Dynamics and Changes the dominant driving factors?

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Abstract

The Indus-River-Basin, with its High Mountain Basin of Hindukush-Karakoram-Himalaya as its dominant runoff-input system, and the semi-arid to arid lowlands, as mainly agricultural, urbanized, industrialized regions, are in a complex, and extremely sensitive and vulnerable way interlinked. In addition: Water scarcity versus an extremely growing population and its basic need for water is a frightening perspective, as it leads to further marginalization and vulnerability of millions of habitants. Therefore, the scientific assessment and validation of environmental status and dynamics requires the understanding of global, regional and local processes, to prevent in many cases wrong or simplified statements and actions. Related research has therefore to include long-term environmental, social, economic and cultural determining aspects, also to provide sound recommendations for any kind of practical measures. Central issues related to the Indus River Basin are outlined, based on multidisciplinary local and regional case studies, covering environmental and socio-economic key factors, and documented by numerous research papers. Selected cases from the UIB illustrate the statements. Concluding recommendations summarize research priorities, the need to include and strengthen regional research institutions, mainly universities interlinked within the 'Himalayan University Consortium' (HUC), and the coordinated programs of ICIMOD. Besides worldwide developed and applied process models, local ground-based status and process-oriented investigations, as well as long-term monitoring is a necessity. And a great chance for regional Universities and Research Institutions.

Keywords: Hindukush-Karakoram-Himalaya (HKH): Climate variations, water scarcity, growing population

1. Introduction

Recent unusual heat waves, long dry periods, interrupted by heavy rain spells, followed by large area inundations and regional or local flash-floods – all these environmental events lead to the loss of human lives, and millions of homeless people and create enormous disasters for the socio-economic situation, such as individual housing, agricultural production, traffic infrastructure, etc. – all this in different regions and localities of Pakistan and the Upper Indus Basin. These

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extreme events and damages led to internal political reactions and measures and gained high international attendance. The challenge will be, to gain public awareness of its fundamental messages, and to support immediate and long-term actions.

Climate change, extreme weather conditions, human impacts, and related consequences are doubtless global and regional challenges. However, environmental disasters have to be analyzed and interpreted in a scientific open way, as shown in the following example. Not quite unexpectedly, on May 7th, 2022, the Karakoram-Highway-Bridge across the Hassanabad Valley together with several houses and two power plants was destroyed by the outbreak of a Glacier Lake of Shispar Glacier in Upper Hunza. The Karakoram Highway (KKH) became impassable for buses and trucks for months, a severe impact on its fundamental function in the CPEC-Corridor. The glacier lake outbreak was foreseeable, as Shispar Glacier advanced in the past 2-3 years in several rapid steps, blocking the runoff of neighbouring Muchuhar Glacier. Several minor outbreaks already happened months before. In the media, the disaster was broadly discussed and, in most cases, linked to human-induced climate change. Eventually, the heat waves might have initiated the moment of the outbreak. Nevertheless, the Hassanabad Glacier, with the Shispare and Muchuhar tributaries are very basic examples of surging glaciers. Besides high-altitude snow and ice balance, topography is another key factor for the glacier's mass balance and -movement.

Reliable, in part photographically documented observations since 1889 prove several not primarily climate-linked rapid advances and retreats. The fastest and longest surge of the glacier tongue by roughly 9.3 km happened in 1892/93, and in 1906 (carefully documented in 1907 by Hayden), it reached a position near the destroyed KKH bridge. A summarizing overview of the documented positions is provided and in detail commented on by Bhambri et al. (2020).

Explanations for these extreme events and conditions are required, to react adequately, and to minimize the impacts of comparable future events. But given the environmental reasons for these events, it is just too simple, to primarily focus on 'man-made climate change', as many of the media comments are referring. No question, that climate is the most basic factor for the glacio-hydrologic and ecologic characteristics, especially of vertical and expositional differentiations and dynamics of mountain landscapes. However, socio-economic factors create and, in many cases, highly increase the vulnerability of communities and infrastructure. Pakistan's national and regional differentiated scales - the enormous growth of population by a factor of 7 in the past 75 years, and a forecasted doubling in the

coming 25 years. All this will lead to fundamental changes in land-use patterns, massive urbanization procedures, extension and densification of traffic networks, a dramatic decrease of water availability per head and its quality, etc. These processes are also linked to worldwide similar developments. However, their characteristics and consequences are rather specific in the Indus-Basin landscapes, mainly due to the very limited extension potential of fundamental resources, such as water, and arable land, as well as very specific highland-lowland-linkages. As one of the consequences, marginalization and occupation of environmental high-risk areas increase vulnerability and disaster impacts to a dramatic degree. Of course, climate changes and weather conditions are additional superimposing, regionally strongly steering factors and processes, as the actual extreme events prove.

Focused research is one of the basic fundaments for understanding the man-environment systems and their specific components, all depending on time and scales. The outcomes of research activities over more than a century resulted in thousands of publications, covering specific or integrated aspects of environmental, societal, economic, and cultural issues on local, regional and basin-wide scales. To hold a continuous and integrated overview of these research outcomes is a real challenge. The more, it should be appreciated, that several wide-focussed and integrating publications are available. Three thematically representative examples are mentioned. Kenneth Hewitt's "Glaciers of the Karakoram Himalaya", broadly covers 'Glacial Environments, Processes, Hazards and Resources' (Hewitt, 2014). Hermann Kreutzmann's "Hunza Matters – Bordering and Ordering between Ancient and New Silk Roads", summarizes the very complex local to regional socio-cultural facts from pre-colonial to present times, including the perspective of the actual most determining implementation of the China-Pakistan Economic Corridor (CPEC). And as a thematic and spatially very broad summary of the whole Hindu Kush Himalaya (HKH)-Area, "The Hindu Kush Himalaya Assessment - Mountains, Climate Change, Sustainability and People", edited by Wester et al. (2019), provides a focus on the integrating visions and access to widespread information by ICIMOD.

Originally mainly based on field research, for some decades the inclusion of remotely sensed data sets and model approaches, led to comparable information on climate, snow and glacier dynamics, vegetation and land use patterns, urbanization, traffic systems, etc. However, to fully understand the time-dependant system dynamics, the inclusion of many-fold environmental, as well as socio-cultural proxy data and -information is required. In this respect, field-based research in all environmental and society-linked issues is more needed, as

practiced. The systematic combination of modeling remotely sensed data analysis, and detailed photo-monitoring of landscape dynamics, completed with multidisciplinary fieldwork, is a basic must. It has to be systematically coordinated in the frame of regional, national and international research programs, partially standardized, and partially adapted to locally specific situations. It's a chance for international cooperation, explicitly also in the frame of the 'Himalayan University Consortium' (HUC).

2. Basic Issues related to the Indus River Basin

There are several basic facts and questions related to the environmental and socio-economic spatial and temporal differentiation of the HKH highland/lowland system, and more specifically, to the Indus River Basin. Focussing on the long-term hydro-climatic aspects, the fundamental differentiation has to be understood between the dominant input of water from the high mountains, and its irrigation-related input to the semi-arid to arid lowlands, where the majority of Pakistan's population is settled. This characteristic Indus-related input/output system approach is shown in Fig. 1. Simplified, three main questions are underlined: (a) Input of partially sediment-loaded water to the Indus, mainly from the highlands, partially controlled and seasonally modified by a sequence of high dams, is set as 100%, (b) Use and management of water, dominantly in the agricultural and

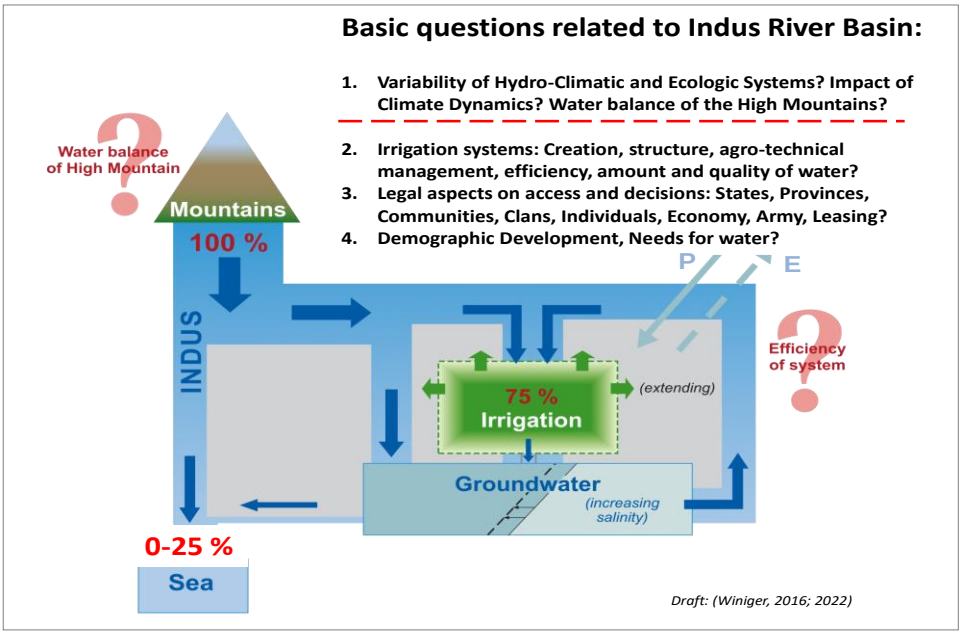

Figure 1. Basic Questions related to the Water Balance of the Indus River Basin *(Winiger, 2020, slightly adapted).*

urbanized lowland-areas, resulting in a continuous reduction of the outflow to the sea (rapid annual increase of seasonal zero-flow), heavily affecting the surface and groundwater status and quality, and (c) how will these topical complexes be affected by fundamental climate changes?

The challenge to fully understand the interlinked complexity of these water-related systems and sub-systems, their climate-induced changes and their future-oriented management, asks for coordinated science and public management programs. Its urgency is underlined by the fact that related to the rapid growth of the population, increasing water scarcity is unavoidable (Fig. 2). And this will lead to further marginalization and related vulnerability of a high percentage of the population. These facts have been rather well known for decades (Briscoe and Qamar, 2006), but have of course to be restudied, under the inclusion of changing steering factors (e.g., climate change, socio-economic and political conditions and dynamics).

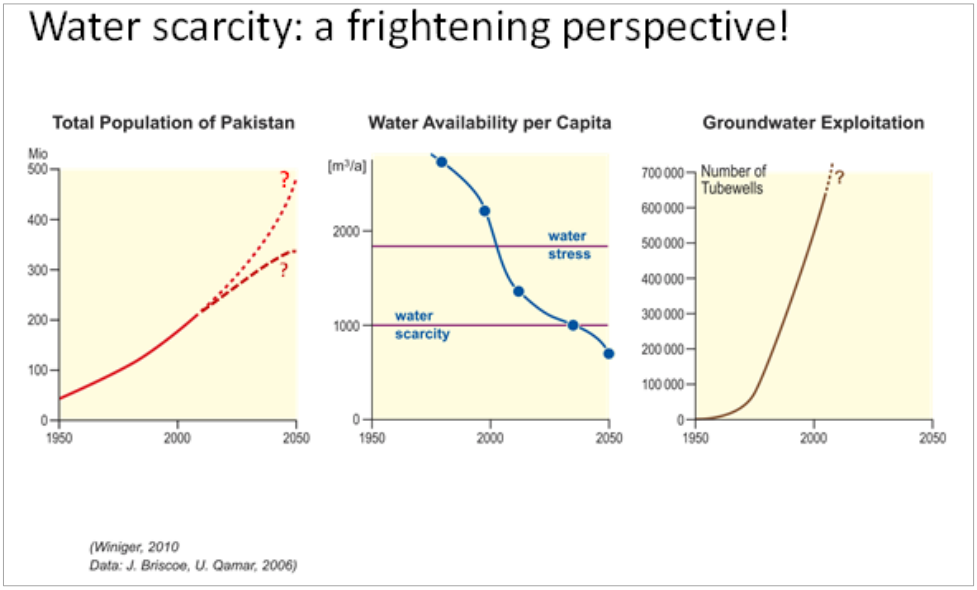

Figure 2. Assumed population growth and water availability in Pakistan 1950-2050 *(Briscoe and Qamar, 2006); Draft adapted: Winiger 2010.*

3. Scientific Approaches: Models, Remote Sensing, Field Evidence, Scales

The determination of hydro-dynamic input of rainfall, snow as well as ice-melt in the high mountains, contributing to the runoff and final outlet of the Indus River to the lowlands is complex and differs in many aspects from the methodological standards applied in flat areas. Combined methodological approaches are a

necessity, to eliminate fundamental differences in vertical precipitation input-gradients, as different research results document (Fig. 3).

Measurement of meteorological variables, e.g., air temperature and liquid rainfall usually follow the defined WMO standards and enable spatial and temporal comparison. The few meteorological stations in the UIB, measuring over several decades, are all located in the arid valleys (e.g., Gilgit, Chitral, Skardu), where meanwhile urbanization and a drastic increase of dusty air pollution have a significant impact on local climate and reduce comparability to neighboring valley bottom sections, as well as to larger scale climate changes.

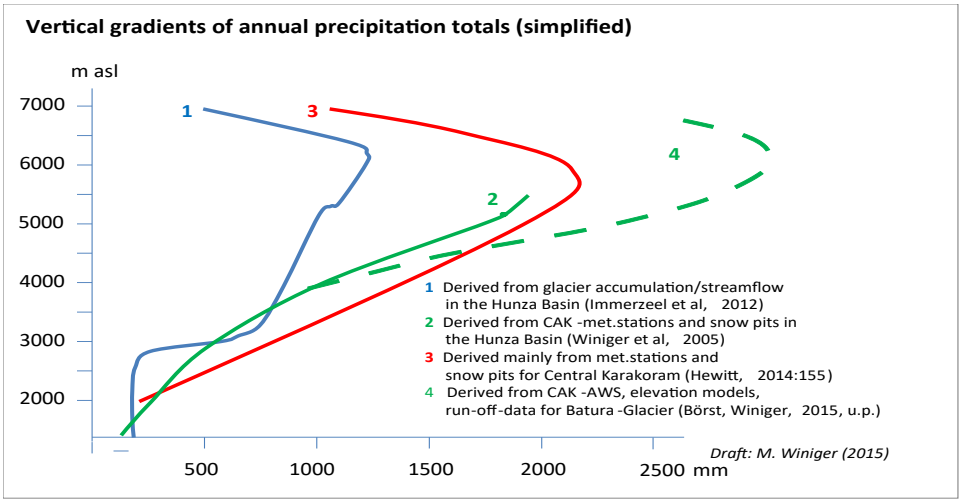

Figure 3. Vertical gradients of annual rainfall totals for selected glacier sub-areas of the Upper Hunza River Basin, based on different approaches and temporal references. *(Winiger, 2018; further authors and some unpublished reports are indicated in the graph*).

At high altitudes and in topographically complex terrain, the WMO rules cannot always be followed comparably. As an example: snowfall amount and its liquid transformation is at some stations measured by snow pillows (weight of snow package), or by ultrasonic sensors (deriving snow depth). In addition, windblown accumulation or reduction – both not directly related to snowfall, have to be taken into account. Avalanches and strong exposition-dependent wind-drift effects lead to distinct regional and altitudinal variations. Meanwhile, WAPDA and PMD started to establish to some extent comparable networks in the altitudinal range of 3000-4750 msl. These stations are needed to verify and improve the quality of status- and process-oriented model approaches.

Like in other mountain regions around the globe, the inclusion of proxy-data analysis is a necessity, to evaluate environmental processes and long-term

variations on a local, regional to continental scale, meanwhile also with annual and seasonal solutions of relevant climatic aspects or geomorphologic processes (Fig. 4).

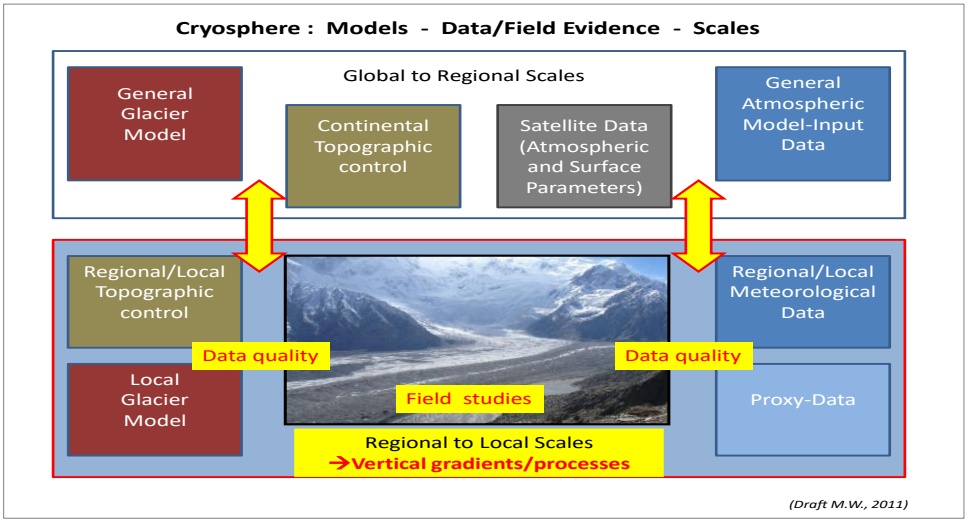

Figure 4. Assessing the cryosphere: Models, Data & Field Evidence, from Global to Regional Scales *(Winiger, 2018; draft based on the unpublished report,2011).*

The analysis of sediments, soil profiles, pollen and dendro-chronologic proxies has reached a high standard, and improved the setting of long-term time series, covering centuries to several millennia. As an example, the dendro-chronologic- and isotope analysis of a great number of Pinus tree-ring samples, collected in different valleys of the Karakoram indicated, that the 'hockey-stick-trend' of air temperature has to be modified (Esper et al., 2015) and that an average increase of rain and snowfall is highest in the Karakoram for the last 1000 years, due to the growing impact of westerly atmospheric circulation patterns in the cold season (Büntgen et al., 2005). And again, these multi- and interdisciplinary analytical approaches have to be further coordinated and extended in a time- and space-overarching way.

4. Socio-economic drivers and changes, increasing marginalization and risks

In the HKH-mountain regions, land use, communication, cultural characteristics and political processes were for centuries highly determined also by the local and regional landscape characteristics – where and how could living conditions be established, long-term secured, to some extent linked to neighboring communities or controlled by external rulers. Colonial times also had modified impacts, also on

the mountain areas. A very broad view on a multitude of aspects of change dynamics was one of the fundamental outcomes of the Pakistan-German Research Project “Culture Area Karakorum” (Stellrecht, 2003).

In most cases, and dominantly valid until some 50 years ago, and in remote areas still a fact, the rural societies developed agriculture-based self-sufficiency land-use systems. They were, and still are, highly adapted to the topographic, above all vertical and exposition-differentiated landscapes. Seasonal agricultural production, animal herding, labor sharing, etc., had (and have) to ensure long-term and temporal varying conditions. Villages and intensively used farmland and gardens, were in most cases located on terraces positioned not in the valley grounds, but on the valley slopes or debris cones (in many cases postglacial relicts). Establishing and maintaining channel systems to secure irrigation, mainly for agricultural production, was (and is) in most cases a fundamental requirement. It was linked to sometimes outstanding and still nowadays most impressive construction efforts. Their annual and long-term maintenance had society-forming effects: who has to provide labor, what amount of water will be distributed, etc. Irrigation channels, fed by glacier melt-water across side moraines, are of course strongly dependent on climate-dependent glacier dynamics. This leads in the extreme case to partial or complete giving-up of localities in Upper-Hunza (Parveen et al., 2015).

Forests provide wood for construction and energy and have also been used for extensive grazing in spring and autumn. Grass- and bush-covered areas, mostly above the timberline or along glaciers (e.g., Batura Glacier) were used for herding goats, sheep, cows and yaks, sometimes around seasonal settlements also for plantation of selected crops – and again: depending on the regional and the historic cultural links of the population. Several regionally differentiated case studies are available and outline these extremely differentiated and adapted high-mountain societies and their land-use approaches (Ehlers, 2000).

A rather critical development was (in part still is) the large-scale deforestation of mountain forests for commercial purposes, which led to a partial or complete clearance of valley slopes. In many cases, consequences have been disastrous, as avalanches, landslides and rock falls became very distinct hazards for settlements and connecting routes in many valleys of HKH. Efforts to manage timber export to the lowlands or out of the country in a sustainable way were, and still are, under legal and practiced competencies a challenge. In addition, reforestation is in many cases ecologically not adapted and creates further problems, such as enhanced risks of forest fires or reduced insect resistance of forest monocultures.

However, and almost trivial to mention, the most effective driver of changes is – as in most parts of the world - the increasing interlinking of steering factors of socio-economic structures, worldwide communication and values. Internationally adopted formal education, interlinked economy, mobility, etc., lead worldwide to socio-economic changes, with impacts on traditional practices of regionally diverse land use systems, social structures and their management. Traditional, family and community-based land-use processes cannot be maintained, as a significant number of family members leave their home places in the context of educational or income-linked purposes. In many cases, new private and public buildings are also set to rather risk-exposed locations, mainly on low-level river banks or debris-fans. A small-scale example is shown in Fig. 5

Figure 5. Modern buildings on the outlet fan of a small side valley (upward Dassu), were flooded and partially destroyed by high floods of the Indus River and the stream from the side valley *(Photo: M. Winiger, 29.5.2016).*

Extensive urbanization is one of the results of the abovementioned processes. Large settlements provide to some extent nationally and internationally competitive living conditions (housing, infrastructure, schools, health services, etc.). All this needs space, which in mountain regions is rather limited or only available on stream terraces or large debris fans. As an example, the extension of Gilgit/Jutial is shown in Fig. 6a/b. The large debris fan was initially linked to the postglacial retreat of valley-filling glaciers. But it is still nowadays exposed to and fed by destructive floods and debris flows from the Jutial Nallah. Dams and terraces, constructed after a big flood in 2004, protect to some extent nearby

houses, but the risk of large destruction further exists. The same is true for houses and roads on low-level banks along the Gilgit and Hunza Rivers, and further down along the Indus River.

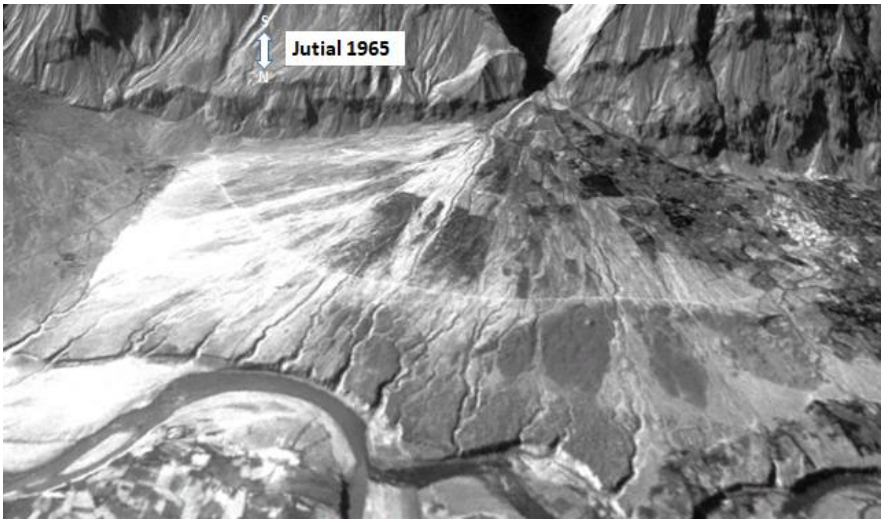

Figure 6a. Gilgit-Jutial on October 8th, 1965: Occasional floods and debris flow from Jutial-Nallah are rather erosive and/or leave deposits *(Source: Corona-satellite, south-oriented view).*

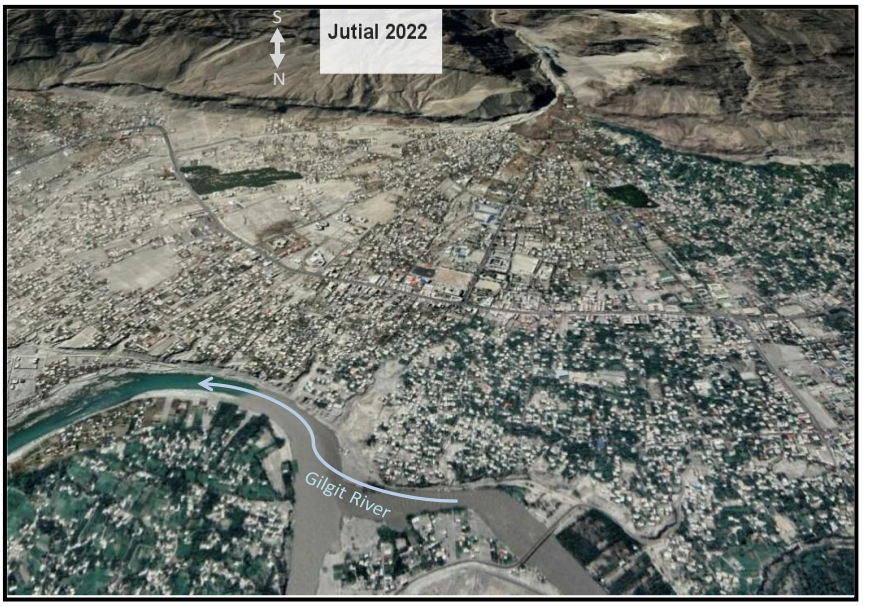

Figure 6b. Gilgit-Jutial in 2021/22: Rapid urbanizing processes on the debris-fan, (Jutial Nallah: top right of centre) and along the riverbanks of Gilgit River *(Source: Google Earth; south-oriented view)*.

In other words: the rapid extension of towns and urbanized infrastructure in the high mountains of HKH result in distinctly increasing environmental risks – and this is in part unpredictable because of changing climate and weather patterns, and their interlinked processes. Establishing and applying differentiated risk maps, are both a scientific and application-oriented need and challenge. As for other areas, also for Gilgit, an overall environmental assessment and Master Plan have been worked out and published (Annandale & Bailly, 2014). Of course, it has to be adapted, following fundamental changes – and equally important: it has to be implemented in a consequent way.

5. Conclusions: Challenges and Chances for the Upper Indus Basin Network (UIBN) and the Himalayan University Consortium (HUC)

In the HKH mountain region are climate dynamics and changes the dominant driving factors related to the fundamental and regionally diverse processes of land-use and livelihood transition? The answer to this question, outlined in the title of this discussion paper, should be clear: climate modifications are a fact, extreme events (extended droughts, intensive rainfall) result in hydrologic modifications,

with impacts on livelihood patterns in the highlands and even more pronounced in the lowland basins. Rapidly increasing population, fundamental socio-economic changes, urbanization, and mobility reduce socio-spatial flexibility and increase marginalization and vulnerability.

The actual setting-up of a gigantesque water management infrastructure related to the construction of large dams in the UIB creates new chances, but at the same time, new risks: the sequence of giant dams of Tarbela, Dassu, Diamer Basha, and further up Indus will completely change the natural run-off patterns, as well as the sediment transport and sedimentation. The KKH has to be rebuilt over great distances, numerous settlements in side valleys will lose their direct link to KKH, and the regional capital Chilas has to a great extent be shifted and rebuilt. Again, a big challenge, creating positive mid-term water-management potentials, mainly for the water storage for lower basins. But at the same time, and as important, the avoidance of complex environmental risks for the flooded Upper Indus has to be controlled, such as landslides, floods, earthquakes, lake sedimentation, destructed dam infrastructures, and loss of cultural landscapes (e.g., ten-thousands of ancient rock-carvings).

The focus is on the complexity of the UIB-water balance, its determining link to the lowland Indus system, the impact of extreme weather conditions, their link to global climate dynamics (induced naturally, or enforced by human activities), and

the in part catastrophic consequences lead to comparable conclusions: further deepen scientifically based understanding, long term visions, recommendations to urgently required action plans - and of course a consequent implementation and control by the society and governments.

Need for coordinated steps forward: A highly competent team of scientists formulated 100 basic questions, based on a broad range of existing research outcomes, and given setting knowledge priorities on climate change and water aspects in the UIB. They summarize and recommend specific research strategies and ways forward (Orr et al., 2022). These are also considered in this paper.

Also, on the occasion of several UIBN and HUC meetings at ICIMOD, concrete research approaches and steps forward have been discussed, based on the learning from existing programs. They included: (1) Preparative workshops; (2) Joint field visits; (3) Annual programs; and (4) Defined responsibilities for parts and overall programs.

Challenges and Chances for the 'Himalayan University Consortium' (HUC): Several Universities and Research Institutions, located predominantly in the HKH, in addition to some Universities from Europe, America and China, with long-term experiences in high-mountain research, are cooperating in the context of HUC. The inclusion and promotion of regional universities provide the chance to create sensibility for fundamental regional scientific challenges, secure local to regional long-term ground-based research, including careful documentation of actual processes (e.g., photo-monitoring), and must be linked to relevant international programs. Finally, all this creates ownership in the research policy, based on agreements that have to be achieved on several aspects:

1. Topics: Regional aspects of global relevance – in this case, mountain issues under high-/lowland perspectives. 2. Methodologies, following international standards. 3. Regional research clusters, internationally linked. 4. Focus on the HKH-mountain transects, defined by ICIMOD. 5. Development of coordinated curricula/field experiments and stations.

Considering all these aspects and proposals, basic questions have been and will further be formulated. Secured differentiated scientific outcomes are available and will further be developed. The absolute need for concrete actions is obvious, to secure sustainable development, to reduce and limit constraints and catastrophic events, and to prevent a rapidly increasing marginalization of the population. But unfortunately, it is already for a long time a partially neglected challenge. Regaining and securing Pakistan's future and stability will depend on action!

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