DOI: 10.24850/j-tyca-14-06-03

Articles

Glacier retreat and the value of ecosystem services associated with water resources in the Parón basin-Huascarán National Park (Cordillera Blanca), 2009-2018

Retroceso glaciar y el valor de los servicios ecosistémicos asociados con el recurso hídrico en la cuenca Parón-Parque Nacional Huascarán (Cordillera Blanca), 2009-2018

Ricardo Pozada-Rengifo[1], ORCID: https://orcid.org/0000-0001-5894-7860

Luigi Bravo-Toledo[2], ORCID: ORCID: https://orcid.org/0000-0002-2229-9467

Joshua Iparraguirre[3], ORCID: https://orcid.org/0000-0001-8893-4112

[1]Facultad de Ingeniería Geológica, Minera, Metalúrgica y Geográfica, Universidad Nacional Mayor de San Marcos, Lima, Perú, ricardo.pozada@unmsm.edu.pe

[2]Facultad de Ingeniería Ambiental y de Recursos Naturales, Universidad Nacional del Callao, Callao, Perú, labravot@unac.edu.pe

[3]Instituto Geológico, Minero y Metalúrgico, San Borja, Perú, iparraguirrea.joshua@gmail.com

Corresponding author: Ricardo Pozada-Rengifo, ricardo.pozada@unmsm.edu.pe

Abstract

Tropical glaciers are sensitive indicators of climate change. The loss of the volume of tropical glaciers in the Parón basin (Cordillera Blanca, Peru), is an example of this at a global level and these changes are expected to affect ecosystem services that are unique and irreplaceable. This study estimated the economic value of ecosystem services associated with water resources impacted by glacial retreat in the Parón basin-Huascarán National Park (Cordillera Blanca, Peru) between the years 2009 and 2018. The methodology started by mapping glaciers from 2009 to 2018 using high-resolution satellite images taken during the dry season. Then, the 3D surfaces of the glaciers were reconstructed using the GLABTOP tool to calculate the volume. With the data obtained, the value of the Tourism and Recreation ecosystem service, provision of Water Flow, was calculated. The results indicate that the glaciers of the Parón basin have been reduced by ~1.82% of the glacial area and at a maximum deglaciation rate of 0.08 (km^2/year). The results of the 3D reconstruction show 1.8% more thickness between 40 and 60 m with an ice loss of 1.02 km^3, at a maximum rate of 0.14 km^3/year. The present monetary values of the services from 2009 to 2018 were estimated at $52 029.34 for the tourism and recreation service and $3 213 258.21 for the water flow provision service, calculated at 8% discount rate. Therefore, it is recommended that investment in programs on the Parón watershed water network, such as increased services, population or industrial use, should be increased.

Keywords: Cryosphere, ecosystem services, economic valuation, Cordillera Blanca, climatic change.

Resumen

Los glaciares tropicales son indicadores sensibles del cambio climático. La pérdida del volumen de los glaciares tropicales en la cuenca Parón (Cordillera Blanca, Perú) es una muestra de esto a nivel global y se espera que tales cambios afecten a los servicios ecosistémicos que son únicos e insustituibles. Este estudio estimó el valor económico de los servicios ecosistémicos asociados con el recurso hídrico impactados por el retroceso glaciar en la cuenca de Parón-Parque Nacional Huascarán (Cordillera Blanca, Perú) entre los años 2009 y 2018. La metodología inició cartografiando los glaciares de 2009 a 2018 usando imágenes satelitales de alta resolución tomadas en temporada seca. Luego, se reconstruyeron las superficies 3D de los mismos usando la herramienta GLABTOP permitiendo calcular el volumen. Con los datos obtenidos se calculó el valor del servicio ecosistémico del turismo y recreación, y provisión de flujo hídrico. Los resultados indican que los glaciares de la cuenca Parón se han reducción de ~1.82% del área glaciar y en una tasa de deglaciación máxima de 0.08 (km^2/año). Los resultados de la reconstrucción 3D muestran un 1.8% más de espesores entre los 40 y 60 m, con una pérdida de hielo de 1.02 km^3, a una tasa máxima de 0.14 km^3/año. Los valores monetarios presentes de los servicios de 2009 a 2018 se estimaron en $52 029.34 para el servicio de turismo y recreación y de $3 213 258.21 para el servicio de provisión de flujo hídricos, calculados a 8% de tasa de descuento. Por lo tanto, se recomienda que se debe incrementar la inversión en programas sobre la red hídrica de la cuenca de Parón, como mayores servicios, usos poblacionales o industriales.

Palabras clave: criósfera, servicios ecosistémicos, valoración económica, Cordillera Blanca, cambio climático.

Received: 24/03/2021

Accepted: 12/04/2022

Published online: 07/07/2022

Introduction

Glaciers are freshwater reserves throughout the year; since in tropical glaciers ablation is throughout the year (Cogley *et al*., 2011) providing water continuously according to the hydrological cycle (Rumbaur *et al*., 2015). The progressive retreat of glaciers in the Andes has been known since the twentieth century to the present, and the change in their mass balance is a problem that generates great socio-environmental impact (Mark & Seltzer, 2005). According to Urrutia and Vuille (2009) by the year 2050, all glaciers located below 5 500 masl would disappear, having a significant effect on the regulation of the hydrological regime (Jia *et al*., 2020). Peru has the largest area of tropical glaciers globally, approximately 71% covering an area of 1200 km². Most of its population resides on the Pacific Ocean coast, one of the driest regions on Earth. Its water supply depends largely on glaciers in the Andes Mountains (Kaser & Osmaston, 2002), and to a greater extent in the dry season (Schauwecker *et al*., 2017). The Cordillera Blanca is the most extensive glacial mountain range in the tropics (Kaser, Ames, & Zamora, 1990)). Perhaps for this reason and because of its relative ease of accessibility to different glacial areas, it is the most studied area with the greatest amount of data available. It is located in the province of Ancash and had about 348 km^2 (Rabatel *et al*., 2012). Studies in recent years have indicated that during 1980 and 2010 the glaciers of the tropical Andes lost on average between 0.6 and 1.2 m/year (Rabatel *et al*., 2013) of their mass. But 2004-2014 the Cordillera Blanca presented a glacial retreat of 31 km^2, representing a loss of 6% (Yap, 2015).

A large number of methodologies have been postulated to reconstruct current glacier thicknesses (and indirectly calculate the water store), because making direct measurements on the glacier is not possible in all mountains (Farinotti *et al*., 2017). These numerical modelings can be of easy application (Chen & Ohmura, 1990; Bahr, Meier, & Peckham, 1997; Lüthi, Walter, Jouvet, & Werder, 2006; Radić & Hock, 2011; Grinsted, 2013) or of higher complexity (Farinotti, Huss, Bauder, Funk, & Truffer, 2009; Linsbauer *et al*., 2009; Li, Ng, Li, Qin, & Cheng, 2012; Linsbauer, Paul, & Haeberli, 2012; Farinotti, King, Albrecht, Huss, & Gudmundsson, 2014; Frey *et al*., 2014; James & Carrivick, 2016). The calculation of volume in the Peruvian Andes has not been widely estimated. Currently there are data for point glaciers in the Cordillera

Blanca, as well as for areas south of the Andes. The most commonly used methodology so far is GlaBTop (Linsbauer *et al*., 2009; Linsbauer *et al*., 2012; Iparraguirre *et al*., 2020) for the estimation of future potential risk lakes but which also allows the calculation of the water store (Iparraguirre *et al*., 2020).

Glacier retreat and anomalies in precipitation patterns, pose a serious threat in water availability (Bury *et al*., 2011) and high variability that will significantly affect ecosystem services (Heikkinen, 2017) being a potential source of social and political tensions that can turn into instability or even serious conflicts (Hijioka *et al*., 2014). These conflicts could result in restricted access to certain services such as the use of potable water for drinking and irrigation, heavy dependence on agriculture, and limited alternative livelihood opportunities (Das, 2009).

Evaluations of these services can be performed through economic valuation, using market value-based methods, revealed preference methods, and stated preference methods (MINAM, 2016). Currently, there are few studies of its application in China (Yuan & Wang, 2018; Zhang *et al*., 2019), Spain (Grima & Campos, 2020), Chile (Segovia, 2014) and Peru (Boyano, 2016). Therefore, identifying and assessing the impacts generated by glacial retreat on ecosystem services will allow decision making for conservation, prevention measures, control and development of targeted projects (Boyano, 2016).

The Parón-Huascarán National Park (Cordillera Blanca) watershed has its own intrinsic characteristics such as the paramos (lower part of the mountain ranges) and the Cryosphere (upper part of the mountain range) that provide ecosystem services for the populations in the watershed (Boyano, 2016) such as support, provisioning and regulation (Liekens *et al*. 2013). Glaciers in the Parón basin are highly vulnerable to climate change, which have induced significant changes in volume loss, surface area and permafrost loss (Medina & Mejía, 2014; Navarro *et al*., 2017) as already discussed. However, this vulnerability directly affects ecosystem services related to water resources and there is currently no quantification of their value.

Therefore, this research attempts to fill this gap by (1) examining the changes in glacial retreat as surface area and volume lost between the years 2009 and 2018; (2) approximating to obtain a baseline value of the ecosystem services of: tourism and recreation and continuous water flow provision, using the real markets method for this purpose.

Methodology

Study area

The Cordillera Blanca is located in northern Peru and is the most extensive glaciated mountain range in the tropics (Kaser *et al*., 1990). For all analyses in this study, we refer to the Parón watershed, one of the ten glaciated watersheds within and adjacent to the Callejón de Huaylas (Figure 1).

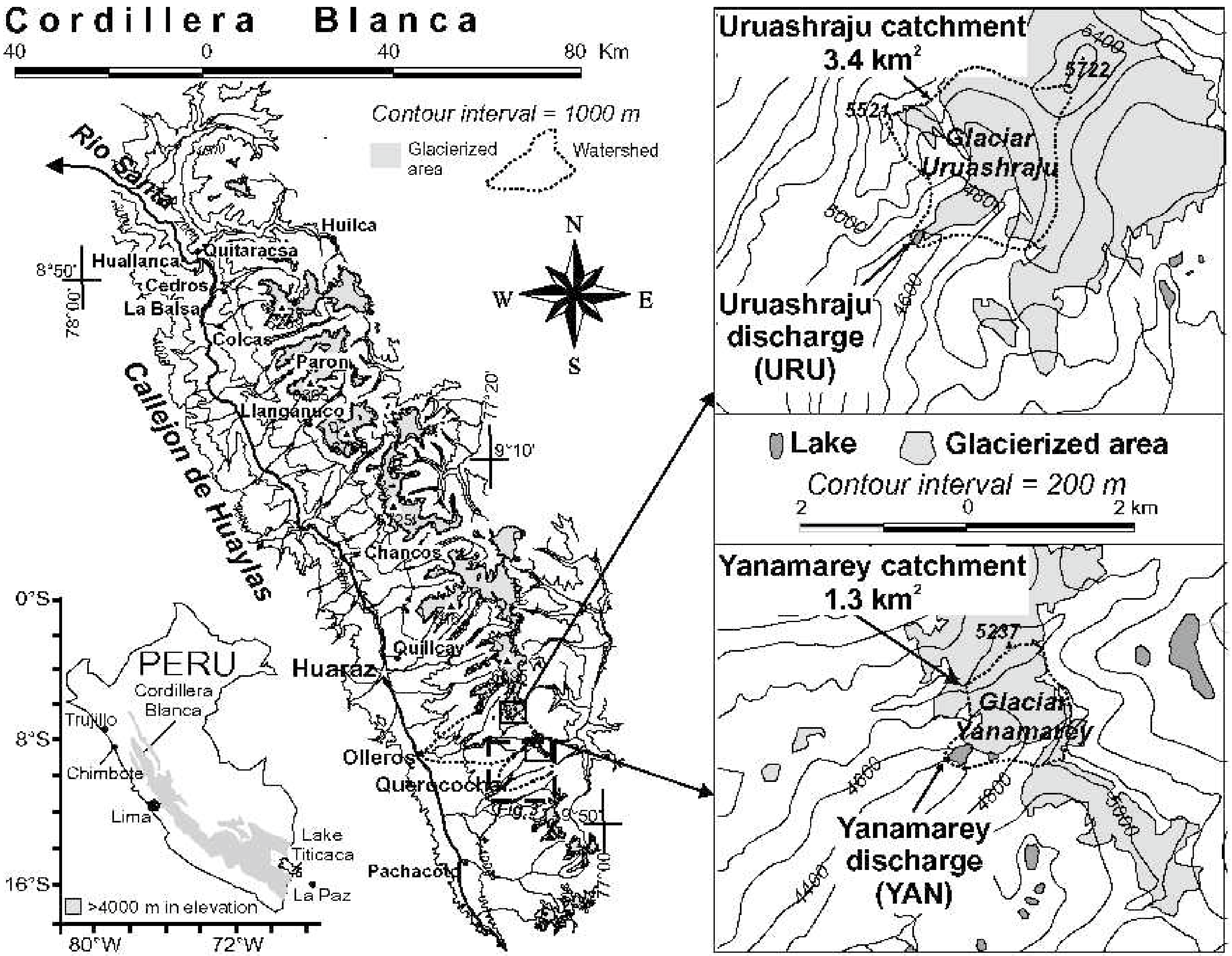

Figure 1. Location of the glacial basins of the Cordillera Blanca Source: Mark and Seltzer (2003).

The Parón basin is located north of the Cordillera Blanca ~90 km east of the Pacific Ocean (taking Isla Blanca del Callao as a reference). It is located in the district of Caraz, province of Huaylas, in the department of Ancash, ~57 km from the city of Huaraz, extending between 8°S/77°W. It drains its waters into the Santa River basin and one of the first inventories estimated that in 1962, 55% of its area was glaciated (Table 1).

Table 1. Physical characteristics of the hydrographic basins of the Cordillera Blanca.

Watershed	Glaciated area (1962) (%)	Basin area (km^2)	Average elevation (aslm)	Min. elevation (aslm)	Max. elevation (aslm)
Parón	55	41	4920	4152	5965
Llanganuco	41	89	4832	3831	6670
Marcara (Chancos)	25	259	4454	2887	6196
Cedros	22	114	4544	1975	6128
Colcas	19	236	4313	2022	6178
Quilcay	18	240	4522	3131	6195
Pachacoto	12	206	4610	3713	5574
Olleros	11	174	4437	3461	5673
Santa (La Balsa)	9	4784	4056	1858	6733
Quitarasca	8	384	4237	1587	5921
Querococha	6	63	4524	3992	5291

Source: Taken from Mark and Seltzer (2003).

Tourism in glacial areas is also an important source of income and employment for local communities adjacent to tourist sites (Haimayer, 1989). The Parón basin is an important tourism and recreation site within Huascarán National Park.

Extraction of information for the change of the glacier area

The delimitation of the glacier surface, as well as the 3D reconstruction of its surfaces was carried out using ArcGIS 10.5 software. The materials used as inputs were: satellite images obtained from Google Earth in dry seasons corresponding to each year of study (from 2009 to 2018); a Digital Elevation Model (or DEM) with 30 m resolution corresponding to the years of analysis; and, finally, the contour lines (equidistance=50 m) of the study area. All these inputs were provided by the Instituto Geológico, Minero y Metalúrgico (INGEMMET).

Delimitation of current glaciers and paleoglaciers

The delimitation of the glacier extent was based on a Google Earth satellite image of 30 meters per pixel resolution.

The delimitation was performed on the satellite image with the ArcMap mapping tool of ArcGIS. Each glacier device was manually digitized from the cirque to the glacier tongue at a mapping scale of 1:250. In addition, other inputs were used such as the Hillshade of the satellite image (30m/px), 1962 aerial photographs of the study area and supporting tools such as ArcScene and historical images from Google Earth.

To avoid an overestimation of the glacier area due to a possible snow mapping, a low-water season satellite image was chosen.

Reconstruction of the 3D geometry of glacial and paleoglacial surfaces

Knowing the 3D geometry of current and past glaciers is of great importance because it allows us to quantify the mountain's water reserves, its deglaciation rate and therefore its evolution over a given period of time.

The 3D reconstructions of the Peruvian Andes have been carried out using Ground Penetrating Radar (GPR) and because Andean glaciers are very difficult to access, GPR has been used in specific glacier mountains: Artesonraju (Cordillera Blanca, Ancash), Coropuna (Cordillera Occidental, Arequipa) and Quelccaya (Cordillera Oriental, Cusco-Puno). Therefore, it is necessary to complement the GPR work with indirect measurements using numerical models that reconstruct the glacier surface as close to reality as possible.

Currently, the most widely used methodologies for 3D reconstruction of current and past glaciers are GlaBTop and GlaRe, respectively.

GlaBTop

This methodology allows estimating ice thicknesses along flow lines, which represent the path of the glaciers (Figure 2). Subsequently, the thicknesses were interpolated (Figure 3) covering the entire glacier area, obtaining a raster (3D representation). The sum of all the thicknesses multiplied by the cell size of the raster made it possible to obtain the water volume represented by the mountain. On the other hand, these thicknesses were subtracted from the current Digital Elevation Model (original DEM minus thickness DEM), to obtain the basal topography (Linsbauer *et al*., 2009; Paul & Linsbauer 2012).

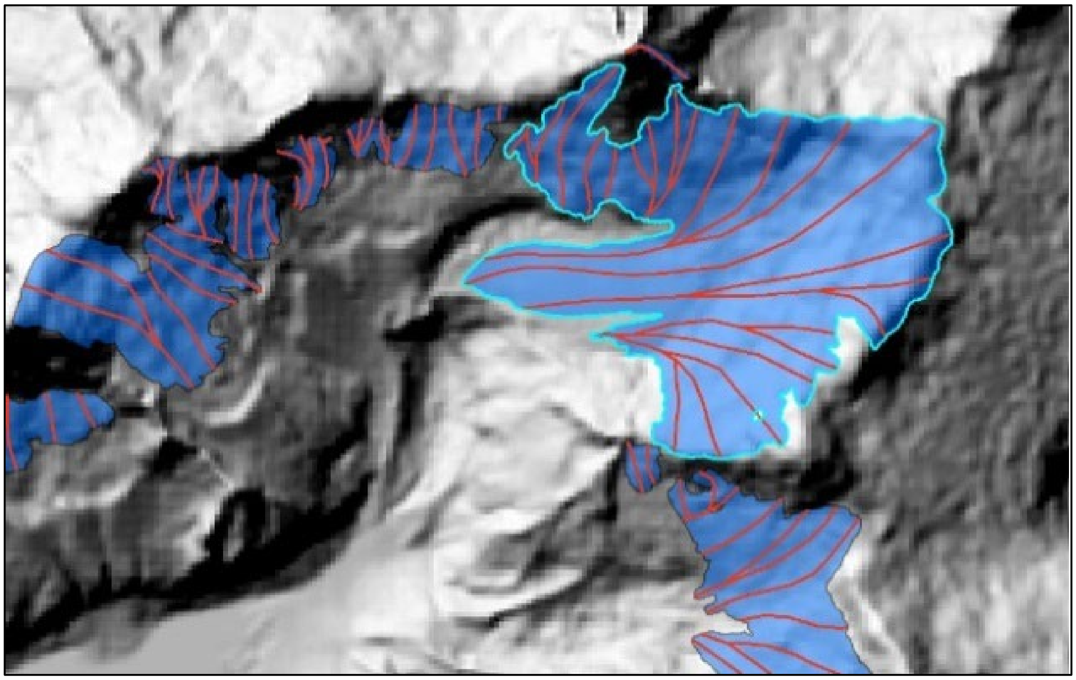

Figure 2. Mapping of flow lines in some glaciers of the Parón basin on the Hillshade of the digital elevation model (DEM).

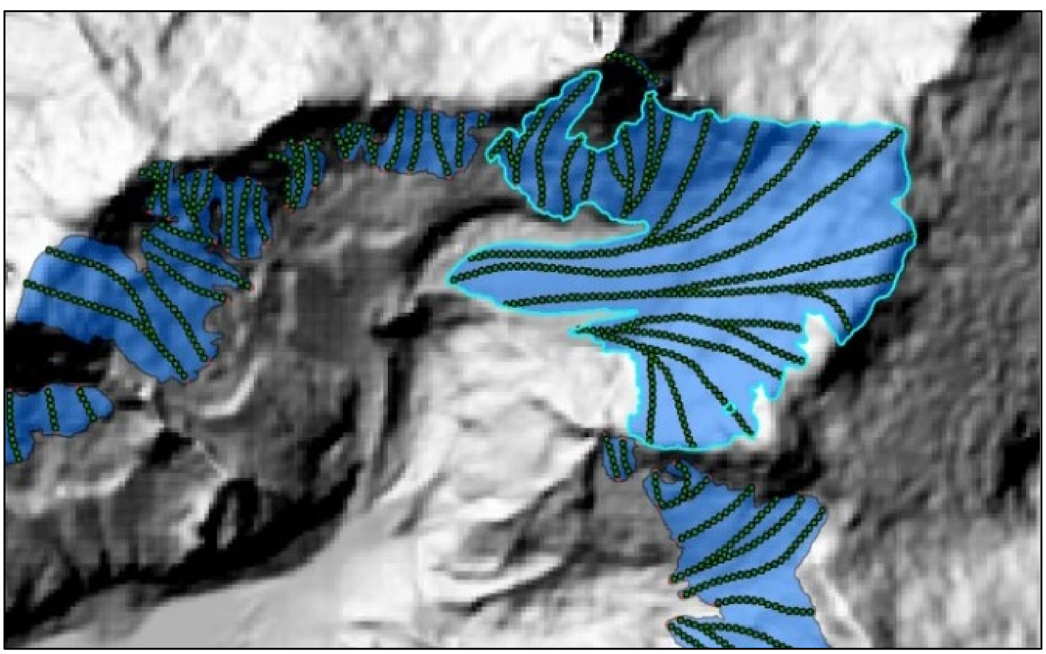

Figure 3. Interpolation of thicknesses using the "topo to raster" tool of the GlaRe tool.

GlaRe

GIS tool (Pellitero *et al*., 2016), which semi-automatically reconstructs the three-dimensional geometry of paleoglaciers (in this article all scenarios for years prior to 2018), based on the basal topography calculated with the GLABTOP methodology and new flow lines of its own for each scenario. The tool requires three input elements: On the one hand, the flow lines converted into centroids (where the generated thicknesses will be stored), the DEM of the basal topography, and finally, since the model does not reflect the stress generated by the lateral walls of the valley, shape factors were required based on evidence of glacier thickness observed by satellite images, lateral moraines and valley geometry following the equation proposed by Nye (1952), adjusting the thicknesses generated in the paleoglacial front.

Method for estimating the economic value of ecosystem services

To measure the Ecosystem Service Value of Tourism and Recreation, the Market Price Method was used, as it is the best known and allows estimating direct use values (MINAM, 2015). It is proposed that at least the value of the ecosystem service is equal to the value incurred by visiting them, it has been established that for each entry fee to Huascarán Park,% corresponds to the ice present inside the park, *i.e.*, that amount would correspond to the monetary value of the ecosystem service (Segovia, 2014) of tourism provided by the entire surface area of Huascarán National Park (Cordillera Blanca) and the equivalent value of the glaciers present in the park. The entrance fee in the last 10 years has been between S./15.00 (<> 3.87 dollars) for national tourists and S./ 30.00 (<> 7.74 dollars) for international tourists:

$$As = VPse \tag{1}$$

$$As \equiv Ag \tag{2}$$

Where:

As: Surface area of Huascarán Park.

VPs: Present value of the tourism and recreation service.

Ag: Glacial area of lake Parón as part of Huascarán National Park.

For the monetary valuation of the glaciers present in the study area, it was established that for each entry value to Huascarán National Park, there is a certain amount of surface area of the glaciers present in the Parón basin, i.e., this amount of glacier would correspond to the monetary value of the ecosystem service of tourism and recreation that has been lost due to glacier retreat. Therefore, the value of the deglaciation rate due to loss of ecosystem service would be equal to the% loss of surface area in the 2009-2018 time periods.

$$VTD = \%\, Agp\ x\ VPse \qquad (3)$$

Where:

VTD: Value of the rate of deglaciation due to loss of ecosystem service.

VPse: Present value of Tourism and Recreation Service.

Agp: Glacial area retreated in the Parón watershed from 2009 to 2018.

The calculation of the monetary value of the ecosystem service of "provisioning of continuous water flow" was estimated based on the average annual flow expressed in cubic meters per second (m^3/s) provided by the glaciers of the Parón-Huascarán National Park (Cordillera Blanca) basin and the price of water rights markets are according to the Supreme Decree that approves values of economic retribution to be paid for surface water use (El Peruano, 2018):

$$VSE_{\mathrm{FHC}} = Pr\ x\ \mathrm{QM}_{\mathrm{AG}} \qquad (4)$$

Where:

VSE_{FHC} = Continuous water flow ecosystem service value.

Pr = Non-consumptive DAA price.

QM_{AG} = Mean annual glacial inflow (m^3/s).

Estimation of the economic value of glacial retreat

The monetary value was estimated based on real prices of the ecosystem services of "Tourism and Recreation", "Water Storage" and "Continuous Water Flow" of glacial retreat in the Parón Basin. For this, the annual values (annual economic benefits) were calculated for being within a protected site, the ecosystem services valued by the glacier loss will maintain such services for a defined period of time. In addition, to obtain the present value (PV) of the valued ecosystem services, a social discount rate of 8% was used (MINJUS, 2017), which is the one considered for social projects by the Peruvian Ministry of Justice:

$$Fi = Pi\ x\ (1 + \mathrm{r})^{T} \quad (5)$$

Where:

Fi = Initial value of the service flow *i* (annual economic benefit).

Pi = present value of the flows, the stock value of the service.

T = Time.

r = Constant discount rate for the whole period (8%).

Results and discussion

Variation of glacier characteristics

Glacier delimitation

The behavior of glaciers in the Parón Basin during this 10-year period must be inferred from the retreat of glacier surface cover suffered by the Cordillera Blanca that has accelerated since 1987 (Burns & Nolin, 2014). And considering that the observations of Georges (2004), already estimated a 1% increase in the rate of glacier loss per year from 1987 to 1996 in the Cordillera Blanca.

The calculation of the extension for each period analyzed in this work is presented in Figure 4.

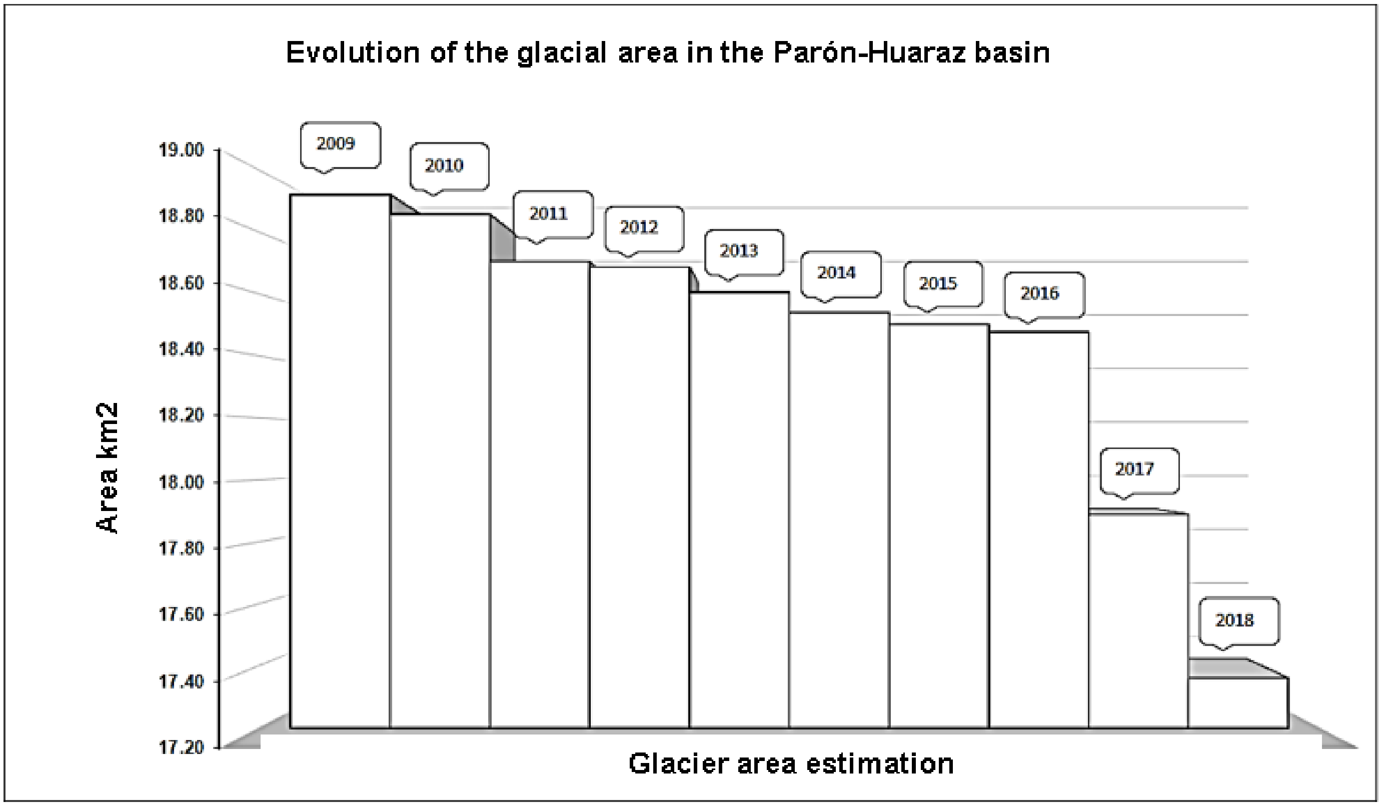

Figure 4. Comparison of glacier area decrease between 2009-2018 in the Parón watershed.

All these results have only considered discovered ice masses where the glacial extent of the Parón Basin for 2009 covered an area of 18.82 km^2, while for 2018 it was reduced to 18.48 km^2. This meant a reduction of ~1.82% of the glacier area and can be translated into a deglaciation rate (km^2/year) minimum from 0.02 and maximum of 0.08 from 2009 to 2018; meaning that the deglaciation rate in the last 10 years remains constant (Figure 5).

Tecnología y Ciencias del Agua
OPEN ACCESS
Check for updates

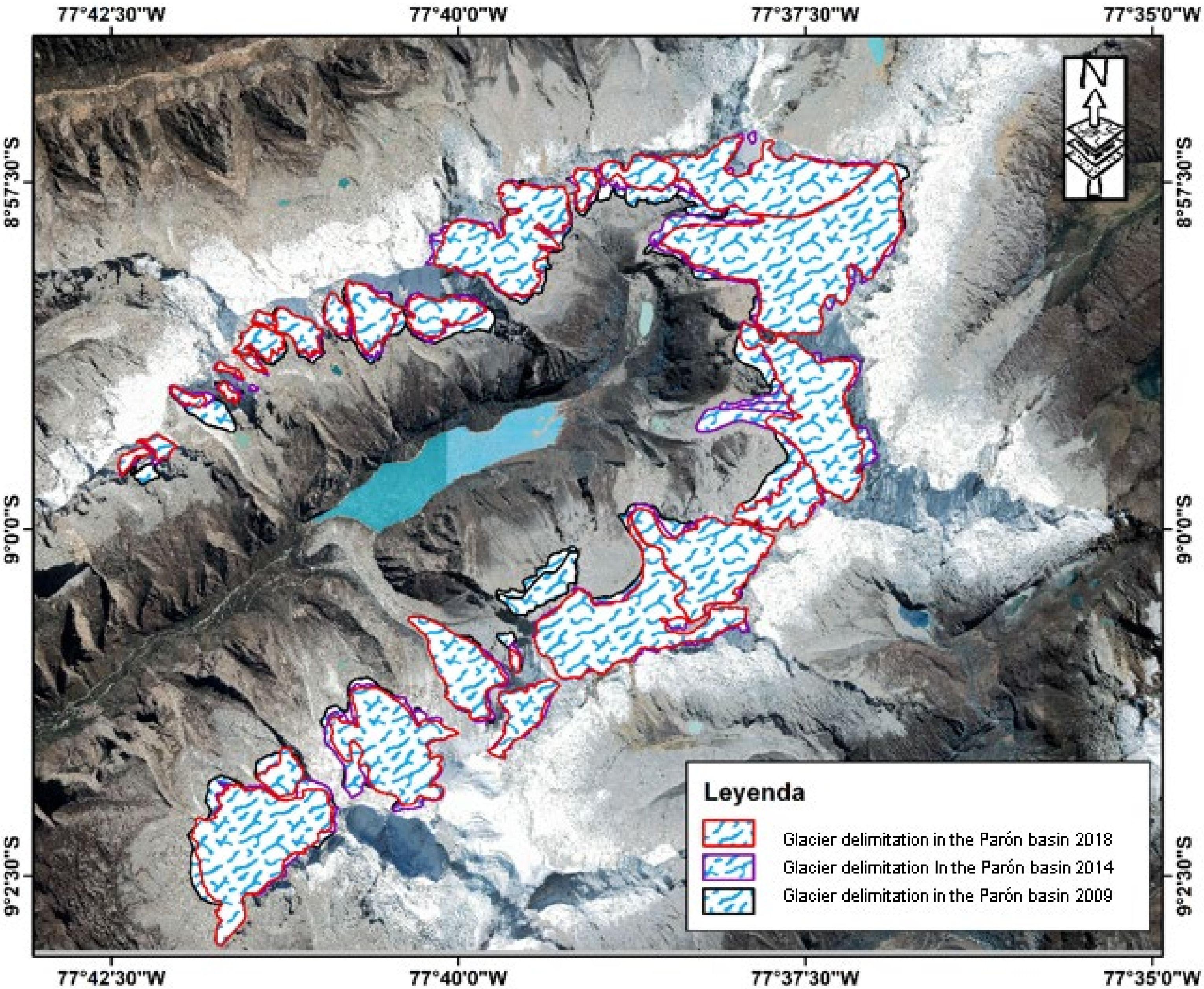

Figure 5. Satellite model of glacier cover retreat between 2009-2018.

Thus, our estimates of glacial change are aligned with important works (Georges (2004), Burns & Nolin, 2014) that agree on an acceleration in the loss of glacier surface area in the Cordillera Blanca since 1970, where it went from 723 to 482 km^2.

3D reconstruction of the geometry of glaciers and paleoglaciers

Deducing how much the glacier area has been reduced in terms of area, in a way, can be misleading. Because when viewed in a 2D plane, we cannot perceive how the volume of water in solid state has changed, since the thicknesses that would be disappearing are unknown. For this reason, this research applies novel numerical modeling that can give an indication of how glacier masses are evolving. It is worth mentioning that the glaciers delimited, the greatest range of thicknesses oscillate between 20 and 40 m, but the great difference lies in the prevalence of ice masses of greater thickness (Figure 6). That is, the difference in glacier volume in 2009 was maintained with greater power; whereas, by 2018 they have been affected.

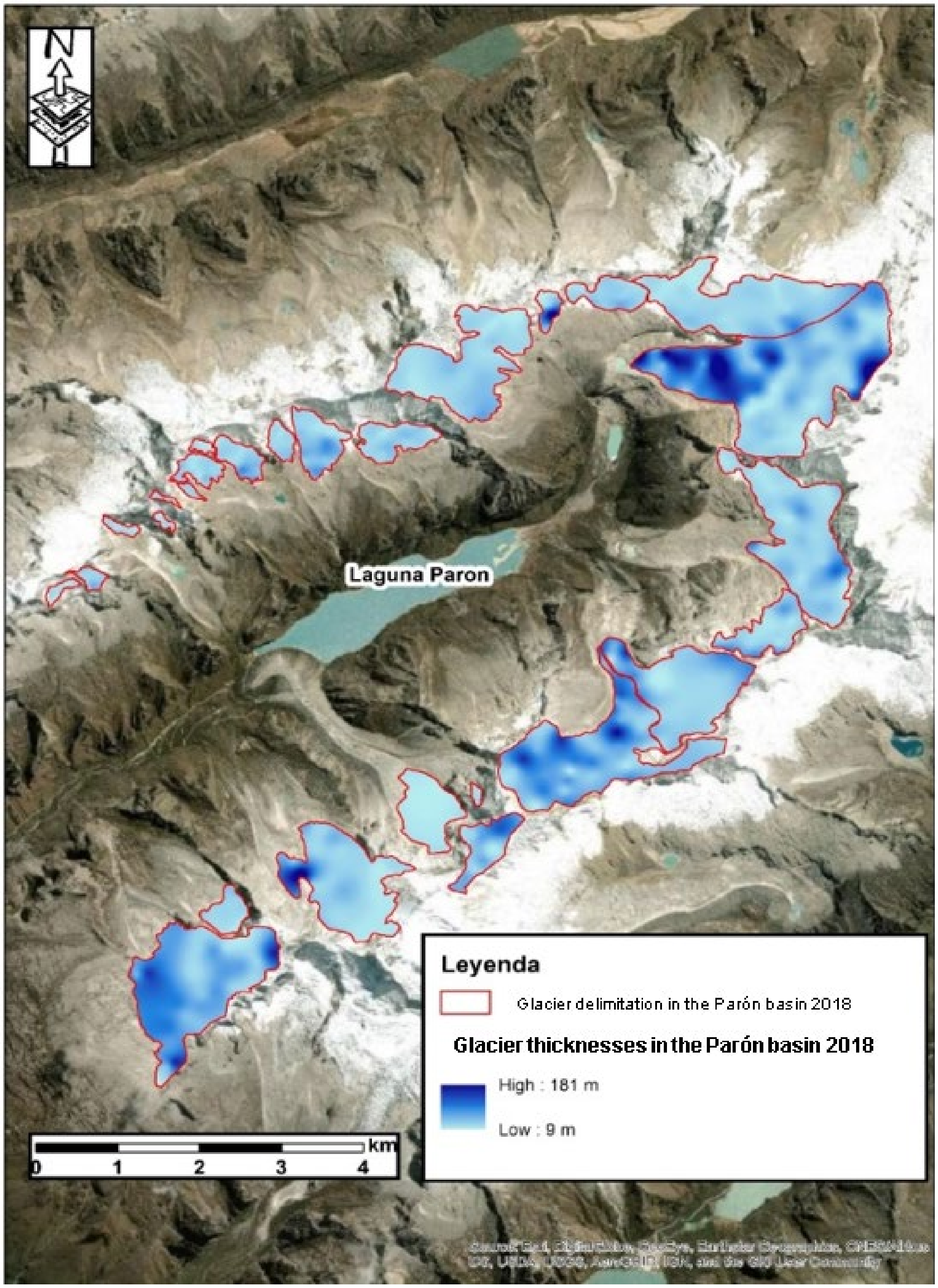

Figure 6. Satellite 3D reconstruction model of glacier volume loss between 2009-2018.

Thickness distributions reveal that on the 2018 glaciers (maximum thickness = 180 m on snow-capped Artesonraju) thicknesses between 20 and 40 m predominated. These thicknesses cover 68% of the glacier area representing ~11 km^2. The greatest thicknesses are found specifically in the Artesonraju (maximum thicknesses of 180 m and greater than 100 m). This is explained by the fact that this mountain is considered as an ice field; that is, where the slope is low. Glaciers in 2009, although it is true, anyway, predominantly thicknesses between 20 and 40 m (66% <> 12 km^2), there were still thicknesses between 40 and 60 m (at least 12% more compared to 2018).

For example, Colonia *et al*. (2017) estimated using this 3D reconstruction methodology the possible lake formations throughout the Peruvian Andes. This work is an excellent indicator of the areas with greater thickness at the regional level, but at the local level it loses precision. One of the drawbacks is that the input DEM has a 90 m resolution. Torres *et al*. (2014) calculated the total volume of the Peruvian Andes based on two approaches: area-volume and slope-thickness being 35 and 34.39 km^3, respectively. These results have also been based on low resolution DEMs (60 m) that are useful for large-scale estimates, but do not allow obtaining a detailed basal topography necessary for paleoglacial reconstruction. But at the local level, compared to those estimated in this work, the results are close. Basically, these small differences are linked to the processing and input data (Figure 7).

Tecnología y Ciencias del Agua
OPEN ACCESS
Check for updates

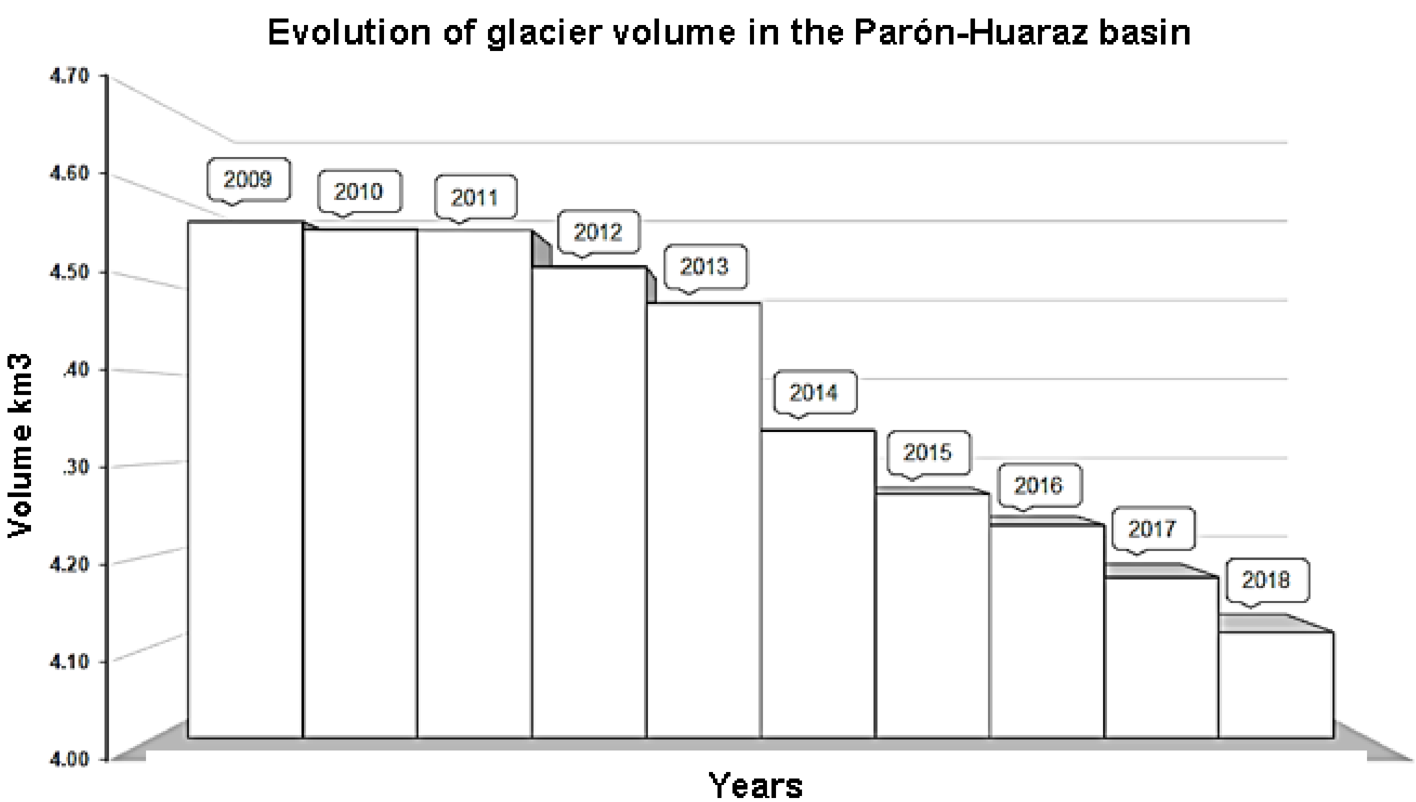

Figure 7. Glacier volume reduction in the Parón basin 2009-2018.

From the glaciers of 2009, we have 1.8% more thicknesses between 40 and 60 m compared to the glaciers in 2018 with 1.02 km^3 lost, with a maximum rate of 0.14 km^3/year. This difference between these scenarios, show us that, despite having a low deglaciation rate in reference to the estimated area, we can deduce that the best indicator is the 3D reconstruction because it allows us to observe what potential ice volume has been lost in that area.

Tecnología y Ciencias del Agua

Ecosystem service value analysis associated with glacial retreat

Tourism and recreation ecosystem service valuation

Tourism in the Cordillera Blanca, the highest mountain range in the Peruvian Andes, has developed greatly in the last 30 years due to the number of domestic and foreign tourists visiting the area (Grötzbach, 2003). Huascarán National Park is the largest park in the Cordillera Blanca, promoting many local activities and influencing environmental, social, economic and tourism aspects of the region (Maguiña, Angulo, Gonzales, & López, 2020).

The total number of visitors to Huascarán National Park in the last 10 years (2009-2018) was 990 306 for domestic tourism and 320 065 foreign tourists, showing an annual growth trend (Figure 8a). There are more than 100 known mountain glacier resorts in the world that operate as special natural attractions (Wang, Zhao, & He, 2012); among the most important ones the Huascarán National Park that in the years after 2014, glacier tourism in the different basins has been developed and operated successfully, obtaining high economic benefits (Izaguirre, 2021).

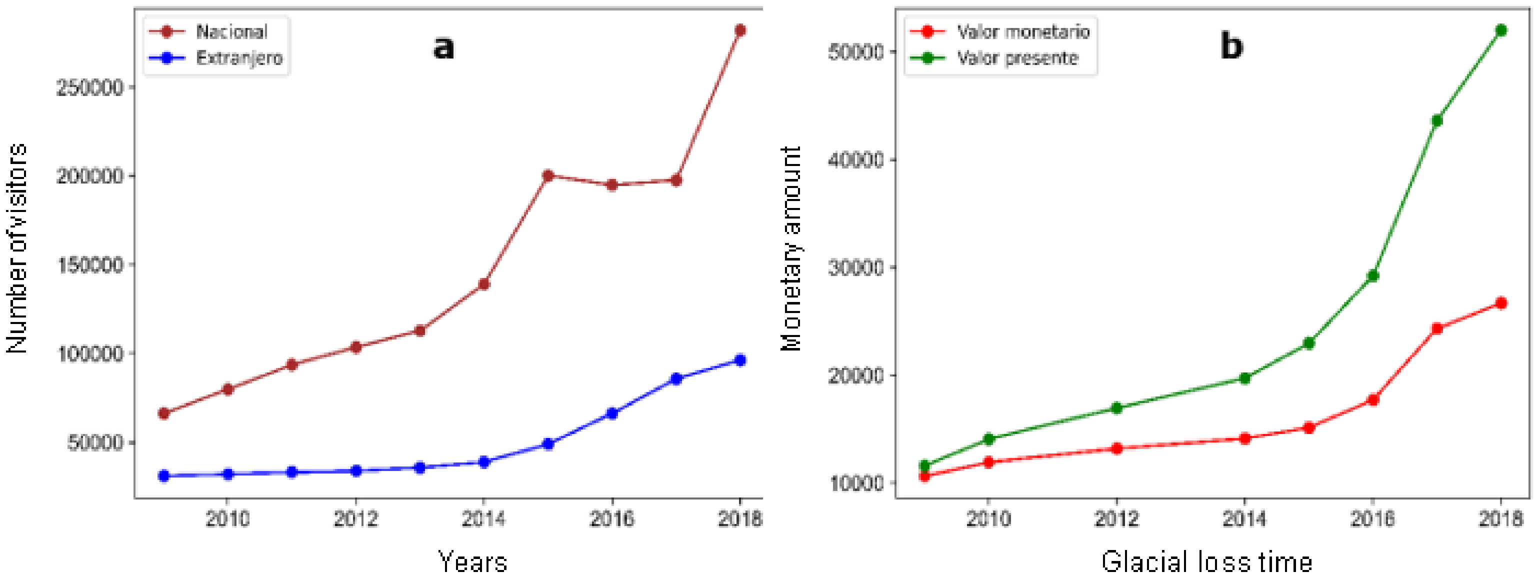

Figure 8. Variation in tourism and economic value of glacial retreat in the Parón Basin (2009-2018). Left (a): Number of visitors per year. Right (b): Variation of monetary income as a function of glacial retreat.

With the rapid growth of the world economy, accessibility to transportation and the increasing demand of visitors tourism has improved and increased considerably, positioning itself with an average of 163 796.375 visitors per year, being an average income compared to the world trend of other high mountain glacier tourist sites as an example the national park of "Glacier Bay" (Alaska) with 400 000 visitors per year (Pirhalla, Gende, & Mölders, 2014); Athabasca glaciers (Canada) with 600 000 visitors per year; Glaciares national park (Argentina) with 167 000 visitors per year; "Jostedal Glacier" national park (Norway) with 40 000 visitors per year (Welling, Árnason, & Ólafsdottír, 2015), and "Franz

Jozef" Glacier (New Zealand) with 346 000 visitors per year (Purdie, 2013).

Figure 8b shows that economic value is being lost whenever there is a loss of glacial area in Parón, it is recognized that glacial retreat significantly impacts tourism and recreation (Vuille *et al*., 2018) reducing the number of visitors in tourism-dependent cities (Purdie, Gomez, & Espiner, 2015), progressively affecting the economic value of the Parón watershed that it can provide as an ecosystem service.

The valuation method of personal preferences based on real prices used to calculate the monetary value of the ecosystem service of tourism and recreation showed that the total equivalent to the surface area lost due to glacial retreat between 2009 and 2018 in the interior of Huascarán National Park has a total economic value of s. /133 788.19 (equivalent to $33 122.46 dollars at an exchange rate of 4.04), which, updated to present value at a rate of 8%, corresponds to a value of S/210 156.82 (equivalent to $52 029.34) (Table 2). This shows that there is an annual increase in monetary value lost to glacial retreat. Studies such as Zhang, Zhuoran and Seenprachawong (2015) estimated that annual monetary valuation of glaciers in Mt. Yulong, Yunnan, China for tourists was $500 million, while the studies conducted to the El Morado glacier in Chile (Segovia, 2014) shows monetary values of $25 554 annually, with values closer to those obtained in this study, indicating that the value of glaciers for the tourism sector is substantial.

Table 2. Annual flows of the monetary amount of the ecosystem service of Tourism and Recreation in the Parón watershed.

N°	Year	National	Foreigners	Total annual monetary value to Parque Huascarán	Surface area loss	Total annual deglaciation value (S./ /m²/year)	
						Monetary value	Current value
1	2009	66278	31071	S/1,926,300.00	18819080.00	S/10,662.12	S/11,589.26
2	2010	79852	32067	S/2,159,790.00	18755666.21	S/11,914.21	S/14,076.33
3	2012	93635	33185	S/2,400,075.00	18704096.37	S/13,203.30	S/16,955.83
4	2014	103584	33950	S/2,572,260.00	18686107.44	S/14,136.92	S/19,733.47
5	2015	112818	35758	S/2,765,010.00	18604096.37	S/15,129.56	S/22,955.53
6	2016	139063	38799	S/3,249,915.00	18538561.70	S/17,720.22	S/29,224.17
7	2017	200189	48971	S/4,471,965.00	18500997.58	S/24,334.06	S/43,621.42
8	2018	194887	66264	S/4,911,225.00	18475738.22	S/26,687.80	S/52,000.81

Valuation of the Ecosystem Service of Water Flow Provisioning

Deglaciation as part of the natural dynamics of the Cryosphere a provisioning function to meet a social-ecological demand and may pose new challenges for societies (Zhang *et al*., 2021b). The use of water flow provision due to deglaciation is not only reflected in an annual contribution, but also in a seasonal one, which is currently undergoing alterations due to climate change.

The water flow provision service is subject to an increase in temperatures due to climate change, which, generates a surplus of snowmelt increasing the water flow in the basin and a decrease of permafrost in the ice sheet (Sotillo, 2017). Permafrost is scarce in the Cordillera Blanca; therefore, melting due to temperature increase causes an increase in the water flow provision service in the different basins (Iparraguirre *et al*., 2020), thus giving rise to unusual water flow increases.

Table 3 shows that the economic value of the ecosystem service provision of water flow due to the natural dynamics of the permafrost added to the deglaciation due to climate change in the Parón watershed in the last 10 years was S./7 762 276.36 with a present value of S./12 981 563.18 (equivalent to $3 213 258.21 with an exchange rate of 4.04) at an 8% discount rate.

Table 3. Annual flows of monetary value foregone for the ecosystem service of hydrological flow provisioning by type of use in the Parón watershed.

N°	Year	Flows discharged by glaciers (m^3/year)	Type of surface water use right	Economic retributions to be paid for water use (S./ /m^3)	Total annual deglaciation value (S./ /m^3/año)	
					Monetary value	Current value
1	2009	4565299.84	Poblacional	S/0.0050	S/22,826.50	S/24,811.41
			Industrial*	S/0.0792	S/361,571.75	S/393,012.77
			Minero	S/0.1017	S/464,290.99	S/504,664.12
			Other uses **	S/0.0330	S/150,654.89	S/163,755.32

N°	Year	Flows discharged by glaciers (m³/year)	Type of surface water use right	Economic retributions to be paid for water use (S./ /m³)	Total annual deglaciation value (S./ /m³/año)	
					Monetary value	Current value
2	2010	4556897.77	Poblacional	S/0.0050	S/22,784.49	S/26,919.29
			Industrial*	S/0.0792	S/360,906.30	S/426,401.59
			Minero	S/0.1017	S/463,436.50	S/547,538.40
			Other uses **	S/0.0330	S/150,377.63	S/177,667.33
4	2012	4555888.81	Poblacional	S/0.0050	S/22,779.44	S/31,797.41
			Industrial*	S/0.0792	S/360,826.39	S/503,671.05
			Minero	S/0.1017	S/463,333.89	S/646,759.42
			Other uses **	S/0.0330	S/150,344.33	S/209,862.94
6	2014	4515760.89	Poblacional	S/0.0050	S/22,578.80	S/37,236.94
			Industrial*	S/0.0792	S/357,648.26	S/589,833.12
			Minero	S/0.1017	S/459,252.88	S/757,399.35
			Other uses **	S/0.0330	S/149,020.11	S/245,763.80
7	2015	4475986.41	Poblacional	S/0.0050	S/22,379.93	S/40,118.43
			Industrial*	S/0.0792	S/354,498.12	S/635,475.99
			Minero	S/0.1017	S/455,207.82	S/816,008.95
			Other uses **	S/0.0330	S/147,707.55	S/264,781.66
8	2016	4333027.11	Poblacional	S/0.0050	S/21,665.14	S/42,214.22
			Industrial*	S/0.0792	S/343,175.75	S/668,673.28
			Minero	S/0.1017	S/440,668.86	S/858,637.28
			Other uses **	S/0.0330	S/142,989.89	S/278,613.87

N°	Year	Flows discharged by glaciers (m^3/year)	Type of surface water use right	Economic retributions to be paid for water use (S./ /m^3)	Total annual deglaciation value (S./ /m^3/año)	
					Monetary value	Current value
9	2017	4267081.52	Poblacional	S/0.0050	S/21,335.41	S/45,186.69
			Industrial*	S/0.0792	S/337,952.86	S/715,757.12
			Minero	S/0.1017	S/433,962.19	S/919,097.21
			Other uses **	S/0.0330	S/140,813.69	S/298,232.13
10	2018	4190433.90	Poblacional	S/0.0050	S/20,952.17	S/48,233.72
			Industrial*	S/0.0792	S/331,882.36	S/764,022.07
			Minero	S/0.1017	S/426,167.13	S/981,073.79
			Other uses **	S/0.0330	S/138,284.32	S/318,342.53

Studies such as Jeong, Sushama and Naveed-Khaliq (2017) show that in the Northern Hemisphere the average snow cover mass decreases at a rate of 10.2 Mt per year, or decreases by 0.3% per year due to a global warming effect. So also, projecting to 2030 the effects of climate change, the value of snowpack losses in western China would be reduced by CN¥2.9 billion (Wu *et al*., 2021). This research suggests that climate change is affecting all glaciers worldwide and will have a direct effect on the economic values of ecosystem services.

Direct effects such as those shown in this study are also present in glaciers in the Quilian regions (China) where they show that the service value of glacier meltwater provision to river runoff was 8 072 million yuan equivalent to 33% ($1 277 million USD), the service value of freshwater supply was 844 million yuan ($133 million USD) (Sun *et al*., 2020).

Some studies such as in Latin America as Segovia (2014) has as a result that the present value of the ecosystem service of continuous water flow from the glaciers of El Morado Natural Monument, Chile, is clp$2 327 683 926 ($15.53 million dollars) and the annual value of this service with a discount rate of 6% reaches clp$139 661 036 ($175 thousand dollars). This study is the closest to the reality present in the Parón basin, the economic values are not as far away as those presented by Wu *et al*. (2021) and Sun *et al*. (2020).

Regarding the service of water flow provision, it is necessary to emphasize that the cost of water is based on market prices for its type of use. In general, the cost of water use in Peru is reflected in terms of mining, urban, rural and industrial use. As shown in Figure 9, the present value of the ecosystem service of water flow provision in the industrial or mining sector has the highest values as opposed to the other types of use. Similarly, the study by Zhang *et al*. (2021b) reports that the average annual economic value of water uses for agriculture, services, urban use and industry estimated at 1.7, 4.4, 9.9 and 15.7 million yuan with the industrial sector having the highest consumption.

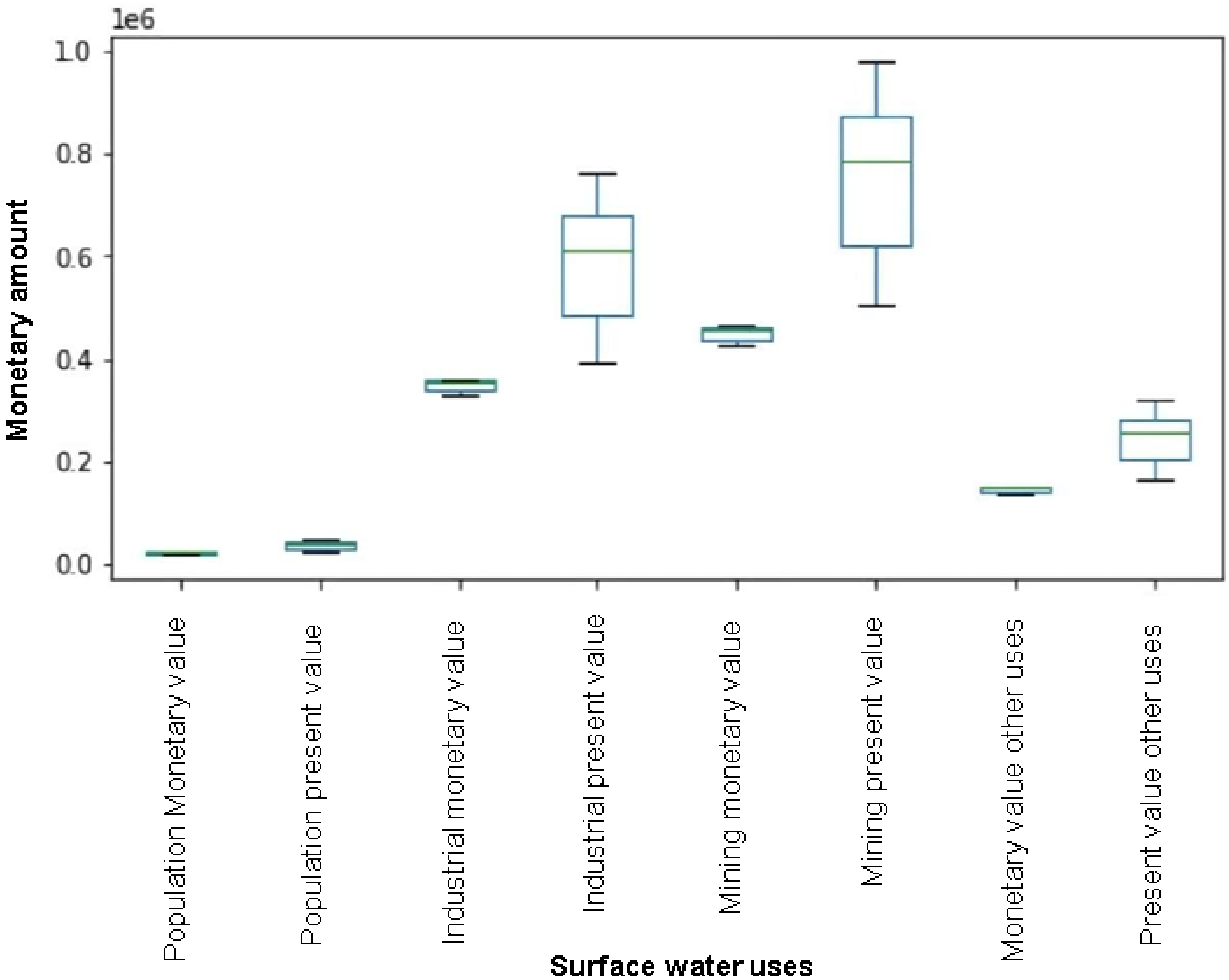

Figure 9. Variability of the economic value of the ecosystem service of water flow provisioning according to the type of use in the Parón watershed.

Conclusions

This research presents the glacier loss in the Parón Basin (Cordillera Blanca), the retreat of which directly influences the ecosystem services associated with water resources. The Parón watershed is characterized by the tourism/recreation service and the provisioning of water flows presenting a high economic valuation that has grown in recent years (2009-2018).

The Parón basin in 2009 covered an area of 18.82 km^2, while by 2018 it was reduced to 18.48 km^2. This meant a reduction of ~1.82% of the glacier area and can be translated into a deglaciation rate (km^2/year) minimum from 0.02 and maximum of 0.08 from 2009 to 2018. Similarly, from the 2009 glaciers, we have 1.8% more thicknesses between 40 and 60 m compared to the glaciers in 2018 with 1.02 km^3 lost, with a maximum rate of 0.14 km^3/year. These results evidence an effect of climate change on the Parón watershed.

The economic value of the ecosystem service of tourism and recreation was calculated using the method of valuation of personal preferences based on real prices. The results show that the monetary amount lost due to the retreat of the glacier surface area between 2009 and 2018 in the interior of Huascarán National Park is s./133 788.19 (equivalent to $33 122.46 dollars at an exchange rate of 4.04), which, updated to present value at a rate of 8%, corresponds to a value of S/210 156.82 (equivalent to $52 029.34).

The corresponding economic value of the water flow provisioning services in the different water uses (Population, Industrial, Mining, Other uses) generated by the meltwater from the Parón watershed between 2009 and 2018 was S./7 762 276.36 with a present value of S./12 981 563.18 (equivalent to $3 213 258.21 with an exchange rate of 4.04) at a rate of 8%.

Although it was complex to capture the values of the services of glacial retreat in the basin in economic terms, it is shown that the service of water flow provision has a higher monetary value than recreation and tourism, suggesting that climate change associated with deglaciation is generating a loss of water value that is not being taken advantage of. It is recommended that current investment in programs on the water network of the Parón watershed should be increased, such as greater services, population or industrial use.

References

Bahr, D. B., Meier, M. F., & Peckham, S. D. (1997). The physical basis of glacier volume-area scaling. *Journal of Geophysical Research: Solid Earth*, 102(B9), 20355-20362.

Boyano, P. (2016). Servicios ecosistémicos de la criósfera y los páramos de la Cordillera Blanca, Perú. *Boletín del Colegio de Geográfos del Perú*, 3, 1-20.

Burns, P., & Nolin, A. (2014). Using atmospherically-corrected Landsat imagery to measure glacier area change in the Cordillera Blanca, Peru from 1987 to 2010. *Remote Sensing of Environment*, 140, 165-178.

Bury, J. T., Mark, B. G., McKenzie, J. M., French, A., Baraer, M., Huh, K. I., Luyo, M. A. Z., & López, R. J. G. (2011). Glacier recession and human vulnerability in the Yanamarey watershed of the Cordillera Blanca, Peru. *Climatic Change*, 105(1-2), 179-206.

Chen, J., & Ohmura, A. (1990). Estimation of Alpine glacier water resources and their change since the 1870s. I*AHS Publications*, 193, 127-135.

Cogley, J. G., Hock, R., Rasmussen, L. A., Arendt, A. A., Bauder, A., Braithwaite, R. J., Jansson, P., Kaser, G., Möller, M., & Nicholson, L. (2011). Glossary of glacier mass balance and related terms. *IHP-VII Technical Documents in Hydrology*, 86(2), 1-124. Recovered from https://wgms.ch/downloads/Cogley_etal_2011.pdf

Colonia, D., Torres, J., Haeberli, W., Schauwecker, S., Braendle, E., Giraldez, C., & Cochachin, A. (2017). Compiling an inventory of glacier-bed overdeepenings and potential new lakes in de-glaciating areas of the Peruvian Andes: approach, first results, and perspectives for adaptation to climate change. *Water*, 9(5), 336.

Das, N. R. (2009). Human Development Report 2007/2008 Fighting Climate Change: Human Solidarity in a Divided World, UNDP, New York. *Social Change*, 39(1), 154-159.

El Peruano. (2018). *Decreto Supremo N° 014-2018-MINAGRI -Valores de retribuciones económicas a pagar por uso de agua superficial y subterránea y por el vertimiento de agua residual tratada a aplicarse en el año 2019*. Retrieved from https://www.gob.pe/institucion/midagri/normas-legales/239331-014-2018-minagri

Farinotti, D., Brinkerhoff, D. J., Clarke, G. K. C., Fürst, J. J., Frey, H., Gantayat, P., Gillet-Chaulet, F., Girard, C., Huss, M., & Leclercq, P. W. (2017). How accurate are estimates of glacier ice thickness? Results from ITMIX, the ice thickness models intercomparison experiment. *The Cryosphere*, 11(2), 949-970.

Farinotti, D., Huss, M., Bauder, A., Funk, M., & Truffer, M. (2009). A method to estimate the ice volume and ice-thickness distribution of alpine glaciers. *Journal of Glaciology*, 55(191), 422-430.

Farinotti, D., King, E. C., Albrecht, A., Huss, M., & Gudmundsson, G. H. (2014). The bedrock topography of Starbuck Glacier, Antarctic Peninsula, as determined by radio-echo soundings and flow modeling. *Annals of Glaciology*, 55(67), 22-28.

Frey, H., Machguth, H., Huss, M., Huggel, C., Bajracharya, S., Bolch, T., Kulkarni, A., Linsbauer, A., Salzmann, N., & Stoffel, M. (2014). Estimating the volume of glaciers in the Himalayan-Karakoram region using different methods. *The Cryosphere*, 8(6), 2313-2333.

Georges, C. (2004). 20th-century glacier fluctuations in the tropical Cordillera Blanca, Peru. *Arctic, Antarctic, and Alpine Research*, 36(1), 100-107.

Grima, N., & Campos, N. (2020). A farewell to glaciers: Ecosystem services loss in the Spanish Pyrenees. *Journal of Environmental Management*, 269, 110789.

Grinsted, A. (2013). An estimate of global glacier volume. *The Cryosphere*, 7(1), 141-151.

Grötzbach, E. (2003). Tourism in the Cordillera Blanca Region, Peru. *Revista Geográfica*, 133, 53-72.

Haimayer, P. (1989). Glacier-skiing areas in Austria: A socio-political perspective. *Mountain Research and Development*, 9(1), 51-58.

Heikkinen, A. (2017). Climate change in the Peruvian Andes: A case study on small-scale farmers' vulnerability in the Quillcay River Basin. *Iberoamericana – Nordic Journal of Latin American and Caribbean Studies*, 46(1), 77-88. Recovered from https://doi.org/10.16993/iberoamericana.211

Hijioka, Y., Lin, E., Pereira, J. J., Corlett, R. T., Cui, X., Insarov, G. E., Lasco, R. D., Lindgren, E., & Surjan, A. (2014). Asia. Climate change 2014: *Impacts, Adaptation, and Vulnerability. Part B: Regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1327-1370). Cambridge, UK, and New York, USA: Cambridge University Press.

Iparraguirre, J. E., Úbeda, J., Concha, R. F., Pellitero, R., De-Marcos, F. J., Dávila, L., Vásquez, P., Gómez, J., & Araujo, J. E. (2020). Paleoclimatic reconstruction during the Little Ice Age in the Llanganuco Basin, Cordillera Blanca (Peru). *EGUGA*, 1726. Recovered from https://doi.org/10.5194/egusphere-egu2020-1726

Izaguirre, M. F. (2021). *Impactos del retroceso glaciar y disponibilidad hídrica en la subcuenca Ilullán-Parón, cuenca del río Santa*. Lima, Perú: Pontificia Universidad Católica del Perú.

James, W. H. M., & Carrivick, J. L. (2016). Automated modelling of spatially-distributed glacier ice thickness and volume. *Computers & Geosciences*, 92, 90-103.

Jeong, D. I., Sushama, L., & Naveed-Khaliq, M. (2017). Attribution of spring snow water equivalent (SWE) changes over the northern hemisphere to anthropogenic effects. *Climate Dynamics*, 48(11), 3645-3658.

Jia, Y., Li, Z., Jin, S., Xu, C., Deng, H., & Zhang, M. (2020). Runoff changes from Urumqi Glacier No. 1 over the Past 60 Years, Eastern Tianshan, Central Asia. *Water*, 12(5), 1286.

Kaser, G., Ames, A., & Zamora, M. (1990). Glacier fluctuations and climate in the Cordillera Blanca, Peru. *Annals of Glaciology*, 14, 136-140.

Kaser, G., & Osmaston, H. (2002). *Tropical glaciers*. Cambridge, UK: Cambridge University Press.

Li, H., Ng, F., Li, Z., Qin, D., & Cheng, G. (2012). An extended "perfect-plasticity" method for estimating ice thickness along the flow line of mountain glaciers. *Journal of Geophysical Research: Earth Surface*, 117(F1). Recovered from https://doi.org/10.1029/2011JF002104

Liekens, I., Broekx, S., Smeets, N., Staes, J., Van-der-Biest, K., Schaafsma, M., De-Nocker, L., Meire, P., & Cerulus, T. (2013). The ecosystem services valuation tool and its future developments environmental impact assessment review. In: *Ecosystem services: Global issues, local practices*. Ámsterdam, The Netherlands: Elsevier. Recovered from https://doi.org/10.1016/B978-0-12-419964-4.00019-6

Linsbauer, A, Paul, F., Hoelzle, M., Frey, H., Haeberli, W., & Purves, R. S. (2009). The Swiss Alps without glaciers–a GIS-based modelling approach for reconstruction of glacier beds. In: Purves, Ross S et al. *Proceedings of Geomorphometry 2009* (pp. 243-247). Zurich, Switzerland: Department of Geography, University of Zurich. DOI: 10.5167/uzh-27834

Linsbauer, A., Paul, F., & Haeberli, W. (2012). Modeling glacier thickness distribution and bed topography over entire mountain ranges with GlabTop: Application of a fast and robust approach. *Journal of Geophysical Research: Earth Surface*, 117(F3). Recovered from https://doi.org/10.1029/2011JF002313

Lüthi, M., Walter, F., Jouvet, G., & Werder, M. (2006). *Physics of glaciers (Versuchsan)*. Bern, Switzerland: Geographisches Institut, Universität Bern.

Maguiña, M. E., Angulo, H. G., Gonzales, J. E., & López, M. A. (2020). Tourist support in Llanganuco Lagoon-Huascarán National Park, Perú. *RIAT: Revista Interamericana de Medioambiente y Turismo*, 16(1), 15-22.

Mark, B. G., & Seltzer, G. O. (2003). Tropical glacier meltwater contribution to stream discharge: a case study in the Cordillera Blanca, Peru. *Journal of Glaciology*, 49(165), 271-281.

Mark, B. G., & Seltzer, G. O. (2005). Evaluation of recent glacier recession in the Cordillera Blanca, Peru (AD 1962–1999): spatial distribution of mass loss and climatic forcing. *Quaternary Science Reviews*, 24(20-21), 2265-2280.

Medina, G., & Mejía, A. (2014). Análisis multitemporal y multifractal de la deglaciación de la Cordillera Parón en los Andes de Perú. *Ecología Aplicada*, 13(1), 35-42.

MINAM, Ministerio del Ambiente. (2015). *Manual de valoración económica del patrimonio natural*. Magdalena del Mar, Perú: Dirección General de Evaluación, Valoración y Financiamiento del Patrimonio.

MINAM, Ministerio del Ambiente. (2016). *Guía de valoración económica y patrimonio cultural*. Magdalena del Mar, Perú: Ministerio del Ambiente.

MINJUS, Ministerio de Justicia y Derechos Humanos. (2017). *RD-002-2017-EF-63.01-2, Tasa Social de Descuento*. Lima, Perú: Ministerio de Justicia y Derechos Humanos.

Navarro, Á., Úbeda, J., Santillán, N., Dávila, L., Concha N, R. F., Cochachín, A., Gómez, J., Cruz, R., & Torres, L. (2017). *Reconstrucción de ELAAABI en glaciares de la cuenca Parón (Cordillera Blanca)*. Recovered from https://hdl.handle.net/20.500.12544/1065

Nye, J. F. (1952). The mechanics of glacier flow. *Journal of Glaciology*, 2(12), 82-93.

Paul, F., & Linsbauer, A. (2012). Modeling of glacier bed topography from glacier outlines, central branch lines and a DEM. *International Journal of Geographical Information Science*, 26(7), 1173-1190. DOI: 10.1080/13658816.2011.627859

Pellitero, R., Rea, B. R., Spagnolo, M., Bakke, J., Ivy-Ochs, S., Frew, C. R., Hughes, P., Ribolini, A., Lukas, S., & Renssen, H. (2016). GlaRe, a GIS tool to reconstruct the 3D surface of palaeoglaciers. *Computers & Geosciences*, 94, 77-85.

Pirhalla, M., Gende, S., & Mölders, N. (2014). Fate of particulate matter from cruise-ship emissions in Glacier Bay during the 2008 tourist season. *Journal of Environmental Protection*, 5(12), 1235.

Purdie, H. (2013). Glacier retreat and tourism: Insights from New Zealand. *Mountain Research and Development*, 33(4), 463-472.

Purdie, H., Gomez, C., & Espiner, S. (2015). Glacier recession and the changing rockfall hazard: Implications for glacier tourism. *New Zealand Geographer*, 71(3), 189-202.

Rabatel, A., Francou, B., Soruco, A., Gomez, J., Cáceres, B., Ceballos, J. L., Basantes, R., Vuille, M., Sicart, J.-E., & Huggel, C. (2012). Current state of glaciers in the tropical Andes: A multi-century perspective on glacier evolution and climate change. *The Cryosphere*, 7(1), 81-102.

Rabatel, A., Francou, B., Soruco, Á., Gomez, J., Cáceres, B., Ceballos, J. L., Basantes, R., Vuille, M., Sicart, J.-E., & Huggel, C. (2013). Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change. *The Cryosphere*, 7(1), 81-102.

Radić, V., & Hock, R. (2011). Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise. *Nature Geoscience*, 4(2), 91-94.

Rumbaur, C., Thevs, N., Disse, M., Ahlheim, M., Brieden, A., Cyffka, B., Duethmann, D., Feike, T., Frör, O., & Gärtner, P. (2015). Sustainable management of river oases along the Tarim River (SuMaRiO) in Northwest China under conditions of climate change. *Earth System Dynamics*, 6, 83-107.

Schauwecker, S., Rohrer, M., Huggel, C., Endries, J., Montoya, N., Neukom, R., Perry, B., Salzmann, N., Schwarb, M., & Suarez, W. (2017). The freezing level in the tropical Andes, Peru: An indicator for present and future glacier extents. *Journal of Geophysical Research: Atmospheres*, 122(10), 5172-5189.

Segovia, A. (2014). Caracterización glaciológica de Chile y valoración de servicios ecosistémicos de glaciares en base a mercados reales: estudio de caso del monumento natural El Morado. Memoria de Magíster. En: *Áreas silvestres y conservación de la naturaleza* (168 pp.). Santiago, Chile: Universidad de Chile, Facultad de Ciencias Forestales y de la Conservación de la Naturaleza.

Sotillo, D. B. (2017). Una breve descripción de los servicios ecosistémicos, hídricos y culturales de la Cordillera Blanca y su entorno. *Revista de Glaciares y Ecosistemas de Montaña*, 3, 14.

Sun, M., Ma, W., Yao, X., Zhao, L., Li, Z., & Qin, D. (2020). Evaluation and spatiotemporal characteristics of glacier service value in the Qilian Mountains. *Journal of Geographical Sciences*, 30(8), 1233-1248.

Torres, J., Colonia, D., Haeberli, W., Giráldez, C., Frey, H., & Huggel, C. (2014). Thicknesses and volumes of glaciers in the Andes of Peru estimated with satellite data and digital terrain information. EGU General Assembly Conference Abstracts. *Geophysical Research Abstracts*, 16, EGU2014-13759. Recovered from https://meetingorganizer.copernicus.org/EGU2014/EGU2014-13759.pdf

Urrutia, R., & Vuille, M. (2009). Climate change projections for the tropical Andes using a regional climate model: Temperature and precipitation simulations for the end of the 21st century. *Journal of Geophysical Research: Atmospheres*, 114(D2). Recovered from https://doi.org/10.1029/2008JD011021

Vuille, M., Carey, M., Huggel, C., Buytaert, W., Rabatel, A., Jacobsen, D., Soruco, A., Villacis, M., Yarleque, C., & Timm, O. E. (2018). Rapid decline of snow and ice in the tropical Andes–Impacts, uncertainties and challenges ahead. *Earth-Science Reviews*, 176, 195-213.

Wang, S. J., Zhao, J. D., & He, Y. Q. (2012). Adaptative strategy of mountain glacier tourism under climate warming background-- A case study of Mt. Yulong Snow-Glacier-Geological Park. *Journal of Glaciology and Geocryology*, 34(1), 207-213.

Welling, J. T., Árnason, Þ., & Ólafsdottír, R. (2015). Glacier tourism: A scoping review. *Tourism Geographies*, 17(5), 635-662.

Wu, X., Wang, X., Liu, S., Yang, Y., Xu, G., Xu, Y., Jiang, T., & Xiao, C. (2021). Snow cover loss compounding the future economic vulnerability of western China. *Science of the Total Environment*, 755, 143025. Recovered from https://doi.org/10.1016/j.scitotenv.2020.143025

Yap, A. (2015). *Análisis multitemporal de glaciares y lagunas glaciares en la Cordillera Blanca e identificación de potenciales amenazas GLOFs*. Lima, Perú: Pontificia Universidad Católica del Perú.

Yuan, L., & Wang, S. (2018). Recreational value of glacier tourism resources: A travel cost analysis for Yulong Snow Mountain. *Journal of Mountain Science*, 15(7), 1446-1459.

Zhang, W., Wang, X., Shen, Y.-P., Yang, X.-W., Wu, Y.-W., Chen, A.-A., Wu, X.-J., Liu, S.-W., Yang, Y., Zhang, J.-L., & Li, C.-Y. (2021a). Cryospheric water regime by its functions and services in China. *Advances in Climate Change Research*, 12(3), 430-443. Recovered from https://doi.org/10.1016/j.accre.2021.05.008

Zhang, X.-T., Chen, R.-S., Liu, G.-H., Yang, Y., & Feng, T.-W. (2021b). Economic value of freshwater provisioning services of the cryosphere in the Urumqi River, Northwest China. *Advances in Climate Change Research*, 12(6), 894-902. Recovered from https://doi.org/10.1016/j.accre.2021.09.003

Zhang, Zhengyong, Liu, L., He, X., Li, Z., & Wang, P. (2019). Evaluation on glaciers ecological services value in the Tianshan Mountains, Northwest China. *Journal of Geographical Sciences*, 29(1), 101-114.

Zhang, Zhuoran, & Seenprachawong, U. (2015). Estimating recreational benefits of the glacier-based highland ecosystem. *AU Journal of Management*, 13(2), 1-10.