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Assessment of Pumped Storage Hydropower Potential along the Beas River using DEM-based Longitudinal Profile Analysis.

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Executive summary

Pumped Storage Hydropower (PSP) is increasingly viewed as a strategic solution for balancing large shares of renewable energy. Mountain states such as Himachal Pradesh are often assumed to have high PSP potential due to steep terrain and large rivers. However, most proposed sites are identified through reconnaissance surveys or isolated project studies, without systematic basin-scale assessment. This report presents a terrain-based, data-driven screening of PSP potential along the Beas River using Digital Elevation Model (DEM) analysis and longitudinal river profiling. Elevation values were extracted from a single DEM, river distance was calculated numerically, and elevation changes were analysed to identify zones of usable head. The results show that although the Beas River has substantial total relief, elevation drop is largely distributed over long distances, limiting compact PSP opportunities. The method provides a transparent planning tool for early-stage PSP decision-making.

Why this assessment was needed

India's renewable energy expansion has increased the need for grid-scale energy storage. PSP remains the most mature and proven technology for this purpose. In Himalayan regions, steep slopes are often equated with PSP suitability, yet what actually matters is the availability of concentrated height difference over manageable distances. The Beas River has long supported run-of-river hydropower, but its suitability for pumped storage diversion has not been systematically evaluated at basin scale. This assessment addresses that gap by analysing terrain characteristics along the entire river course rather than pre-selecting sites.

Study area context

The Beas River originates in the central Himalaya and flows through deeply incised valleys, structurally controlled ridges, and zones of varying slope before entering the plains. While the river descends several thousand metres from source to downstream reaches, this elevation loss is not uniformly concentrated. For PSP planning, the key question is not total relief, but how elevation changes along distance.

Data used

The assessment used a Digital Elevation Model (DEM) in GeoTIFF format with approximately 85-metre spatial resolution, projected in WGS 84 / UTM Zone 43N (EPSG:32643). River profile points were extracted along the Beas River and stored as ordered spatial coordinates. All elevation values used in the analysis were extracted directly from the DEM to ensure internal consistency and to avoid mixing elevation sources.

Step-wise assessment approach

The assessment followed a logical sequence, with each step answering a specific planning question.

Elevation extraction from DEM

For each river profile point *i*, elevation was extracted from the DEM using its spatial coordinates according to

$$E_i = DEM(x_i , y_i)$$

Where E_i is the elevation at point *i* in metres, and x_i , y_i are UTM coordinates in metres. This ensures that the river profile reflects terrain elevation from a single, consistent dataset, which is essential for reliable basin-scale screening.

Distance along the river (chainage)

Distance between consecutive river profile points was calculated using the Euclidean distance formula

$$d_i = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}$$

The cumulative distance along the river, or chainage, was then calculated as

$$D_i = \Sigma\, d_i \text{ for } i = 1 \text{ to } n$$

Where D_i represents the total distance from the starting point of the profile to point *i*. This step is necessary because rivers flow diagonally across terrain, and accurate distance measurement is required to relate elevation change to horizontal separation.

Construction of the longitudinal profile

Elevation values E_i were paired with cumulative river distance D_i to represent elevation as a function of distance along the river, conceptually expressed as

$$\text{Elevation} = f\,(\text{Distance})$$

This numerical longitudinal profile describes how the river descends downstream. Instead of relying on visual interpretation, the profile was analysed quantitatively to identify sections where elevation loss occurs more rapidly.

Calculation of local elevation drop (head)

Local elevation change between consecutive points was calculated as

$$\Delta H_i = E_i - E_{i-1}$$

Negative values indicate downward drop along the flow direction. For hydropower screening, the absolute elevation drop was used:

$$|\Delta H_i| = |E_i - E_{i-1}|$$

This provides a direct measure of local head contribution along the river course.

Smoothing of elevation drops

DEM-derived elevation profiles contain noise due to terrain roughness and grid resolution. To remove false spikes, a moving average filter was applied:

$$H_s(i) = (1/k) \Sigma |\Delta H_{i-j}|$$

for $j = -m$ to $+m$, with window size $k = 5$. The smoothed elevation drop $H_s(i)$ highlights geomorphologically meaningful elevation changes relevant for pumped storage screening.

Identification of high-head segments

River segments were screened using a threshold condition

$$H_s(i) \geq H_{threshold}$$

where $H_{threshold}$ was set to 15 m after sensitivity testing. Points exceeding this threshold were considered potential candidates for pumped storage diversion. This step reduces the river course to a smaller set of meaningful zones.

Grouping of diversion zones

Adjacent high-head points were grouped into continuous zones based on spacing criteria. Points separated by less than 2000 m were treated as part of the same zone, while larger gaps defined new zones. This ensures that identified locations represent sustained terrain advantage rather than isolated anomalies.

Identification of inlet and outlet locations

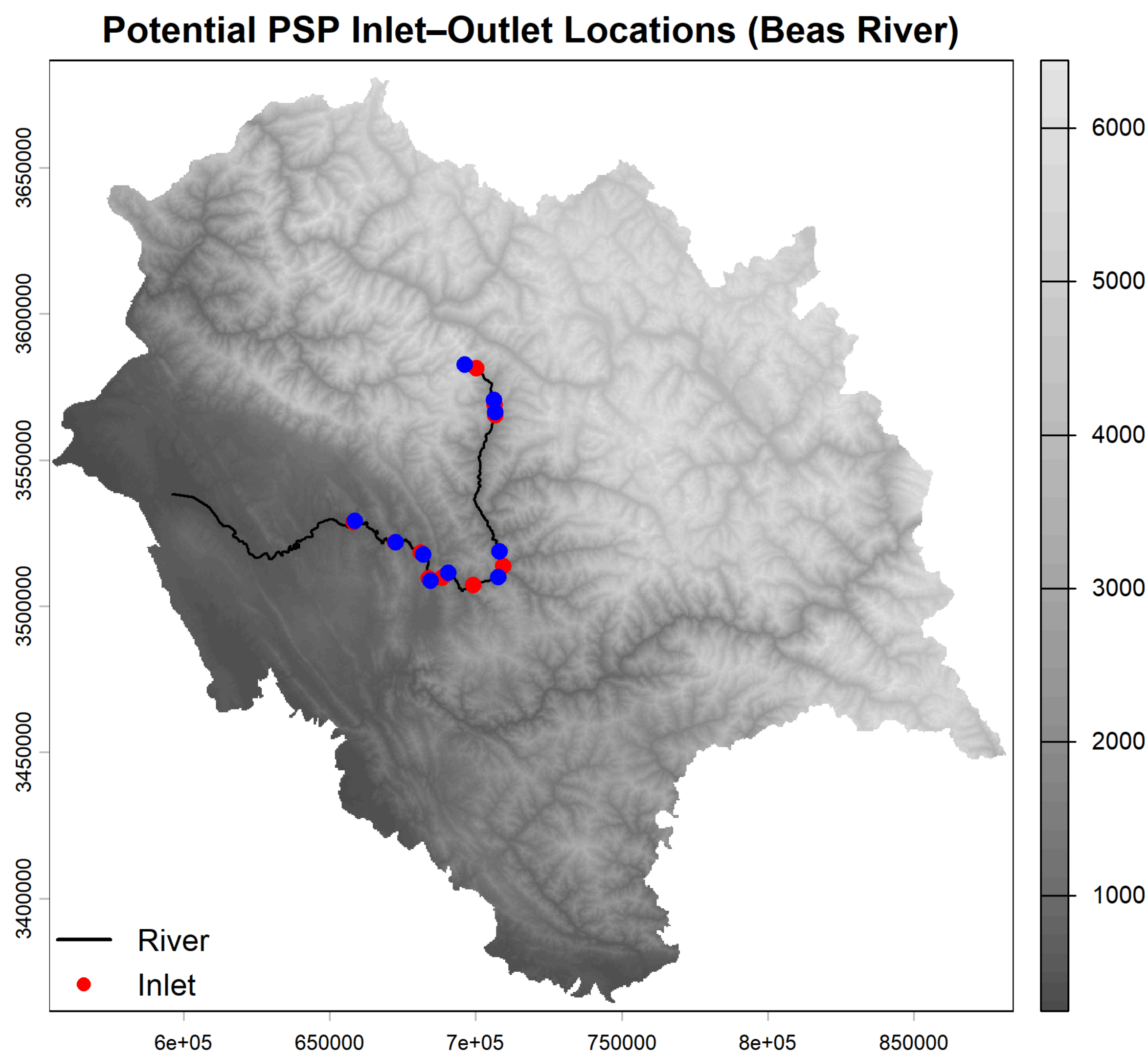
For each diversion zone, the highest elevation point was identified as a potential inlet and the lowest elevation point as a potential outlet. The effective head for each zone was calculated as

$$H_{zone} = E_{inlet} - E_{outlet}$$

This inlet–outlet elevation difference provides a first-order indicator of pumped storage feasibility. Detailed tunnel alignment and length estimation were intentionally excluded, as the objective of the study was early-stage terrain screening rather than project design.

Spatial validation

Identified inlet and outlet locations were exported to a GIS environment and visualised over DEM, slope, and contour layers. This spatial validation helped determine whether the head is created through ridge-crossing terrain or confined valley geometry, and allowed rejection of geomorphologically unsuitable locations.



(Image-1 , DEM , River Profile and Inlet- Outlet Points)

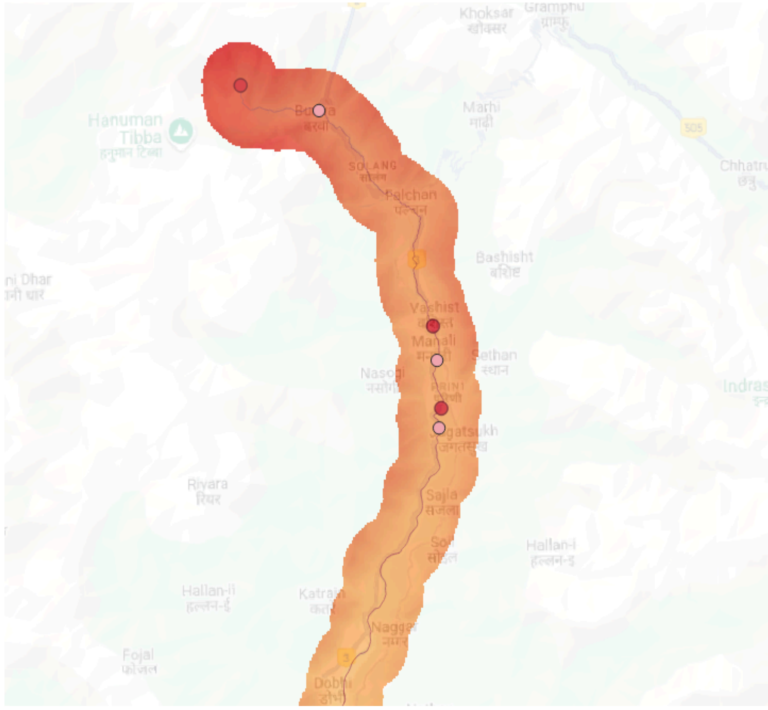


Image- 2, Inlet- Outlet Points , Upper Course.

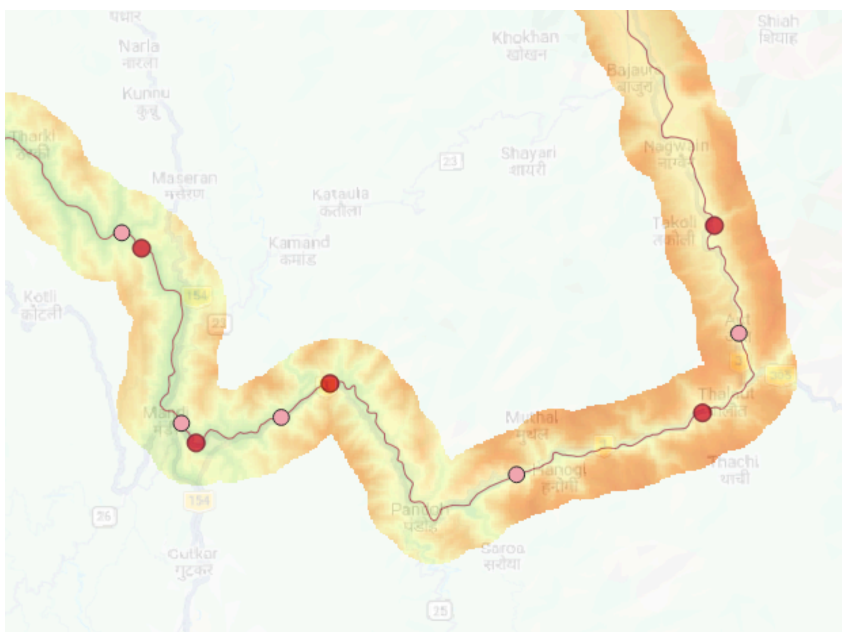


Image- 3, Inlet- Outlet Points , Mid Course.

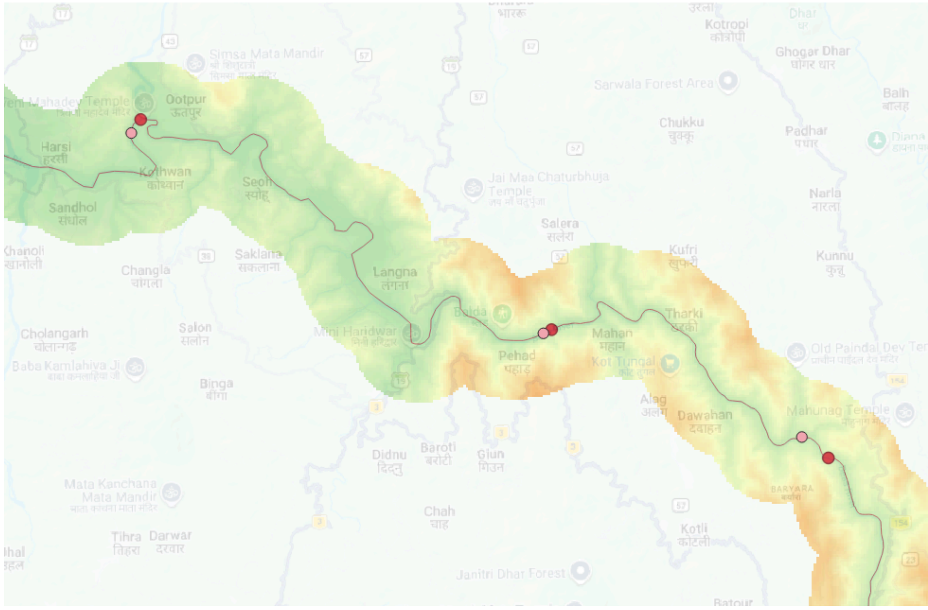
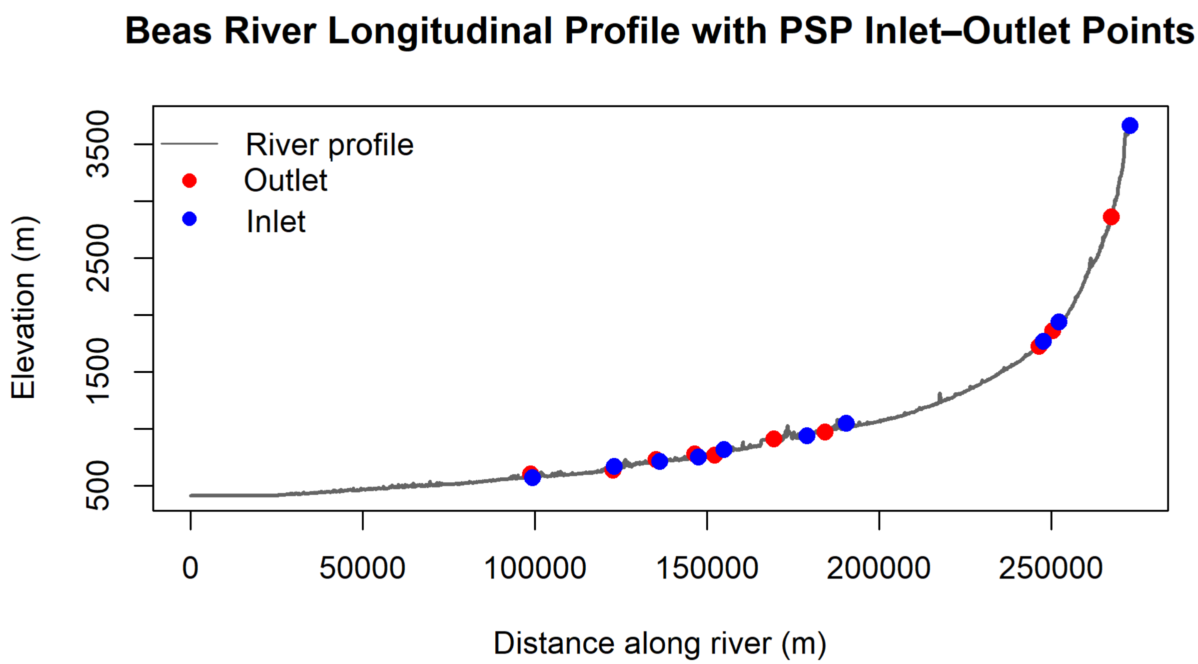


Image- 4, Inlet- Outlet Points , Lower Course.

Key findings

The Beas River exhibits a largely smooth longitudinal profile with gradual elevation loss downstream. High head values are distributed over long distances rather than concentrated over short reaches. Only a limited number of zones show moderate head accumulation suitable for preliminary pumped storage consideration, and many require long horizontal separation between inlet and outlet points. Terrain geometry, rather than total relief, emerges as the dominant limiting factor for PSP feasibility along the Beas River.Further Total PSP Hydro Potential is very small Approximately 300 MW, under assumed presumption.



(Image-5 , River Profile and Inlet-Outlet Points)

Table- 1, Showing Coordinate of Intlet-Outlet Point with Elevation, Gradient and Power.

Zone	Inlet X (m)	Inlet Y (m)	Inlet Elev. (m)	Outlet X (m)	Outlet Y (m)	Outlet Elev. (m)	Head (m)	Tunnel Length (m)	Gradient (m/m)	Power (MW)
1	658215	3528760	601	658534	3529220	569	32	560	0.057	8
2	672252	3521931	634	672531	3522056	670	36	305	0.118	9
3	681058	3518395	726	681961	3517683	712	14	1149	0.012	3.5
4	683779	3509664	778	684446	3508763	752	26	1122	0.023	6.5
5	688329	3509932	765	690555	3511485	818	53	2715	0.02	13.3
6	699066	3507309	911	707544	3510139	939	28	8937	0.003	7
7	709205	3513786	970	708088	3518725	1045	75	5064	0.015	18.8
8	706489	356549	1722	706601	356649	1767	45	998	0.045	11.3

		9			1					
9	706379	356890 9	1860	706167	357063 8	1938	78	1742	0.045	19.5
10	700192	358150 9	2863	696079	358278 1	3663	800	4305	0.186	200.1

Limitations

This assessment represents a strategic screening exercise and does not include geological or rock-mass analysis, landslide susceptibility mapping, reservoir storage assessment, or environmental and social impact evaluation. Any identified locations would require detailed feasibility studies before development.

Conclusion

This report demonstrates a transparent, DEM-based method to screen pumped storage hydropower potential along a Himalayan river. Applied to the Beas River, the analysis shows that although total relief is large, terrain-controlled head suitable for pumped storage is limited and spatially constrained. The approach offers a practical planning framework that can be applied to other Himalayan basins before committing to detailed project development.