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Comprehensive Hydro-Geomorphological Analysis of the Beas River Tributary Network in Himachal Pradesh, India

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Abstract

The Beas River, one of the five major sub-basins of the Indus River System, originates at Beas Kund near the Rohtang Pass in the Pir Panjal Range and drains a catchment area of approximately 13,663 km^2 within Himachal Pradesh which accounts for 24.5% of the state's total geographical area. This research paper provides an in-depth hydro-geomorphological and eco-hydrological assessment of the Beas River tributary network across its 256 km course in central Himachal Pradesh. The drainage architecture is characterized by asymmetric tributary inputs, where snow-fed, glacial-origin left-bank tributaries (e.g., Parbati, Sainj, Tirthan, and Uhl) originate in high-altitude crystalline massifs of the Great Himalayan and Dhauladhar ranges, delivering high discharge and heavy sediment loads. Conversely, right-bank tributaries (e.g., Solang, Manalsu, Phojal, Sarvari, Binwa, Neugal, Banganga, Gaj, and Chakki) drain steep alpine slopes and low-altitude Shivalik hills, exhibiting flash-flood dynamics during the Indian Summer Monsoon (ISM). This paper synthesizes 20 key scientific studies covering snowmelt modeling, GIS-based morphometric prioritization, heavy metal hydrogeochemistry, and bio-monitoring. The study highlights the compound risks of climate change, rapid hydropower construction, and intense urbanization in floodplains.

Key Words: <u>Rivers, Tributaries, Glaciaers, Heavy Metals, the drainage</u>.

1. Introduction & Geographical Overview

The Beas River—historically known as *Arjikiya* in Vedic texts and *Vipasha* in Sanskrit—serves as a vital hydrological lifeline for Himachal Pradesh. Spanning a total length of 470 km from its glacierized source at Beas Kund (4,085 m above mean sea level) to its confluence with the Sutlej River at Harike in Punjab, 256 km of its course flows through the high-relief mountain valleys of Himachal Pradesh.

BEAS RIVER TRIBUTARY NETWORK

RIGHT BANK
(Glacial / High Relief / Rainfed)
- Solang Nala
- Manalsu Nala
- Phojal Khad
- Sarvari Khad
- Binwa River
- Neugal Khad
- Banganga River
- Gaj Khad
- Chakki River

LEFT BANK
(Glacial-Fed / High Discharge)
- Allain Nala
- Parbati River
- Sainj River
- Tirthan River
- Uhl River
- Suketi River
- Juni Khad
- Bakhli Khad

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The basin is bounded by the Pir Panjal Range to the north, the Great Himalayan Range to the east, and the Dhauladhar Range to the south and southwest. Physio-geographically, the sub-basin transitions through three elevation zones:

1. **Upper Alpine Zone (>4,000 m):** Characterized by glacial cirques, moraines, and permanent snowpacks.
2. **Middle Temperate Zone (1,200–4,000 m):** Defined by steep V-shaped valleys, hanging valleys, and deep gorges (e.g., Largi Gorge).
3. **Lower Subtropical Zone (<1,200 m):** Characterized by broad alluvial terraces, polycyclic landforms, and wide floodplains in the Kangra Valley.

2. Hydrological Profile & Drainage System

The hydrological regime of the Beas River network is driven by a dual-supply system: snow and ice melt during late spring and early summer (April–June) and heavy rainfall during the Indian Summer Monsoon (July–September). Snow and glacier melt contribute approximately 35% to 45% of the total annual flow upstream of the Pandoh Dam (Kumar et al., 2007).

Elevation Profile & Main Tributary Confluences

Elevation (in above Mts)	Tributaries
4000	Beas Kund, Solang Nala
3000	Manalsu Nala
2000	Parbati
1000	Sanj, Tirthan, Uhl, Suketi
400	Baner, & Gaj Etc from Dhauladhar

Parameter	**Quantitative Attribute**
Total Catchment Area (HP)	13,663 km^2
Glacier/Snow Cover Area	~780 km^2 (Permanent Ice/Snow)
Stream Order (Strahler)	8th Order Mainstem
Mean Annual Rainfall	1,821.9 mm/year
Hydropower Potential	~5,995 MW (~4,877 MW planned/commissioned)
Major Impoundments	Pandoh Dam, Larji Dam, Pong Dam (Maharana Pratap Sagar)

3. Detailed Tributary Network Analysis

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3.1 Upper Reach Tributaries (Kullu Valley & High Himalaya)

- **Solang Nala (Right Bank):** Originates near the Solang Valley glaciers. It brings high sediment yields from glaciated slopes and joins the main Beas upstream of Manali.
- **Manalsu Nala (Right Bank):** Drains the high mountain ridges above Manali town, contributing swift, cold meltwater streams with extreme seasonality.
- **Parbati River (Left Bank):** The largest and most hydrologically significant tributary of the Beas River. Originating from the Mantilai Lake and glaciers near Pin Parbati Pass (>5,200 m), it traverses the Parbati Valley past Manikaran and Kasol before converging with the Beas at Bhuntar (altitude ~1,080 m). Its sub-basin contributes nearly 25-30% of the Beas flow above Pandoh.
- **Sainj River (Left Bank):** Originates within the Great Himalayan National Park (GHNP) from high glacial catchments. It flows southwest to join the Beas at Larji.
- **Tirthan River (Left Bank):** Originates in the snowfields of GHNP, flowing through pristine forest valleys. Known for high dissolve oxygen levels and trout fisheries, it joins the Sainj and Beas at Larji Gorge.

3.2 Middle Reach Tributaries (Mandi Region & Dhauladhar Intersection)

- **Sarvari Khad (Right Bank):** Drains the steep terrain near Lug Valley and merges with the Beas River at Kullu town.
- **Uhl River (Left Bank):** Originates from the Thamsar Glacier in the Dhauladhar Range. It flows through the Chhota Bhangal and Barot valleys before joining the Beas at Karshog near Mandi. It feeds the Shanan Hydroelectric Power station.
- **Suketi River (Left Bank):** Drains the fertile, agricultural Suketi Basin (Balh Valley) south of Mandi. Unlike eastern tributaries, Suketi is low-gradient, yielding heavy agricultural runoff and silt.
- **Juni Khad & Bakhli Khad (Left Bank):** Moderate, rain-fed and spring-fed rivulets discharging into the Beas near the Pandoh reservoir.

3.3 Lower Reach Tributaries (Kangra Valley & Foothills)

- **Binwa River (Right Bank):** Rises on the southern slopes of the Dhauladhar Range above Baijnath and flows southwest through agricultural valley floors.

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- **Neugal Khad (Right Bank):** A prominent glacier-fed torrent originating near the Dhauladhar crest above Palampur. It experiences extreme discharge spikes during monsoon cloudbursts.
- **Banganga (Baner) River (Right Bank):** Drains the southern slopes of the Dhauladhar near Dharamshala and Kangra Fort, characterized by expansive boulder beds and heavy bedload transport.
- **Gaj Khad & Awa River (Right Bank):** Rain- and snowmelt-fed rivulets draining central Kangra; they exhibit acute flash-flood traits.
- **Chakki River (Right Bank):** Forms part of the boundary between Himachal Pradesh and Punjab before joining the Beas downstream of Pong Dam.

3. Comprehensive Literature Review

Following literature from various literary works was reviewed for the present study:

Singh et al. (2021) analyzed the biomonitoring and physico-chemical indices across four mid-Himalayan sites, demonstrating that anthropogenic activities near Manali and Mandi significantly reduce the Ephemeroptera, Plecoptera, and Trichoptera (EPT) index compared to forested sub-catchments like Tirthan.

Bhattacharya et al. (2019) performed a cumulative impact assessment of 51 planned and operational hydropower projects in the Beas basin, finding that fragmentation of tributaries like Parbati and Sainj severely disrupts environmental flow (E-flow) regimes.

RS Envirolink Technologies (2019) prepared the carrying capacity report for the MoEFCC, establishing minimum environmental flow release thresholds (15–20% of lean season flow) for dams constructed on tributaries like Malana Nala and Sainj.

Sharma & Walia (2017) investigated heavy metal concentration in the water of river Beas and its tributaries, revealing that Lead (Pb) and Cadmium (Cd) exceeded WHO and BIS drinking limits at downstream stations due to vehicular emissions and galena rock weathering.

Sahu et al. (2017) evaluated the hydrogeochemistry of springs and surface streams in the Parbati and Kullu valleys, identifying rock-water interaction and geothermal inputs (hot springs) as key drivers of elevated fluoride and silica levels.

Mishra et al. (2017) applied geospatial modeling to prioritize sub-watersheds in the upper Beas basin based on sediment yield index (SYI), showing that steep right-bank tributaries contribute disproportionately to dam siltation.

Batabyal & Chakraborty (2015) highlighted hydrogeochemical index techniques for evaluating surface water suitability in mountain catchments, correlating high rock dissolution rates with seasonal stream discharge.

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Jindal & Sharma (2011) evaluated seasonal limnological variations in upper Himalayan tributaries, highlighting the relationship between water temperature, dissolved oxygen, and macroinvertebrate density.

Kumar (2010) documented the hydrobiological conditions and ichthyofaunal diversity in the Kullu Valley, identifying six fish species and emphasizing the role of snow-fed tributaries as critical spawning habitats for Brown Trout (*Salmo trutta fario*).

Paaijmans et al. (2008) examined the micro-habitat thermal properties of mountain streams, demonstrating that canopy cover and stream velocity in tributaries play a vital role in preserving cold-water aquatic organisms.

Kumar et al. (2007) applied a water balance model to estimate that snowmelt and glacier-melt contribute approximately 35% of the total annual water flow into the Beas River at Pandoh Dam, emphasizing the sensitivity of upper tributaries to thermal warming.

Singh & Jain (2002) compared meltwater contributions in western Himalayan rivers, highlighting that high-elevation sub-basins of the Beas show distinct diurnal flow oscillations during spring.

Horton (1965) developed the water quality indexing and hydro-morphological rating systems used to evaluate stream health in steep mountain tributaries.

Strahler (1957) established quantitative watershed geomorphology principles, which serve as the foundation for drainage density (D_d) and stream frequency (F_s) calculations in Himalayan tributary prioritization.

5. Hydro-Ecological Impacts & Environmental Dynamics

5.1 Hydropower Cascade & Tributary Fragmentation

With over 359 planned or operational hydroelectric projects (HEPs) across the state, key tributaries such as the Parbati (Parbati II & III), Sainj, and Uhl have been converted into dammed run-of-the-river schemes. Diversions through headrace tunnels (HRTs) dry out several-kilometer stretches of natural riverbeds, severing biological corridors for migratory fish species like *Schizothorax richardsonii* (Snow Trout).

5.2 Hydrogeochemistry and Metal Contamination

Geothermal discharge along the Parbati tributary (at Manikaran) introduces elevated natural background levels of arsenic, fluoride, and heavy minerals. Concurrently, rapid urbanization along the mainstem (Manali, Kullu, Mandi) discharges untreated municipal sewage and solid waste into tributary junctions.

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5.3 Climate Vulnerability & Multi-Hazard Disasters

The upper Beas catchment is highly susceptible to cloudbursts, glacial lake outburst floods (GLOFs), and massive landslides. The July 2023 extreme rainfall event demonstrated how tributaries such as Solang, Phojal, and Pin-Parbati streams act as funnels for torrential runoff, bringing down large boulders and logs that destroyed bridges, highways (NH-3), and riparian infrastructure.

6. Strategic Framework for Sustainable Basin Management

6.1 Mandatory Environmental Flow (E-Flow) Enforcement: Ensure real-time monitoring of a minimum 15–20% lean-season flow release from all hydro-diversions on tributaries.

6.2 Sub-Watershed Prioritization: Focus soil conservation and bio-engineering (reforestation, check dams) on high-yield sediment tributaries like Solang and Neugal.

6.3 Floodplain Zoning Legislation: Strictly enforce the Himachal Pradesh Flood Plain Zoning Act to prevent construction within the 100-year flood zone of the Beas and its major tributaries.

6.4 Integrated Water Quality Monitoring: Establish automated, continuous water quality monitoring stations at major tributary-mainstem confluences (e.g., Bhuntar, Larji, Mandi).

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