Geography of the Uppermost Indus River Basin in southwest Tibet

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Abstract

The Uppermost Indus River Basin (UIB) in the Ngari Prefecture of southwest Tibet is a region of exceptional geographical, geological, hydrological, and ecological importance. The Indus River originates near the Mount Kailash, and its two main tributaries, Sênggê Zangbo and Gar Tsangpo, merge near Tashigang before flowing northwest through Tibet, Ladakh, and into Pakistan. The UIB features high-altitude plateaus, extreme cold desert climates, and rugged terrain with minimal vegetation, supporting a sparse population that primarily relies on pastoralism and limited agriculture. The basin's geology is dominated by the Gangdese magmatic arc, shaped by subduction-related tectono-magmatic activity, resulting in diverse rock formations and significant faulting. Hydrologically, the Indus River depends on glacial meltwater, permafrost thaw, and seasonal precipitation, with climate change threatening its long-term sustainability. The region's ecosystem supports cold-climate-adapted wildlife, including Tibetan antelope, wild yaks, and migratory birds such as the black-necked crane. Despite its remote location, the UIB holds cultural and religious significance due to Mount Kailash and Lake Mansarovar. The fragile environment faces increasing challenges from global warming, potential hydropower development, and other human activities. Sustainable management and conservation efforts are essential to protect the region's water resources, biodiversity, and traditional ways of life.

Keywords: Uppermost Indus Basin, Mount Kailash, Lake Mansarovar, Gangdese magmatic arc, Glacial meltwater, Cold desert climate

1. Introduction

The Indus, known also as the Sengge Zangbo (or Lion River) in the Tibet autonomous region of China, is one of the major rivers in Asia. The length of some 3,180 km (23rd in the world), total basin area of around 1.12 million km^2 (12th

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largest in the world), and total annual flow estimated at approximately 173 billion cubic meters (BCM) (WWF, 2019), make it one of the 50 largest rivers in the world in terms of average annual flow (Wikipedia). It originates in the Mount Kailash (6,638 m above sea level)-Lake Mansarovar area of the Ngari Prefecture of Tibet (Fig. 1) and flows NW through Tibet and Ladakh region for about 800 km before entering Gilgit-Baltistan in Pakistan at Turluk in the Ghanche district. From there, it traverses the length of Pakistan through the Karakoram-Kohistan-Himalayan ranges (Fig. 2) and, south of Attock, the plains of Punjab and Sindh, eventually draining into the Indus canyon of the Arabian Sea, some 150 km southeast of Karachi (Inam et al., 2007). The UIB in southwest Tibet covers an area of about 451,000 km2.

Figure 1. (Left). Map of the Ngari Prefacture, western Tibet, with the location of the Mount Kailash (6638 m). and Rakshal Tall lake and Lake Mansarover to its south near Nepal and India borders (www.tibettravel.org). The sources of the rivers Indus, Sutlej, Brahmaputra, and Karnali (Ganges) lie in the vicinity. Right: Image of the Rakshas Taal Lake (left) and Lake Mansarovar (Right). The Rakshal lake is salty and also called by different names, such as the ghost lake, the lake of demons, and the dark lake of prison. It covers 70 km^2 and is 40 m deep. The Mansarovar is also refered to as brightness, the holiest fresh water lake, and a spiritual oasis. With a surface at 4600+ m, it covers 320 km^2, and is 100 m deep.

Initially, the Indus River has two branches that merge near Tashigang in Gar County, about 130 km east of the Tibet-Ladakh border near Denmock, to make the main Indus River. The 300 km long Sênggê Zangbo (Lion River) northern branch, its main stem, originates from a spring northeast of the Mount Kailash at about 5,180 m, and the southern Gar Tsangpo (Elephant River) branch originates from Kangrinboqê Glacier on the southwest side of the Mount Kailash at about 4600 m and flows for some 150 km before joining the Sênggê Zangbo (Fig. 4 and 5). According to Hussain (2024), in the Kailash mountains, the proto- or juvenile Indus is a lonely stream originating at Sengge Kanbab (the Mouth of the Lion) at the base of a non-descript low hill at 5180 m. There "it flows meekly and without any fanfare", but as it gets water from dozens of tributaries, it gathers speed and runs full by the time it reaches Ali, the largest town of the Ngari region and 120 km upstream of the confluence at Tashigang. (It may be noted that these distances are tentative and subject to revision). At its entry in Ladakh near Demchok, the discharge is estimated at around 5,000–6,000 CMS during the peak summer season and much lower in winter. Annual flow volumes in Ladakh near Demchok are likely to be around 20–30 BCM, depending on seasonal variations and additional input from local glaciers. After the confluence of the two stems, the combined Indus River continues northwestward through deep gorges and mountain valleys of Ladakh, Baltistan and Nanga Parbat-Haramosh massif of the western Himalaya, after which it follows a SWS course through Kohistan and Hazara Himalaya, eventually entering the Pakistan plain to the south of Attock.

The UIB in southwest Tibet, where the river originates, is a region of unique geographical, agricultural, and demographic characteristics (Kumar and Srivastava, 2018). It nurtures the nomads, their animals and birds, as well as wildlife, e.g., animals, birds and other living organisms of cold climates, such as kiang (wild asses), antelopes, wild yaks, swans and black-necked cranes. The Ngari area encompasses diverse aspects such as geomorphology, hydrology, and agriculture. Here we provide basic information on various geographic features of the UIB in the Ngari Prefecture, west Tibet. Much of this information is derived from the published literature and internet sources, such as Google, Research Gate, and ChatGPT.

2. Geology and Geomorphology

The UIB, spread over Mount Kailash-Lake Mansarovar to the west Ngari region, is a part of the Gangdese Belt/magmatic arc (GB), a subduction-related terrain in the Tibetan block of southern Eurasia. According to some researchers, the GB is a continuity of the Kohistan-Ladakh Cretaceous Island arc (KLA) system which became an Andean-type margin in the Late Cretaceous and a continental collision zone in the Eocene (Jan et al., 2024; Kazmi and Jan, 1997). The two belts are juxtaposed along the Karakoram right-lateral strike-slip fault. The GB and KLA developed during the Late Jurassic to Late Cretaceous-Paleocene in response to the subduction of Neo-Tethyan oceanic lithosphere underneath the Eurasian Plate, however, collision-related magmatism continued in the Cenozoic. The Mount Kailash region is the remnant of large Quaternary ice sheets which retreated some 10,000 years ago. The Mount Kailash might be a large roof pendant of metasedimentary rocks supported by a granitoid foundation. The area around the Indus headwaters is characterized by wide-scale faulting in metamorphosed late-

Cretaceous to mid-Cenozoic sedimentary and interbedded volcanic rocks and Cenozoic granitic intrusions. The rocks are offshore marine limestones deposited on the southern margin of the Asian block during the northward subduction of the Tethys oceanic lithosphere before the India-Eurasian collision. The area also contains sand dunes covering late Eocene volcanic rocks which are interspersed with Creto-Eocene sediments (Winn, 2014; MGMRC, 2014). The Kailash flysch extends for 20 km from the mountain and marks the northern edge of the Himalayas and the start of the Trans-Himalayan GB, which was formed by the subduction of sediments from the collision zone of the Indo-Eurasian plates (Debon, 1986).

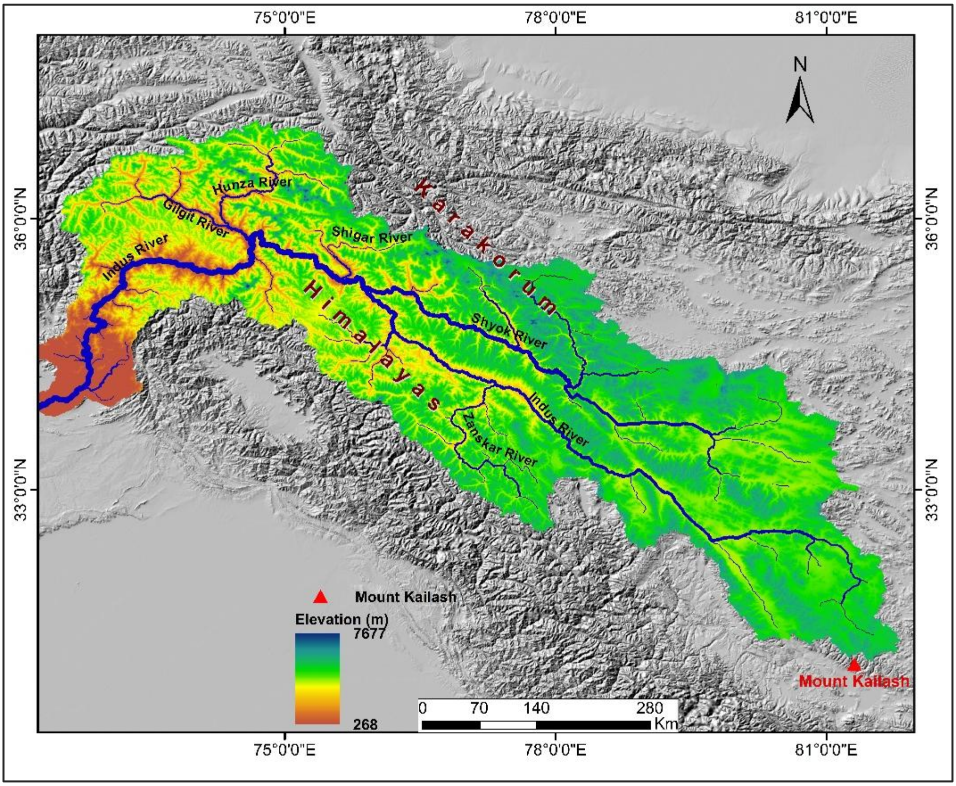

Figure 2. Topographic and hydrological map of the UIB, highlighting major rivers, elevation variations, and key geographical features such as the Karakoram and Himalayas.

The flysch zone comprises peridotites, dolomites and sandy shales, covered by gravel terraces. The Kailash Mountain itself comprises thick conglomerates, extending from 4,700 m to the top and sitting on granite (Gansser, 1964). It contains abundant clasts of volcanics (probably Eocene, mostly andesitic and some silicic) and subordinate granitoids of the Gangdese belt (Waltham, 1998).

Continued subduction of the Indian plate beneath the Eurasian plate led to continental collision during the Early Cenozoic (ca. 50–55 Ma). The resulting crustal shortening and attending thickening contributed to the uplift of the Tibetan plateau and exhumation of Mount Kailash, although it has been argued that some uplift in Tibet had taken place earlier than this collision (Kher, 2019). Post-collisional extension and magmatism further influenced the geotectonic and petrological evolution of the Tibetan region. Early magmatism in the GB comprises intermediate to felsic volcanic rocks, granodiorite and diorites. These were emplaced during the subduction phase, which spanned the Late Jurassic to Early Cretaceous. Post-India-Eurasia collision magmatism consists of adakites and leucogranites, thought to have been derived from partial melting of the thickened lower crust under high temperature and pressure conditions. A simplified geological map of the Mount Kailash area is given in Fig. 3, and details can be seen in Shen et al. (2020, and references therein).

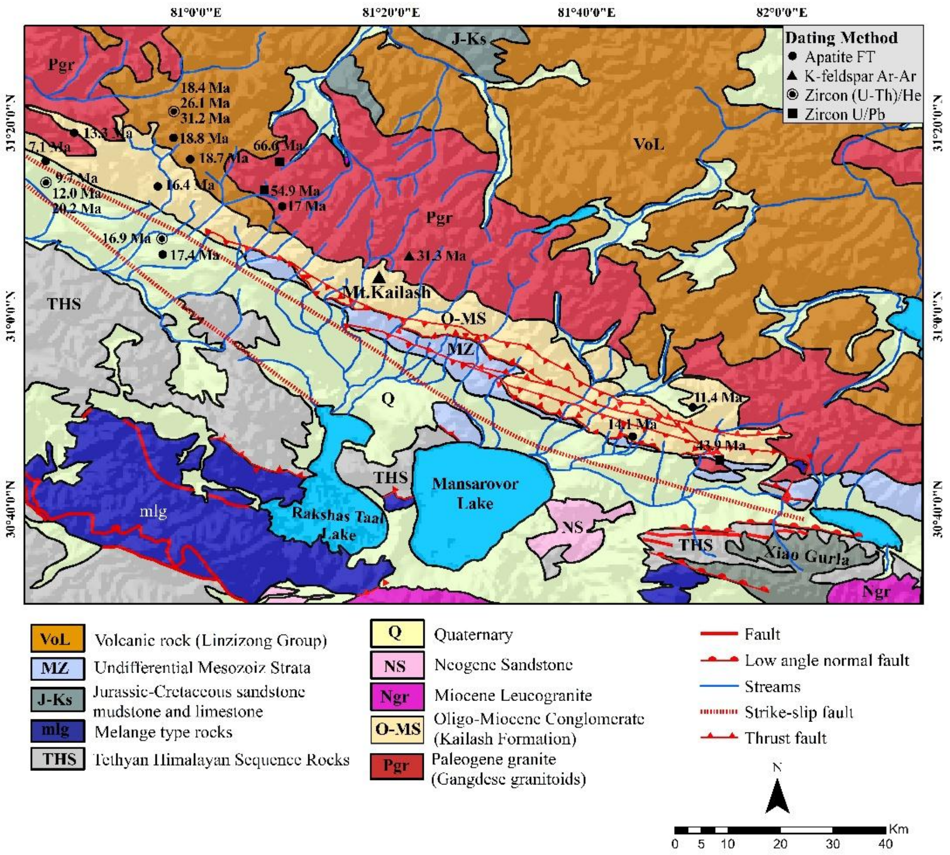

Figure 3. Detailed geological map of the Mt. Kailash area, modified from Shen et al. (2020, and others therein). Numbers refer to locations of samples radiometrically dated from the Gagdese batholith north of the now-closed Kailash basin.

Mount Kailash, situated in the west GB of the Tibetan Plateau, is a distinct geomorphic feature formed through complex tectono-magmatic processes (Fig. 6). Its evolution is tied to the broader geodynamic history of southwest Tibet, which involves the Early Cenozoic collision between the Indian and Eurasian Plate. The Kailash range is made up of thousands of feet thick pile of sediments of the Kailash Formation, apparently sitting on top of the granitoids of the Gangdese batholith. The Kailash Formation was deposited in a narrow extensional basin during southward rollback of the Indian slab below southern Tibet before Miocene slab breakoff (for references, see Shen et al., 2020). The granitoids formed within the Andean-type southern margin of the Eurasian continent. But as the subduction of the Indian plate continued underneath Asia, magmatism also formed inside the Eurasian plate, resulting in the formation of the huge Gangdese batholith. The magmatism took place between 100 and 45 million years ago. Radiometric dating of the lava flows inter-layered with sediment suggests that the Kailash Formation was deposited between 26 and 21 Ma ago (Saurat Kher, 2019). The Kailash basin, according to Shen et al. (2020) is a unique occurrence of a perched basin resulting from dynamic deflection within a mountain belt. Northward migration of the Indian plate created a dynamic topography which resulted in successive subsidence and uplift. They also suggested that the Gangdese batholith underwent reheating between ~28 and 20 Ma, and was followed by rapid cooling of ~50 °C/Myr between 20–17 Ma.

Intense thrusting and folding due to subduction and plate collision resulted in crustal deformation and uplift in the Gangdese belt, including Mount Kailash. Later tectonic activity, heralded by strike-slip faulting, such as the Karakoram Fault, resulted in further modification of the structural framework of the region. Medium- to high-grade Barrovian regional metamorphism in the Gangdese belt is suggestive of significant crustal burial and exhumation. Sedimentary sequences in the surrounding areas, e.g., the Indus-Suture Zone, record the tectono-sedimentary evolution of the rocks to the closing of the Neo-Tethys and subsequent continental collision (ChatGPT, 2024). The geomorphology of the Upper Indus Basin is shaped by its location within the GB, Himalayas, Karakoram, and Kohistan ranges, featuring steep valleys, deep gorges, and structurally controlled river courses. Glacial and fluvial processes have carved U and V-shaped valleys, deposited moraines, and created extensive alluvial fans. The steep gradient in the upper reaches causes rapid erosion and high sediment transport, influencing the basin's evolving landscape. Mass movements and paraglacial processes are significant in modifying the landforms and landscape of the region (Owen, 1993). Many lakes have been formed by damming of the Tributary valley by glacial ice, rockfall, landslides and debris flows (Owen, 1993, 1989).

Figure 4. Sênggê Zangbo, flowing NW of Mount Kailash toward Tashigang, its confluence with the southerly Gar Tsangpo (Elephant River) branch. Note the rugged geomorphology and nearly complete lack of vegetation (ChatGPT).

Figure 5. The confluence of the northern and southern stems of the Indus River at Tashigang in Gar County, southwest Tibet (ChatGPT). The image highlights the amazing and striking natural features and calm and serene atmosphere of the region.

The 3,180 km long Indus River is initially made up of two major stems that flow westward and join near Ngari to become the Indus River. One of the two stems (Sênggê Zangbo) originates from a spring at 5,555 m near Upper Gêgyai, NE of Mount Kailash, and the other (Gar Tsangpo) originates at 4,600 m from Lake Mansarovar, and drains the Nganglong Kangri and Gangdise Shan (Gang Rinpoche, Mt. Kailash) mountain ranges (Hussain, 2024; Wikipedia, 2024). The region is characteristically a high-altitude plateau, with elevations often exceeding 4,500 m. It has a harsh cold desert climate, rugged topography, high relief, indeed an inhospitable terrain with not much infrastructural development, low population density and limited agriculture opportunities. The river passes through a deeply incised rugged topography (Fig. 4, 5) and enters Ladakh near Demchok with an elevation of 4150 m. These elevations reflect the gradual descent of the Indus River as it traverses the high-altitude western regions of the Tibetan Plateau and enters the more rugged terrain of Ladakh. In comparison to its course between Ngari and Demchok, the two branches have much steeper slopes even as they approach their confluence. In the last 50 km before their confluence, the two branches show a slope of about 10 m per km, whereas the slope of the Indus between Ngari confluence and Demchok at the Ladakh-Tibet border reduces to 0.3 m/km. Further on, the slope varies from rather flat mountain valleys to steep gorges in Ladakh, Baltistan, Gilgit, Kohistan, and higher Himalayas. The Indus passes through gigantic gorges 4,500–5,200 m (15,000–17,000 ft) deep in the Nanga Parbat-Haramosh massif (Fig. 6; Wikipedia, 2024). The active tectonics in the region also lead to active seismicity resulting in frequent earthquakes, landslides, and rockfall in this mountainous terrain.


Figure 6. (Left). Sacred Mount Kailash, the birthplace of the Sengge Zangbo, the northern main stem of the Indus River. (Right) Chizuo Tsangpo, a tributary of Sengge Zangbo, near its confluence (Wikipedia. https://en.wikipedia.org/wiki/Sengge_Zangbo).

Soon after the confluence, the Indus flows northwest along the Karakoram Fault, then shifts westward to follow the Indus suture before entering the Kohistan-Ladakh island arc terrain. It changes the direction of its path after crossing the Nanga Parbat-Haramosh massif and starts flowing south-west-south through much of Pakistan, before emptying into the Arabian Sea. The river drains through tectonically active zones of Karakoram in Tibet, Ladakh, Baltistan, and Nanga Parbat in the western syntaxis of Himalaya. It is joined by well over a dozen major tributaries which contribute significant water and sediments. Some studies reported that silt and sand from western Tibet was reaching the Arabian Sea by some 45 my ago, suggesting the existence of an ancient (Indus?) river by that time. The delta of this proto-Indus was subsequently reported in the Katawaz Basin in Balochistan, on the Afghanistan-Pakistan border. Space does not permit to go into details regarding the age and flow history of the Indus River; the readers may consult Kumar and Srivastava (2018), Clift et al. (2001), Sinclair and Jaffey (2001), and other sources.

3. Geohydrology

The Indus River derives its hydrological resources through the melting of glaciers, thawing permafrost, westerlies, and summer monsoons. Glacial meltwater derived from Gangdise, Zanskar, Karakoram, Ladakh, Kohistan, Hindu Kush and Himalaya Mountain ranges contribute some 50% of the Indus water flow. However, the flow of the water is season-dependent and much less during winter months. Most of the floods in the UIB of Pakistan are rain-related and occur during the precipitation regime of the summer monsoons. Some floods are related to damming by the landslides and glacial lake outbursts. Indus is one of the few rivers in the world to exhibit tidal bore, defined as a 'large wave caused by funneling of a flood tide as it enters a long, narrow, shallow inlet'.

Figure 7. The Indus Gorge formed as the Indus cut through the Haramosh massif, towering behind and defining the western anchor of the greater Himalaya range (*Wikipedia*. https://en.wikipedia.org/wiki/Indus_Gorge).

Eighteen major tributaries contribute to maintaining the discharge and sediment load of the river before it finally sinks into the Indus canyon in the Arabian Sea (Kumar and Srivastava, 2018; Inam et al., 2007). The more important of these are Zanskar, Suru, Shyok, Shigar, Gilgit, Kabul, and the five rivers of Punjab (for further information, see Shafique and Jan, this volume). However, rainfall is scanty in the UIB, and hydrologically it essentially depends on the melting of snow and permafrost. Based on the altitude model, the lower limit of alpine permafrost in the UIB is approximately at a mean altitude of 4919 ± 590 m above sea level (Hassan et al., 2023). The upper stretches of the Indus in Tibet are characterized by significant gradients and fast-flowing waters, offering substantial hydropower potential. Many sites throughout the northern Indus basin can be considered for the generation of clean and cheap hydropower. Several projects are under development or consideration in the UIB in Pakistan. Finally, agriculture and domestic use of the Indus waters have substantially increased due to population growth.

4. Climate, Ecology and Agriculture

4.1. Climate

The Ngari prefecture hosting the UIB constitutes one of the highest areas of Tibet and has an average altitude of over 4,500 m. It is characterized by a semi-arid to arid climate. Temperature varies greatly during the day. Over 20°C summer day time temperature may drop to < 0°C at night. The winters are harsh with temperature drops to -20°C and even colder in some areas. But the temperature difference during a year is small. It is also the coldest area in the Tibetan Plateau, with an annual average temperature of 0°C. The prefecture is characterized by high ultraviolet radiation, and thin and dry air all the time. Because of its high altitude and wind, the region frequently experiences strong winds and low precipitation over much of the year, except for seasonal snow and rainfall. It experiences cold desert (BWk) climate conditions, with extremely low temperatures in winter and limited rainfall, primarily from summer monsoons and occasional snowmelt.

Precipitation in this region primarily occurs as winter snowfall due to the influence of westerly winds, with limited summer monsoon rainfall and localized orographic effects (Kumar & Srivastava, 2018). The mean annual rainfall is relatively low, ranging from 50 to 350 mm, with most precipitation falling between July and September as a result of the weakened Indian monsoon at this latitude. The Himalayas significantly reduce monsoonal influence, creating a rain-shadow effect over the Tibetan Plateau. Winter and early spring westerly snowfall accounts for approximately 70% of the total annual precipitation (Li et al., 2020). The estimated mean annual snowfall, in terms of water equivalent, is about 100–150 mm across much of the area. The combined total annual precipitation, including both rainfall and snow equivalent, generally varies between 150 and 350 mm, influenced by local topography and elevation. For instance, areas near Mount Kailash may receive slightly higher precipitation. This limited moisture highlights the crucial role of snow accumulation, glacial contributions, and snowmelt in sustaining the flow of the Indus River, which originates in the Kailash-Mansarovar region of Tibet. Li et al. (2020) noted that the eastern and western parts of the Tibetan Plateau experience a wetter climate due to strong water vapor transport from the South Asian summer monsoons and mid-latitude westerlies. In contrast, central Tibet remains arid due to the blocking effect of the Himalayan mountains and the gradual depletion of water vapor during its long-distance transport.

The world is already witnessing the effects of global warming and climate change, with mountain regions being particularly vulnerable due to their fragile ecosystems. As a result, the water stored in glaciers and long-term food security face significant threats. The Tibetan Plateau holds the world's third-largest reserve of ice and, along with the Himalayas, Karakoram, Hindukush, and Pamirs, forms what is called the Third Pole. Qin Dahe, former head of the China Meteorological Administration, warned in an interview cited by The Guardian (2019; as referenced in Wikipedia, 2024) that while rising temperatures and rapid glacial melting in the region may temporarily benefit agriculture and tourism, the long-term consequences are severe. He highlighted that "Temperatures in Tibet are rising four times faster than in the rest of China, and the Tibetan glaciers are melting faster than anywhere else in the world." In the short term, this will lead to expanding lakes, increased flooding, and mudflows. However, in the long run, the loss of these glaciers poses a serious threat to water resources, particularly for the Indus River, which is a crucial water source for Pakistan.

4.2. Ecology

The Ngari Prefecture shares high-altitude and harshly cold environmental conditions with other regions of western Tibet, which support limited vegetation, mainly shrubs and hardy grasses adapted to arid conditions. The waters of the two main stems of the Indus in the Ngari Prefecture provide critical hydration to plants, create microhabitats, and sustain precious life in an otherwise harsh, arid and high-altitude environment. Hence, species dependent on the more vegetated or forested habitats likely have a limited presence due to Ngari's predominantly barren and arid landscapes. Despite its harsh conditions for survival, the UIB is ecologically significant and supports a variety of animals and birds adapted to the high-altitude, cold desert environment. The water in the stream and river courses nurtures the nomads and their beasts, as well as the wild animals and birds, including wild yaks (Hussain, 2024). Mammals include kiang (wild ass-Equus kiang), Tibetan Antelope (Pantholops hodgsonii), Blue Sheep (Pseudois nayaur), Snow Leopard (Panthera uncia), and Tibetan Wolf (Canis lupus chanco) (ChatGPT). Here is a summary of the ecology of the Ngari area:

Many of the non-migratory birds mentioned earlier are indeed permanent residents of the Ngari Prefecture due to its suitable habitats for birds, such as local grasslands, rocky slopes, wetlands, and alpine shrublands. However, their presence depends on habitat availability and specific ecological niches within the prefecture. The UIB serves as an important stopover for migratory birds and supports grazing for herbivores, creating an interconnected web of life. Given climate change and the expected population increase, more conservation efforts in the region are needed to protect these unique ecosystems and their inhabitants.

The birds can be grouped into three types, 1) Permanent, 2) Migratory but laying eggs and raising chicken, and 3) Pure migratory. Many of the birds observed in the area are likely to be permanent residents of Ngari Prefecture, particularly those adapted to arid grasslands, rocky terrains, and alpine environments. The common permanently resident birds include Black-necked Crane (Grus nigricollis), Brown Accentor (Prunella fulvescens), Chukar Partridge (Alectoris chukar), Ground Tit (Pseudopodoces humilis), Himalayan Snowcock (Tetraogallus himalayensis), Lammergeier (the scavenger Gypaetus barbatus), Tibetan Lark (Melanocorypha maxima), Tibetan Partridge (Perdix hodgsoniae), Tibetan Snowcock (Tetraogallus tibetanus), White-browed Tit-Warbler (Leptopoecile sophiae) and, possibly limited Himalayan Snowcock (Tetraogallus himalayensis), Tibetan Blackbird (Turdus maximus), and Tibetan Eared Pheasant (Crossoptilon harmani).

In western Tibet, several species of migratory birds breed, lay eggs and raise chicks. Notable among them are: Bar-headed Goose (Anser indicus), Black-necked Crane (Grus nigricollis), Brown-headed Gull (Chroicocephalus brunnicephalus), Common Redshank (Tringa totanus), Great Crested and Grebe (Podiceps cristatus), and Ruddy Shelduck, also called the Brahminy duck (Tadorna ferruginea). The plateau's unique geography and high-altitude wetlands provide appropriate breeding habitats for these migratory bird species.

Some of the migratory birds use the high-altitude wetlands and other habitats as critical stopover points, visit the region seasonally for resting and foraging during their long migrations, but do not lay eggs or breed there. These birds typically use Ngari as a stopover or wintering ground rather than a breeding site. These purely migratory visitors comprise Black-tailed Godwit (Limosa limosa), Common Teal (Anas crecca), Demoiselle Crane (Grus virgo), Eurasian Wigeon (Mareca penelope), Greater Flamingo (Phoenicopterus roseus), Northern Pintail (Anas acuta), and Ruddy Shelduck (Tadorna ferruginea).

4.3. Agriculture

Agriculture in southwest Tibet is constrained and inhibited by a number of factors: harsh environment, dry climate, cold temperatures, short growing seasons due to high altitude, limited availability of arable land due to rocky terrain, and poor quality of soil. Farming relies heavily on meltwater from the nearby glaciers, which feed the Indus and its tributaries, but much of the area is in need of water for crops.

The principal crops grown in the UIB depend primarily on the altitude, climate, and availability of water. Irrigation in the region generally relies on glacier-fed streams, snowmelt, and some small, local irrigation systems that are adapted to the harsh and challenging environment. The cultivated crops reflect the resourcefulness and resilience of the local communities. Staple crops that are cultivated include high-altitude Tibetan barley or "tsampa" and some hardy vegetables, along with potatoes, reddish, and turnips. Millets, buckwheat, mustard, and even wheat are locally grown. Due to limited arable land and harsh terrain, pastoralism is a significantly dominant activity in the region. People rely heavily on grazing livestock (yaks, sheep, and goat herding) for milk, meat, and wool. However, climate change, soil degradation and water scarcity due to retreating glaciers pose major challenges for agriculture and livestock and, therefore, need improved irrigation, modern techniques of agriculture, and climate-resilient seeds.

5. Demography/Population

The southwest Tibet region is one of the most sparsely populated areas in Tibet, with a population density of < 1 persons per km^2. (according to one estimate, only about 0.2 persons/km^2). This low density is due to its rugged terrain and harsh climate, which make large parts of the Ngari region inhospitable and uninhabitable. In contrast, the overall population density of the Tibet Plateau is much higher, approximately 3 inhabitants per km^2 (China Culture, in ChatGpt).

The settlements in the uppermost Indus Basin are typically small and sparsely populated communities relying on river resources, subsistence agriculture and pastoralism. But there are villages located along both the branches of the Indus. The notable of these along the Sênggê Zangbo include, 1) Tirthapuri, known for hot springs, is a small settlement and sacred pilgrimage site for Buddhists, Hindus and others. It is situated about 55 km upstream from the Tashigang confluence, at 4800 m elevation, and 2) Shiquanhe (Ali Town), 120 km from the confluence, at ~4,300 m, it is the largest town in the Ngari region (2008 population estimate > 20,000) and a significant hub near the river. Southern Branch (Langqên Zangbo): 1) Gar, ~45 km from the confluence at ~4,500 m, is the administrative center of the Ngari Prefecture. It's a small town with government offices and basic facilities, and the county had a total population of 31,052 as of 2020, and 2) Burang/Purang (Taklakot), ~150 km from the confluence and 35 km SW of Lake Mansarovar, near the border with Nepal, at ~4,600 m. It is a trade and religious hub near Mount Kailash, with an area population of 9,657 according to the 2010 census (Wikipedia, 2024). It is to be noted that the area was historically part of the trade routes linking Tibet, India, and Central Asia. It might even have promoted the spread of Buddhism by travelers and traders using the Indus River and other roots to and from the Gandhara region of NW India (now Pakistan) and Afghanistan.

The harsh environment, high altitude, and sparse population mean settlements in the region are small, widely spaced and clustered around water resources or in valleys. These settlement locations serve as important waypoints for local life, societal engagements, trade, and pilgrimage. These are predominantly inhabited by ethnic Tibetans, who maintain traditional lifestyles, including nomadic herding of yaks, goats, sheep, and small-scale subsistence farming. The area is culturally very significant because of its proximity to the majestic Mount Kailash and high-altitude freshwater Lake Manasarovar, which are considered sacred and revered for their spiritual significance by those believing in Buddhism, Hinduism, Jainism, and Bon religions. However, the Ngai prefecture and its population have faced the key challenges of isolation, remoteness, inhospitable terrain, and a nearly complete lack of infrastructure and development. A road connecting Lhasa with Xinjiang passes near Mount Kailash. Global warming and climate change threaten snow melting, water supply and food security. On the other hand, infrastructure development, potential hydropower projects, increased tourism, population growth and excessive grazing could further impact negatively the fragile environment as well as the traditional way of life and livelihoods.

6. Economic activities in the UIB

The economy of UIB in Tibet is primarily based on subsistence agriculture, pastoralism, trade, tourism, and hydropower development. Farming relies on glacier-fed irrigation, while yak and sheep herding provide dairy, meat, and wool, including high-value cashmere. Traditional trade, handicrafts, and medicinal herb collection contribute to local livelihoods. Eco-tourism and religious tourism, particularly around Mount Kailash, support businesses and infrastructure growth. Additionally, hydropower and renewable energy projects are expanding, supplying electricity locally and beyond. The growing population has also resulted in increased agricultural activity. However, challenges such as climate change, glacier retreat, and limited market access threaten economic stability, highlighting the need for sustainable development and improved infrastructure.

7. Summary

The uppermost Indus River Basin, located in Ngari Prefecture, southwest Tibet, is a region of remarkable geographic, climatic, and cultural significance. Spanning approximately 310,000 km^2, it is characterized by its extreme remoteness, high altitude (above 4,500 m), rugged topography, and harsh cold desert climate. Winters are severe, precipitation is minimal, agriculture is nearly non-existent, and the population density is extremely low—less than one person/km^2. Despite these challenging conditions, Ngari is home to one of the most sacred landmarks in the world: Mount Kailash due to its profound religious importance in Hinduism, Buddhism, Jainism, and Bon. Geologically, much of UIB falls within the Cretaceous-Tertiary subduction-related Gangdese belt, which is faulted against the Karakoram mountain range and the Ladakh island arc along the Karakoram Thrust, making it an area of significant tectonic activity. This region is also a critical hydrological zone, serving as the source of four major rivers, the Brahmaputra, Karnali tributary of the Ganges, the Indus, and the Sutlej, which originate from the Mount Kailash-Lake Mansarovar area. The Indus River is formed by the confluence of two branches emanating from the Mount Kailash and Lake Masarovar neighborhood. The longer northern branch (300 km) merges with the southern branch (150 km) near Tashigang, about 170 km east of the Tibet-Ladakh border near Demchok. Along its course, numerous streams fed by snow and glacial melt contribute to its flow, making it a lifeline for downstream regions. The UIB in southwest Tibet covers approximately 451,000 km^2, playing a crucial role in regional water security. Given the region's poor soil fertility and harsh climate, agriculture is minimal, and traditional herding remains the primary livelihood. Historically, Ngari was a key hub along ancient trade routes linking Tibet, India, and Central Asia, facilitating cultural and economic exchanges and potentially playing a pivotal role in the early spread of Buddhism into Tibet. Today, the population, though sparse, remains deeply rooted in Tibetan Buddhist traditions, maintaining a way of life that has persisted for centuries despite modern challenges.

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References

Clift, P.D., Shimizu, N., Layne, G., Gaedicke, C., Schlüter, H.U., Clark, M., Amjad, S., 2001. Development of the Indus fan and its significance for the erosional history of the western Himalaya and Karakoram. Geological Society of America Bulletin, 113, 1039–1051

Debon, F., 1986. The Four Plutonic Belts of the Transhimalaya-Himalaya: a Chemical, Mineralogical, Isotopic, and Chronological Synthesis along a Tibet-Nepal Section. Journal of Petrology, 27(1): 219–250. Retrieved 22 June 2022. CiteSeerX 10.1.1.1018.511. doi:10.1093/petrology/27.1.219.

Gansser, A., 1964. Geology Of The Himalayas. Wiley. ISBN 978-0-47029-055-2.

Guardian, 2019. "The world has a third pole – and it's melting quickly". The Guardian. 15 September 2019. Archived from the original on 20 August 2024. Retrieved 1 June 2024. (Wikipedia, 2024)

Hassan, W., Jeelani, G., Dimri, A.P., Nusser, M., 2023. Assessment of the spatial extent of permafrost in the Upper Indus Basin (UIB). Journal of Mountain Science, 20, 1508–1525.

Hussain, S.A., 2024. A Short Biography of the Indus River based on personal observations. In: Jan, M.Q., Shafique, M., Raynolds, B., Jan, I.U., Ghani, M. (eds) Indus Water System. National Centre of Excellence in Geology, University of Peshawar & Pakistan Academy of Sciences, Islamabad, Pakistan (2024).

Inam, A., Clift, P.D., Giosan, L., Tabrez, A.R., Tahir, M., Rabbani, M.M., Danish, M., 2007. The Geographic, Geological and Oceanographic Setting of the Indus River. In, Gupta, A. (Ed.), Large Rivers: Geomorphology and Management, 333–346. © 2007 John Wiley & Sons, Ltd.

Jan, M. Q., Ullah, R., Anjum, M.N., 2024. Magmatic (Cr-Ni-PGE) and secondary/hydrothermal (emersld- peridot-rodingite-nephrite jade) mineralization associated with mafic-ultramafic rock complexes of Pakistan. Geological Society London, Special Publication, 552. DOI:https://doi.org/101144/SP552-2023-99

Kumar, A., Srivastava, P., 2018. Landscape of the Indus River. In: Springer Nature Singapore Pte Ltd. 2018 D.S. Singh (ed.), The Indian Rivers, Springer Hydrogeology DOI: 10.1007/978-981-10-2984-4_4

Kher, S., 2019. Is Mount Kailash The Oldest Mountain In The Himalaya? Posted by Saurat Kher 20119, downloaded January 9, 2025).

Li, D., Yang, K., Tang, W.,Li, X., Zhou, X., Guo. D., 2020. Characterizing precipitation in high altitudes of the western Tibetan plateau with a focus on major glacier areas. International Journal of Climatology, 40, 5114–5127. https://doi.org/10.1002/joc.6509

MGMRC (Ministry of Geology and Mineral Resources, China), 2014. Geology and Geography of the Mt. Kailash area and Indus River headwaters in southwestern Tibet. Archived from the original on 15 January 2014). Retrieved 1 January 2014.

Owen, L.A., 1989. Terraces, uplift and climate in the Karakoram Mountain, northern Pakistan: Karakoram intermontane basin evolution. Zeit fur Geomorphology, 76, 117–146

Owen, L.A., 1993. Mass movement deposits in the Karakoram Mountains: their sedimentary characteristics, recognition and role in Karakorum landform evolution. Zeit fur Geomorphology. 35 (4), 401–424.

Shafique, M., Jan, M.Q., 2024. Introduction to the Indus Water System. In: Jan, M.Q., Shafique, M., Raynolds, B., Jan, I.U., Ghani, M. (eds) Indus Water System. National Centre of Excellence in Geology, University of Peshawar & Pakistan Academy of Sciences, Islamabad, Pakistan (2024).

Shen, T., Wang, G., Replumaz, A., Husson, L., Webb, A.A.G., Bernet, M., Leloup4 , P.H. Zhang, P., Mahéo, G., Zhang, K., 2020. Miocene subsidence and surface uplift of southernmost Tibet induced by Indian subduction dynamics. Geochemistry, Geophysics, Geosystems, 21, e2020GC009078.https://doi.org/10.1029/2020GC009078

Sinclair HD, Jaffey N (2001) Sedimentology of the Indus Group, Ladakh, northern India: Implications for the timing of initiation of the palaeo-Indus River. J Geol Soc 158:151–162.

Waltham, T., 1998. Kailas: geology of a sacred mountain. Geology today, 67–70.

Wikipedia, 2024. Indus River. https://en.wikipedia.org/wiki/Indus_River

Winn, P., 2014. Archived from the original on 28 December 2014. Retrieved 1 January 2014.

WWF, 2019. Indus Basin Pakistan. https://wwfint.awsassets.panda.org/downloads/wwf_pakistan_stewardship_web.pdf