IRRIGATION IN UPPER HUNZA: EVOLUTION OF SOCIO-HYDROLOGICAL INTERACTIONS IN THE KARAKORAM, NORTHERN PAKISTAN

Sitara Parveen, Matthias Winiger, Susanne Schmidt and Marcus Nüsser

With 5 figures, 1 table and 4 photos
Received 2 October 2014 · Accepted 18 March 2015

Summary: Based on three case studies, this paper describes and analyzes the structure and dynamics of irrigation systems in Upper Hunza, located in the western Karakoram, Pakistan. In these deeply incised and arid valleys, glacier and snow melt-water are the primary water sources for agricultural production. The study shows how glacio-fluvial dynamics impact upon irrigation systems and land use practices, and how, in turn, local communities adapt to these changing conditions: framed here as socio-hydrological interactions. A combined methodological approach, including field observations, interviews, mapping and remote sensing analysis, was used to trace historical and recent changes in irrigation networks and land use patterns.

Zusammenfassung: Auf Grundlage von drei Fallstudien behandelt der Beitrag die Struktur und Dynamik von Bewässerungssystemen im oberen Hunza-Tal, einer Hochgebirgsregion im westlichen Karakorum, Pakistan. In den tief eingeschnittenen Tälern bilden die Schnee- und Gletscherschmelzwässer eine essentielle Voraussetzung für die landwirtschaftliche Nutzung. Die Fallstudien zeigen den Einfluss von Gletscherveränderungen auf die Bewässerungssysteme und Landnutzungsmuster und wie sich die lokalen Gemeinschaften wiederum auf diese Veränderungen einstellen. Diese Anpassungsstrategien werden hier als Teil eines sozio-hydrologischen Interaktionsmodells behandelt. Zur Erfassung und Analyse der historischen und rezenten Veränderungen des Bewässerungssystems und der Landnutzungsmuster dient ein Methodenverbund in dem sowohl Interviews und mündliche Überlieferungen, als auch detaillierte Feldaufnahmen und Fernerkundungsdaten einbezogen werden.

Keywords: Irrigation systems, glacier change, livelihoods, high mountains, Pakistan

1 Introduction

The importance of mountains as 'water-towers' for adjacent lowlands (Viviroli et al. 2003, 32; Viviroli and Weingartner 2008, 16) is widely acknowledged by scientific and political actors, with the result that much effort has been invested for a better understanding of the sensitivity and dynamics of these hydro-climatic highland-lowland systems (Immerzeel et al. 2010; Kaser et al. 2010).

In the case of the Indus Basin, the discussion foregrounds lowland oriented development priorities, which include the demands for secure potable, industrial and agricultural water, as well as energy supply for a rapidly growing population. Less attention, however, is paid to the concerns of mountain communities, who also depend on these water resources for their livelihood (Kreutzmann 1998, 194ff.; 2000, 13ff., 2011, 529ff.).

The upper Indus Basin is fed by water originating in the western Himalaya, the Karakoram and the Hindu Kush. Unlike other Himalayan regions, where glacier retreat dominates, glaciers in the upper Indus catchment are characterised by an overall increase of total snow and ice volume with significant regional differences, also called the 'Karakoram anomaly' (Hewitt 2005, 332). However, there are many cases where glacier termini are in retreat and where ablation reduces glacier extent, often resulting in the desiccation of irrigation channels across lateral moraines. At various scales, these dynamics have been documented through field studies and remote sensing analysis (BGIG 1979; Schmidt and Nüsser 2009, 2012; Scherler et al. 2011; Gardelle et al. 2012; Kääb et al. 2012; Rankl et al. 2014). Furthermore, remote sensing data has been used to investigate seasonal snow cover dynamics (Winiger et al. 2005; Immerzeel et al. 2009; Forsythe et al. 2012). The question of how glacial dynamics affect the livelihoods of mountain communities living in close proximity to these ice bodies has been largely neglected.

DOI: 10.3112/erdkunde.2015.01.05 ISSN 0014-0015 http://www.erdkunde.uni-bonn.de

Local irrigation systems in high mountain regions are unique examples of socio-hydrological interactions, which are characterised by an interplay of site-specific glacio-hydrological conditions, socio-economic development, institutional arrangements and external development interventions. Despite an increase in the diversity of household strategies, irrigated agriculture remains the main component of livelihood security for mountain dwellers. Reliable crop production requires constant and sufficient melt-water supply from glaciers and snowfields. A number of local studies on irrigation systems have been carried out in the arid to semi-arid mountain environments of the upper Indus Basin. Most investigations were carried out in Gilgit-Baltistan – which until 2009 was known as Northern Areas of Pakistan (Kreutzmann 1989; 2011, Schmidt 2004), and in Ladakh, India (Labbal 2000; Nüsser et al. 2012). These studies foregrounded site-specific differences of water abstraction and distribution, often based on ingenious and sophisticated designs. A remarkable persistence, with relatively little transformation of land use patterns, was detected; in spite of the vagaries of environmental dynamics and challenging socio-economic conditions (Nüsser 2000, 353; 2001, 253; Dame and Mankelow 2010, 368).

In this paper, a detailed and historically informed case study on the strategies of water management in Upper Hunza (also known as Gojal), located in the Western Karakoram is presented. In order to trace the role of environmental and socio-economic dynamics influencing irrigation systems, three disparate, yet neighbouring villages, namely: Passu, Borith and Ghulkin, are investigated, taking into account the role of different actors in shaping water abstraction and irrigation networks. Here, socio-hydrological interactions are characterised by several environmental, social, cultural and historical aspects, including (a) arid conditions at the valley floors, where permanent settlements are located; (b) snow and ice cover dynamics at higher altitudes, which provide melt water; (c) flexible water abstraction practices; (d) diverse socio-economic conditions. The case study departs from a classification of different settlements according to their site-specific conditions for irrigation, which vary according to topography, melt-water access, local capacity and external development interventions. The aim of this paper is to analyse the implications of glacial fluctuation on irrigation systems, and local adaptation strategies.

2 Methodological approach and specific data

A combined approach based on field observations, mapping, household and expert interviews as well as remote sensing analyses was used to trace temporal and spatial changes of irrigated crop cultivation. As only few written records exist, information about socio-economic and environmental conditions relied mainly on oral history (George and Stratford 2005, 140ff.). Historical timelines, such as rule periods of the hereditary rulers (Mirs) of Hunza, or collectively remembered events such as the partition of British India (1947), were used to reconstruct the development of irrigation networks in the area. Structured and semi-structured interviews were conducted during 2012 and 2013 in order to assess more recent socio-economic and environmental changes affecting local livelihoods.

Village Numberdars (leaders) and representatives of water management committees and development organizations were consulted for their insights into the historical development of different channels and to discuss earlier measures to improve the irrigation system, for example regarding the mobilization of the community for construction, maintenance and restoration of channels. The database was complemented with photography and maps from previous expeditions (Paffen et al. 1956; BGIG 1979; Finsterwalder 1996, suppl. III). The current operational status of the channels (desiccated, working, or prone to destruction) and their relation to specific water sources was classified in the field in order to identify different adaptation strategies on changing water availability and natural hazards. Together with land use patterns, these channels were digitized on a pan-sharpened and ortho-rectified Quickbird image (27th May 2007) for the northern part of the study area and on a KOMPSAT image (23th March 2011) for the irrigated area of Ghulkin. In combination with the information from the interviews, the mapping of channels enables a visualization of temporal and spatial changes of the irrigation system.

3 Study area: Upper Hunza

Upper Hunza is located in Hunza-Nager district of Gilgit-Baltistan. The Hunza River flows north to south, and is joined by the Shimshal River at the northeast part of the study area, and by the Batura, Passu, Ghulkin and Gulmit Glaciers from the west (Fig. 1).

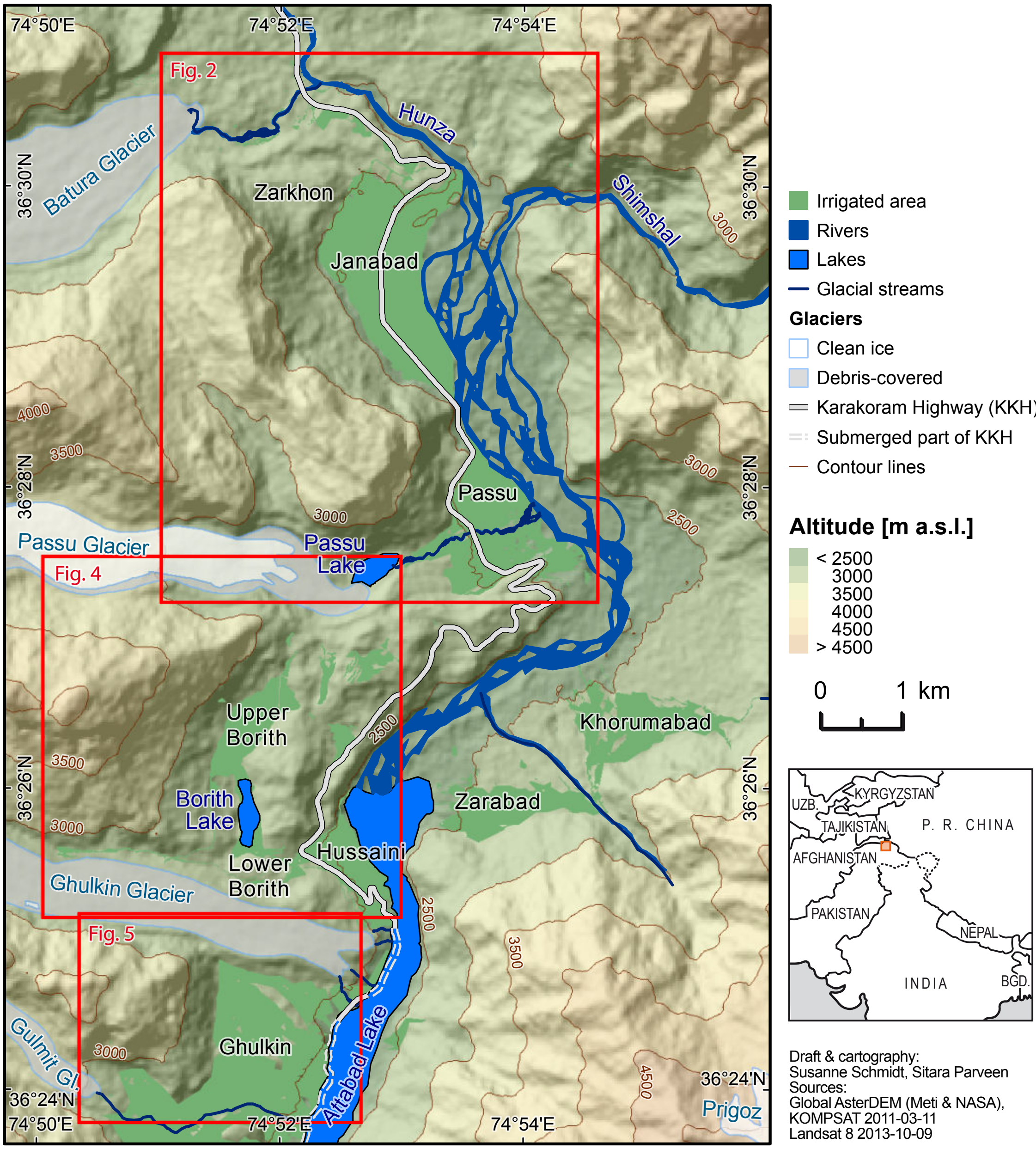

Fig. 1: Three investigated villages Passu, Borith and Ghulkin in Upper Hunza, Pakistan

The Batura Glacier, which is the largest of the four glaciers, marks the northern edge of the study site, and covers an area of about 289 km². The Gulmit Glacier covers an area of 13 km² and marks the southern border. All four valley glaciers flow from west to east and are characterized by remarkably low positions of their termini, which lie between 2560 m a.s.l. and 2620 m a.s.l. These glaciers were earlier studied by several researchers (Visser 1928, 180ff.; Mason 1930, 236ff.; Visser and Visser-Hooft 1935, 39ff.; Paffen et al. 1956, 15–22; BGIG 1979; Goudie et al. 1984b, 439ff.; Yafeng and Xiangsong 1984; Xiangsong 1984). Hewitt (2014, 305, 308f.) analysed the glaciers based on these previous studies and showed a general retreat interrupted by small fluctuations since the end of the 19th century.

The study area falls under the Northwest Karakoram climatic regime with maximum precipitation in winter and occasional rainfall in spring and summer (Winiger et al. 2005, 2332). Annual precipitation is deposited predominantly as snow at around 5000 m a.s.l., whereas in the lowest parts of the valleys the snow contributes no more than 10 % of the total. Vertical humidity rates vary from arid valley bottoms to humid mountain ridges and upper watersheds. Thus, in the Batura catchment mean annual precipitation is as low as 80–120 mm at the glacier terminus and increases to 1800 mm (Weiers 1995, 72) or even more than 2500 mm at 5000 m a.s.l. The mean annual temperature at the terminus is 10 °C, and -5 °C at 5000 m a.s.l. (BGIG 1979, 961; Yafeng and Xiangsong 1984, 56). Between 1994 and 2013 the mean annual temperature increased by about 0.6 °C, while the mean summer temperature shows a negative trend of approximately -1.2 °C (personal communication, U. Börst 2014).

The total population of Upper Hunza is 20,000, of which 5,700 people (2010, unpubl. Ismaili Council Gulmit) live within the three investigated villages – Passu, Borith and Ghulkin. By and large, these villages are located on fluvial terraces and debris fans at altitudes between 2400 and 2800 m a.s.l. On their irrigated fields wheat and potatoes are the dominant crops grown. Apricot, apple and cherry trees are dominantly cultivated in orchards and are intercropped with vegetables such as peas, onions, tomatoes, carrots, cabbage and other greens. Seabuckthorn (*Hippophae rhamnoides*) and poplar trees (*Populus nigra*) are important for fodder and fuel. These woody species, interspersed with grass, grow near the glacier termini, on slopes steeper than 12°, adjacent to glacial streams or lining the irrigation channels, and are used to stabilize such locations (Eberhardt et al. 2007: 107). Land use and cropping patterns vary between the investigated villages, and are dependent on topography, water availability, risk of natural hazards and socio-economic conditions. In addition to crop cultivation the husbandry of cattle, yaks, sheep and goats contributes to household incomes.

4 Irrigation systems

4.1 Historical overview

The sophisticated irrigation systems of Upper Hunza were first described by Visser and Visser-Hooft (1935: 62) and Paffen et al. (1956: 30). The earliest recorded channels in the valley date back to at least 1780 and diverted water from the Batura Glacier to Zarkhon Passu (Yafeng and Xiangsong 1984: 60). Later the irrigation network was extended and flourished under different feudal rulers (Mirs of Hunza). They used state authority to enforce the construction of channels in a bid to develop barren land for crop cultivation. Parts of these new lands were granted to the Mir's relatives or to migrants from Central Hunza. With the enlargement of irrigated areas, the Mir's income and power increased, partly through the imposition of taxes (Staley 1969, 233ff.; Sidky 1997, 1004f.; Kreutzmann 1989, 53). The expansion of the irrigation systems had already decreased over the last decades of the Mirs' rule (AKRSP 1987, 31). After the Central Government of Pakistan abolished the principalities of Hunza and Nager in the early 1970s, the Bhutto Government initiated an Integrated Rural Development Project (Kreutzmann 1989, 200) in order to improve the farmer's income. Furthermore, in December 1982 the developmental organization Aga Khan Rural Support Programme (AKRSP) started projects to construct new primary channels and attendant irrigation networks (Kreutzmann 1989, 203; Khan and Hunzai 2000, 136f.).

4.2 Physical structure of irrigation system and water utilization

The main water sources for the cultivated areas are the melt-runoff of Batura, Passu, Ghulkin and Gulmit Glaciers. Due to the Hunza Rivers' steep incision and strong currents, the river discharge is not used for irrigation - as already described by Clark (1956, 82). The irrigation systems and water use differ significantly between and within the three investigated villages, depending largely on site-specific potentials and constraints for water abstraction and distribution (Tab. 1). Considerable heterogeneity exists owing to the location of water sources, which reveal a range of spatial and temporal constraints. Geographical features determine the location of water intakes, so that in some cases water is abstracted from sub-glacial streams emerging from the glacier snout, whilst in others, supra-glacial discharge has to be diverted across lateral moraines. Furthermore, where water sources are located at higher altitudes, melt water availability is delayed by both daily and seasonal temperatures.

Water usage from the sub-glacial stream is restricted to settlements that are located below the glacier tongues, such as Central Passu and Yashvenden. These channels are exposed to glacier lake outburst floods (GLOFs) and periodic advances of fluctuating glacier tongues, including surging

Tab. 1: Physical structure of irrigation systems and water utilization in Upper Hunza

	Source	Water availability	Limitations and institutional arrangement
Passu	Glacio-fluvial stream of Passu and Batura Glacier		E
	Seasonal snow cover and perennial snowfield of Prigoz		↔
Borith	Supra-glacial lake of Ghulkin Glacier		↔ E
	Supra-glacial melt water of Passu and Ghulkin Glacier		↔ E
	Ablation valley lake of Passu Glacier (dried up in the 1960s)		
Ghulkin	Ablation valley lake of Ghulkin Glacier (dried up in the 1950s)		
	Supra-glacial lake of Gulmit Glacier		↔ E
	Glacio-fluvial stream of Ghulkin and Gulmit Glacier		↔ E
	Spring		↔

- water available / water source vanished / no water available during winter
- degree to which water discharge depends on temperature
- water discharge mainly depends on seasonal and perennial snow cover
↔ - water rotation system exists
- sediment accumulation in the channels hinders water runoff and requires permanent channel repair work
- water overflows the lateral moraine, human work force is needed to constrain and maintain the channels and to divert water into the channels; water usage is restricted to dwellers, who are able to work on the glaciers
- GLOFs and sudden glacier advances frequently destroy the channels
- lake desiccates by overflowing its banks or due to formation of crevasses
- high vulnerability against glacier retreat
E - erosion of channel intakes

events. However, this water source is less vulnerable to glacier retreat compared to channels crossing lateral moraines.

Settlements situated above the glacier snouts source their water from supra-glacial meltwater which then flow through ablation valleys, located beside the glacier. A precondition for this type of abstraction is a glacier surface level above or close to the height of the lateral moraine, in order to secure regular water flow. In such cases the water source is highly vulnerable to changes in the elevation of glacier surface. Lowering of the glacier surface (down-wasting) disconnects the irrigation network from its source, and requires constant structural modifications to the intake and its channel, as in the case of Borith.

Other non-glacial sources of water, including seasonal snowmelt and springs, are of minor importance. However, in Khorumabad Passu snow melt is the dominant source of irrigation water, making cropping vulnerable to highly variable inter-annual snow fall. Spring water is largely restricted to domestic use. Only in the case of Ghulkin can one find summer spring water used for irrigation. The absence of springs in Borith forces villagers to use proglacial discharge for household purposes.

4.3 Passu Village fed by glacio-fluvial streams

Today, Passu has a population of 940 people (2010, unpubl. Ismaili Council Gulmit), with most people settled in Central Passu and Yashvenden[1], whilst Janabad and Khorumabad mainly serve as croplands and summer pastures, respectively. The largest settlement, Central Passu (1.4 km²), is situated on three fluvial terraces, at an elevation of about 2500 m a.s.l. These terraces are cultivated with potato and wheat (20 %) and are separated by orchards (16 %). Grasses and sea-buckthorn are dominant along the glacio-fluvial valley floor between Passu Glacier and Hunza River and cover 62 % of the settlement area.

Over the past 400 years several natural disasters have shaped settlement patterns. The earliest recorded settlers were the Wakhi who migrated from the Wakhan corridor of Afghanistan (Kreutzmann 2012, 53). Local people refer to the village as the "Sih Sad Khona" village (Persian: 300 houses), which spread from Kipghar to Birkati or even up to Janabad. The initial fortified and compact settlement located on the lower terrace was destroyed by the rising waters of the Sarat Lake[2] (field interviews), which flooded almost all of Passu's arable land in 1857; Drew 1875, 419f.; Kreutzmann 2012, 58f.). In addition, several GLOFs from Batura Glacier and recurring floods from the Shimshal River have eroded agricultural lands and destroyed houses (Drew 1875, 414ff.; Goudie et al. 1984a, 389; Hewitt 1982, 261; Kreutzmann 1994, 340; Iturrizaga 2005, 547; Kreutzmann 2012, 59ff.; Hewitt 2014, 254f.). The area also witnessed cropland devastation in the 19th century from the advancing Passu Glacier (field interviews).

According to local elders, the effects of these natural disasters led villagers to move their homes to higher ground and to attempt to recover and rehabilitate barren land for crop cultivation (see also Beg 1962). One such example is the move made to the elevated Nobod terrace, which local elders said was cultivated and settled later than Central Passu. According to them, the channel leading to this terrace was built by local initiative to avoid paying taxes to Mir Silum Khan (1790–1824)[3]. Another example is that of Suronobod terrace, located above Nobod, where attempts were made to develop it as an irrigated cropland during Mir Muhammad Nazim Khan's era (1892–1938). This attempt was undertaken as a result of the Sarat Lake flood of 1857. It remains unclear whether or not the irrigation channel sourcing water from the Passu Glacier lateral moraine was in operation, as no field patterns are detectable on satellite images or in the field (Fig. 2, Photo 1). A further failed attempt to irrigate this terrace was made in the last years of Mir Muhammad Jamal Khan's rule (1945–1974). This project was cancelled in 1974 by the Finance Minister of Pakistan during the abrogation of the kingdom.

A new expansion of irrigable land was carried out by AKRSP in Janabad (2.9 km²) in 1983 and 1984. This project sources water from the Batura Glacier, however its utilization is prone to interruptions owing to glacial fluctuations. According to local elders, the historical settlement of Zarkhon, situated in the southern vicinity of Batura Valley, was settled up until the 18th century[4]. It was abandoned as the Batura Glacier advanced and destroyed the intakes of all irrigation channels (Yafeng and Xiangsong 1984, 60; field interviews; Fig 2). During Mir Mohammad Nazim Khan's (1892–1938) and Mir Mohammad Jamal Khan's (1945–1974) rule,

[1] Yashvenden was fed by a main channel diverting water from Ghyper Zhui (see Fig. 4) until the mid of the 20th century. At least until the 1970s, this region was used as Mir's horse pasture. Nowadays, it is used as a permanent settlement of Passu.

[2] Becher (1859, 223–227) described in his letter a flood, which destroyed many villages downstream the Indus. According to local narratives, the flood was caused by a landslide blocking the Hunza River. This landslide (see also Goudie et al. 1984a, 388) was located almost in the same area where the Attabad rock avalanche blocked the Hunza River in 2010 (Hewitt 2010).

[3] In contrast to local responses, Beg (1962) mentioned that Nobod was cultivated after the flood during Muhammad Nazim Khan's era (1892–1938). As verification, the former lake level was virtually modelled using digital elevation data with the baseline set to the altitude of a reported partly flooded house in Gulmit.

[4] The foundations of two old houses were given as evidence of this earlier settlement of Zarkhon (field interviews).

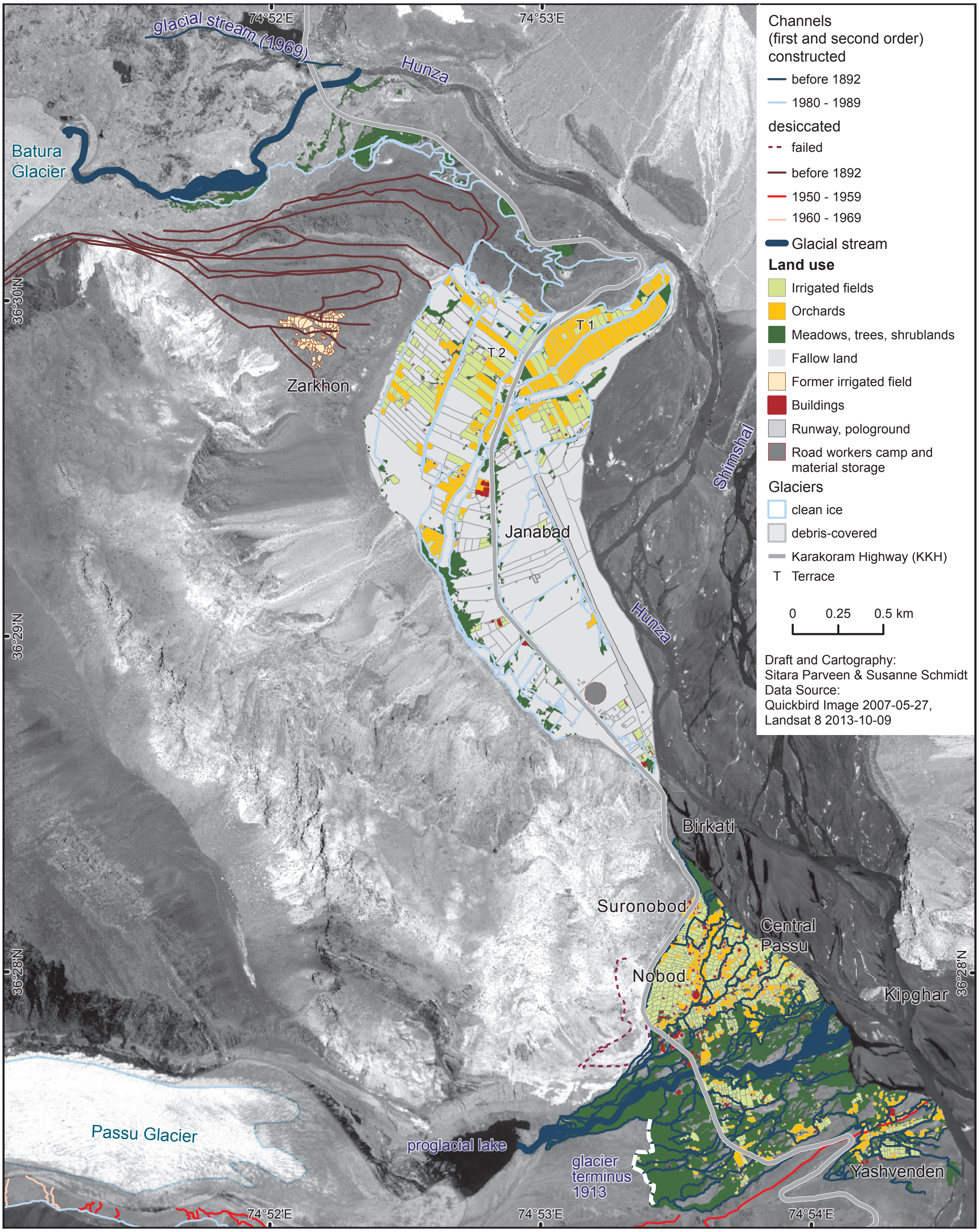

Fig. 2: Irrigation and land use in Passu village

several attempts had been made to restore these channels for irrigation of the areas around Zarkhon and Janabad. However, these plans failed as the glacier began to down-waste and because the glacio-fluvial outlet was located in the inaccessible northern side of the ice body. It was only after 1973, that the massive shift (approx. 700 m) of the glacier snout southwards (Goudie et al. 1984b, 393) opened up the

Photo 1: Failed irrigation channels to divert water from Passu Glacier to Suronobod Passu. (Photo: Sitara Parveen 2013)

possibility for the abstraction of water to Janabad. This new opportunity was taken by AKRSP in the 1980s through the extension of an irrigation channel over 4 km to newly developed arable lands on two fluvial terraces. These two terraces are allocated for crops, orchards and residential use (AKRSP 1985, 22ff.). According to the project report, each household received one field on each terrace. The 2007 satellite image shows that 53 % of the project area is transformed to irrigated fields, 19 % are orchards, combined with the cultivation of fodder and vegetables, 9 % are potato or wheat fields, and the remaining areas are a combination of fallow fields, trees and shrubland (Fig. 3). Despite the large areas of non-cultivated croplands, these fields are more intensively used than those found in their traditional settlement of Khorumabad (Fig. 1), located on the opposite bank of the Hunza River, owing to their proximity to the Karakoram Highway (KKH) and the relative abundance of water.

Though poorly accessible, Khorumabad is an important summer settlement and winter pasture (Kreutzmann 2012, 55f.). Smaller areas are covered by poplars and sea-buckthorn, which are grown for fuel and fodder. Even smaller irrigated fields were once cultivated with different fodder plants, but this was replaced by potatoes in the 1980s due to the increasing profitability of this cash crop with improved market accessibility by the KKH (Kreutzmann 1991, 732; 2006, 335). The

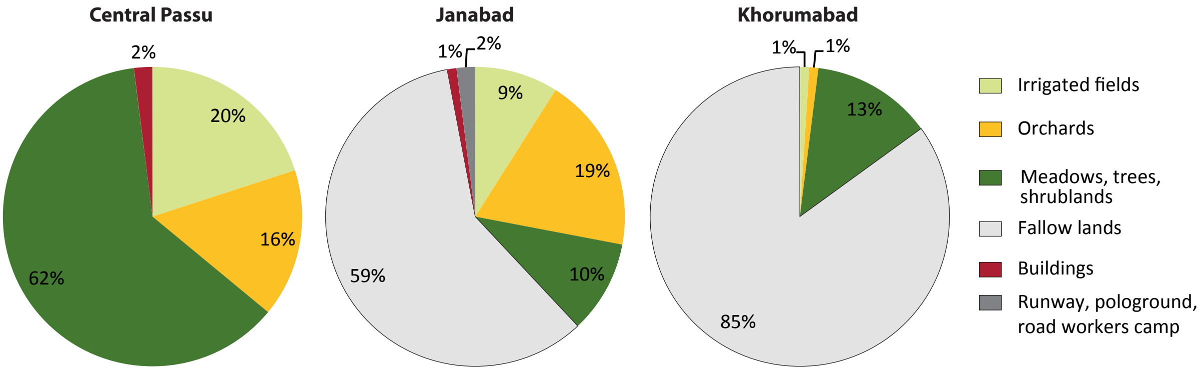

Fig. 3: Land use pattern in different localities of Passu village (2007)

productivity of these irrigated fields is limited by the high variability and low water discharge from the Prigoz snowfields. This shortage is compounded by the fact that water is shared with Zarabad, a settlement belonging to Hussaini, a village east of Ghulkin. Therefore large areas of land are left under fallow.

4.4 Borith: an endangered hamlet

Borith hamlet, which is part of Ghulkin village, has a population of 115 (2010, unpubl. Ismaili Council Gulmit) and is located at 2600 m a.s.l., in the vicinity of the brackish Borith Lake. Their main water sources are the Passu and Ghulkin Glaciers, which border north and south of the hamlet, respectively. Owing to glacier decrease this community has faced many water crises since the 1950s. As a result they have made varied and frequent efforts to secure access to water (Fig. 4).

The northern part of Borith, which includes Upper Borith, Shahbad, Lup Dur, Jalalabad and Sholimol, was up until the 1950s served by Lake Ghyper Zhui (2900 m a.s.l.). This now dry lake was once located in the ablation valley south of Passu Glacier, from which melt water flowing over the lateral moraine was the main recharge (Photo 2). Local elders stated that in the 1950s water was plentiful - as underlined by the existence of a large watermill stone still lying at Jalalabad.

The Lake level began to decrease in the 1940s as the Passu Glacier started to down-waste, this process took place concurrently with that of Ghulkin Glacier. Several attempts were made to conserve the melt water inflow to the lake; with natural channels expanded across the lateral moraine through daily excavation works. Due to an increasing gap between the lateral moraine ridge and the glacier surface these channels dried up between the 1950s and 1960s. Consequently, Shahbad, Jalalabad, and Lup Dur had to be abandoned, with the inhabitants then moving to Ghulkin

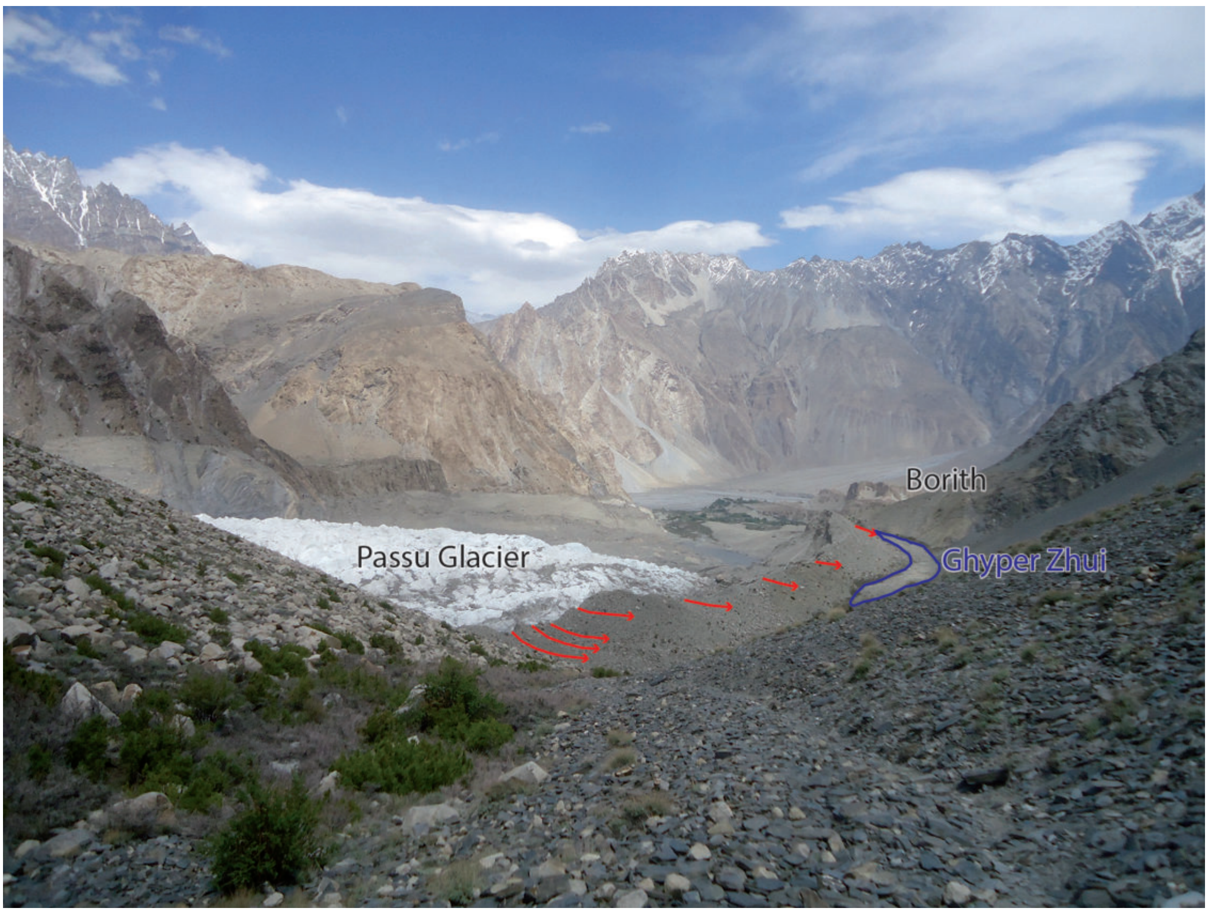

Photo 2: The lake Ghyper Zhui fed by Passu Glacier over the lateral moraine via a number of channels (red arrows). These channels are desiccated due to the down-wasting of the glacier. (Photo: Sitara Parveen 2013)

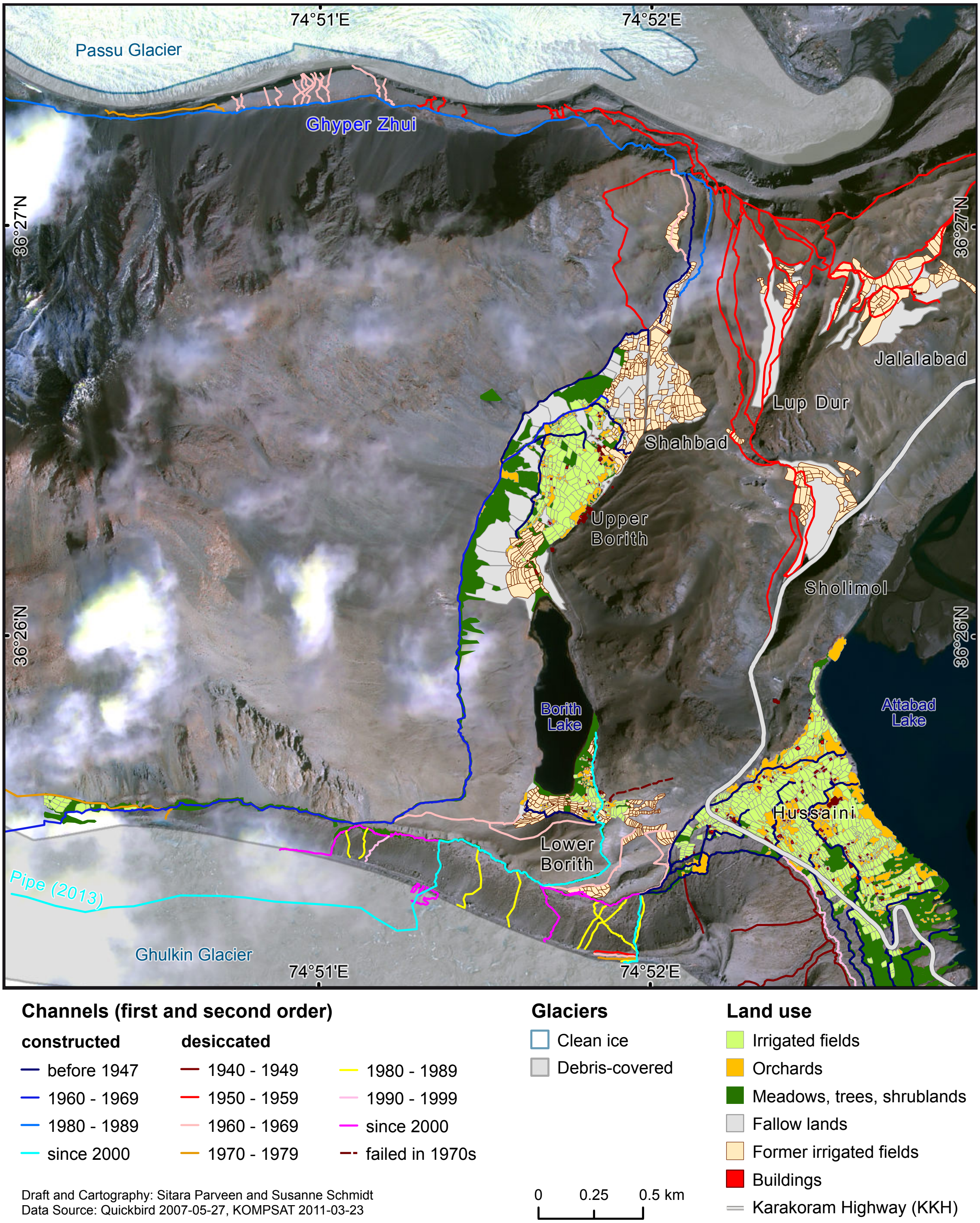

Fig. 4: Irrigation and land use in Borith village

or Jamalabad Morkhoon. Only a few fields in Upper Borith could be maintained owing to a community constructed 5 km long channel - which diverted melt water from Ghulkin Glacier at 2880 m a.s.l. However, this effort was futile, as the glacial runoff proved to be insufficient and the land returned to a barren state.

In 1973 the Government of Pakistan attempted to preserve Upper Borith's irrigated fields, as well as to re-develop the agricultural fields in Shahbad and Lup Dur. This project sought to tap water from above the former lake Ghyper Zhui through excisions made in the lateral moraine at 3380 m a.s.l. However, as the glacier continued to down-waste, this channel dried out after a few years, and the project failed. A similar attempt was carried out with the support of AKRSP ten years later, between 1983 and 1984. An underground pipeline was installed to extend the previous channel by another 1.7 km to a new intake[5)] situated at 3500 m a.s.l. (Photo 3).

Photo 3: Currently working (blue) and desiccated (red arrows) water diversion channels sourced by Passu Glacier. The recent water intake is more than 5 km upwards from the settlements and has to pass through landslide-prone sections. Therefore, underground pipelines have been used (yellow line) to protect the channel against mass movements. (Photo: Sitara Parveen 2013)

By 2007, with an accelerated down-wasting of the glacier, the water discharge declined. Today, villagers impound and divert glacial melt-water by infilling the gap between the glacier and the lateral moraine with stones, sacks and cloths. The higher elevation of the intake and therefore shorter period for melt, and the rather limited runoff means that water only reaches the cultivated fields in the late afternoon. This reduces the success of local re-development efforts. Figure 4 shows that of the former 0.9 km² of utilized land, only about 0.3 km² are currently used as cultivated fields and orchards.

Lower Borith, located in the northern proximity of Ghulkin Glacier, sources all of its water from this glacier. Since 1960 many channels have been constructed to divert water from across the lateral moraine, in response to the continuous down-wasting of the glacier. Villagers cut or relocate intakes and channels across the lateral moraines on a daily basis, as they try to secure water flow. The high-demand for man-hours means that other adaptation strategies are also sought, for-example through a reduction in the irrigation of farmland and an expansion of tree cultivation, whilst a schedule has been devised where each household is allocated a time slot to work on the maintenance of intakes and channels. The majority of households have escaped

[5)] The intake is off the map, further upslope and along the glacier.

this drudgery by migrating to other regions, principally Gilgit town. As a result, the population of Lower Borith decreased from 31 to 13 inhabitants between 1998 and 2013. Field observations show that between March and August 2012, six alternative channel intakes were built (Photo 4).

Fields in the western part of Lower Borith that were in use in 2007 (Fig. 4), were observed to be idle in 2012. Local elders confirmed that this was because of a decrease in water volume. A new AKRSP funded pipeline, installed in 2013, and which sources its water from an ice cliff situated at an altitude of 2920 m a.s.l. promises a more secure flow. Pipelines have the advantage of needing less maintenance when compared to open channels, and can also be routed more easily over undulating terrain. However, at this altitude melt water is only available in the late spring and summer periods, and, as confirmed by local people, the problem of shifting sources of water means that the intake to be relocated on several occasions.

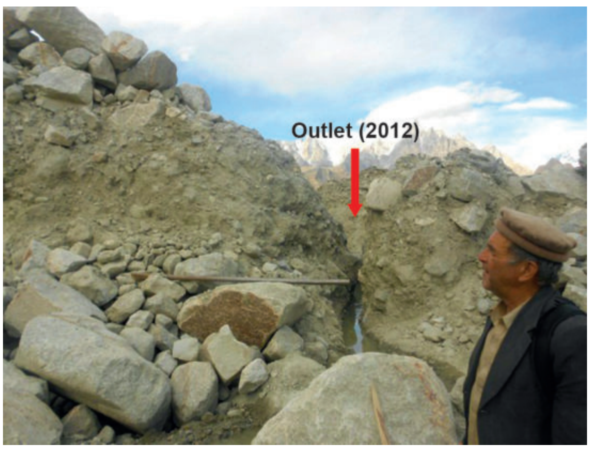

Photo 4: Lateral moraine of Ghulkin Glacier with one of 6 outlets in the year 2012. (Photo: Sitara Parveen 2012)

4.5 Ghulkin: irrigation water from supra glacial lakes across lateral moraines

Ghulkin, the third case study village, has a population of 1278 (2010, unpubl. Ismaili Council Gulmit) and is situated at an altitude of 2600 m a.s.l. between the two glaciers Ghulkin and Gulmit (Fig. 5). The village is divided into two parts, the older southern and a smaller younger northern part, which includes Chutghust. The northern part was first settled by in-migrants under Mir Silum Khan's rule (1790–1824). Under his reign, this land was allocated to the new migrants and brought into irrigated cultivation through the construction of a new channel that sourced its waters from the Ghulkin Glacier (Beg 1962)[6]. Ghulkin (2.5 km²) is spread across several fluvial terraces, which are separated by steep slopes covered with sea-buckthorn and poplar trees, and which cover up to 70 % of the village area. Compared to Passu, orchards are less prominent (3 %), and 25 % of the irrigated area are used as crop fields.

Different to Passu, but similar to Borith, Ghulkin village sources its water from supra-glacial runoff crossing the lateral moraines of Ghulkin and Gulmit. This source is supplemented by summer spring water from Rawd Yupk. As with the other villages, water availability is sensitive to glacier down-wasting, and the community has had to face shortages since the 1940s. Access to water has been compounded by contestations over use rights between the original inhabitants and the relatively new in-migrants[7].

Up until the first half of the last century, supra-glacial melt-water crossing the lateral moraine fed three adjacent lakes. This water, sourced from the Ghulkin Glacier, was diverted into a 1.5 km main channel to the village. With the glacier down-wasting in the 1940s water supply decreased and the three lakes began to dry out. In order to secure the irrigation system, the intake was shifted from Ghulkin to a supraglacial lake on the Gulmit Glacier. This project was supervised by Mir Mohammad Jamal Khan (1945–1974) who also had to preside over a 20-year negotiation over use-rights between the earlier and later settlers. Despite the project, water shortages became more acute as population numbers increased and discharge decreased.

To ensure an equitable supply of this limited resource, a water management committee was constituted to schedule a new distribution arrangement - called *nobat* (turn/rotation). However, the upstream residents (southern Ghulkin) often ignore the rotational schedule based on their perceived ownership of water as the original settlers. As a consequence, the downstream inhabitants (northern Ghulkin) not only lost their water source from Ghulkin Glacier but also became dependent on the upstream villagers for access to water.

[6] During Mir Silum Khan's regime Upper Borith belonged to Ghulkin village.

[7] In different phases, Ghulkin was settled by people from Yasin, Central Hunza and other areas, mostly supported by the Mir. These people are still considered non-local.

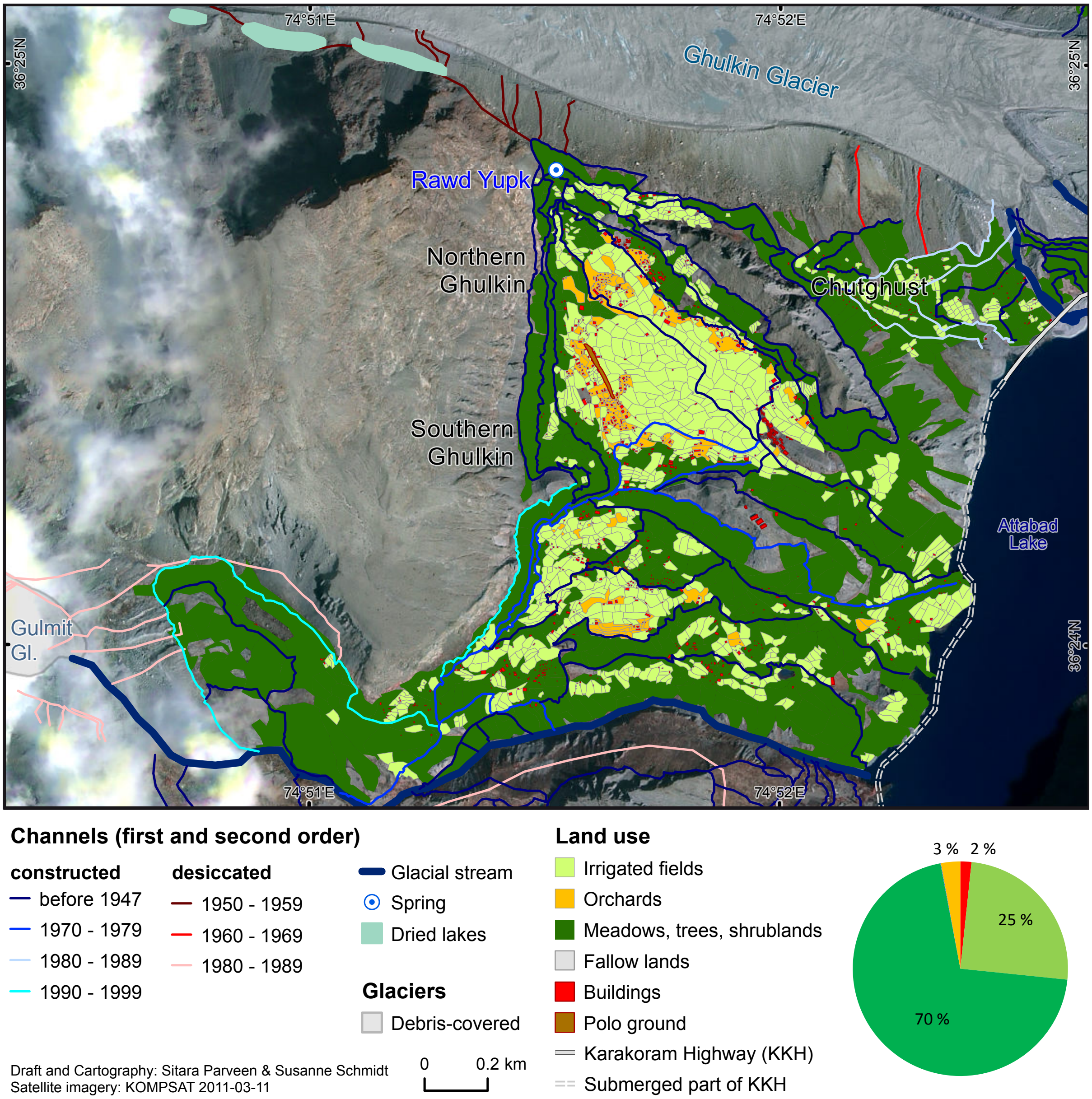

Fig. 5: Irrigation and land use in Ghulkin village

The third part of the village called Chutghust is located in close proximity to the Ghulkin Glacier snout. Here water supply has been affected by glacier fluctuations and periodic GLOF-events since the 1960s. Until then, two channels diverted melt-water to the fields, but these desiccated because of glacier-down-wasting (Fig. 5). Local respondents reported that, at that time, crop fields were suspended above the new water source, and became underutilized. However, in the 1980s the retreat of the glacier terminus enabled the usage of the main glacio-fluvial stream to irrigate these fields. The villagers constructed new irrigation channels and different crops were cultivated until 2008. In that year a glacier surge caused several GLOFs which overflowed the terminal moraine and destroyed their fields and irrigation networks. Since then, the glacier has retreated, and the glacio-fluvial stream has again become the sole water source for Chutghust. Owing to their vulnerability to varying water availability, many farmers have turned their crop fields to more drought tolerant sea-buckthorn and poplar trees.

5 Discussion and conclusions

The study illustrates the diversity of socio-hydrological interactions in Upper Hunza over the past three centuries. One underlying commonality of all villages is the dominance of glacial fluctuations and glacio-fluvial hazards in shaping local adaptation and land use practices. With low and variable amounts of precipitation in the settlement zone, melt water becomes the prerequisite for human habitation. However, variations in the supply of water from glaciers and snowfields as well as the labour and capital intensive nature of irrigation network maintenance, are major constraints in the three presented villages of Upper Hunza. Great effort is expended to ensure water inflow to the channels and eventually to the irrigated fields. These exertions range from daily excavation works to align intakes and channels, to complete restructuring of the irrigation system. In this context, fast and slow processes of different frequencies and magnitudes, such as retreat of the glacial tongue, lowering of the ice surface, and episodic events of surges and GLOFs call for a constant effort to secure irrigation water supply.

Both, the topographical position of the channels and the location of the settlements expose the irrigation system to varying degrees of risk. After glacio-hydrological events, experienced as natural disasters, limited local capacity results in considerable time lags before irrigation systems can be re-established. Such limitations in socio-hydrological systems are characteristic for most of the upper Indus Basin. However, some site-specific peculiarities temper the impact of these events, for example the location of Upper Hunza within the economic corridor of the Karakoram Highway improves access to non-farm opportunities (labour and market) and provides easier access for external development actors (Kreutzmann 1991, 731f.; 2006, 352). The social and hydrological systems appear to be closely coupled, as a result of the sole reliance on glacier-fed irrigation and consequent vulnerability of mountain communities. This can be seen in changing social status of villages as a result of dessication of channels, increased emigration and social conflicts. However, these connections require closer examination.

The structure and vulnerability of the irrigation networks are partly determined by the location of channel intakes and irrigated areas. Cultivated fields fed by discharge from main glacio-fluvial streams are less prone to the impacts of glacier retreat, as water flow from the large valley glaciers is regular and sufficient to meet the agricultural demand. Where glacier tongues reach relatively low elevations, glacier and snowmelt coincides with the onset of the growing season.

However, sudden shifts of glacier snouts or glacio-fluvial streams interrupt the flow of water to intakes, whilst in some cases, as with the Ghulkin Glacier, advancing or surging glaciers as well as GLOFs destroy agricultural fields and infrastructure. Agricultural fields located on terraces above the glaciers are highly exposed to glacier fluctuations because melt water is diverted across the side-moraines. Even small down-wasting rates can severely hamper the functionality of irrigation systems, as exceedingly large gaps open up between glacier surfaces and channel intakes. Whether these problems can be managed strongly depends on the available workforce, and in some cases, on the support of external development actors. All three villages lack sufficient manpower to maintain the irrigation systems and agricultural fields, partly as a result of high rates of young emigrants from the area, leaving an elderly population behind; as in the pronounced case of Borith. As a consequence, many once productive fields have altered to fallows. In the case of Ghulkin village, changes in the irrigation system owing to glacial down-wasting reignited historical disputes between two neighbouring settlements, highlighting the importance for appropriate institutional regulations to manage the equitable distribution of a scarce resource.

Over the past centuries all communities of Upper Hunza have been subject to substantial external development interventions. Under the rule of the Mirs, arable land was secured and developed, often by coercive means. After 1974 the Government of Pakistan and since the 1980s the AKRSP as well as other NGOs initiated new projects, including the relocation of water intakes and of piped irrigations systems. The information derived from this study may be useful for initiating future interventions that seek to improve irrigation systems in this high mountain area. On the other hand, the historical record of relocated irrigation intakes and channels can be taken as proxy indicators for glacial dynamics. Lessons can also be learned regarding the adaptation capacities of high mountain communities in coping with the adverse outcomes of climate change.

Acknowledgements

This research was generously funded by Schlumberger Foundation under the Faculty for the Future Program. The authors thank the two anonymous reviewers for helpful comments and suggestions. We would like to express our gratitude to the interview partners in Hunza for their most valuable information and comments during the compilation of this paper. We would like to thank the European Space Agency (ESA) for providing satellite images. Paul Roden (Heidelberg) helped with proof-reading the final manuscript.

References

AKRSP (AGA KHAN RURAL SUPPORT PROGRAMME) (1985): Agroecosystem analysis and development for the Northern Areas of Pakistan. Gilgit.

– (1987): Fifth annual review 1987: Incorporating the twentieth progress report. Gilgit.

Becher, M. J. (1859): Letter addressed to R. H. David Esquire, Secretary to the Government of the Punjab and its Dependencies. In: Asiatic Society of Bengal 28, 219–228.

Beg, Q. (1962): History of ancient era Hunza state. Part 1. Engl. ed. 2006, translation by Saadullah Beg. Baltit.

BGIG (BATURA GLACIER INVESTIGATION GROUP) (1979): The Batura Glacier in the Karakoram Mountains and its variations. In: Scientia Sinica 22 (8), 958–974.

Clark, J. (1956): Hunza: lost kingdom of the Himalayas. New York.

Dame, J. and Mankelow, J. S. (2010): Stongde revisited: land-use change in Central Zangskar. In: Erdkunde 64 (4), 355–370. DOI: 10.3112/erdkunde.2010.04.05

Drew, F. (1875): The Jammoo and Kashmir territories. London.

Eberhardt, E.; Dickoré, B. and Miehe, G. (2007): Vegetation Map of the Batura Valley (Hunza Karakorum, North Pakistan). In: Erdkunde 61 (1), 93–112. DOI: 10.3112/erdkunde.2007.01.06

Finsterwalder, R. (1996): Accompanying text for the "Hunza-Karakorum 1:100000" Map. In: Erdkunde 50 (3), 169–172. DOI: 10.3112/erdkunde.1996.03.01

Forsythe, N.; Kilsby, C. G.; Fowler, H. J. and Archer, D. R. (2012): Assessment of runoff sensitivity in the Upper Indus Basin to interannual climate variability and potential change using MODIS satellite data products. In: Mountain Research and Development 32 (1), 16–29. DOI: 10.1659/MRD-JOURNAL-D-11-00027.1

Gardelle, J.; Berthier, E. and Arnaud, Y. (2012): Slight mass gain of Karakoram glaciers in the early twenty-first century. In: Nature Geoscience 5 (5), 322–325. DOI: 10.1038/ngeo1450

George, K. and Stratford, E. (2005): Oral history and human geography. In: Hay, I. (ed.): Qualitative research methods in Human Geography. South Melbourne, 139–151.

Goudie, A. S.; Brunsden, D.; Collins, D. N.; Derbyshire, E.; Ferguson, R. I.; Hashmet, Z.; Jones, D. K. C.; Perrott, F. A.; Said, M.; Waters, R. S. and Whalley, W. B. (1984a): The geomorphology of the Hunza Valley, Karakoram Mountains, Pakistan. In: Miller, K. J. (ed.): The International Karakoram Project Vol. 2. Cambridge, 359–410.

Goudie, A. S.; Jones, D. K. and Brunsden, D. (1984b): Recent fluctuations in some glaciers of the Western Karakoram mountains, Hunza, Pakistan. In: Miller, K. J. (ed.): The Internatinoal Karakorum Project Vol. 2. Cambridge, 411–455.

Hewitt, K. (1982): Natural dams and outburst floods of the Karakoram Himalaya: hydrological aspects of alpine high mountain areas. In: IAHS-Publ. 138, 259–269.

– (2005): The Karakoram anomaly? Glacier expansion and the 'elevation effect', Karakoram Himalaya. In: Mountain Research and Development 25 (4), 332–340. DOI: 10.2307/3674440

– (2010): Gifts and perils of landslides – Catastrophic rockslides and related landscape developments are an integral part of human settlement along upper Indus streams. In: American Scientist 10, 410–419. DOI: 10.1511/2010.86.410

– (2014): Glaciers of the Karakoram Himalaya: glacial environments, processes, hazards and resources. Dordrecht.

Immerzeel, W. W.; Droogers, P.; de Jong, S. M. and Bierkens, M. F. P. (2009): Large-scale monitoring of snow cover and runoff simulation in Himalayan river basins using remote sensing. In: Remote Sensing of Environment 113, 40–49. DOI: 10.1016/j.rse.2008.08.010

Immerzeel, W. W.; van Beek, L. P. and Bierkens, M. F. (2010): Climate change will affect the Asian water towers. In: Science 328, 1382–1385. DOI: 10.1126/science.1183188

Iturrizaga, L. (2005): New observations on present and prehistorical glacier-dammed lakes in the Shimshal valley (Karakoram Mountains). In: Journal of Asian Earth Sciences 25, 545–555. DOI: 10.1016/j.jseaes.2004.04.011

Kääb, A.; Berthier, E.; Nuth, C.; Gardelle, J. and Arnaud, Y. (2012): Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas. In: Nature 488 (7412), 495–498. DOI: 10.1038/nature11324

Kaser, G.; Grosshauser, M. and Marzeion, B. (2010): Contribution potential of glaciers to water availability in different climate regimes. In: PNAS 107 (47), 20223–20227. DOI: 10.1073/pnas.1008162107

Khan, H. W. and Hunzai, I. A. (2000): Bridging institutional gaps in the irrigation management. The post- "Ibexhorn" innovations in Northern Pakistan. In: Kreutzmann, H. (ed.): Sharing water. Irrigation and water management in the Hindukush – Karakoram – Himalaya. Karachi, 132–145.

Kreutzmann, H. (1989): Hunza – Ländliche Entwicklung im Karakorum. Abhandlungen – Anthropogeographie 44. Berlin.

– (1991): The Karakoram Highway: The impact of road construction on mountain societies. In: Modern Asian Studies 25 (4), 711–736.

– (1994): Habitat conditions and settlement processes in the Hindukush-Karakoram. In: Petermanns Geographische Mitteilungen 138 (6), 337–356.

– (1998): From water towers of mankind to livelihood strategies of mountain dwellers: approaches and perspectives for high mountain research. In: Erdkunde 52 (3), 185–200. DOI: 10.3112/erdkunde.1998.03.01

– (2000): Water towers of human kind: approaches and perspectives for research on hydraulic resources in the mountains of South and Central Asia. In: Kretuzmann, H. (ed.): Sharing water. Irrigation and water management in the Hindukush – Karakoram – Himalaya. Karachi, 13–31.

– (2006): High mountain agriculture and its transformation in a changing socio-economic environment. In: Kreutzmann, H. (ed.): Karakoram in transition: culture, development and ecology in the Hunza Valley. Oxford, 329–358.

– (2011): Scarcity within opulence: water management in the Karakoram Mountains revisited. In: Journal of Mountain Science 8 (4), 525–534. DOI: 10.1007/s11629-011-2213-5

– (2012): After the flood. Mobility as an adaptation strategy in high mountain oases. The case of Pasu in Gojal, Hunza Valley, Karakoram. In: Die Erde 143 (1–2), 49–73.

Labbal, V. (2000): Traditional oases of Ladakh: a case study of equity in water management. In: Kreutzmann, H. (ed.): Sharing water: irrigation and water management in the Hindukush – Karakorum – Himalaya. Karachi, 161–183.

Mason, K. (1930): The glaciers of the Karakoram and neighbourhood. In: Records of the Geological Survey of India 63 (2), 214–278.

Nüsser, M. (2000): Change and persistence: contemporary landscape transformation in the Nanga Parbat Area, northern Pakistan. In: Mountain Research and Development 20 (4), 348–355. DOI: 10.2307/3674056

– (2001): Understanding cultural landscape transformation: a re-photographic survey in Chitral, eastern Hindukush, Pakistan. In: Landscape and Urban Planning 57 (3–4), 241–255. DOI: 10.1016/S0169-2046(01)00207-9

Nüsser, M.; Schmidt, S. and Dame, J. (2012): Irrigation and development in the upper Indus Basin: characteristics and recent changes of a socio-hydrological system in Central Ladakh, India. In: Mountain Research and Development 32 (1), 51–61. DOI: 10.1659/MRD-JOURNAL-D-11-00091.1

Paffen, K. H.; Pillewizer, W. and Schneider, H.-J. (1956): Forschungen im Hunza-Karakorum. In: Erdkunde 10 (1), 1–33. DOI: 10.3112/erdkunde.1956.01.01

Rankl, M.; Kienholz, C. and Braun, M. (2014): Glacier changes in the Karakoram region mapped by multimission satellite imagery. In: The Cryosphere 8 (3), 977–989. DOI: 10.5194/tc-8-977-2014

Scherler, D.; Bookhagen, B. and Strecker, M. R. (2011): Spatially variable response of Himalayan glaciers to climate change affected by debris cover. In: Nature Geoscience 4 (3), 156–159. DOI: 10.1038/ngeo1068

Schmidt, M. (2004): Interdependencies and reciprocity of private and common property resources in the central Karakorum. In: Erdkunde 58 (4), 319–330. DOI: 10.3112/erdkunde.2004.04.03

Schmidt, S. and Nüsser, M. (2009): Fluctuations of Raikot glacier during the last 70 years: a case study from the Nanga Parbat Massif, northern Pakistan. In: Journal of Glaciology 55 (194), 949–959. DOI: 10.3189/002214309790794878

– (2012): Changes of high altitude glaciers from 1969 to 2010 in the Trans-Himalayan Kang Yatze Massif, Ladakh, northwest India. In: Arctic, Antarctic, and Alpine Research 44 (1), 107–121. DOI: 10.1657/1938-4246-44.1.107

Sidky, H. (1997): Irrigation and the rise of the State in Hunza: a case for the hydraulic hypothesis. In: Modern Asian Studies 31 (4), 995–1017. DOI: 10.1017/S0026749X00017236

Staley, J. (1969): Economy and society in the high mountains of Northern Pakistan. In: Modern Asian Studies 3 (3), 252–243. DOI: 10.1017/S0026749X00002341

Visser, P. C. (1928): Von den Gletschern am obersten Indus. In: Zeitschrift für Gletscherkunde und Glazialgeologie 16, 169–229.

Visser, P. C. and Visser-Hooft, J. (1935): Geographie. In: Visser, P. C. (ed.): Wissenschaftliche Ergebnisse der Niederländischen Expedition in den Karakorum und die angrenzenden Gebiete in den Jahren 1922, 1925 und 1929/30. Leipzig, 5–120.

Viviroli, D. and Weingartner, R. (2008): "Water towers" – a global view of the hydrological importance of mountains. In: Wiegandt, E. (ed.): Mountains: sources of water, sources of knowledge. Dordrecht, 15–20.

Viviroli, D.; Weingartner, R. and Messerli, B. (2003): Assessing the hydrological significance of the world's mountains. In: Mountain Research and Development 23 (1), 32–40. DOI: 10.1659/0276-4741(2003)023[0032:ATHSOT]2.0.CO;2

Weiers, S. (1995): Zur Klimatologie des NW-Karakorum und angrenzender Gebiete. Bonner Geogr. Abh. 92. Bonn.

Winiger, M.; Gumpert, M. and Yamout, H. (2005): Karakorum – Hindukush – western Himalaya: assessing high-altitude water resources. In: Hydrological Processes 19 (12), 2329–2338. DOI: 10.1002/hyp.5887

Xiangsong, Z. (1984): Recent variations of some glaciers in the Karakoram mountains. In: Miller, K. J. (ed.): The International Karakoram Project Vol. 1. Cambridge, 39–50.

Yafeng, S. and Xiangsong, Z. (1984): Some studies of the Batura Glacier in the Karakoram Mountains. In: Miller, K. J. (ed.): The international Karakoram Project Vol. 1. Cambridge, 51–63.

Authors

Sitara Parveen
Prof. Dr. Matthias Winiger
Department of Geography
University of Bonn
Meckenheimer Allee 166
53115 Bonn
Germany
parveen@uni-bonn.de
winiger@uni-bonn.de

Dr. Susanne Schmidt
Prof. Dr. Marcus Nüsser
South Asia Institute
Universität Heidelberg
Im Neuenheimer Feld 330
69120 Heidelberg
Germany
s.schmidt@sai.uni-heidelberg.de
marcus.nuesser@uni-heidelberg.de