higher and higher up the mountain, which could then escalate glacial melt off. In some cases, glaciers have pushed debris down the mountain, and under escalated melt-off, melt water is building up behind these walls of debris, creating risks for glacial lake outburst floods (GLOFS).

Though the map shows the spatial extent of the glaciers, it does not show the total volume of ice/water in each glacier. Each glacier has its own particularities that explains its existence, how it accumulates snow, and releases its water. To get a full understanding about the functioning of glacial water release would require detailed insights at the glacier level.

Landscape context

An –estimated- fifth of the landscape's area is covered under glaciers. The glaciated areas do not coincide with where the freeze line retreats to in summer, the freezeline retreat much further; just around the Kangchenjunga peak; leaving the glaciers "exposed" to months of thaw, from June to September. This indicates that every winter, the exposed glaciers must have accumulated enough snow to last through the summer; the seasonal snow melts off, but the perennial glaciers remain. This would imply a very precarious balance:

- under decreased snowfall, the glaciers would be exposed during the summer months,
- under increased temperatures, the seasonal snow will melt off earlier and start melting off the glaciers.

Methodology

This is a map of the GLIMS database.

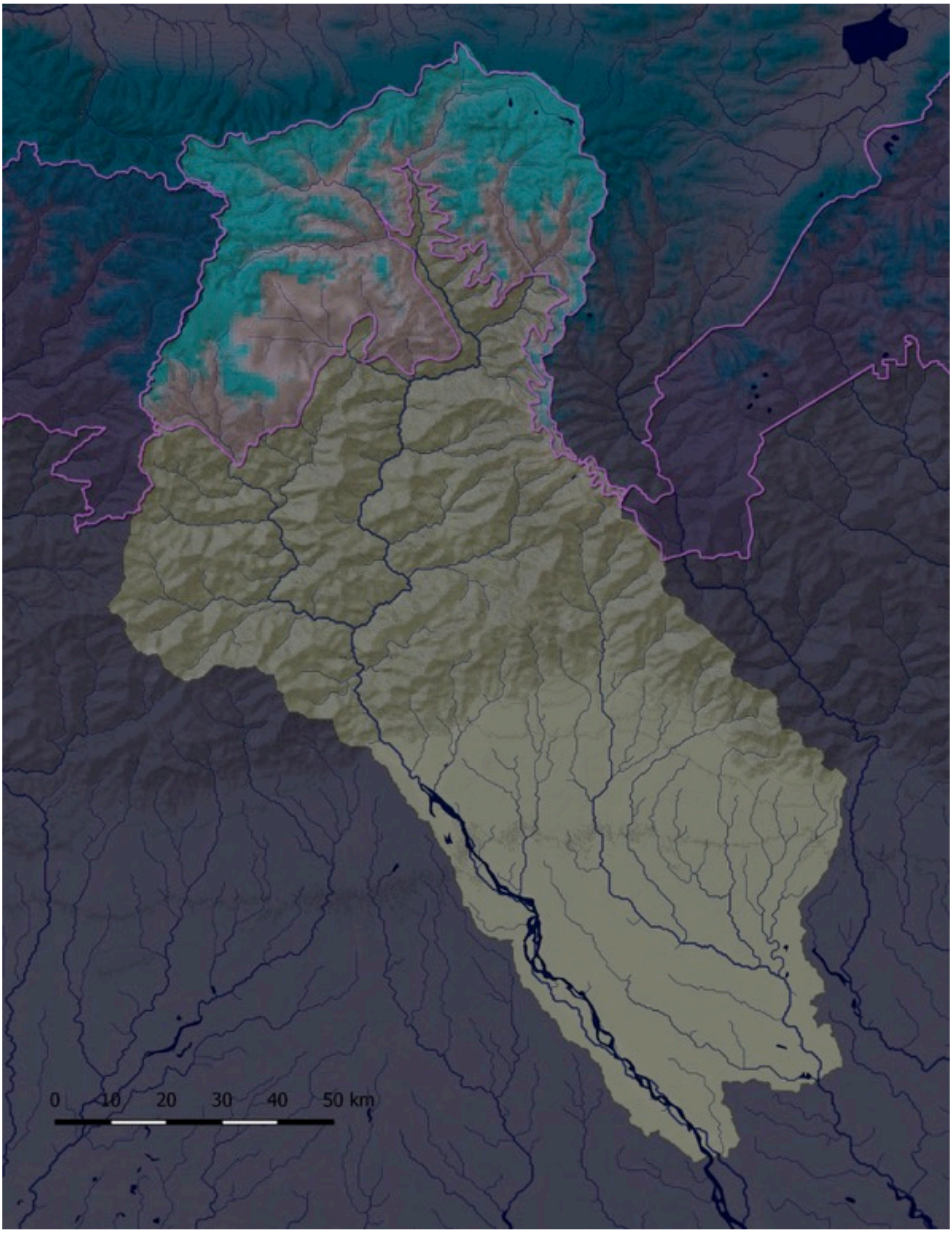
The glacial streams were created with HydroSHEDS 15s drainage directions. For that, the GLIMS polygons were converted to a 15s grid, and ran through a flow accumulation. A stream network was defined using HydroSHEDS 15s drainage direction, with the glacial flow accumulation attributed.

Data

GLIMS glacier database; GLIMS, and National Snow and Ice Data Center. 2005, updated 2012. GLIMS Glacier Database, Version 1. [polygons]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: http://dx.doi.org/10.7265/N5V98602. [April 2016].

HydroSHEDS 15s drainage directions; Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94. Data is available at www.hydrosheds.org

Water provision functions; permafrosts



Analysis

Subbasin context

The permafrost database is the work of Gruber (2012). It is a function of air temperature, ruggedness, and permafrost extents from earlier global assessments. The study acknowledges that the permafrost extents are mapped for consistent reference, but due to the lack of consistent information on permafrost, it is does not provide a reliable groundtruth (Gruber, 2012).

Overall, it provides a consistent and best-informed overview where permafrosts are located in the wider subbasin, contained in the snow leopard landscape: i.e. on high slopes in the headwaters, but not in the river valleys. So there is a component of being in the upstream source areas. Being located on the slopes implies that under increased temperatures, the spatial footprint of change will be relative small; since temperature slopes fare steep as well.

Though this map provides essential insight on the extent of permafrost, actually there are a wide range of permafrosts all with their specific seasonal impact on the landscapes in which they occur. The characteristic of each permafrost is essential to know in order to understand its role in landscape hydrology, or its vulnerability to climate change. At the moment, the map therefore illustrates the matter of uncertainty where permafrosts do occur; it depicts where changes are likely to happen under changing climate, but does not indicate how the landscape will change.

Possible changes already observed to coincide with permafrost degradation can be, but are not limited to:

- increased landslides, due to loss of permafrost slopes will lose their stability,
- decreased seasonal levels of groundwater, if permafrost dissolve or sink deeper, the active layer also sinks deeper, possible causing the disappearance of seasonal wetlands in alpine meadows, but also changes (or degradation) of surface vegetation,
- changed runoff patterns as sub-surface hydrology changes,
- release of greenhouse gasses that have been stored in permafrosts, and changes in runoff water chemistry.

These changes will become more dramatic at the frontier between permafrost and none-permafrost lands. This frontier runs throughout all the headwaters of this subbasin, and any climate change impacts on permafrosts will likely trigger unprecedented change at the subbasin level.

Landscape context

The permafrosts here are located at the highest elevations on the mountain slopes, as inside the landscape, the permafrosts are mainly located on the mountain slopes, under increased temperatures the spatial footprint of any change will be minimal, yet small changes to slope stability will have dramatic local impacts.

Methodology

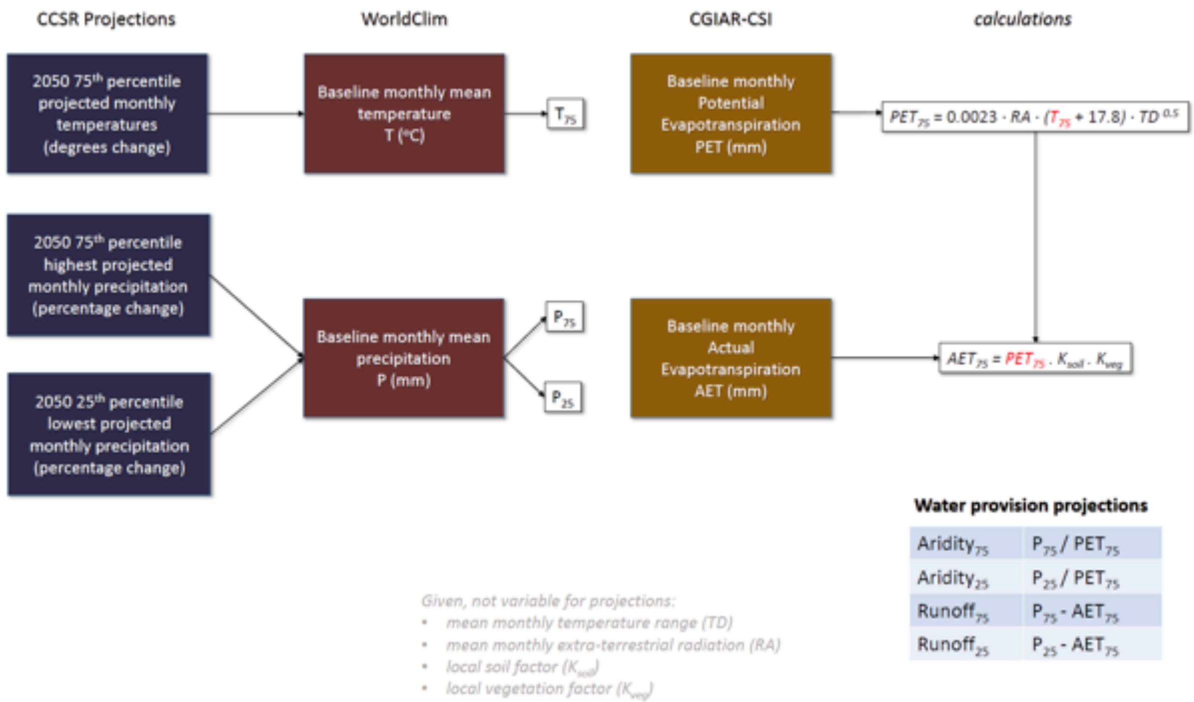
This is a map of the PZI database.

Data

Global permafrost database, Permafrost Zonation Index (PZI); Gruber, S.: *Derivation and analysis of a high-resolution estimate of global permafrost zonation*, The Cryosphere, 6, 221-233, doi:10.5194/tc-6-221-2012, 2012. http://www.geo.uzh.ch/microsite/cryodata/pf_global/

Eastern Nepal Climate Projections

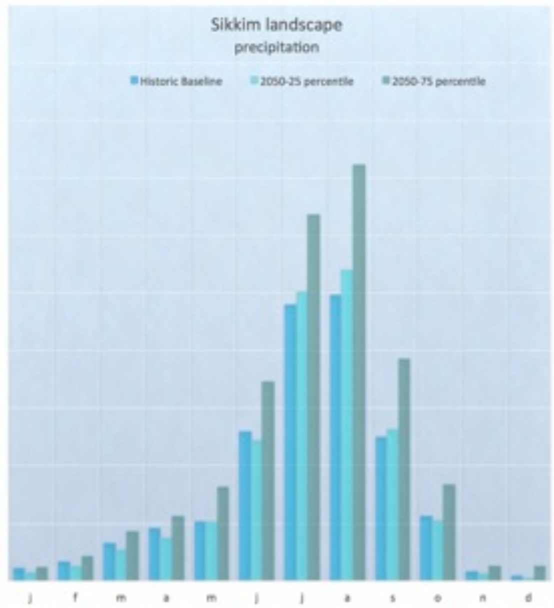
This section discusses how sensitive the different water provision functions are to different projections of climate change. It makes use of the same datasets as were being used for the water provision functions and applies the projections produced by the Center for Climate Systems Research, under the ADVANCE partnership with the WWF (CCSR, 2016)



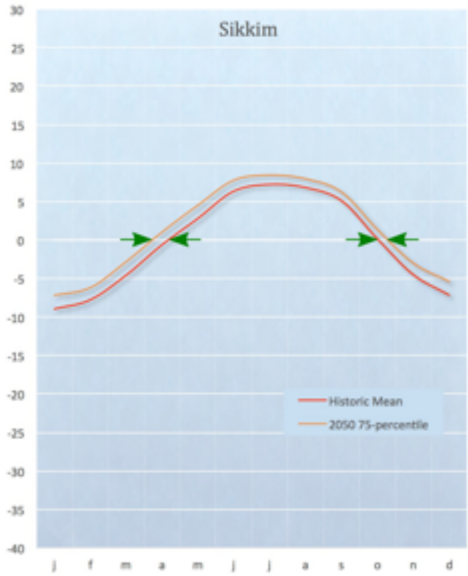
- CSSR Projections are calculated at 0.25 degree resolution; WorldClim and CGIAR-CSI datasets are at 1 km^2 resolution
- Calculations are upscaled/downscaled to HydroSHEDS level 12 (~100 km^2) watersheds, both for the snowleopard landscape and their larger subbasins
- The results are presented as graphs, this is in order to communicate *relative* changes to seasonality and to identify uncertainties in the projections; hence the water balances are not presented in millimetres of change
- In the annex, one quantitative example is given of a single (watershed) entry, representative for the snow leopard landscape; this quantitative example provides an insight in why certain graphs show the variability and uncertainty.

These projections are based on bias-corrected output from 21 General Circulation Models run under 2 scenarios of future emissions (moderate-emissions RCP 4.5 and high-emissions RCP 8.5), for a total of 42 projections. Projections for 2050 reflect average climate over 2041-2070. A most likely range of future climate change is defined from the 25th to the 75th percentiles of the suite of projections for precipitation. For temperature, a single higher-end estimate (75th percentile) is used for simplicity. While changes within this range are most likely, changes outside the range are also possible based on the full suite of projections.

Precipitation and temperature projections



Historic precipitation compared to the low end of the range of climate projections (25th percentile) and the high end of the range of climate projections (75th percentile) in the 2050s, horizontal axis crosses at 0 mm.



Historic temperature compared to the maximum projection (75th percentile) of 2050 (reference to CCSR-report, 2016). Arrows denote projected future loss of freeze season duration. Note that this figure only depicts the higher end of the most likely range of future temperatures

Observations:

- From July to September, both the high- and the low-ends of the most likely range of projected changes show an increase in precipitation compared to the baseline; this coincides with the peak monsoon, so it is likely that monsoon floodings will increase in severity
- In the high-end-projection, there will be annually 33.5 % extra precipitation, in the low end projection there will be 4.4 % less precipitation annually
- The largest difference in amounts of precipitation between high- and low end projection occurs in August, and the low-projection is about 33.7% lower than the high-projection; this is a measure of uncertainty in the projections
- Due to increased temperatures, there is an approximate five-week decrease in freeze/winter season; about 3 weeks in April, and about 2 weeks in October, indicated by the green arrows in the temperature chart

Data

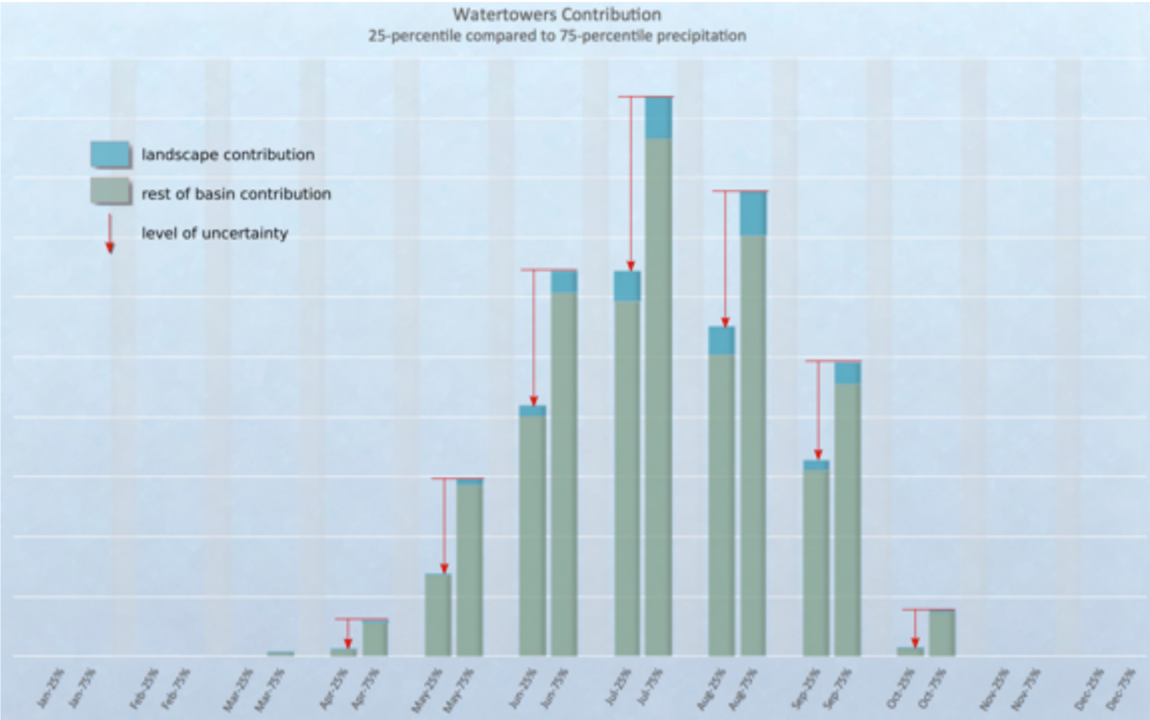
Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate

surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Climate Projections on future temperatures and precipitation by Center for Climate Systems Research, Earth Institute, Columbia University, under the ADVANCE partnership, 2016.

Watertower projections



Analysis

This graph shows how much water will locally runoff based on two 2050 estimates, one with the low 25 percentile precipitation and one with the high 75 percentile precipitation. Red arrows show the range of changes in runoff based on the range of climate changes, and therefore illustrate uncertainty in future climate impacts on runoff. The figure compares the overall sub-basin runoff (green colors under at the bottom of the bar chart) to the runoff specific to the snow leopard landscape (blue colors at the top of the bar chart). The horizontal axis crosses at 0 mm.

This graph would help to identify if the role of the snow leopard landscape in water provision would change under the climate projections. But there is certain proportionality in changes to the landscape versus the rest of the subbasin; if the subbasin gets drier, so would the landscape; if the subbasin would get wetter, so would the landscape. So it is not expected that the relative role of the landscape in water provision would change much.

In the annex, a graph shows the same range of projections in comparison with the historic baseline. That graph shows that the low-end estimate is more closely related to the baseline than the high-end estimate. The high-end estimate would create a more extreme peak around the monsoon season, which would indefinitely result in in extra floods towards the immediate downstream.

Data

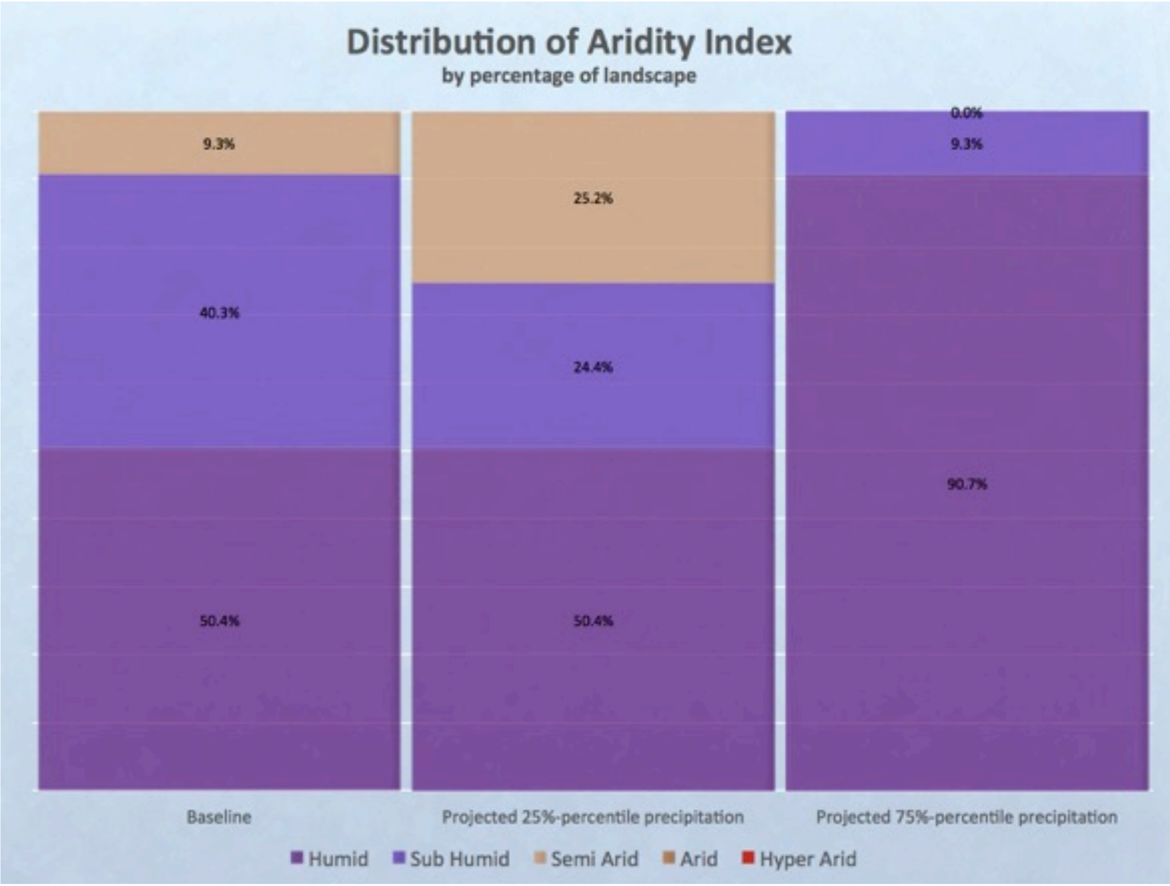
Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution; Trabucco, A., and Zomer, R.J. 2010. Global Soil Water Balance Geospatial Database. CGIAR Consortium for Spatial Information. Published online, available from the CGIAR-CSI GeoPortal at: http://www.cgiar-csi.org

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Climate Projections on future temperatures and precipitation by Center for Climate Systems Research, Earth Institute, Columbia University, under the ADVANCE partnership, 2016

Projected change in aridity index inside the landscape (annual)



Analysis

These graphs compare the current (baseline) situation of aridity versus humidity to the high and low ends of the range of projected climate change defined from the 25th percentile of projected change in precipitation for 2050 (in this case, drier) to the 75th percentile projected of change in precipitation for 2050 (in this case, wetter) among 42 climate model runs. The range between the low and high estimates represents the most likely range future changes, and therefore illustrates a measure of uncertainty.

The classification of aridity versus humidity is a measure to which extent the precipitation is a limiting factor in vegetation growth; more arid landscape will have more drought resistant vegetation. The aridity puts this in perpective of other climatic parameters, such as temperature or solar radiation.

In the annual balance, most of the seasonality is balanced-out. The difference between to low and high ends of the most likely range of future precipitation in this context seemt to be significant in terms of water provision. The difference between the low- and high- estimates shows that under the low-estimate, 25 % of the landscape would classify as semi-arid, while under the high-estimate only 9 % would classify as sub-humid, the rest of the landscape being more humid. Both changes are very different from eachother would leave lasting impact on the composition of the landscape’s vegetation and land cover.

Data

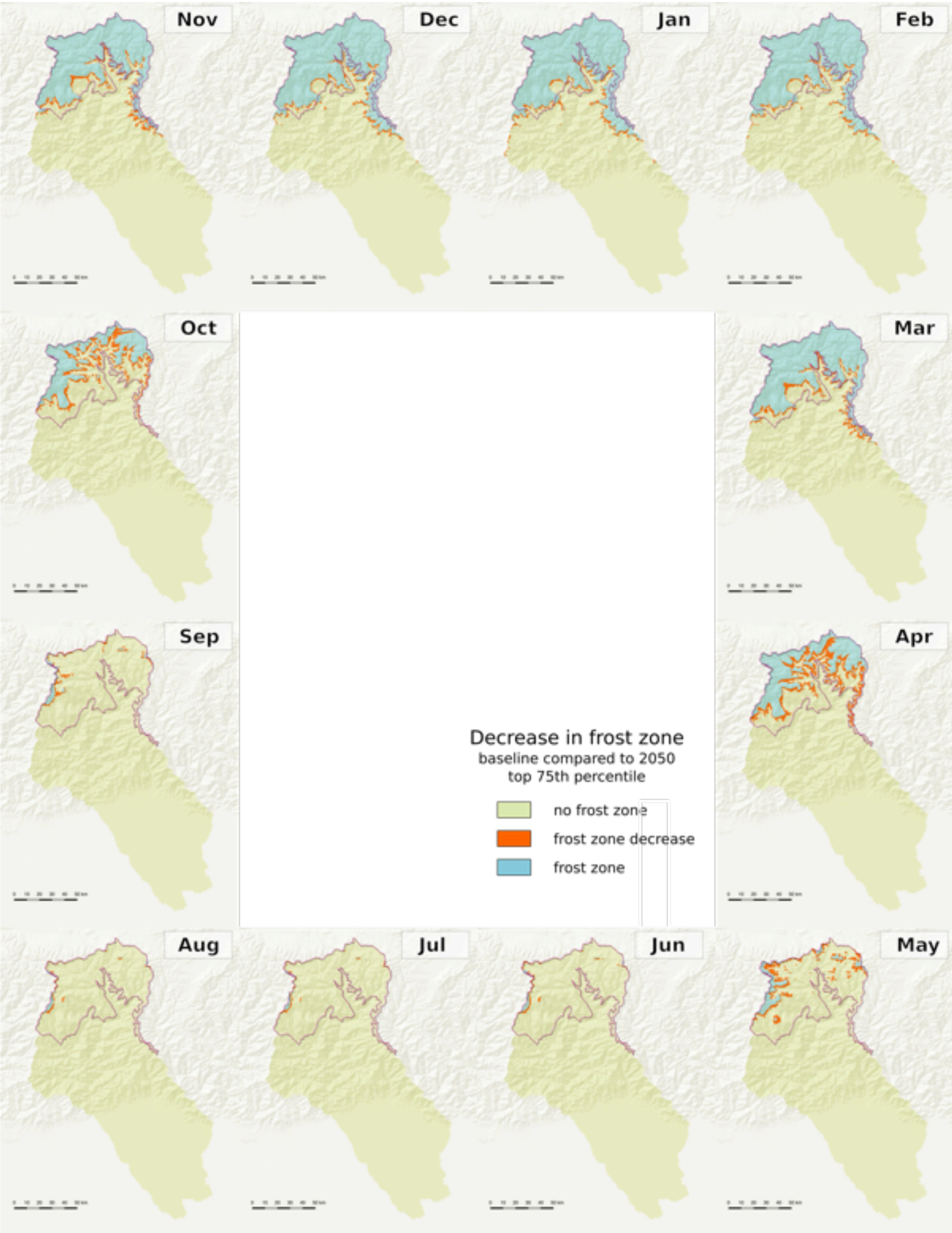
Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution; Zomer RJ, Trabucco A, Bossio DA, van Straaten O, Verchot LV, 2008. Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. Agric. Ecosystems and Envir. 126: 67-80.

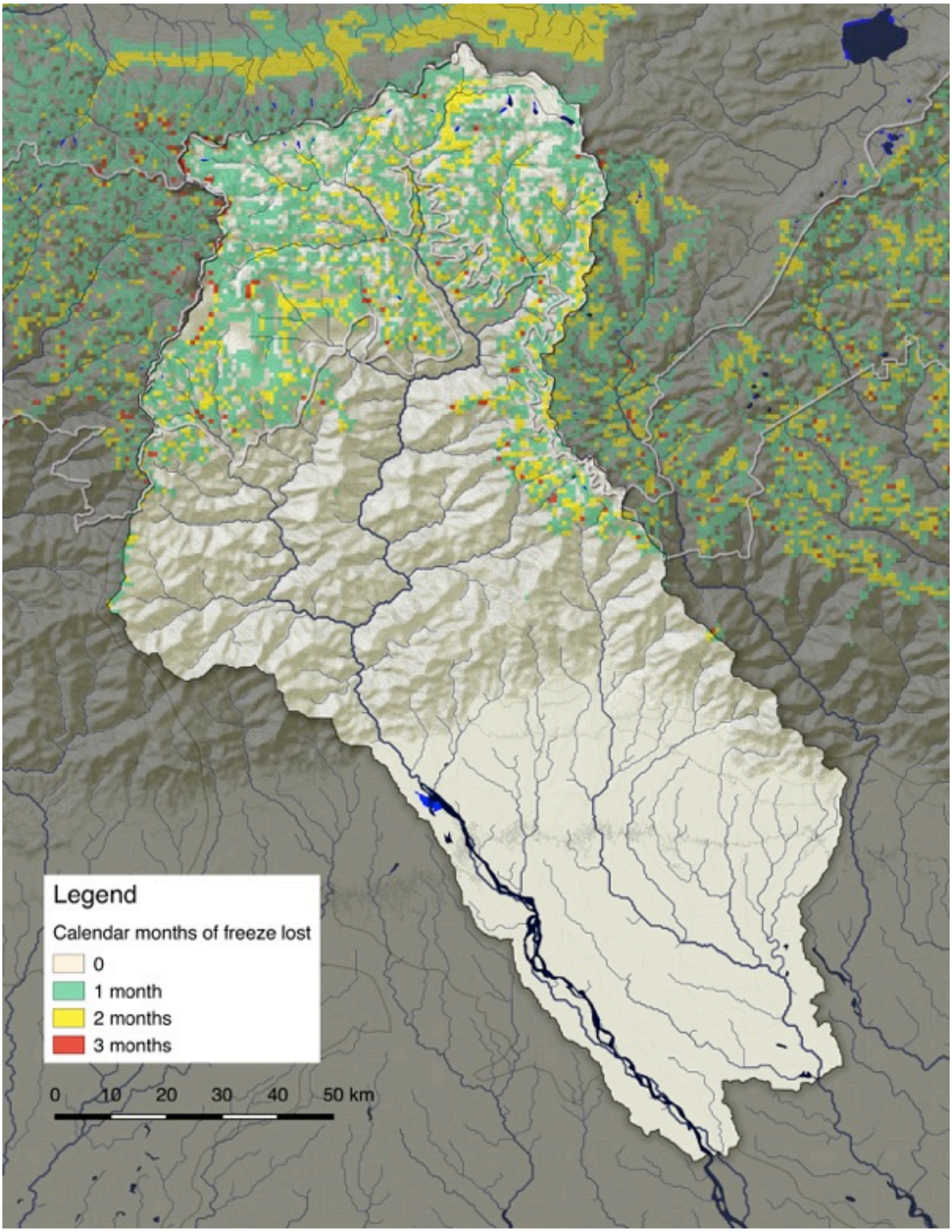
Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Climate Projections on future temperatures and precipitation by Center for Climate Systems Research, Earth Institute, Columbia University, under the ADVANCE partnership, 2016

Decrease in monthly freeze extent under temperature rise



Calendar Months of Freeze-loss



Analysis

This mapset illustrates for each month what the spatial footprint would be on the freeze frontier under projected temperature rise. The baseline freeze extent guides a landscape's freeze and thaw cycles, and any change to this will result in different patterns of snowfall and snowmelt, and other cryosphere interactions (e.g. glaciers, permafrost).

In order to visualize those interactions, the online version of this mapset would allow for each monthly map to be overlaid with the baseline snowfall, snowmelt, glacier and permafrost maps. In such a way it could be visualized how the timing and spatial footprint of the freeze/thaw cycle would change under projected temperature rise.

There are three clear patterns emerging from the projected temperature change inside the landscape and the wider sub-basin;

- In winter (November to March), the freeze extent is on the slopes. Any increase in temperature will leave a minimal shift in the extent, while the temperatures on top of themountain ranges are too low to be influenced in freeze extent.
- In April and October, the historic seasonal temperatures rise quickly from summer to winter and vice versa, any increase in these temperatures will therefore leave a somewhat larger spatial footprint.
- In the summer months (May/June to September) the spatial footprint is limited but surrounding important mountaintops. These mountaintops would historically accummulate the largest amount of snow during the monsoon season due to the combination of relatively large amounts of precipitation and freezing temperatures. Under changing temperatures, less snow will accummulate, more snow will melt off directly, in coincidence with the monsoon; this will very likely result in a dramatic increase in the size and timing of downstream floodings.

Data

Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

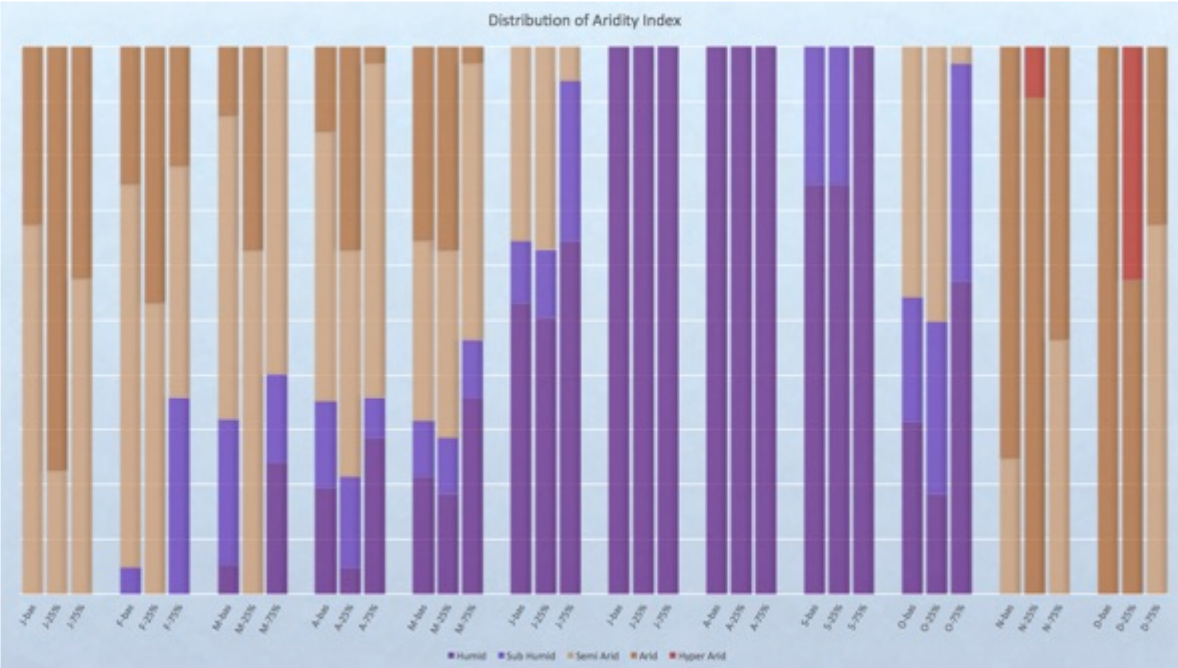
Climate Projections on future temperatures and precipitation by Center for Climate Systems Research, Earth Institute, Columbia University, under the ADVANCE partnership, 2016

Annexes

Watertower contributions (baseline vs 25-percentile vs 75-percentile)

This graph confirms that for the low-end estimate, runoff is very closely-tied to the historic baseline, and that the high-end estimate would result in peak runoff on top of the monsoon water towers.

Projected change in aridity index inside the landscape (monthly)



The montlhy distribution of aridity index shows to which extent the landscape is changing towards a drier or wetter landscape, by the distribution of aridity and humidity classes as percentage of the snowleopard landscape. In terms of water use, this would imply to which extent crops could depend on precipitation or require additional irrigation. But it also indicates the changed durations and intensities of the wet- and dry-seasons

This graph illustrates that from the onset of the monsoon –April- towards the end of the monsoon, the aridity/humidity classes of the baseline and both estimates are more-or-less in accordance, the high-end being slightly wetter, the low-end very closely follows the baseline. The monsoon will reamin the most humid season of the year, no matter how climate is projected to change.

For the rest of the year, the high-end estimate overall shows a humidity that is almost one complete classification higher (more humid) than the low-end estimate; this indicates a high level of uncertainty; under the high-end estimate the landscape will shift its aridity/humidity balance which will leave direct impact on vegetation and soils.

Quantitative example

Basin ID: 807	area_km^2:	114.4	lat:	27.500	lon:	88.750								
Sikkim Landscape			jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
baseline														
temperature	°C		-4.13	-2.92	0.42	4.10	7.18	9.98	11.03	10.67	9.23	4.77	0.26	-2.62
precipitation	mm		9.38	18.75	34.30	49.91	58.35	114.85	165.97	153.80	100.36	45.19	8.91	3.64
AET	mm		22.46	24.13	37.23	47.29	55.92	59.97	69.45	74.24	66.34	54.69	34.56	24.98
PET	mm		34.69	39.30	62.64	81.73	99.09	97.63	97.99	92.80	79.16	66.96	46.01	37.08
runoff	mm x km^2		0.00	0.00	0.00	0.00	0.00	6277.51	11041.13	9101.66	3891.89	0.00	0.00	0.00
2050_25 percentile														
precipitation change	%		71.52	78.20	83.06	83.65	100.02	94.47	102.18	106.79	102.82	91.36	73.13	34.12
precipitation$_{25}$	mm		6.71	14.66	28.49	41.75	58.36	108.50	169.59	164.25	103.19	41.28	6.52	1.24
runoff$_{25\ (T75)}$	mm		0.00	0.00	0.00	0.00	0.00	5212.34	11134.96	9967.23	3902.46	0.00	0.00	0.00
2050_75 percentile														
temperature change	°C		1.71	1.51	1.62	1.60	1.65	1.37	1.16	1.10	1.11	1.18	1.50	1.65
temperature$_{75}$	°C		-2.41	-1.41	2.05	5.69	8.83	11.35	12.20	11.77	10.35	5.94	1.76	-0.97
precipitation change	%		110.12	126.21	131.78	127.02	155.49	135.20	129.89	145.83	150.38	146.87	155.75	283.60
precipitation$_{75}$	mm		10.33	23.67	45.20	63.40	90.73	155.28	215.57	224.28	150.92	66.37	13.88	10.32
AET$_{75}$	mm		25.28	26.58	40.54	50.73	59.61	62.93	72.26	77.12	69.07	57.54	37.42	27.70
PET$_{75}$	mm		39.04	43.28	68.21	87.69	105.62	102.45	101.95	96.40	82.42	70.45	49.83	41.12
runoff$_{75}$	mm x km^2		0.00	0.00	533.34	1449.00	3560.04	10563.93	16394.57	16835.36	9362.83	1010.16	0.00	0.00

These numbers are presented as reference to the different graphs; they will explain why certain values occur in a randomly selected watershed inside the Sikkim landscape.

From the numbers it becomes clear, that the monsoon precipitation is driving runoff values; in the baseline and low-end estimate there are 4 months of *some* flow, in the high-end estimate there are 8 months, for this particular watershed.