ISSN: 0973-4929, Vol. 18, No. (3) 2023, Pg. 1345-1355

Current World Environment

www.cwejournal.org

# Climate Extremes and Sustainability Issues: A Case of Proposed Hydropower Projects in Lahaul Valley, Himachal Pradesh

**VISHWA B.S. CHANDEL* and BEANT SINGH RANA**

[1]Department of Geography, Panjab University, Chandigarh, India.

**Abstract**

Water and energy are the key to development; however, a great deal of contestation is at the very core of hydropower and sustainability debate in the context climate change and risk of disasters. A vast potential for renewable energy in the Himalayas has led to planning for hydropower projects since 1990s. However, social, economic and environmental issues linked to such development has also led to a fear among local communities in light of climate change. This study analysed the relation between climate extremes, disaster risk and hydropower development in Lahaul Valley of Himachal Pradesh. The study examined long-term climate data for precipitation and temperature trends while daily rainfall gridded data was used for the analysis of climate extremes. The results show statistically significant increase in precipitation intensity and rise of winter and post winter temperature. Also, heavy and very heavy rainfall days, daily rainfall intensity shows increasing trends that may have serious repercussions on local economy, livelihood and hydropower development. The field observations reveal discontentment of local population to proposed development. It is important that this debate must be reviewed logically to ensure safe future of the area with sound understanding of disasters and climate change risk.

**Article History**

Received: 23 August 2023

Accepted: 21 November 2023

**Keywords**

Climate Change; Himalayas; Hydropower; Risk; Sustainability.

## Introduction

The culmination of the twentieth century marked the fruition of globalisation and liberalisation around the world. The developing nations took a leap forward to boost their economy and began to make their presence felt globally. The visible impacts on external trade in India showed doubling of the ratio of total exports to GDP from 7.3 percent in 1990 to 14 percent in 2000.[1] Realising the fact that countries like India and China are not only the biggest markets but also leading the production and global trade, a new world order is in the making. A huge market potential,

**CONTACT** Vishwa B.S. Chandel vishwa.geoinvader@gmail.com Department of Geography, Panjab University, Chandigarh, India.



Doi: https://dx.doi.org/10.12944/CWE.18.3.34

lower production costs, low-wage skilled labour, and self-reliant technology have positioned India as a major contributor and a global production hub of goods and services. Consequently, the economy has grown considerable in past decades[2,3]

One of the key drivers for economic growth is energy resource; economies depend on energy and development is inseparable of energy.[4] In fact, two vital and interlinked factors of economic development and political discourse relate to energy and water. These are not only the most sought resources but also have been the bone of contentions between countries and economies. At the same time, these issues occupy a central position in ongoing society-economy-environment debates. The reasons are but obvious; the word 'development' in contemporary capitalist world order, is incomplete without energy and water. Every country, economy, and people rely on these resources that dictate global politics and diplomacy.

A key challenge to contemporary development vision is the risk posed by climate change and resultant sustainability issues. Water resource is at the core of sustainable development issues and goals. Be it the agricultural sector, energy or any significant aspect of economy, water is undoubtedly the crucial component. With observable climatic changes not only the global water cycle and precipitation patterns is being impact but also posing threat to a wide range of aspects, viz. food security, affordable energy, health and hygiene, and ecology.[5] The impacts might be far reaching and impacting human vulnerability in terms of water stress and conflicts, governance, climatic change driven refugees, and socio-economic injustice.[6] In this context, our current and future economic development is greatly dependent on expected environmental challenges. Therefore, the global commitments on environmental protection, combating climate change, and disaster risk has pushed humanity to look for safer ways of sustained energy. The emergence of hydropower as key resource stems from the fact that demands for energy have escalated manifold in past few decades while conventional sources are neither available to all nor sufficient. However, these definitely are ecologically hazardous.[7,8] The fossil fuel based non-renewable sources have led to an ecological crisis. The projected impacts are even more damming. In this era of anthropogenically triggered climate change and escalating disaster risk, humanity is obligated to keep the global pledge on reducing carbon footprints by gradually turning to green energy.

In the quest for sustainable energy, hydropower seemed a reliable option to ensure uninterrupted energy supply without damaging the ecological.[9] India too, has been pushing for hydropower to boost its economy and ensure ecological sustainability. In early post-independence era, the first Prime Minister of India Jawaharlal Nehru symbolised and personified large dams as 'Temples of Modern India'.[10] Gradually, the country attained third position globally in terms of large dam construction. Since 1990s, our energy production and consumption increased massively by 104 per cent and 459 per cent, respectively. India's energy consumption has more than doubled since 2000 while electricity consumption has nearly tripled.

Currently, as fourth-largest global energy consumer, India would surpass European Union to reach at third position by 2030.[11] Despite a marked progress in energy production, its deficit continues to escalate as its demand for industry, agriculture and domestic use is disproportionately higher than its production. It is for this reason, the country is committed to hydropower development; endowed with immense possibility of hydropower, India has been ranked fifth globally for its usable potential, however, only a fourth of this was developed till the first decade of 21$^{st}$ century.[12] India, post 2000, has prioritized and strategized to boost its energy production through hydropower projects. The country is expected to achieve 40 per cent of its installed capacity from this renewable resource by 2030. For this, the majority of hydropower projects were commissioned in the Himalayan states of abundant water stored in the glaciers and flowing through several big and small perennial rivers.

Like any other complex reality, this fairy-tale of green-clean hydropower has a darker side. Through this paper, we intended to draw the attentions about sensitive linkages between climate change interface and hydropower development in the Lahaul Valley of Himachal Pradesh which has been one hot-spot of proposed hydropower projects. The objective of this paper is twofold. Firstly, the research seeks to examine the nature and magnitude of change in key climatic parameter, i.e., rainfall and its extremes in the study area, and secondly to place any such observed changes in the context of implications for proposed hydropower projects in the area. In doing so, we intend to debate the ongoing development paradigm in light of climate change and sustainability issues in a mountainous tribal area.

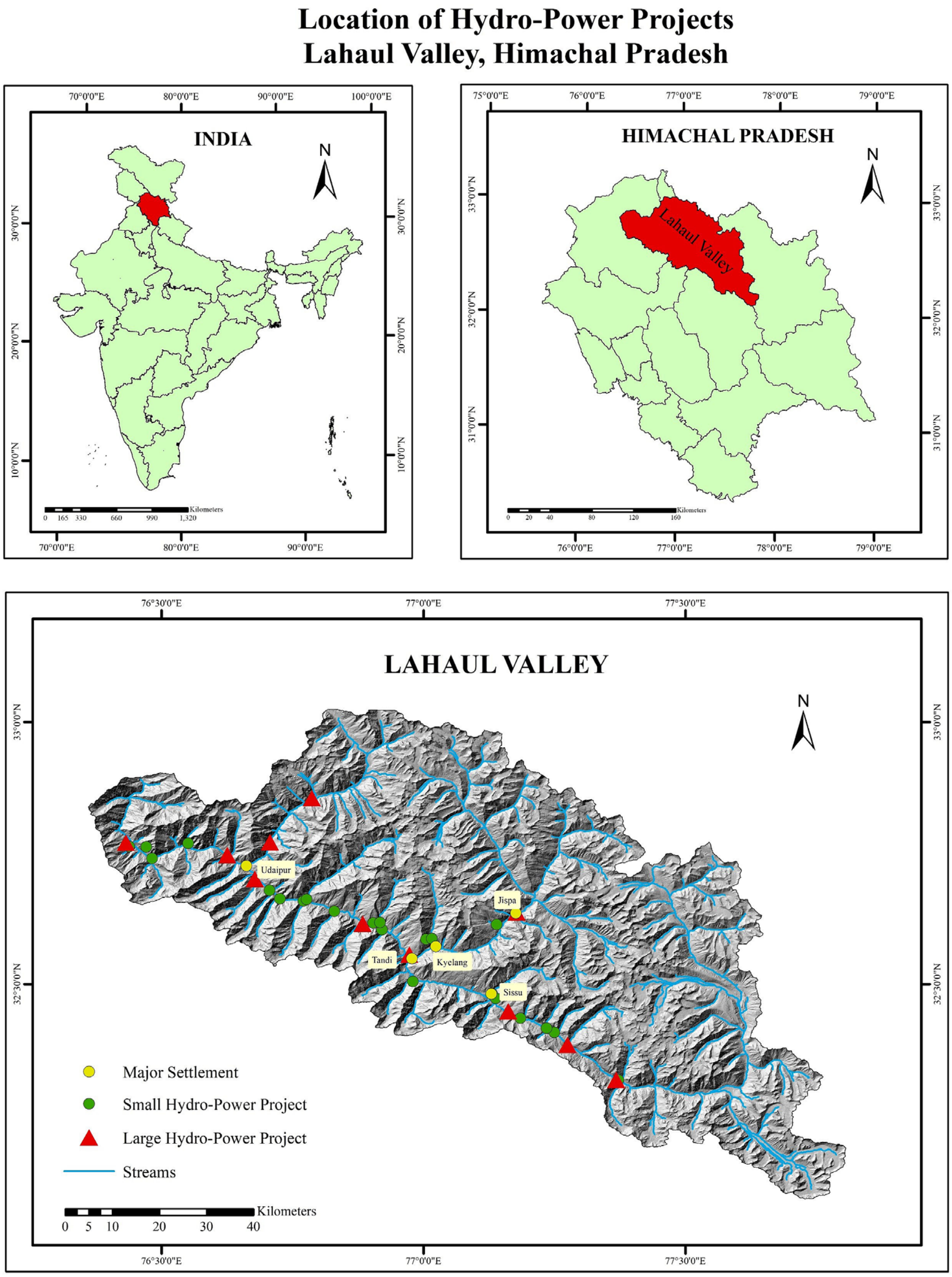


**Fig. 1: Study Area and Location of Proposed Hydropower Projects**

**Source:** Dem: Alos Palsar; Survey Of India Toposheet (1:50,000)

## Study Area

Lahaul valley of Himachal Pradesh is a tribal enclave drained by glacial fed River Chandra and Bhaga (together these form River Chenab) and their countless tributaries originating the higher Himalayas. Bounded by high mountains, i.e., the Great Himalayas in the east and northeast and the Pir-Panjal range of the middle Himalayas in the south and southwest, Lahaul valley exhibits a wide range of topographic variations. An ample supply of water in its snow and glacial fed streams is the reason this area has been marked as a hot-spot for hydropower project development. More than 70 percent of its area is above 4000 meters above the mean sea level; only 5 per cent area along the narrow valley zone and adjacent river terraces is suitable for human habitations that support nearly 19107 people.[13] Despite a harsh cold climate during winters and a short duration growing season (April-September), the first wave of development led to commercial agriculture in this area since late 1980s. Consequently, this valley became an economically prosperous region. The basic infrastructure, however, remained neglected till recent. During the first decade of 21st century, this area became an important site for mega and micro hydropower projects (Figure 1) that were sanctioned considering its high potential for renewable energy production. As many as 34 hydropower projects with a total capacity above 2,000 MW were sanctioned for this area since 2000; some of these are mega projects exceeding 100 MW capacity. Almost every possible tributary stream along River Chenab has also been marked for hydropower.

Lately, the opening of long-awaited tunnel to Lahaul Valley in October 2020 is further enabling faster execution of hydropower projects alongside promotion of tourism in the area. Consequently, this tribal enclave is likely to witness hydropower development as next economic venture with a promise of prosperity to land and its people. However, this seemingly green hydropower is not as safe as it is generally perceived considering the nature of climatic changes and resultant disaster risk in the area. In this paper, we have discussed the aspects of climatic changes and extreme precipitation events in the context of its implications for hydropower project and overall development of the valley.

## Material and Methods

This study is based on two types of climate datasets- long-term climate data and gridded data. The long-term climate data (1901-2020) of IMD station located at Keylong (the administrative headquarter of Lahaul & Spiti district) was examined for precipitation and temperature trends. For precipitation analysis, researcher computed annual and seasonal rainfall trend, rainy days and rainfall intensity. The long-term temperature conditions were examined in terms of change in temperature parameters. The trends were analysed in terms of deviations from the mean, standard deviation and coefficient of variation whereas the direction of change and significance levels were evaluated using the Mann-Kendall and Sen's Slope tests. The former is a non-parametric procedure suitable for skewed variables[14,15] that is used for non-normally distributed data (such as the climate parameters) containing outliers.[16] The second method used is also a non-parametric method used for analysing magnitude and trend in time series data.[17,18]

The analysis of precipitation extreme events is based on daily rainfall gridded data from 2000-2021 collected from the India Meteorological Department (IMD) at a spatial resolution of 0.25 degree. The data is pre-processed using Shephard's Interpolation and hence homogenous. A total of 17 grid points covering the Lahaul valley were analysed for following precipitation extreme indices using the gridded dataset. The evaluation of rainfall extremes (2000-2021) is based on Sector Specific Climate Indices (ET-SCI) given by the Commission for Climatology (CCI-17, 2018) of World Meteorological Organization. These indices were developed by experts from agriculture, health and water sectors. The long-term precipitation data was analysed using *Climpact* software for twelve select indices of precipitation extremes (Table 1). These indices provide information of duration (CDD and CWD), intensity (PRCPTOT, Rx1day, Rx3day, Rx5day, R95pTOT, R99pTOT and SDII) and frequency (R10mm, R20mm and R30mm) of extremes events. The selected extreme indices have been calculated annually.

**Table 1: Description of Indices of Precipitation Extremes**

| Parameter | Description |
|---|---|
| Consecutive Dry Days (CDD) | It defines the length of dry period, i.e., number of consecutive days wherein daily precipitation amount remains below 1 mm |
| Consecutive Wet Days (CWD) | It defines the length of dry period, i.e., number of consecutive days wherein daily precipitation amount remains above 1 mm |
| Annual total wet-day precipitation (PRCPTOT) | Total amount of precipitation from wet days during a year |
| Very heavy rain days (R10) | Number of days in a year when precipitation remains above 10 mm per day |
| Very heavy rain days (R20) | Number of days in a year when precipitation remains above 20 mm per day |
| Customised index for rain days (R30) | Number of days in a year when precipitation exceeds 30 mm per day |
| Daily PR intensity (SDII) | The total precipitation from wet days divided by total number of wet days during the given period. |
| Rx1day (Maximum One day precipitation) | The maximum daily rainfall during the given period. It is measured in millimetre |
| Rx3day (Researcher defined consecutive days precipitation) | The maximum three-day rainfall during the given period. It is measured in millimetre |
| Rx5day (Maximum five -day precipitation) | The maximum five-day precipitation during the given period. It is measured in millimetre |
| R95pTOT (Contribution of very wet days) | Precipitation in those days wherein daily precipitation is above the $95^{th}$ percentile. It is computed as: R95pTOT = R95p/PRCPTOT×100 |
| R99pTOT (Contribution of extremely wet days) | Precipitation in those days wherein daily precipitation is more than $99^{th}$ percentile. It is computed as: R99pTOT = R99p/PRCPTOT×100 |

The results obtained from secondary data sources were interpreted in the context of location of hydropower projects and implication on proposed hydropower projects and people in the valley. For this purpose, researcher conducted field-work to understand the local context and reality of issues related to climate change, disaster risk and on ground implementation of hydro-projects in the valley. To understand the social context to hydropower development and likely implications of climate change for this rural tribal setup, primary information was collected through interviews and discussion with local community, people/societies that were sanctioned power projects, people employed with hydro-power societies, and people protesting against the power projects groups. The discussion is presented under three heads: first deals with long term variations in rainfall and temperature patterns during since the beginning of $20^{th}$ century followed by a detailed analysis of rainfall extremes in past 20 years. Finally, the analysis collates observed change scenario with its implications for proposed hydropower projects and people of Lahaul Valley.

## Results and Discussion

### Long Term Climatic Changes in Lahaul Valley

The study area exhibits strong topographic influence on its climate; its high altitude above the mean seal level (average altitude of 3000 meters) and location on the leeward slopes of the Pir-Panjal range that limits the further movement of monsoon winds makes the valley cold semi-arid in character with severe harsh winters and heavy snowfall. The impact of its interior continental location is evident from the general climatic conditions.[19] The overall annual rainfall in this region is less than 600 mm with a higher inter annual fluctuations exceeding over 1000 mm. The uncertainty in rainfall is evident from its exceedingly higher standard deviation by 250 point and coefficient of variability (> 40 percent) which means less dependable and highly fluctuating precipitation. The area does not show significant change in annual rainfall over past 100 years; though it has increased (statistically non-significant) by 0.17 mm/year. The number of rainy days has declined (-0.12 days/year) since 1901 (Zs= -2.0, statistically significant change). A slight increase in rainfall and significant decline in rainy days thus has resulted in statistically significant (Zs= 3.2) increase in rainfall intensity (0.4 mm/decade). The seasonal patterns also confirm increase in rainfall intensity during winter, post-winter, summer, and monsoon seasons while no change is observed in post-monsoon season. These trends show spiraling up of the potential for rainfall extremes in the area.

The long-term analysis of temperature conditions shows that Lahaul Valley has recorded consistent warming in past 100 years; the trends are statistically significant (Zs >2.96). The annual mean and mean minimum temperature have increase by more than 0.6 degree Celsius whereas annual mean maximum has increased by half a degree.[20] The same is true for seasonal temperature trends. A statistically significant high magnitude of winter (+1.1°C) and post winter (+1.2°C) warming is observed in the valley; summer and post monsoon temperature has increased by 0.3-0.6°C. The monsoon season, however, shows a slight cooling (0.2°C) since last century. Such trends of temperature increase especially in the winter, post-winter and summer seasons in this cold-arid region indicate low accumulation of winter snowfall and high ablation rates. This is likely to escalate river discharge during post-winter and early summer season. Such a scenario is not good signs for horticulture and hydropower development in the area.

**Precipitation Extremes in Lahaul Valley**

The spatial distribution of precipitation extremes shows that majority of indices have high annual average values in the north-west part, moderate in the central part and low in the southwest part of the Lahaul Valley, except for R95pTOT and R99pTOT indices. For very wet days (R95pTOT), the annual average value is high in the north-western parts whereas extremely wet day (R99pTOT) has high value in central parts of the study area. The analysis suggests that the length, occurrence and magnitude of extreme rainfall events have been significantly higher in northwestern parts, moderate in the central and low in the south-western Lahaul Valley.

**Table 2: Precipitation Extreme Indices: Trends and Significance Level (2000-2021)**

| Indices | Unit | Average | Min | Max | Trend (Linear) | Sen-Slope | M-K Test (z-value) | M-K Test (p-value) |
|---|---|---|---|---|---|---|---|---|
| CDD | Days | 40 | 18 | 90 | Negative | -0.4545 | -0.9595 | 0.3373 |
| CWD | Days | 12 | 6 | 28 | Negative | 0 | -0.2275 | 0.82 |
| PRCPT | mm | 979.11 | 563.312 | 1448.18 | Positive | 8.2312 | 1.579 | 0.114 |
| SDII | mm/Day | 8.18 | 5.87 | 12.43 | Positive | 0.1059 | 2.2558 | 0.02408 |
| Rx1day | mm | 55.67 | 32.18 | 132.5 | Positive | 0.4523 | 1.0151 | 0.31 |
| Rx3day | mm | 97 | 57.07 | 192.91 | Positive | 0.49104 | 0.33838 | 0.7351 |
| Rx5day | mm | 110.47 | 69.28 | 203.95 | Positive | 0.1299 | 0.0564 | 0.955 |
| R95pTOT | Per cent | 21.73 | 6.99 | 44.02 | Positive | 0.5935 | 2.0303 | 0.04233 |
| R99pTOT | Per cent | 6.57 | 0 | 25.16 | Positive | 0.2014 | 1.0715 | 0.2839 |
| R10mm | Days | 31 | 16 | 49 | Positive | 0.5 | 1.6946 | 0.0901 |
| R20mm | Days | 11 | 5 | 19 | Positive | 0.2308 | 1.5935 | 0.111 |
| R30mm | Days | 4 | 1 | 10 | Positive | 0.1429 | 1.9551 | 0.0505 |

The variations in precipitation indices over a period of time has been calculated from the base year 2000 and time series graphs were plotted for all indices for 22 years from 2000 to 2021. The duration indices, viz. CDD and CWD shows an overall declining trend (Table 2 and Figure 2-a, b) meaning a lesser frequency of consecutive dry and wet spells except for some areas in the northwest, central and southeast. The reduced duration of these suggests temporal concentration of precipitation. This scenario becomes apparent by the trends in the spatial distribution of change in intensity indices (PRCPTOT, SDII, Rx1day, Rx3day, Rx5day, R95pTOT, and R99pTOT). These indices show increasing trend in the daily precipitation amount and intensity (Figure 2-c, d) especially in northwestern Lahaul Valley. More importantly, the indices confirm increasing contribution in 1-day, 3-day and 5-day maximum rainfall (Figure 2-e, f, g). It is found that the impact of very wet and extremely wet days (Figure 2-h, i) has also increased.

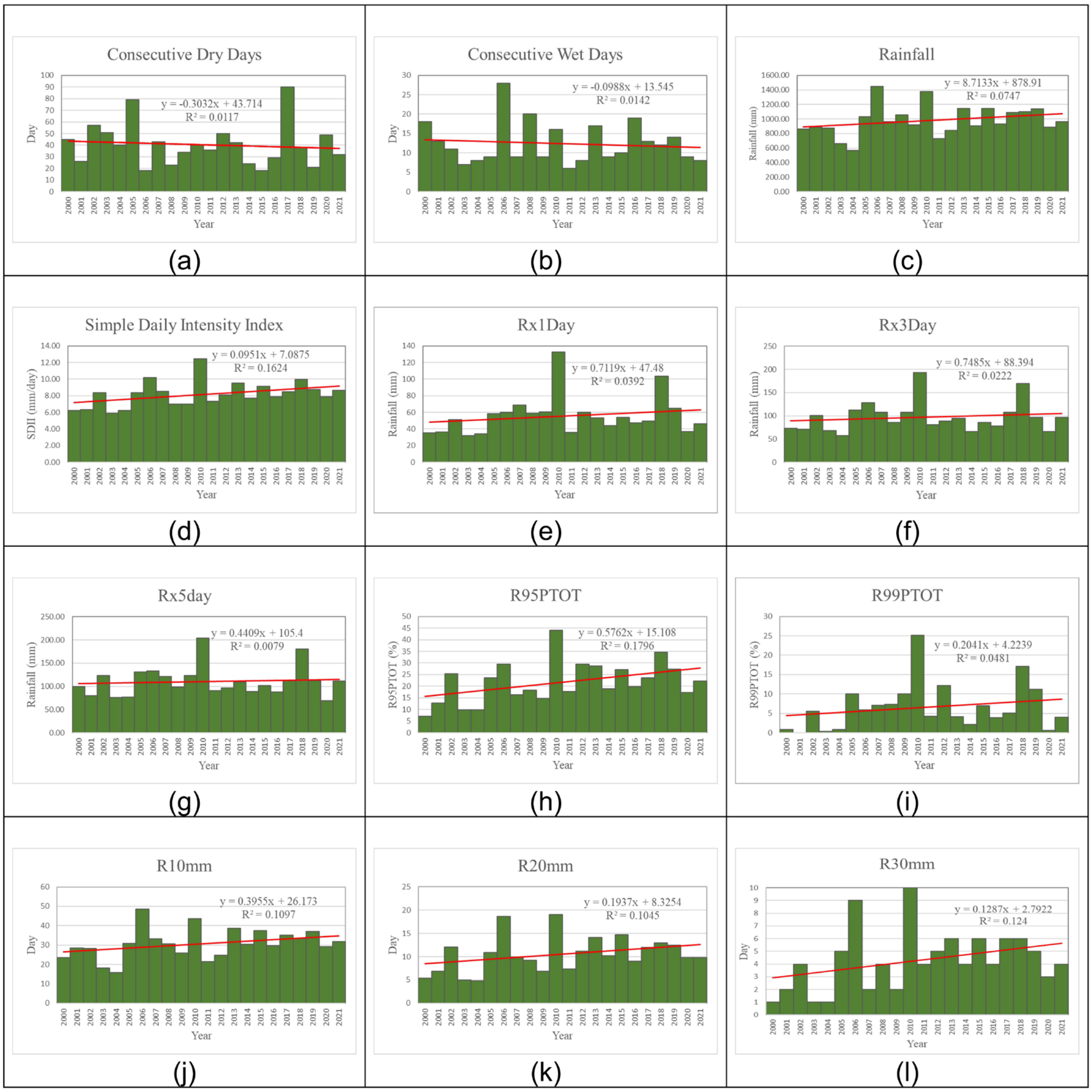


**Fig. 2: Precipitation Extreme Indices- Temporal Distribution and Trends**

The equally significant is the trends of frequency indices (R10mm, R20mm, R30mm) which also show overall change is in a positive direction, i.e., increasing frequency of spatial and temporal distribution. The study area is a semi-arid cold region with a low annual precipitation. However, increasing episodes of extreme precipitation exceeding 30 mm in one day has drastically increased and so is the occurrence of events receiving daily precipitation of 10mm and 20mm. Of the total indices, SDII, R95pTOT, R30mm and R10mm shows statistically significant increasing trends whereas total precipitation and R20mm exhibit near statistical significance. The others are not statistically significant but points towards escalation of extreme precipitation incidences. Hence, a simple conclusion can be drawn that precipitation extremes in the area has become stronger during past 2 decades thus has amplified the probability of extreme events related to flash-floods, cloudbursts and excess of water in a shorter span of time. The frequent occurrence of such events might have severe implications on the key sectors of local economy in Lahaul Valley.

### Climate Change Implications for Hydropower Development and Sustainability

The observed trends in long-term climatic parameters and recent precipitation attributes pose a worrisome picture for hydropower development in the area. The area has 34 sanctioned hydropower projects with capacity above 2,000 MW. Many of these that are proposed on the main rivers of Chandra and Bhaga large size power projects, such as the Reoli-Dugli hydropower project (420 MW), Seli Hydroelectric Project (400 MW), Gyspa hydropower project (300 MW), Rashil hydropower project (130 MW), Bardang hydropower project (126 MW), Tandi hydropower project (104 MW), and Chatru project (120 MW) etc. The others fall in the category of medium size, small, mini and micro hydroelectric power projects are to be built on tributary streams. One of the basic conditions for the full utilisation of hydro-projects is to have a consistent supply of water throughout the year. However, observed trends of warming of winter and post-winter seasons is likely to cause huge flux in tributary streams during early summers while late autumn the water availability may get reduced. Both scenarios may not be conducive for the functioning of micro and mini hydro-power projects. More importantly the precipitation shows increasing trends along with the escalation of rainfall intensity. This situation is problematic from the perspective of extremes events. The researchers observed such situations during the field-work in June 2022 and May 2023. In the first visit, researcher witnessed flashfloods in some of the tributary streams where small hydro-power projects are proposed. A short duration intense rainfall led to massive flow in streams that caused massive damages and slope erosion. In another events, a massive landslide dammed River Chenab for few hours that submerged some settlement and agricultural land. Similarly in the month of July 2023, there were incidents of flooding and extremely high stream flow at places in the valley. Unfortunately, many of these locations are for hydropower projects. Such variability in the flow regime of streams makes power production. Moreover, it also raises the issue of siltation and high soil sediments in the water that may render turbines non-functional particularly in case of small power projects.

Associated with this is another issue of potential glacial lake outburst floods. The valley is under constant threat of increasing lake size in higher reaches that may make the hydro-power projects a riskier venture. Due to climatic changes, some of the lakes have grown in size which during any extreme precipitation event may trigger unprecedented flooding in the valley. This bring into light the risks involved with development of hydropower projects; we are borne witness to recent Chamoli floods of February 2021 in Uttarakhand; flash floods and landslides in Kullu, Kinnaur and Lahaul & Spiti districts of Himachal Pradesh in July-August 2021 and July 2023 where massive damage to infrastructure was caused by extreme events.

As these hydro-power projects has begun to materialise, another side of the story is unfolding that relates to serious environmental and social implications. Local community in Lahaul Valley has already been gearing up for opposing the hydro-power development in the area. People are raising objection to these projects as it might not only cause ecological problems but also may cause displacement of tribal people, social injustice and political-social conflicts. The voices from local communities across the Himalayan landscape echoes fear and rejection to hydropower projects in the light of climate change, disaster risk and indiscriminate development. The interviews and discussions conducted by researcher with the people and community representatives reveals concerns regarding loss of cultivable fertile land, bureaucratic hurdles in executing allocated community based micro power projects, and impacts of local farming community. It was found that all sanctioned small and micro projects allocated to local people/societies have not completed the initial survey process. Many have not even initiated the process yet. The lack of management skills, insufficiency of funds, technical expertise are the key challenges for the execution of these projects. People are apprehensive of impacts on their commercial farming and tourism activities that for them has been a boon so far. The fear of losing their existing livelihood is one of the prime reasons for their opposition to hydro-power projects.

So far, the researchers during the field survey found two divergent view-points. Local people in favour of hydro-power development feel it would bring economic prosperity to the valley but are not clear about the procedural requirements, financial and technological knowhow. For them such development would bring more resources, better infrastructure and employment opportunities and diversification in local economy. The opposing segment, however, is skeptical of this development model. People are apprehensive of issues related to climate change, disasters, loss of land and local economy. However, they lack objective and substantial scientific basis of these challenges. It is, therefore, important to examine the ground reality of hydropower development, risk and resilience of the community, and economically viable and sustainable ways of organising the resources of the area.

## Conclusion

At the juncture, Lahaul valley appears to in a state of dilemma in context of hydropower development and visible signs of climate change and disasters. This ultimately translate in a larger context of sustainable development. The emerging problems that link hydropower development and climate change relates to water discharge uncertainty in winter and post winter seasons for a sustainable power generation. The high ratio of siltation in stream water and turbine functioning for power generation are the key issues during early summers and monsoon. In light of observed scenario of climate extremes in the valley, it is likely that the overall development of hydropower projects might get affected due to the increased risk of disaster occurrence. Another key issue relates to shift in economic development from already established commercial farming and self-generated livelihoods in favour of hydropower production. Here, emerging concerns and environmental contestations regarding reliability of projects in terms of safety and risk are the points of local opposition that needs to tackled. Local community is apprehensive of the outside world that is powerful and resourceful. People fear losing their land and local livelihoods with the establishment of hydropower projects. This has created a situation of predicament that has halted the process of hydro-power development. It would be interesting to see how the government and local people would negotiate these issues and challenges. Only time would tell if this valley would choose 'dams for people' or 'dam vs people' scenario for a sustainable future of the Valley.

As a way forward, to this state of dilemma, researchers suggest a balanced approach to economic development in the valley. First and foremost, a detailed analysis of climate regime, hydrological aspects, and disaster potential must be carried out to have a scientific base for determining the sensitivity and magnitude of risk. It must be followed by a viability analysis of both large and small hydropower projects in terms of their impacts on land, exposure to extreme events, and economic benefits that the area would receive. Here, is also important that the social contexts in terms of local livelihood opportunities and ecological implications, viz. impact on key resources, i.e., land and water are also taken into consideration.

## Acknowledgements

The work is part of ongoing major research project awarded by Indian Council for Social Science and Research (ICSSR) New Delhi. The authors are grateful to ICSSR for generous funding that enable researchers to carry out this study.

## Funding

The work is funded by Indian Council for Social Science and Research (ICSSR), New Delhi vide letter F.No.02/105/GN/2021-22/ICSSR/RP/MJ.

## Conflict of Interest

The authors declare no conflict of interest.

**References**


1. Panagariya A. India in the 1980s and 1990s: A Triumph of Reforms. *IMF Working Paper.* 2004; (43): 1-36. https://doi.org/10.5089/9781451846355.001
2. Agarwal A. India in The World Economy. *Review of Market Integration.* 2010; 2(2-3): 181-228. https://doi.org/10.1177/097492921000200302
3. Kumar S. The growth of Dynamic India - India becomes fifth largest economy. New Delhi, India: *Research and Information Division,* LARRDIS; 2022. 10.
4. Dai L., Jia R., Wang X. Relationship between Economic Growth and Energy Consumption from the Perspective of Sustainable Development. *Journal of Environmental and Public Health.* 2022; 2004: 10. https://doi.org/10.1155/2022/6884273
5. Sukanya S., Joseph S. Climate change impacts on water resources: An overview. In Editor(s): Srivastav A, Dubey A, Kumar A, Narang S. K, Khan M. A. Visualization Techniques for Climate Change with Machine Learning and Artificial Intelligence, *Elsevier,* 2023: 55-76, ISBN 9780323997140, https://doi.org/10.1016/B978-0-323-99714-0.00008-X.
6. Immerzeel W. W., Lutz A. F., Andrade M., Bahi A., Biemans H., Bolch T., Hyde S., Brumby S., Davies B. J., Elmore A. C., Emmer A., Feng M., Fernández A., Haritashya U., Kargel J. S., Koppes M., Kraaijenbrink P. D. A., Kulkarni A. V., Mayewski P. A., Nepal S., Pacheco P., Painter T. H., Pellicciotti F., Rajaram H., Rupper S., Sinisalo A., Shrestha A. B., Viviroli D., Wada Y., Xiao C., Yao T., Baillie J. E. M. Importance and vulnerability of the world's water towers. Nature. 2020; 577(7790): 364-369.
7. Bildirici M. E., Bakirtas T. The relationship among oil, natural gas and coal consumption and economic growth in BRICTS (Brazil, Russian, India, China, Turkey and South Africa) countries. *Energy.* 2014; 65: 134-144. https://doi.org/10.1016/j.energy.2013.12.006
8. Bildirici M., Ozaksoy F. Woody Biomass Energy Consumption and Economic Growth in Sub-Saharan Africa. *Procedia Economics and Finance.* 2016; 38: 287-293. https://doi.org/10.1016/S2212-5671(16)30202-7
9. Ummalla M., Samal A. The impact of hydro -power energy consumption on economic growth and $CO_2$ emissions in China. *Environmental Science and Pollution Research.* 2018; 25: 35725-35737. https://doi.org/10.1007/s11356-018-3525-6
10. Raina V. Why People Oppose Dams: Environment and Culture in Subsistence Communities. *Inter-Asia Cultural Studies.* 2000; 1(1): 145-161. https://doi.org/10.1080/146493700361051
11. IEA. India Energy Outlook 2021-World Energy Outlook Special Report. 2021. https://iea.blob.core.windows.net/assets/1de6d91e-e23f-4e02-b1fb-51fdd6283b22/India_Energy_Outlook_2021.pdf
12. Ramanathan K., Abeygunawardena P. Hydropower Development in India: A Sector Assessment. *Asian Development Bank*; 2007. 70.
13. Census of India. 2011. District Census Handbook, Series-03, Part-XII-A. District Census Handbook Lahaul and Spiti, Village & Town Directory. Director of Census Operations: Himachal Pradesh.
14. Mann H. B. Non-parametric test against trend. *Econometrica.* 1945; 13: 245-259.
15. Kendall M. G. Rank Correlation Methods, 4th ed. London: Charles Griffin; 1975.
16. Helsel D. R., Hirsch R. M. *Statistical methods in water resources.* New York, NY: Elsevier Science; 1992.
17. Tabari H., Marofi S. Changes of pan evaporation in the west of Iran. *Water Resources Management.* 2011; 25: 97–111.
18. Tabari H., Somee B. S., Zadeh M. R. Testing for long-term trends in climatic variables in Iran. *Atmospheric Research.* 2011; 100(1): 132–140.
19. Sharma M., Brar K. K., Chandel V. B. S. Long-Term Analysis of Trend and Variability in Annual Rainfall in Punjab and Himachal Pradesh. *The Deccan Geographer.* 2017; 55(1,2): 1-16.

20. Sharma M., Chandel V. B. S., Brar K. K. Punjab and Himachal Pradesh: Temperature Variability and Trends since 1900 AD. *Punjab Geographer.* 2018; 14: 5-32. https://www.punjabgeographer.org/journals/readmore/vol14/punjabgeographer-vol-14-2.pdf