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An Estimated Contribution of Glacier Runoff to Mongolia's Upper Khovd River Basin in the Altai Mountains

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In the semiarid climate of northwestern Mongolia, glaciers are critical contributors to water resources, particularly during the dry summer months. Nevertheless, our knowledge of the contribution of glacier runoff in the Upper Khovd River Basin (UKRB) is limited. This study investigates the impact of glacier recession on the UKRB's hydrology in western Mongolia's Altai Mountains. The analysis included glaciological method measurements, satellite-derived glacier extent records, and a simple ice ablation model. Our modeling used a mass balance gradient of 0.50 meters water equivalent 100 m^{-1} for the years 2000, 2010, and 2016 and included a sensitivity analysis that applied lower and upper mass balance gradient values and ±200 m around the equilibrium line altitude (ELA). The glacier contribution to the UKRB's water resources decreased from almost 8% in 2000 to 6.7% in 2016. Hypsometries revealed that glacier areas decreased at all elevations, indicating that only small accumulation zones exist. Therefore, applying a modeled increased ELA better represents glacier contribution to total runoff, at 18.7% in 2000 and 15.4% in 2016. The decreasing glacier runoff contribution indicates that the UKRB glaciers have passed the tipping point of an increased contribution that first follows enhanced melting. The continued glacier recession and uncertain water availability represent challenges for water resource management and future human–water relations in the Mongolian Altai.

Keywords: *Altai Mountains; glaciers; water security; climate change; Mongolia.*

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Introduction

The Altai Mountains of Mongolia are uniquely positioned in an extreme continental climate that governs a semiarid to arid landscape. Arid mountainous landscapes of the Altai and elsewhere in Central Asia are limited by the availability of water, naturally reflected in the dry-tolerant grass and scrublands that dominate the region (Li et al 2015). However, as Central Asia's populations increase, water demand will increase in synchrony, placing greater importance on regional water security issues (Karthe et al 2017). Water insecurity and related vulnerabilities are amplified through several mechanisms in Central Asia, such as agricultural consumption as a result of transitioning dry-tolerant vegetation for crops that require irrigation (Mosello 2008), the development of hydropower plants (HPPs) as a solution to increasing energy demand but also as regulators of downstream water flows (Gaudard et al 2014), and continued amplified warming (Chen et al 2009) coupled with decreasing precipitation (Batima 2005).

The glaciers and snowpack in the Altai Mountains are part of what are known as the regional "water towers" or "wet islands"—an oasis providing water to the surrounding arid landscape and downstream services (Viviroli et al 2007; Kaser et al 2010; Sorg et al 2012). Yet, as accelerated glacier recession continues in the 21st century with amplified warming (Zemp et al 2015), understanding the role of glacier runoff in water availability has become urgent and has therefore received much attention from scientists, water planners, and development organizations. Much of the glaciohydrological research has focused on Central Asia's Amu Darya and Syr Darya because these 2 basins extend across seven countries (see Hagg et al 2011, 2013).

Studies of the relationship of glaciers and hydrology at the eastern fringes of Central Asia, in the Mongolian Altai, are rare: to our knowledge, only one such study is available (Tsutomu and Gombo 2007). The earliest glaciological research in Mongolia used a volume–area scaling approach to determine that the total cumulative volume of glaciers across the country was 62.8 km^3 (Dashdeleg et al 1983). Using this number and an estimated total surface water value of 599 $km^3\ yr^{-1}$ as an absolute value of water equivalent, it was determined that Mongolia's glaciers store an accumulated 10% of the total annual water resources of the entire country (Davaa et al 2007). Given the relatively small area of glaciers in the Mongolian Altai (334 km^2) (Pan et al 2017), which is the only recently glaciated region in the country, 10% is likely an overestimation. However, streamflow in many glaciated catchments has increased in recent years, relative to nonglaciated basins (Davaa 2010). The initial increase in contribution is in line with the theoretical underpinnings that glacier recession will initially increase the stream discharge as a result of enhanced ice melting (Bury et al 2013). Hence, for now, we know that at a minimum glaciers are important contributors to the UKRB's hydrology.

In this paper, we build upon and extend environmental change research efforts in Central Asia to reevaluate our understanding of water availability issues in the data-scarce Altai Mountains of Mongolia. Specifically, we aim to focus attention on the significance of glacier runoff to the hydrology of the glaciated semiarid UKRB by coupling recent *in situ* glaciological methods (Konya et al 2013; Syromyatina et al 2015) with remote-sensing-derived glacier records (Pan et al 2017), within a simple ice ablation model (Alford 1992; Racoviteanu et al 2013).

Study area: Upper Khovd River Basin

Located within Bayan-Ulgii Province in Mongolia's northwest corner, the UKRB straddles the Russian and Chinese border, forming the headwaters for the Khovd River. The basin covers a total area of approximately 23,000 km^2 and includes the Tavan Bogd massif, where Mongolia's largest glaciers, Potanin and Alexandra, are found. The UKRB's glaciers are well inventoried and include 311 glaciers with a total area of 131.5 km^2, accounting for 40% of the Altai's total glaciated area as of 2016 (Pan et al 2017). In addition to the marked extent of glaciation, the UKRB includes one of the most comprehensive hydrographic datasets recorded at Ulgii (Figure 1).

In 2018, Bayan-Ulgii had a population of 105,090, which has increased at an annual rate of 2269 people since 2010. Western Mongolia, which includes the provinces of Bayan-Ulgii, Khovd, Uvs, Govi-Altai, and Zavkhan, had a total population of 408,979 in 2018, with an annual increase in population of 7206 people since 2010. The growing population across western Mongolia and Mongolia's interest in reducing agricultural and energy imports equate to an increase in water-intensive industries. Since 2008, agricultural production has been developed to reduce agricultural imports from Russia and China. This has increased the extent of irrigated land by 1071 ha annually in western Mongolia (Priess et al 2011).

As part of the National Renewable Energy Program, Mongolia has begun to transition away from fossil fuels to become less dependent on energy imports from China and Russia, leading to hydropower development. Three HPPs are situated in the central parts of the Mongolian Altai. The new 12 MW Durgun HPP and some diesel generators produce energy for its northern parts, where consumption in the Western Energy System more than doubled from 2008 to 2014 (Liu et al 2013). The Durgun HPP is expected to meet more than 90% of the electricity demand of the 3 remote western provinces of Bayan-Ulgii, Khovd, and Uvs (UNFCCC 2005). It is located 120 km northeast of Khovd, the capital of Khovd Province, at the outflow of Khar Us Lake on the Chono Kharaikh River. The primary inflow to Khar Us Lake is the Khovd River.

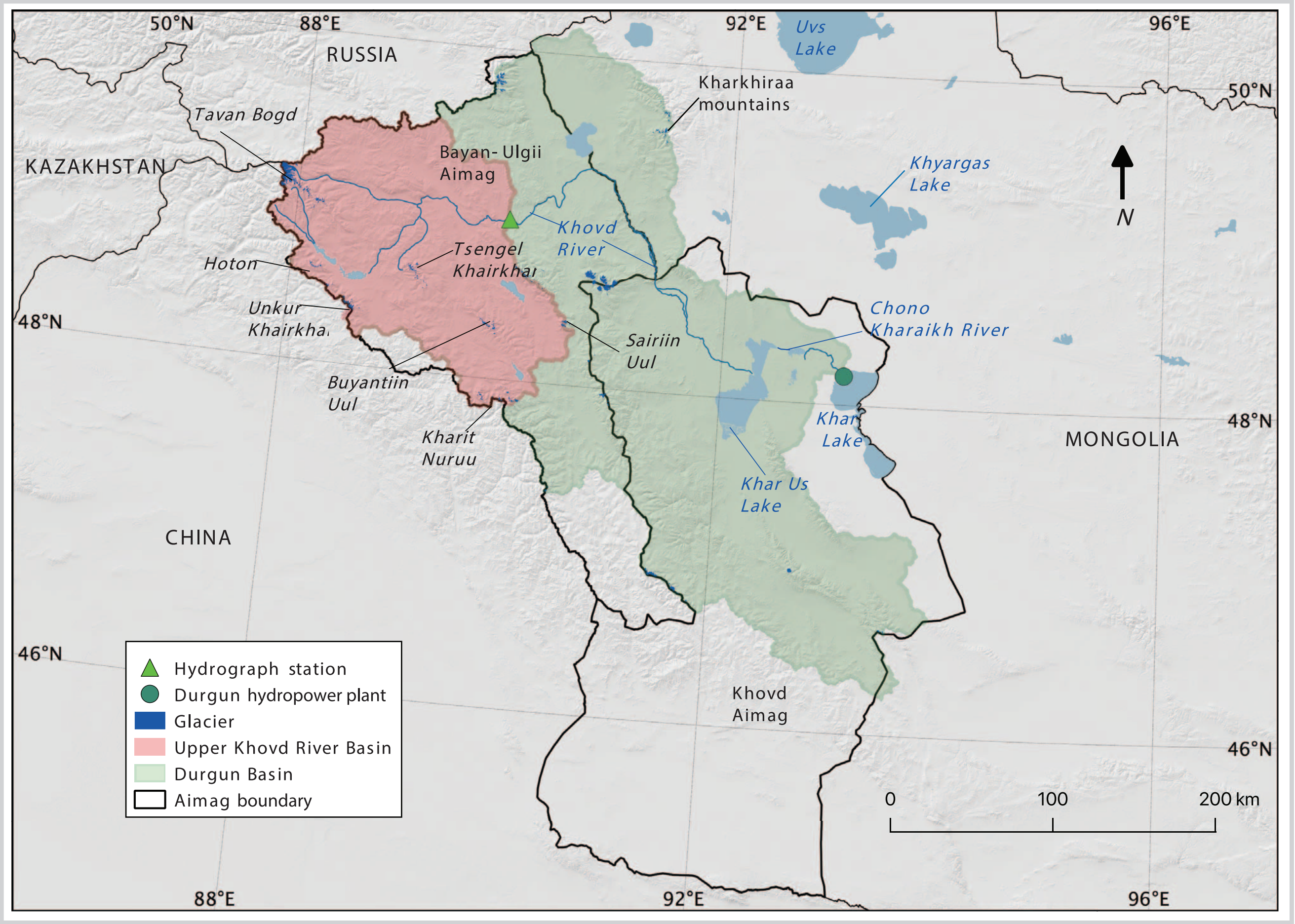
The Altai has a continental climate with long, cold, dry winters and mild, relatively short summers (Rudaya et al 2009). The climate is largely controlled by westerlies, bringing moisture from the Atlantic and Mediterranean (Blomdin et al 2016). As moisture is brought in from the west, the windward side of the Altai receives most of the annual rainfall at around 1000 mm, whereas the leeward side receives only around 130–400 mm. Generally, liquid precipitation totals decrease from west to east across the Altai (Rudaya et al 2009; Lehmkuhl et al 2016). Although annual precipitation is low, its intensity can be high, potentially 40–60 mm in a single day. These rain events result in 90% evaporation; of the remaining 10%, 64% becomes surface runoff, and 36% infiltrates the soils (Batima et al 2005). The mean winter temperatures can be as low as −20°C, and mean summer temperatures range from 15 to 20°C (Rudaya et al 2009; Ganiushkin et al 2015).

Data and methods

Model inputs

We used a simple ice ablation model, first described by Alford (1992) and later applied in several high mountain regions (Racoviteanu et al 2013; Alford et al 2015). The model is heuristic and allows annual glacier runoff to be estimated. It was developed specifically for high mountains, with limited information. It requires 3 input datasets: (1) glacier hypsometries, (2) daily hydrographic

FIGURE 1 The defined study area is the Upper Khovd River Basin (red shading) in the Altai Mountains of western Mongolia. The Durgun Basin (green shading) has its outflow at the Durgun HPP. (Map by Caleb Pan)



measurements, and (3) a mass balance gradient (MBG). Glacier hypsometries were generated from debris-free glacier outlines at 100 m bins for the years 2000, 2010, and 2016, based on glacier outlines downloaded from the Global Land Ice Measurements from Space initiative website (Table 1) (Kamp and Pan 2015; Pan et al 2017). The glaciers' altitudinal distribution was assigned using a 30 m Shuttle Radar Topography Mission digital elevation model downloaded from NASA's EarthData Explorer (www.earthdata.nasa.gov). Hydrographic data were acquired from the Mongolian Ministry of Nature and Environment, spanning from 2000 to 2012, with missing observations from 2003 to 2006 (Figure 2). Mean daily discharge observations (m^3 s^{-1}) were used to create total mean daily discharge (m^3 day^{-1}).

Mass balance gradient

The MBG corresponds to the amount of ice melt for every 100 m of change in elevation (Racoviteanu et al 2013). Within the ice ablation model, we assume a MBG of zero at the equilibrium line altitude (ELA) and for every 100 m below the ELA that the MBG linearly and cumulatively increases by a defined value (meter water equivalent; m w.e.) (Figure 3). For this study, the MBG was drawn from the literature using several recent studies from across Central Asia (Wang et al 2012; Kronenberg et al 2016). During the ablation season of 2008, a MBG of 0.56 m w.e. 100 m^{-1} at was calculated at Potanin glacier and 0.41 m w.e. 100 m^{-1} at Maliy Aktru, a glacier north of Potanin in the Russian Altai (Konya et al 2013). A separate group calculated a similar MBG of 0.54 m w.e. 100 m^{-1} in the Russian Altai (Klok and Oerlemans 2004). We used the mean of the 3 local MBGs from these 2 studies, which resulted in a MBG of 0.50 m w.e. 100 m^{-1}. To accommodate annual climate variability in glacier runoff estimates, we applied a sensitivity analysis using the higher (0.56 m w.e. 100 m^{-1}) and lower (0.41 m w.e. 100 m^{-1}) MBG values from the 2 aforementioned studies.

Calculating the ELA

Previous studies using the ice ablation model applied a basin-wide ELA, calculated as the glaciers' mean elevation

TABLE 1 The number and area of glaciers in the in the Upper Khovd River Basin during 2000, 2010, and 2016. Glacier area numbers are also aggregated for the Bayan-Ulgii Aimag and the entire Altai Mountains for reference.

Year	Upper Khovd River Basin		Bayan-Ulgii Aimag Glacier area (km^2)	Entire Altai Glacier area (km^2)
	Glacier count	Glacier area (km^2)		
2000	345	170.8	307.3	428.6
2010	333	151.5	268.6	371.1
2016	311	131.5	237.3	334.0

(Bolch et al 2010). Since we iteratively applied the ice ablation model to each individual glacier, we calculated each glacier's specific ELA, represented by the mean glacier elevation. Throughout the UKRB, the mean glacier elevation was 3328 m in 2000, 3308 m in 2010, and 3333 m in 2016. As seasonal climate variability and terrain can introduce uncertainty in representing a glacier's ELA, we carried out an additional sensitivity analysis: we applied the ice ablation model to presumed ELAs at 200 m above and below the calculated ELA for 2000, 2010, and 2016 (Racoviteanu et al 2013).

Model setup

This study is concerned with the glacier melt component in the hydrologic continuity equation to describe the relationship between glaciers and streamflow volume:

$$Q_t = R + M_s + M_i - E_t \pm \Delta_s, \tag{1}$$

where Q_t is total runoff, R is rain runoff, M_s is snowmelt runoff, M_i is glacier melt runoff (ablation), E_t is evaporation, and Δ_s is the change in storage as snow, glacier ice, or groundwater. Here we define runoff as the "part of the precipitation [or] snow melt … water that appears in uncontrolled (not regulated by a dam upstream) surface streams [and] rivers" (USGS 2019). In the glacier ablation zone, evaporation is assumed to be minimal, and the change in groundwater storage for the hydrologic year is assumed to be zero (Rasmussen and Tangborn 1976). Rain is excluded because we are interested only in glacier runoff.

FIGURE 2 Mean daily discharge observed at Ulgii in the Upper Khovd River Basin from 2001 to 2012.

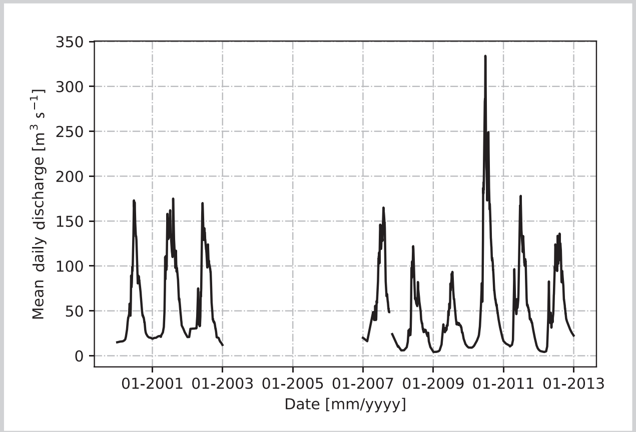
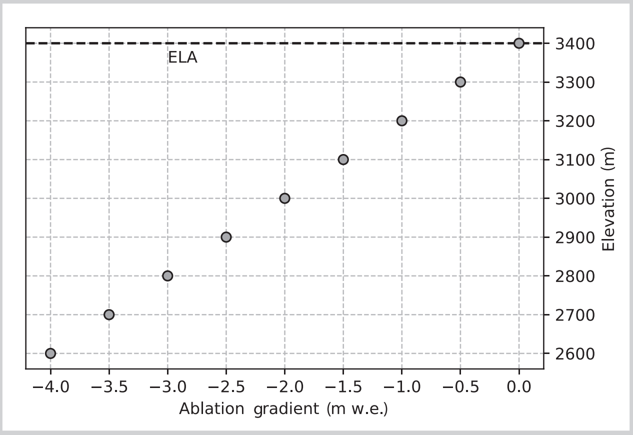


FIGURE 3 The relationship between the ELA (dashed line), elevation, and MBG. At the ELA, the MBG equals zero, but for every 100 m below the ELA, the MBG increases by a defined rate of 0.50 m w.e. 100 m^{-1}. (Figure modeled after Racoviteanu et al 2013)



As a first approximation, the hydrologic continuity equation reduces to a determination of the relative importance of snow and glacier melt in the hydrologic regime of the UKRB:

$$Q_t = M_s + M_i. \tag{2}$$

The ice ablation model takes the following form:

$$B_s = \sum_{=1}^{n} bs_i \times A_i, \tag{3}$$

where B_s is the glacier runoff in cubic meters, b_s is the specific ice melt [m], determined by the MBG for a given elevation range, and A_i is the glacier area within the corresponding elevation range (Racoviteanu et al 2013). Using glacier-specific ELAs, Equation 3 was applied to each glacier in the UKRB and then summed to acquire the total annual specific glacier runoff.

Results

Hydrographic data provide a qualitative assessment in the relative contribution of glaciers to streamflow. Within heavily glaciated basins in (semi-)arid regions, hydrographs will express a second peak during the ablation season, attributed to glacier runoff. In the UKRB, the seasonal hydrologic flow peaks in late June and early July indicate the onset of the ablation season as snow cover has melted (see the red shading in Figure 4). Yet only 1% of the UKRB is glaciated, which makes it difficult to observe a second peak in the hydrograph. However, after the main peak, the total daily discharge decreases sharply before stabilizing in the latter half of July and early August, as glacier runoff begins to contribute to the streamflow during the dry periods of summer (see the blue

FIGURE 4 Mean daily discharge observed at Ulgii in the Upper Khovd River Basin. The red-shaded region indicates the peak discharge; the blue shading highlights the ablation period.

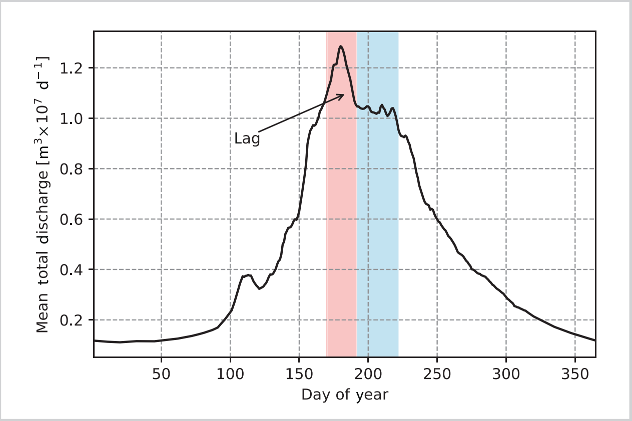
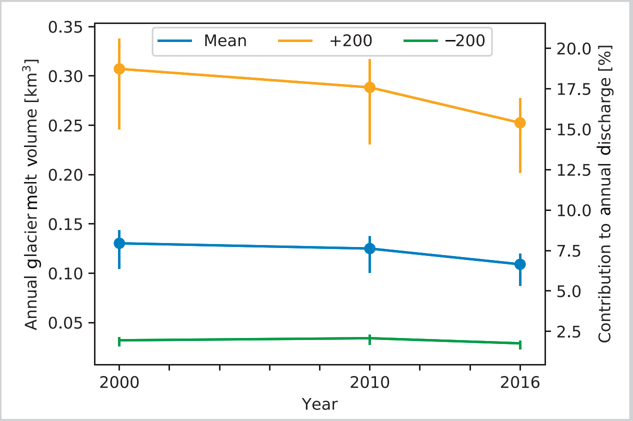


FIGURE 5 Ice ablation model results. The blue line indicates results using the glaciers' mean elevation as the ELA. The yellow line presents model results of the ELA +200 m, and the green line are model results using the ELA −200 m. The vertical bars indicate the model results using the defined higher and lower MBG values from the literature. We did not put points on the green line because they obscure the uncertainty bars.



shading in Figure 4). The duration between the sharp decrease in total daily discharge and the stabilized period can be described as the lag time between the initiation of the ablation season and the moment the early season glacier meltwater reaches Ulgii.

Using the glaciers' mean elevation as the ELA and an MBG of 0.50 m w.e. 100 m^{-1}, we determined that the glacier runoff was 0.13 km^3 in 2000, 0.12 km^3 in 2010, and 0.11 km^3 in 2016. Sensitivity analysis results showed that an increased ELA of 200 m more than doubled the amount of glacier runoff for each year. Further, a decreased ELA of 200 m produced only about one fourth of the annual glacier runoff, relative to the mean elevation (Figure 5; Table 2). As the ELA increases, the MBG introduces greater variability in glacier runoff (see vertical bars in Figure 5): for example, glacier runoff ranges between 0.25 and 0.50 km^3 when using the increased ELA of 200 m, but only between 0.10 and 0.14 km^3 when using the mean elevation.

To contextualize the importance of the annual glacier runoff to streamflow in the UKRB, we calculated the percent of glacier runoff relative to the mean annual stream discharge at the Ulgii station. The discharge was approximately 1.6 km^3 yr^{-1}, of which glaciers contributed 8% in 2000, 7.6% in 2010, and 6.7% in 2016. The glacier contribution increased dramatically when we increased the ELA by 200 m to between 20.6 and 12.3%, the lowest occurring in 2016. Conversely, decreasing the ELA by 200 m showed a marked decrease in glacier contribution ranging from 2.3 to 1.4% (Table 3). In semiarid to arid climates, glacier runoff is most critical during the dry summer periods (Viviroli et al 2007). In the Altai Mountains, the ablation period occurs between July through early September (Kamp et al 2013; Pan et al 2017). We recalculated a mean total discharge of 0.35 km^3 at the Ulgii station during this ablation period. Using the mean total discharge during the ablation period, mean elevation as an ELA, and an MBG of 0.50 m w.e., glacier runoff was 40% for 2000, 39% for 2010, and 34% for 2016.

Glacier area decreased by 19.3 km^2 from 2000 to 2010 in the UKRB, and in both years the glaciers contributed almost the same amount to the total basin discharge. From 2010 to 2016, the decrease in glacier area was 20 km^2, and the glacier contribution decreased by 1.3%. Glacier hypsometries revealed that changes in glacier area between 2000 and 2010 compared to between 2010 and 2016 were distributed differently with respect to elevation. From 2000 to 2010, change in glacier area was confined to elevations below 3600 m, while a significant decrease in glacier area at elevations above 3600 m occurred between 2010 and 2016 (Figure 6). Hence,

TABLE 2 Estimates of glacier runoff (km^3) for 2000, 2010, and 2016 in the Upper Khovd River Basin combining 3 different mass balance gradients and 3 different ELAs.

Mass balance gradient[a]	Glacier runoff (km^3)								
	2000			2010			2016		
	ELA −200	ELA	ELA +200	ELA −200	ELA	ELA +200	ELA −200	ELA	ELA +200
0.40	0.03	0.10	0.25	0.04	0.10	0.23	0.02	0.09	0.20
0.50	0.03	0.13	0.31	0.04	0.12	0.29	0.03	0.11	0.25
0.56	0.04	0.14	0.34	0.03	0.14	0.32	0.03	0.12	0.28

[a] Meters water equivalent 100 m^{-1}.

TABLE 3 Estimates of glacier melt contribution (%) to regional hydrology in the Upper Khovd River Basin for 2000, 2010, and 2016 combining 3 different MBGs and 3 different ELAs.

Mass balance gradient[a]	Glacier melt contribution (%)								
	2000			2010			2016		
	ELA −200	ELA	ELA +200	ELA −200	ELA	ELA +200	ELA −200	ELA	ELA +200
0.40	1.56	6.36	14.98	1.66	6.10	14.07	1.41	5.32	12.32
0.50	1.95	7.95	18.73	2.08	7.62	17.59	1.76	6.65	15.39
0.56	2.15	8.74	20.60	2.29	8.38	19.34	1.94	7.31	16.93

[a] Meters water equivalent 100 m^{-1}.

glaciers at higher elevations had begun to contribute to the streamflow in the UKRB by at least 2016.

Discussion

Glaciers and hydrology

In this study, we used the mean glacier elevation to represent the ELA ranging from 3328 m in 2000 to 3333 m in 2016. The hypsometric changes in glacier area indicate a more realistic ELA at around 3600–3700 m because only minor changes in glacier area occurred above 3600 m. However, from 2010 to 2016, we observed a loss in glacier area up to 4100 m. Hence, in the UKRB, a glacier's mean elevation is likely an underrepresentation of its ablation zone, which demonstrates the model's inability to capture periods of accelerated melting (Buytaert et al 2017). The enhanced decrease in glacier area at higher elevations is in line with our empirical observations in the Kharkhiraa Mountains—a mountain subcomplex within the larger Altai Mountains—just east of the UKRB. At these glaciers, we observed no accumulation zone and rain at their maximum elevations, as of August 2016 (Figure 7). These empirical observations and temporal changes in glacier hypsometries present a cogent argument that the ice ablation model outputs using the presumed ELA +200 m could be more representative for the regional glacier contributions to streamflow. Regardless, the hydrographic data in conjunction with the ice ablation model illustrate the critical contribution of glacier runoff to the UKRB's hydrology, both annually and during the ablation season.

As the glaciers of the Altai Mountains recede in reaction to increasing summer temperature trends (Pan et al 2017), their runoff will continue to be a critical component of water availability in the UKRB. The observed decrease in glacier area near the glaciers' maximum elevations indicates that only disproportionally small accumulation zones remain. Without a substantial accumulation zone and the likelihood of the continued trend in glacier area, the glaciers of the UKRB are currently contributing close to their maximum potential. Unfortunately, in the years to come, the glacier contribution will continue to decrease as the glacier area decreases and accumulation zones cease to exist.

Water scarcity will probably increase across western Mongolia in the near future: from the 1980s to 2010, 63 lakes (>1 km^2) disappeared and about 683 rivers dried up (Tao et al 2015; Szumińska 2016), with many of these water bodies located in the foothills of the Altai. Projected

FIGURE 6 Glacier hypsometries in the Upper Khovd River Basin (horizontal bars) for 2000, 2010, and 2016. The dashed lines indicate the percent change in area for each altitudinal band, the blue dashed line is the change from 2000 to 2010, and the red dashed line is the change from 2010 to 2016.

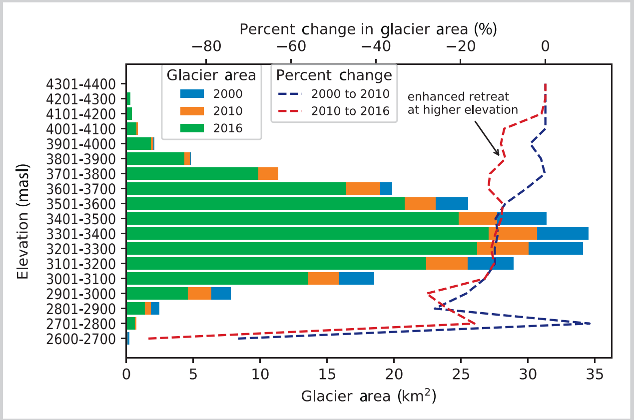


FIGURE 7 A glacier in the Kharkhiraa Mountain complex within the greater Altai Mountain system. Observed at the glacier is rainfall at the top and bottom elevation and no accumulation zone. (Photo by Caleb Pan)

climatic changes that manifest through decreasing precipitation and increasing air temperature are important in the governing of decreasing surface water (Szumińska 2016). Interactions between glacier runoff and surface water dynamics in the UKRB remain uncertain. However, in places like the Tibetan Plateau, cyrospheric contributions are important factors for lake expansion and maintenance (Zhang et al 2017). Here in the UKRB, we posit that continued glacier recession and reduced glacier contributions, coupled with enhanced aridity, will cause a reduction in lake levels across the region.

Glaciers and sociohydrology

The determination of the contribution of glaciers to the UKRB's hydrology is a key step forward in creating adaptations and building resilience within an environment and culture that is vulnerable to slight environmental fluxes. Yet glacier runoff as a contributor to hydroelectricity, with respect to the Durgun HPP, might be negligible, because surface water in the Durgun Basin will be diluted by other sources. Nevertheless, climatic and land use changes (Karthe et al 2015) will likely have more influence on water availability in the Durgun Basin than glacier retreat alone.

Water availability and demand is a complex mosaic of environmental and socioeconomic conditions (Buytaert et al 2017; Nüsser and Schmidt 2017). Mining, as the largest economic driver, has significantly increased since Mongolia's introduction to the free-market economy and is one of the country's most water-intensive industries (Karthe et al 2017). Unfortunately, data on mining (quantity, water consumption, area) are not available for the UKRB and western Mongolia, yet studies have found surface water withdrawals by mining, as well as livestock and irrigation, to be the dominant drivers of decreasing lake levels across Mongolia (Tao et al 2015, Szumińska 2016). However, we do know that livestock in Bayan-Ulgii are increasing at a rate of 50,000 animals per year and at an astounding rate of 420,000 animals per year in western Mongolia. If we assume that mining activities are increasing at a proportional rate across the country, water demands for mining and livestock on glacier-fed surface water in the UKRB and western Mongolia have never been greater.

In 2004 a United Nations water and sanitation report stated that only 30% of Mongolia's rural population had access to an "improved" water source, while the remaining population relied on lakes, rivers, and springs (Batbold et al 2004; Shinneman et al 2009). Within the Durgun Basin and UKRB, the quality of these natural water resources has seen significant degradation, particularly through increased salinity and eutrophication (Shinneman et al 2010), and is likely a consequence of reduced glacier runoff in sync with increased livestock grazing in riparian zones (Vorobyeva et al 2015). In addition to livestock, mining implications also contribute to the deterioration of surface water quality with increased sulfates and pH values from small-scale artisanal mining (McIntyre et al 2016). The socioeconomic development in western Mongolia has created a positive feedback loop, such that the demand for water has increased and the consequence of livestock production and mining further degrade the water quality in the already water-restricted region.

Conclusion

As water demand increases in the UKRB, the role of glacier runoff as a resource remains uncertain. Glaciers do, however, provide an important water surplus during the dry summer months in arid regions (Viviroli et al 2007; Kaser et al 2010; Bury et al 2013). This study has been an attempt to address the lack of knowledge of glacier runoff within the UKRB. Our findings suggest that few accumulation zones still exist on glaciers in the UKRB and that model outputs using an increased ELA (+200 m) better represent glacier contribution to the total runoff. Model results using the increased ELA showed that from 2000 to 2016, glacier runoff contribution reduced from 18.7% to 15.4%, suggesting that the glaciers will continue to contribute less water moving into the future.

As Mongolia continues to develop water-dependent economic sectors, we must reconsider and posit the likelihood that the water availability in the UKRB will begin to decrease as the Altai's glaciers continue to recede. In this case, water-based decisions in western Mongolia must be exceptionally well informed to maintain the country's commitment to sustainable use, household access, protection, and conservation of water resources. We suggest that sustainable economic development is best informed by consistent and long-term environmental monitoring. In this paper, we estimated the contribution of glacier runoff for a data-scarce region using an ice ablation model that required accessible and limited data inputs. Importantly, our model is restricted by its inability to project the future contribution of glacier runoff due to limited data, providing credence for improving data collection for important watersheds within the Altai Mountains to provide a scientific foundation in water-based decisions across western Mongolia.

Regardless of our suggestions, there must be a consensus among stakeholders, nongovernmental organizations, and government sectors as Mongolia's temperature continues to increase at twice the global rate. It is unlikely that any glaciers' lost accumulation zones will be recovered. Therefore, understanding the consequences of a reduced glacier runoff for the livelihoods of western Mongolia's population remains critical. Future water availability in western Mongolia is particularly uncertain because it is dictated by a complex interaction between climate and an evolving land use. HPP development is a possible solution, but the longevity of the region's glaciers must be acknowledged. It is certain, however, that effective water management and strategies must be developed to increase Mongolia's resilience to water vulnerabilities and security in the Altai Mountains.

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