Gandaki Province Policy and Planning Commission
Gandaki Province Government
Pokhara, Nepal

Final
Technical Report on

Preparation of Climatic Atlas of Gandaki Province, Nepal

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Kirtipur, Kathmandu, Nepal

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EXECUTIVE SUMMARY

This technical report, along with the ***Climate Atlas of Gandaki Province ("गण्डकी प्रदेशको जलवायु मानचित्र")***, provides a comprehensive foundation for understanding the region's evolving climate and its implications across critical development sectors. Based on quality-controlled observational data from 1981 to 2024, the project presents a spatially detailed overview of long-term temperature and precipitation patterns. It combines high-resolution climatological mapping, extreme weather analysis, and focused sectorial assessments to support risk-informed planning and climate resilience strategies at the provincial level.

Using a robust network of meteorological stations selected for data continuity and reliability, the study produced monthly, seasonal, and decadal climate surfaces across Gandaki's diverse landscapes. In addition to baseline climatology, the report analyzes five extreme precipitation indices: R1mm, R99p, Rx3day, CWD, and CDD, based on internationally recognized ETCCDI standards. These indices reveal short-duration rainfall extremes and extended dry spells, reflecting exposure to climate-related hazards such as floods, droughts, and landslides.

The findings confirm a persistent warming trend across the province, most strongly observed in the southern lowlands and mid-hills but also evident in high mountain regions. Precipitation remains highly variable, with annual rainfall exceeding 5,000 mm in Lumle and falling below 300 mm in Mustang. Although overall precipitation trends have remained relatively stable, localized intensification and shifting rainfall timing are increasing vulnerability, particularly where natural buffers and adaptive capacity are limited.

Sectorial analyses provide further insights. In Nawalpur, rising temperatures, erratic rainfall, loss of cropland, and shrinking water-retention features have reduced agricultural resilience. While some crops such as maize and spring rice show relative climate tolerance, key staples like paddy and wheat remain highly sensitive to warming and moisture stress. In Kaski, temperature-driven water loss, declining river discharge, and rapid population growth are generating systemic water stress, threatening irrigation, hydropower, and dry-season supply. Urban areas across the province are increasingly exposed to heat island effects, erosion, flooding, and landslides due to land cover changes and expanding settlements. In Mustang, household surveys highlight rising climate risks, repeated disaster experiences, climate-induced migration, and critical gaps in preparedness and insurance coverage, despite strong community willingness to engage in future resilience efforts.

While this atlas provides a strong spatial and temporal baseline, data scarcity in high-altitude and remote areas limits the precision of spatial representations. Expanding the observation network and integrating satellite and model-based datasets are necessary for improving future climate assessments and supporting more localized planning.

To remain effective, the atlas should be maintained as a dynamic resource and periodically updated with new data, improved interpolation techniques, and observed climatic shifts. Further sector-specific research is needed to translate broad climate signals into actionable strategies, including detailed assessments of agricultural impacts, hydrological shifts, infrastructure vulnerability, and community-level risk. Strengthening communication and accessibility of climate information is essential, particularly through capacity-building efforts, decision-support tools, and simplified formats tailored for local governments and communities.

Finally, deeper collaboration among academia, policy makers, development agencies, and grassroots stakeholders will be key to embedding climate knowledge into adaptation planning and sustainable development efforts across Gandaki Province.

Together, this report and the accompanying atlas establish a critical reference point for understanding climate change impacts and guiding evidence-based decisions for a more resilient provincial future.

ACKNOWLEDGEMENTS

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Finally, we express our heartfelt gratitude to the entire project team. Their dedication, technical expertise, and collaborative spirit across data analysis, cartography, writing, fieldwork, and design were crucial to the successful completion of this atlas, and reflect a shared commitment to advancing climate understanding in the region.

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1. Introduction

1.1. Background Information

Climate change represents one of the most profound challenges of our era, driven primarily by anthropogenic greenhouse gas emissions from fossil fuel combustion and land-use changes. It manifests through rising temperatures, shifting precipitation regimes, and intensifying extreme events such as droughts, floods, and heat waves (IPCC, 2007; IPCC, 2023). While large natural variability can obscure detection in the short term, long-term observational records and model simulations consistently reveal a persistent human-induced signal. Even a modest global temperature increase of 1°C has demonstrable impacts on ecosystems and societies (Santer et al., 2011; Deser et al., 2010). The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) confirms that global surface temperatures have already risen by approximately 1.1°C since pre-industrial times, intensifying the hydrological cycle and increasing the frequency of compound hazards globally (IPCC, 2023). To distinguish secular trends from short-term noise, the World Meteorological Organization emphasizes the use of 30-year climate normal, now considered essential for climate risk assessment and local adaptation planning (WMO, 2011; WMO, 2017).

These shifts are particularly consequential in mountainous regions like the Himalayas, where steep topography, ecological sensitivity, and socio-economic dependence on climate-sensitive resources amplify climate risk (Eriksson et al., 2009). In recent decades, the Himalayas have witnessed an increase in climate-related disasters such as landslides, flash floods, and extreme temperature events (Cho et al., 2016; Panday et al., 2014). However, the coarse spatial resolution of global climate models limits their relevance for sub-national decision-making, underscoring the need for downscaled, localized assessments (Rajbhandari et al., 2014; Lutz et al., 2014).

Nepal ranks among the world's most climate-vulnerable nations despite its negligible contribution to global emissions (ND-GAIN Index, 2022). Its vertical terrain-from the Gangetic Plains to the High Himalayas-compresses multiple climate zones into short distances, creating microclimates with distinct vulnerability profiles. Between 1971 and 2014, Nepal has warmed at a rate of approximately 0.056°C per decade, exceeding the global average and carrying profound implications for its cryosphere, water resources, and agriculture (DHM, 2017). Recent studies document accelerating glacier retreat in the

Gandaki, Koshi, and Karnali basins, threatening the water security of millions (Nie et al., 2021). Meanwhile, precipitation patterns reveal high spatial variability, further complicating climate response efforts. These shifts compound existing risks in Gandaki Province, where a significant portion of the population relies on climate-sensitive livelihoods and where infrastructure remains highly exposed to hydro-meteorological hazards. In the five years leading up to 2022 alone, climate-induced disasters in the province resulted in losses exceeding NPR 33.68 billion (Central Bureau of Statistics, Government of Nepal, 2022).

Gandaki Province epitomizes the Himalayan climate challenge. Spanning 11 districts and elevations ranging from 100 meters in Nawalpur to 8,167 meters at Dhaulagiri Peak, it encompasses Nepal’s wettest location (Lumle, ~5,500mm/year) and driest district (Upper Mustang, <300mm/year). This topographic and climatic diversity produces microclimates with differential exposure to climate change impacts. Over 70% of the province’s population depends on rain-fed agriculture, heightening vulnerability to erratic monsoons, glacier retreat, and seasonal water scarcity. Agricultural systems are disrupted by shifting growing seasons; hydropower infrastructure faces altered river regimes; and tourism routes are increasingly unstable due to landslides and other disasters. Trans-Himalayan districts such as Mustang report advancing desertification and water stress, while mid-hill settlements face escalating landslide risk from intense rainfall. Yet adaptation efforts remain hampered by fragmented datasets, a historical lack of standardized observations, and limited integration with sectorial planning frameworks.

Following the federal restructuring in Nepal, local governments have become the frontline institutions for planning and implementing climate resilience and disaster risk reduction (DRR) activities. Their proximity to communities, understanding of local contexts, and direct governance responsibilities position them as crucial actors in building resilient and adaptive societies. Despite their growing role, local governments often face limitations in executing effective climate and disaster-related actions due to a lack of meteorological information.

Therefore, the “Preparation of Climatic Atlas of Gandaki Province” project addresses critical knowledge gaps by systematically analyzing 44 years (1981-2024) of homogenized temperature and precipitation data from quality-controlled province level stations. Developed in alignment with WMO standards for 30-year climate normals, the *Climate Atlas of Gandaki Province (“गण्डकी प्रदेशको जलवायु मानचित्र”)* goes beyond conventional climatological summaries by examining long-term monthly, seasonal, annual, and decadal patterns. It also includes spatial analysis of climate extremes, including very wet days (R99p), multi-day heavy rainfall events (Rx3day), and dry and wet spells (CDD and CWD). All datasets were subjected to rigorous data rescue, quality control, and homogenization procedures to ensure spatial and temporal consistency. By combining robust climatological mapping with sectorial impact assessment and local context, the project lays a strong foundation for climate-informed planning and risk management across Gandaki Province.

In addition to presenting statistical climate summaries, this report and the accompanying atlas provide integrated insights into sector-specific climate impacts across Gandaki Province. These include yield sensitivity and changing crop performance in Nawalpur, hydrological stress and declining discharge in Kaski, and increased heat and flood risks in urban centers. The project also incorporates community-based knowledge, including local perceptions from Mustang, helping to ground scientific findings in lived experiences and practical challenges. This technical report documents the overall approach, key findings, and recommendations of the project, while the standalone atlas, developed as the central output, presents the complete set of maps and visual representations of long-term climate patterns. The report situates the validated outputs of the atlas within both the global climate science framework and the province level policy context. The methodology section details station selection, quality control, and spatial interpolation techniques. Subsequent chapters examine long-term trends and climate extremes across multiple timescales, followed by targeted analyses on agriculture, water resources, urban vulnerability, and community risk. By linking scientific evidence with local development priorities, this work equips the Province Policy and Planning Commission, municipalities, and other stakeholders with essential climate information to support risk-informed planning, targeted adaptation, and long-term resilience across Gandaki's diverse and climate-sensitive landscapes.

2. Objectives of the Assessment

The overall objective of this assessment is to prepare the *Climate Atlas of Gandaki Province (“गण्डकी प्रदेशको जलवायु मानचित्र”)*. The sub-objectives of the proposed project are as follows:

- To prepare the monthly climatology atlas of maximum, minimum and average temperature of the province.
- To prepare the seasonal climatology atlas of maximum, minimum and average temperature of the province.
- To prepare the atlas of decadal variation in maximum, minimum and average temperature of the province.
- To prepare the monthly climatology atlas of precipitation of the province.
- To prepare the seasonal climatology atlas of precipitation of the province.
- To prepare the atlas of decadal variation in precipitation of the province.
- To prepare the atlas of extreme precipitation Gandaki Proviance.
- To analyze the impact of climate change on agriculture in Nawalpur (East).
- To analyze the impact of climate change on water resources of Kaski district.
- To analyze the climate change impacts on urban and human settlements across Gandaki Province.
- To study the impact of climate extremes and people’s perception; a case study in Mustang district.
- To keep the record for future use of data from the research to province information and visualization system.

3. Methodology

3.1. Study Area

Gandaki Province, located in central Nepal (27°20’N-29°20’N, 82°52’E-85°12’E), spans 21,733 km² across 11 districts, covering Nepal’s full agro-climatic gradient from the subtropical Terai plains (100 m elevation) to the trans-Himalayan arid valleys and the Annapurna-Dhaulagiri ranges (8,167 m) (Figure 2). The province’s climatic diversity is stark: Lumle in Kaski District receives ~5,500 mm of annual rainfall, making it one of Nepal’s wettest regions, while Mustang’s arid valleys experience less than 300 mm/year, reflecting cold desert conditions. Hydrologically, the Kali Gandaki, Marsyangdi, and Modi River systems dominate the landscape, with their basins prone to monsoon driven flash floods and glacial lake outburst risks in high-elevation zones like Manang.

The Department of Hydrology and Meteorology (DHM) operates 113 meteorological stations across Gandaki, classified as agro-synoptic (7), agro-meteorological (21), precipitation only (58), climatological (19), and automatic weather stations (AWS, 8). Of these, 20 are temporarily non-operational and 1 is permanently closed, with active stations concentrated in agriculturally critical districts (e.g., Nawalpur, Kaski) and along hydropower corridors. The spatial unevenness of the station network, combined with extreme elevation gradients (Terai plains to Himalayas), necessitates advanced interpolation techniques to ensure representative climate mapping.

Socio-economically, the province relies heavily on climate sensitive sectors; more than half of its 2.4 million residents depend on rain-fed agriculture, while tourism (Annapurna Circuit, lakes in Pokhara) and hydropower contribute significantly to livelihoods. This interdependence amplifies vulnerabilities to hydro-meteorological extremes, including landslides in mid-hills, droughts in Mustang, and flooding in the Terai. Gandaki’s climatic heterogeneity, hydrological risks, and socio-economic exposure underscore the imperative for a spatially explicit climatic atlas to guide adaptation planning and disaster resilience.

3.2. Data Sources and Preprocessing

Daily maximum and minimum temperature records, along with daily precipitation and river discharge data for the period 1981-2024, were obtained from hydro-meteorological monitoring stations operated by the Department of Hydrology and Meteorology (DHM), Nepal. Land use and land cover (LULC) data covering the years 2000-2022 were sourced from Nepal's National Land Cover Monitoring System (NLCMS). Demographic and socioeconomic data used for sectorial analysis were drawn from the 2021 National Census of Nepal. All spatial datasets were geo referenced to the WGS 84 coordinate system to ensure compatibility for GIS-based analysis.

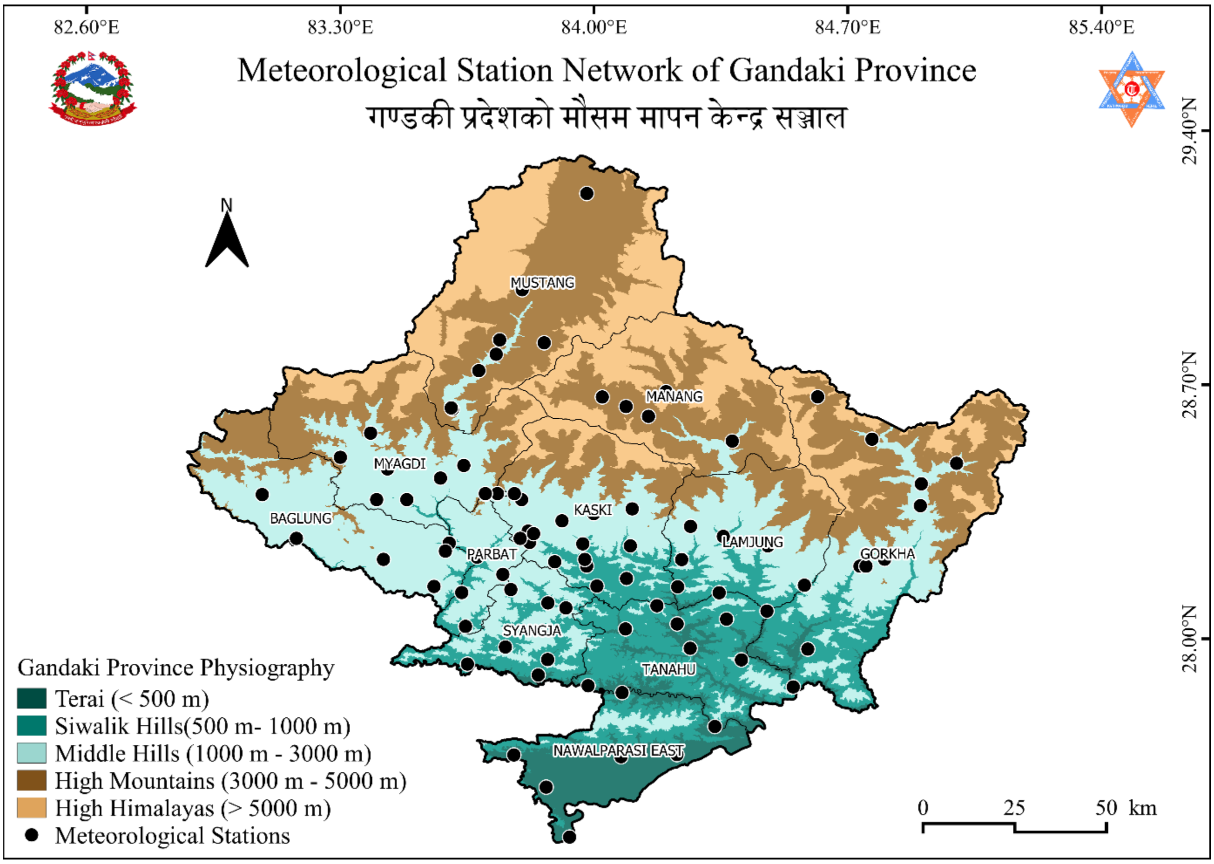

Figure 1 Map of Gandaki Province with the Physiographic zones and active climate monitoring stations

Data quality control, homogenization, and preprocessing were conducted using Microsoft Excel and R programming. These steps included thresholding, outlier detection, and internal consistency checks to ensure reliability of the datasets. Spatial analysis, including interpolation and mapping, was performed using both QGIS and ArcGIS. Climate variable visualization and cartographic outputs were generated primarily in QGIS and ArcGIS, while data plotting and map preparation were carried out using Microsoft Excel and Grapher software.

3.2.1. Climatological data filtering

To ensure the reliability of climate trend analysis, only meteorological stations with at least 90% data completeness over the full study period (1981 to 2024) were selected. This strict quality control significantly reduced the number of stations used in the final analysis, from

113 to 29. Although a relatively large number of weather stations exist across Gandaki Province, only a small subset offered sufficiently long, continuous, and high-quality records suitable for climatological assessment. For temperature (both maximum and minimum), 17 stations met the inclusion criteria, while 25 stations were retained for precipitation analysis. For hydrology based sectorial analysis, the only available hydrological station was selected that fell within the intended district.

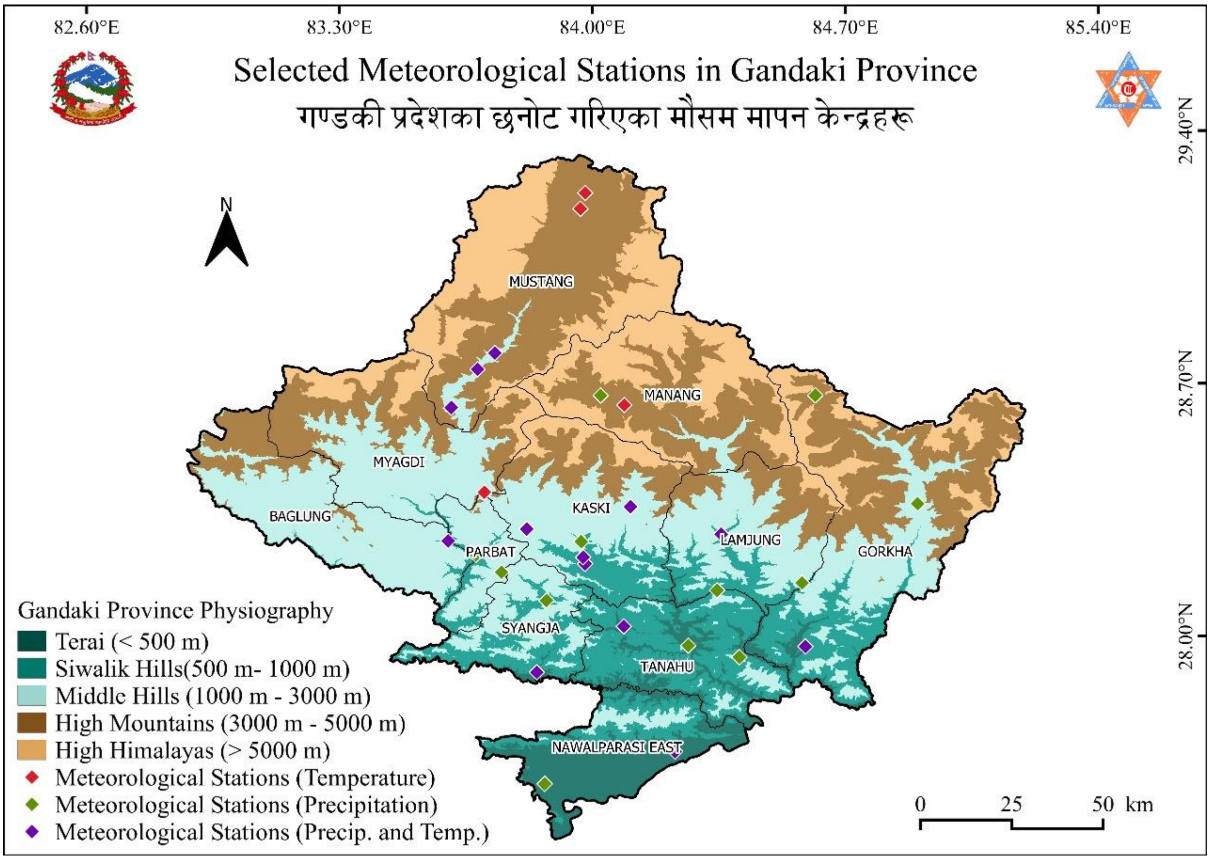

Figure 2 Map of Gandaki Province with the Physiographic zones and selected climate monitoring stations for the climate atlas and analysis

In addition to completeness, spatial representativeness across the province’s varied topography was also considered. However, a major limitation was the absence of station coverage above 4,000 meters in elevation. This represents a key gap in high mountain regions. The sparse and uneven distribution of stations, especially in remote and elevated areas, poses challenges for accurately capturing spatial climate variability. Therefore, mapped climatological patterns must be interpreted cautiously in terrain-constrained environments.

Temperature datasets required relatively simple quality control. Since temperature is generally less sensitive to data gaps and better suited for long-term averaging, daily records were used to compute monthly, seasonal, annual, and decadal averages. A similar approach was applied to river discharge data from the single station used for sectorial water resource analysis.

In contrast, precipitation data required more rigorous filtering due to the event-based nature and high variability of rainfall. Annual totals were computed only for years with at least 90% valid daily records. Monthly and seasonal aggregates required at least 75% completeness. The seasonal breakdown followed standard definitions: Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), and Winter (December to January).

Spatial interpolation of temperature and precipitation was performed using ordinary kriging in ArcGIS, which accounts for topographic influence on climate variables. Final climatological maps were generated at monthly, seasonal, and decadal scales, following the World Meteorological Organization (WMO) recommendation of 30-year climate normals.

3.2.2. Extreme Precipitation Indices

To evaluate the intensity, frequency, and persistence of precipitation extremes across Gandaki Province, five standardized extreme precipitation indices were calculated based on the framework developed by the Expert Team on Climate Change Detection and Indices (ETCCDI). The selected indices are R1mm (number of wet days), R99p (annual total precipitation from extremely wet days), Rx3day (maximum 3-day rainfall), Consecutive Wet Days (CWD), and Consecutive Dry Days (CDD). These indices were selected for their global standardization, relevance to monsoon-dominated climates like South Asia, and their ability to represent a broad range of hydro-meteorological risks including droughts, floods, and impacts on infrastructure.

All calculations were carried out using validated R packages designed for climate extreme analysis, supplemented by custom R scripts developed to handle station-level quality control, data completeness filtering, and spatial harmonization for province-wide mapping.

1. Annual Wet Day Count (R1mm): R1mm is a fundamental yet important index representing the number of days in a year with at least 1 mm of rainfall (≥1 mm). It captures rainfall frequency, which is critical for agricultural planning, irrigation scheduling, and water harvesting strategies. To ensure reliability, R1mm was calculated only for years with at least 90% valid daily precipitation records, maintaining consistency and accuracy across stations.

2. Extremely Wet Days (R99p): R99p measures the total annual precipitation contributed by extremely wet days, defined as days with rainfall exceeding the station-specific 99th percentile. This percentile threshold was established using wet days (≥1 mm) from a high-quality reference period spanning 1981 to 2010. A two-stage data filtering process was applied to ensure accuracy. First, only years with at least 90% daily data availability were used to calculate the 99th percentile threshold. Second, an additional 90% completeness check was applied to the monsoon season (June to September, 122 days), given this index's sensitivity to missing data during peak rainfall months.

Annual R99p values from 1981 to 2024 were then calculated only for years meeting both completeness criteria. For each qualifying year, daily rainfall was compared against the pre-defined threshold, and the total precipitation from exceedance days was summed. This approach ensured that R99p values captured genuine climatological extremes rather than anomalies introduced by missing or sparse data.

3. Maximum 3-Day Precipitation (Rx3day): Rx3day represents the maximum total precipitation accumulated over any three consecutive days within a calendar year. It is a key indicator of short-duration extreme rainfall events and is particularly relevant for assessing flood hazards, landslide potential, and the adequacy of urban drainage systems. For this analysis, only years with at least 90% valid daily precipitation data were considered. Additionally, years containing more than three consecutive days of missing data were excluded to maintain the accuracy of the rolling 3-day calculation.For each qualifying year, a moving 3-day total was computed across the daily rainfall series, and the highest value was recorded as the Rx3day index.

4. Consecutive Wet Days (CWD): CWD (Consecutive Wet Days) represents the longest sequence of consecutive days in a year with rainfall of at least 1 mm (≥1 mm). This index provides valuable insight into prolonged wet periods, which can contribute to waterlogging, landslides, and soil erosion. To ensure accuracy, CWD was calculated only for years with complete daily precipitation records. A binary time series was first generated by assigning a value of 1 to wet days and 0 to dry days. Run-length analysis was then applied to identify and extract the longest uninterrupted sequence of wet days in each year.

5. Consecutive Dry Days (CDD): CDD (Consecutive Dry Days) measures the longest uninterrupted sequence of dry days in a year, where dry days are defined as those receiving less than 1 mm of rainfall. This index is a key drought indicator, especially in regions reliant

on rain-fed agriculture. To maintain accuracy, only years with complete daily precipitation records (365 valid days) were included in the analysis, minimizing the risk of over- or underestimating dry spells. A run-length encoding method was applied in R to identify the longest continuous dry period for each year. After computing annual CDD values at each station, results were averaged over the 1981 to 2024 period to derive long-term climatological patterns.

3.2.3. Perception based study

For the survey conducted in Mustang District on people's perceptions, sample size determination followed William G. Cochran's probability sampling formula, adjusted for effect size, margin of error, and desired precision. This process resulted in an initial target of 78 respondents, later refined to 75 based on a 95% confidence interval, a disaster risk reference proportion of 0.245, and a 9.5% margin of error. Proportional allocation across the four selected Rural Municipalities was based on pooled weights reflecting household abundance. A two-stage semi-probabilistic convenience sampling method was employed: first, identifying urban and rural locations with known disaster histories, then selecting households from five distinct domains. This approach ensured representative coverage for assessing the impacts of extreme precipitation on local socio-economic conditions.

4. Analysis

4.1. Climatological Patterns Based on the Atlas

This analysis is based on the *Climate Atlas of Gandaki Province ("गण्डकी प्रदेशको जलवायु मानचित्र")*. These maps were created using data from 29 meteorological stations, selected after a rigorous filtering process to address missing or inconsistent values, as described in the methodology section. For detailed spatial patterns and comprehensive visualizations of climate parameters over various time intervals, please refer to the accompanying climate atlas.

4.1.1 Monthly Temperature Climatology

The monthly temperature maps for maximum, minimum, and average temperature reveal consistent and coherent patterns across Gandaki Province. January is the coldest month, with notably low temperatures, especially in the high-altitude northern regions of Manang and Mustang. Temperatures rise steadily through the year, peaking in July. During this month, southern lowland areas such as Nawalpur and parts of Tanahun record the highest temperatures. Following July, temperatures gradually decline until December, completing a clear and predictable annual cycle.

Maximum temperatures range from about 4°C to 24°C in January and 16°C to 36°C in July. Minimum temperatures vary from approximately -12°C to 12°C in January to 8°C to 28°C in July. Mean temperatures fall between -4°C and 16°C in January and 12°C to 32°C in July. Throughout the year, the northern high-altitude zones remain consistently colder, while the southern lowlands maintain the warmest conditions.

4.1.2. Seasonal Temperature Climatology

Seasonal temperature patterns for maximum, minimum, and mean temperatures mirror the monthly trends. Winter is the coldest season, with the lowest temperatures observed primarily in the higher elevations of Manang and Mustang. Temperatures increase during the pre-monsoon season and reach their highest during the monsoon, when southern lowlands experience the warmest conditions. Following the monsoon, temperatures decline during the post-monsoon season, marking the transition to cooler months.

Maximum temperatures range from roughly 4°C to 28°C in winter and 16°C to 36°C during monsoon. Minimum temperatures vary between -12°C and 12°C in winter and 4°C to 28°C in monsoon. Mean temperatures range from -4°C to 20°C in winter and 12°C to 32°C during monsoon. The northern high-altitude regions remain cooler across all seasons, while the southern lowlands consistently register the warmest temperatures.

4.1.3. Decadal Temperature Variation

Decadal temperature maps for 1981-1990, 1991-2000, 2001-2010, and 2011-2020 reveal a clear and gradual warming trend across Gandaki Province in all three temperature parameters. The rise is most prominent in maximum temperature, with the southern lowlands showing a steady increase and warm zones progressively expanding northward over time. Warming is also evident in minimum and mean temperatures, particularly in the northwestern districts, with a gradual upward shift in elevation. Overall, the analysis indicates a consistent, province-wide temperature increase, with warming patterns steadily advancing from the southern lowlands toward the central hills and higher mountain regions.

4.1.4. Monthly Precipitation Climatology

Monthly precipitation patterns across Gandaki Province follow a distinct annual cycle. November is the driest month, while July records the highest rainfall. Starting from January, precipitation gradually increases. From March onward, a marked rise is observed, reaching its peak in July. Rainfall then gradually declines in August and September. A sharp drop occurs in October, leading to the lowest values in November. In December, a slight increase is observed, particularly in the northeastern parts of the province.

Spatially, the northernmost areas of the province including Mustang district, the upper parts of Manang, and the northeastern edge of Gorkha consistently receive very low precipitation throughout the year. In contrast, the central region, especially around Kaski district, consistently receives the highest monthly rainfall. The southernmost areas of the province tend to be relatively dry, while the western areas receive moderate rainfall.

In July, precipitation ranges from under 50 mm in the drier northern areas to over 1500 mm in the wetter central region. In November, values range from less than 7.5 mm to around 25 mm across most of the province. This contrast is especially striking in July, when some northern areas receive under 50 mm, while central regions experience over 1500 mm—highlighting the sharp spatial variability in rainfall across the province.

4.1.5. Seasonal Precipitation Climatology

Seasonal precipitation patterns across Gandaki Province show a clear annual rhythm. The monsoon season is the wettest period, while winter is the driest. Precipitation increases in the pre-monsoon season, reaches a peak during the monsoon, and then sharply declines in the post-monsoon season, leading into the dry winter months.

Spatially, the distribution of rainfall closely mirrors the monthly patterns. The northernmost regions including Mustang, upper Manang, and northeastern Gorkha remain consistently dry across all seasons. In contrast, the central part of the province, particularly the region around Kaski district, receives the highest seasonal precipitation and remains the dominant rainfall hotspot. The southern lowlands experience moderate precipitation, while western areas fall between the dry north and wet central zones.

Precipitation during winter ranges from less than 50 mm to around 200 mm across the province. In stark contrast, monsoon season precipitation varies widely, ranging from below 200 mm in the northern dry regions to up to 5000 mm in the central wet zones. This wide range highlights the extreme spatial variability in rainfall, especially during the monsoon, consistent with the patterns observed at the monthly scale.

4.1.6. Decadal Precipitation Variation

Decadal precipitation maps for the periods 1981-1990, 1991-2000, 2001-2010, and 2011-2020 show relatively limited long-term changes in rainfall distribution across Gandaki Province. From the first to the second decade, no substantial shifts are observed, although the southernmost area of Nawalparasi appears to receive noticeably more precipitation.

Between the second and third decades, minor increases in precipitation are noted in the northeastern and northwestern corners of the province. However, these changes are subtle and not widespread. In the final decade, the most notable difference is observed in the driest region of the province: upper Manang and adjacent parts of the Manang district, where a modest increase in precipitation is visible. Outside of this area, especially in the central region including Kaski district, precipitation levels remain largely consistent across all decades.

Overall, while there are small localized increases in rainfall, particularly in the northern highlands, no clear or consistent long-term trend in precipitation can be inferred from the decadal analysis. The spatial patterns remain largely stable over the four decades. In contrast to temperature, long-term trends in precipitation remain weak and spatially inconsistent.

4.1.7. Extreme Precipitation Patterns

This section presents the spatial distribution of five extreme precipitation indices across Gandaki Province, based on long-term average values calculated annually throughout the full study period. These indices help identify patterns of rainfall intensity, duration, and frequency, providing valuable insight into regional climatic variability and hydrological extremes.

1. R1mm (Annual Count of Wet Days ≥1 mm)

R1mm represents the number of days in a year when daily precipitation equals or exceeds 1 mm, reflecting the frequency of wet days. Across Gandaki Province, R1mm values range from less than 60 days to about 180 days. The driest regions which are northern Mustang, upper Manang, and northeastern Gorkha experience fewer than 60 wet days annually. In contrast, the central region around Kaski district records the highest wet-day frequency, with 160 to 180 days. The southernmost parts of Nawalparasi East also show relatively low values of 60 to 80 days. Eastern and western areas of the province exhibit moderate values ranging from 80 to 100 days. This wide range demonstrates substantial spatial variability in precipitation frequency across the province.

2. R99p (Extreme Rainfall from Very Wet Days)

R99p represents the annual total precipitation from days with rainfall above the 99th percentile, indicating the contribution of extremely wet days to total annual rainfall. R99p values range from less than 50 mm to 350 mm. Northern areas including Mustang, upper Manang, and parts of Gorkha consistently record low values under 50 mm. In contrast, central Kaski emerges as a precipitation hotspot with the highest values between 300 and 350 mm. This zone of extreme rainfall extends southward, decreasing gradually toward eastern Nawalparasi where values are around 150 to 200 mm. The spatial pattern shows a clear north-south gradient, with minimal contributions from extreme rain in the north and peak intensities concentrated in the central highlands.

3. Rx3day (Maximum 3-Day Precipitation)

Rx3day captures the highest cumulative rainfall over any three consecutive days in a year, highlighting short-duration intense precipitation events. Rx3day values range from less than 75 mm to 300 to 350 mm, with a distribution that largely mirrors the R99p pattern. The northern districts of Mustang, upper Manang, and northeastern Gorkha record the lowest values below 75 mm. Central Kaski and the southernmost parts of Nawalparasi East show the highest Rx3day values, between 300 and 350 mm. This suggests that both the central hills and adjacent southern plains are exposed to intense short-duration rainfall. The index reveals not only a north-south gradient but also highlights the southern Terai lowlands as another zone prone to rainfall extremes.

4. CWD (Consecutive Wet Days)

CWD refers to the maximum number of consecutive days in a year with at least 1 mm of precipitation, indicating the persistence of wet spells. CWD values show a distinct central concentration. Most of the province experiences moderate values between 10 and 25 days. Drier patches such as northern Mustang, upper Manang, northeastern Gorkha, and the southernmost Nawalparasi East record fewer than 10 consecutive wet days. In contrast, Kaski district stands out with maximum values of 45 to 50 days, indicating prolonged wet spells. Notably, the high CWD zone is sharply localized in central Kaski, unlike other indices which show broader spatial trends.

5. CDD (Consecutive Dry Days)

CDD refers to the longest stretch of consecutive days in a year with less than 1 mm of precipitation, providing insight into the severity and duration of dry spells. CDD exhibits the most distinct and contrasting spatial pattern among all indices. Values range from less than 40 days in central Kaski and the southern edge of Mustang, to 60 to 70 days in upper Manang, Mustang, northeastern Gorkha, and across Nawalparasi East and Tanahun. Surprisingly, the highest CDD values are found in the southernmost Nawalparasi East, defying expectations that the longest dry spells would occur in the far north. This index highlights both high-altitude aridity and lowland seasonal drought, adding a critical dimension to the province’s hydro-climatic understanding.

The spatial variability in extreme precipitation indices across Gandaki Province underscores the complex interplay between topography and regional climate. While central Kaski consistently emerges as the wettest zone across multiple indices, the northern high-altitude regions remain persistently dry. The southern lowlands, though less extreme overall, show unique extremes in short-duration rainfall and prolonged dry spells. This long-term analysis of extreme indices provides a vital foundation for future climate risk assessments and adaptation planning in the region.

4.2. Sectorial Implications

4.2.1. Climate change impact on Agriculture of Nawalpur (East) district

Nawalpur (East) District (Figure 3), covering 1,331.16 km² in Nepal's Gandaki Province, was formed following the 2015 administrative restructuring of the former Nawalparasi District. While long-term climate records (1981 to 2024) from the Department of Hydrology and Meteorology provide historical context, this analysis primarily focuses on the most recent five-year period (fiscal years 2077/78 to 2081/82, or 2020 to 2024), on an annual scale, for which district-specific crop production statistics for major cereals are available from the newly established Agriculture Knowledge Center, Nawalpur. As crop production data is reported by Nepalese fiscal years, it is compared with climate data from the closest corresponding calendar years. Additionally, land cover changes between 2000 and 2022 are assessed using data from Nepal's National Land Cover Monitoring System.

Paddy dominates production (Figure 4), accounting for 62% of total output (79,924 metric tons), largely due to its extensive cultivation area. Maize (24,829 metric tons) and wheat (20,804 metric tons) contribute smaller but still significant shares. Minor cereals such as millet, buckwheat, and barley appear as thin slivers, together making up less than 1% of total grain production, limited by both low yields and small cultivation areas.

Paddy again leads (Figure 5), with an average yield of 4.12 metric tons per hectare, while spring paddy is even more efficient at 5.46 metric tons per hectare, though grown on a much smaller scale. Maize (3.68 mt/ha) and wheat (2.94 mt/ha) occupy middle ground, whereas millet, buckwheat, and barley remain low-yielding (all at or below 1.18 mt/ha).

While spring paddy stands out for its yield efficiency, its limited cultivation area means it contributes little to total production. Conversely, wheat covers substantial area but suffers from low yields, restricting its output. Overall, paddy dominates both land use and total harvest, making it the district's most productive yet climate-vulnerable food anchor.

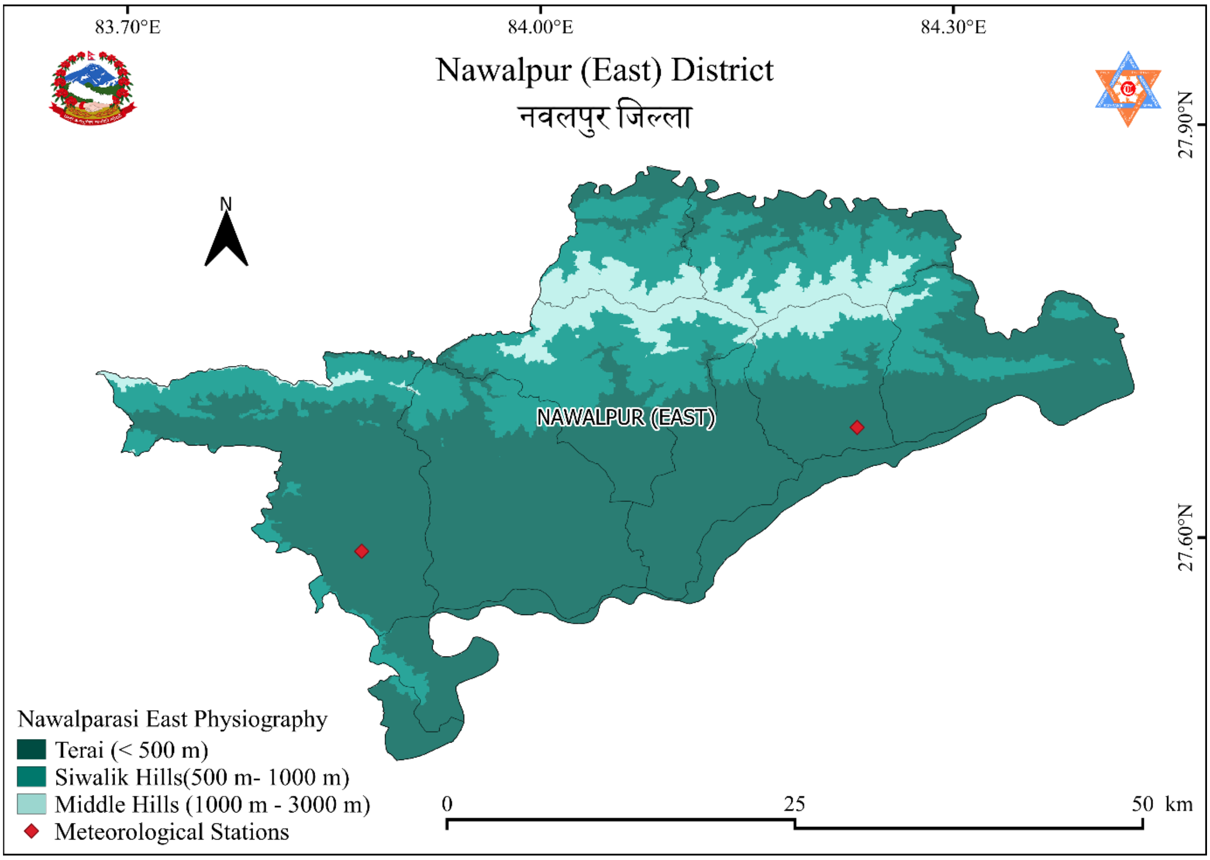

Figure 3 Map of Nawalpur (East) District with the physiographic zones and selected climate stations for analysis

Temperature records indicate a sustained warming trend, with average decadal temperatures increasing by about 1.5°C and a notable acceleration after 2010. Seven of the nine hottest years were recorded after 2015. Precipitation has become increasingly erratic in recent years, reflecting more frequent monsoon disruptions. These climatic shifts pose growing challenges for agriculture in the district, where rain-fed systems dominate and cereal crops remain highly sensitive to temperature and precipitation variability. In Ashoj (September-October) 2024, during paddy flowering, Kawasoti (Nawalpur) recorded temperatures reaching 39°C on September 25 exceeding the critical threshold for rice pollination. This acute heat event, consistent with Dumkauli's observed maxima (~33°C September average, days >39°C), contributed to district-wide paddy losses estimated at NPR 190 million (Agriculture Knowledge Center, Nawalpur, pers. comm.)

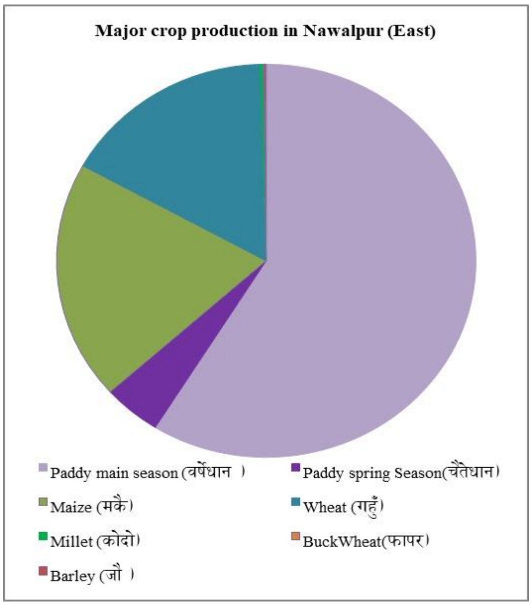

Figure 4 Major crop produced in Nawalpur (East) district

Main-season rice exhibited strong temperature sensitivity (r = 0.79) (Table 1), with yields peaking at 4.18 Mt/ha in fiscal year 2080/81, the hottest year on record (26.44°C), despite experiencing one of the driest periods (1707 mm). While this suggests potential short-term heat tolerance, such performance may not be sustainable under continued warming and rainfall uncertainty. In contrast, wheat showed moderate heat sensitivity (r = -0.52), with persistently low yields not exceeding 3.09 Mt/ha. Maize demonstrated remarkable drought resilience, showing a strong negative correlation with precipitation (r = -0.93), and nearly doubled its yield to 4.80 Mt/ha in drier years, although this coincided with declining cropland coverage. Spring rice (Chaite dhan) maintained consistently high yields (5.06-6.06 Mt/ha), showing moderate drought tolerance (r = -0.62), though its temperature sensitivity was weak (r = 0.27). Barley (r = 0.85) and buckwheat (r = 0.72) both benefitted from warming, with modest yield improvements from 1.09 to 1.25 Mt/ha and 0.93 to 1.14 Mt/ha, respectively. Millet, however, appeared largely unresponsive to climate variables, with stagnant yields around 1.13 Mt/ha and negligible correlation with either temperature or precipitation. Overall, the findings suggest that while warming has supported yield gains in certain crops like maize, barley, and buckwheat, staple crops such as rice and wheat remain highly vulnerable to heat and rainfall variability. This vulnerability is exemplified by the 2024 heat-induced paddy loss during flowering phenophase. These climate yield relationships are synthesized in Figure 6, which plots annual yields against climatology factors (temperature and precipitation) scales. The parallel axes reveal maize and barley yields tracking positively with temperature; buckwheat and wheat responding inversely to precipitation; and main-season paddy showing acute sensitivity to combined heat-precipitation extremes patterns that underscore the necessity of detailed phenological impact studies to minimize climate hazards.

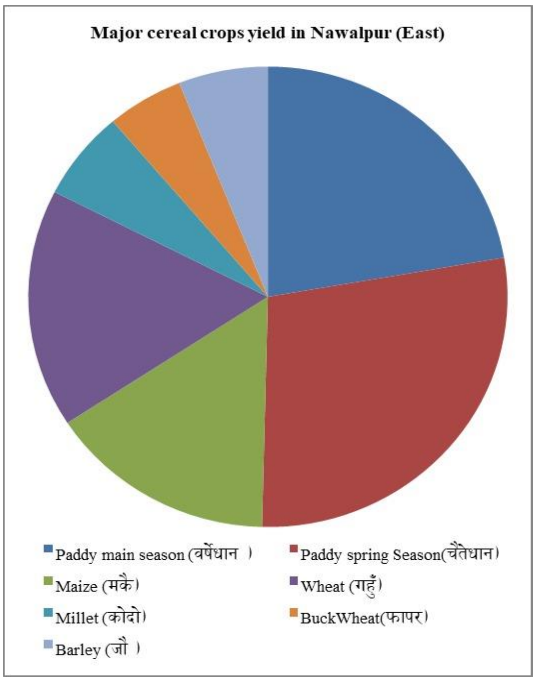

Figure 5 Major cereal crop yield (metric tons per hector) in Nawalpur (East) District

Land use changes compound the district's climate vulnerabilities. Between 2000 and 2022, cropland area declined by 9.4% (45 km²), largely due to urban expansion. Built-up areas increased more than sevenfold, reaching 6.16 km², directly encroaching upon agricultural terrain. At the same time, critical ecological buffers diminished: riverbeds shrank by 61%, and grasslands declined by 6%, weakening the landscape's capacity to absorb and regulate rainfall. These spatial shifts have intensified the district's exposure to both drought and flood risks, further undermining agricultural resilience.

The convergence of rising temperatures, erratic precipitation, and shrinking agricultural and ecological land signals growing threats to the region's food security. Warmer conditions accelerate soil moisture loss and increase irrigation demand, even as natural water retention features such as riverbeds and grasslands continue to decline. The 61% reduction in riverbed area and 6% loss of grasslands compromise watershed resilience, heightening vulnerability to prolonged dry periods. Although crops like maize and spring rice show signs of climate adaptability, these gains are occurring alongside a 9.4% decrease in cropland and rising pressure on agricultural land, challenging per-capita food availability and long-term production sustainability.

Given these intersecting risks, there is an urgent need for in-depth, locally grounded studies to better understand climate change impacts on agriculture in Nawalpur (East). Detailed research is essential not only to quantify the evolving biophysical stresses but also to inform site-specific adaptation strategies in crop planning, land use, and water management that can ensure sustainable agricultural livelihoods under a rapidly changing climate.

Table 1 Statistical Analysis Table for All Crops (2020-2024)

Crop	**vs. temp (r, p)**	**vs. pptn (r, p)**	**Key Yield Pattern**
Main-season rice	0.79 (p=0.11)	-0.03 (p=0.96)	Peak (4.18 Mt/ha) in F.Y. 2080/81 (hottest year)
Spring rice	0.27 (p=0.65)	-0.62 (p=0.26)	Consistently high (5.06-6.06 Mt/ha)
Maize	0.10 (p=0.87)	-0.93 (p=0.02)	Doubled yield (4.80 Mt/ha) in dry years
Wheat	-0.52 (p=0.37)	-0.02 (p=0.96)	Chronically low (≤3.09 Mt/ha)
Barley	0.85 (p=0.07)	-0.31 (p=0.61)	Moderate gains (1.09→1.25 Mt/ha)
Buckwheat	0.72 (p=0.17)	-0.20 (p=0.74)	Steady improvement (0.93→1.14 Mt/ha)
Millet	-0.30 (p=0.62)	0.05 (p=0.94)	Stagnant (~1.13 Mt/ha)

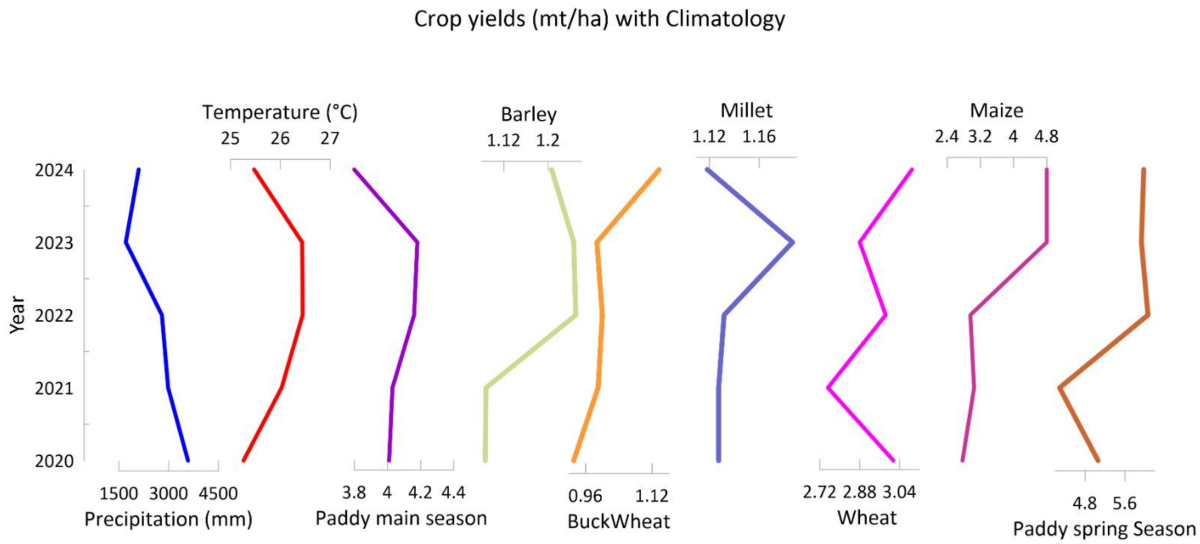

Figure 6 Climate-yield relationships of major cereals Nawalpur (East) District (2020-2024)

4.2.2. Climate Change impact on water resources of Kaski district

This section examines the impacts of climate change on water resources in Kaski District by integrating long-term climate records (1981-2024), river discharge measurements (1981-2017), high-resolution land cover dynamics (2000-2022), and population data from the 2021 National Census. The district has experienced notable climatic and hydrological shifts that increasingly threaten water security for its 600,051 residents, rain-fed agricultural systems, and hydropower infrastructure vital to Gandaki Province's economy.

Long-term climate records reveal clear warming in Kaski District, with annual average temperatures increasing by 1.36°C over the last 44 years. This persistent rise accelerates evaporation from soils and surface water, reducing moisture availability during dry periods. Precipitation patterns are highly variable, ranging from 3,316 mm to 5,513 mm annually, and show a moderate declining trend in recent decades. Discharge records in Figure 9 from the district's sole hydrological monitoring station confirm that these climatic shifts are directly affecting water availability. Average annual discharge decreased by 22%, from 18.03 m^3/s in 1981 to 13.05 m^3/s in 2016, with extreme lows such as 5.83 m^3/s recorded in 2002 during warmer-than-average conditions.

Monthly discharge as shown by Figure 10 is tightly linked to seasonal climate, with 88% of annual flow occurring during the monsoon period (June-September), peaking during August by 30.39 m^3/s, concurrent with maximum rainfall. In contrast, the pre-monsoon months (March-May) combine rising temperatures (17.8-22.4°C) and reduced discharge (9.16-12.32 m^3/s), highlighting the dominance of evaporative loss.

Statistically (Table 2), monthly discharge correlates strongly with precipitation ($r = 0.92$), confirming that rainfall is the primary driver of short-term river flows, especially during the monsoon. A strong inverse correlation with monthly temperature ($r = -0.81$) further suggests that warming reduces dry-season base flows through enhanced evaporation. At the annual scale, discharge still shows a moderate positive correlation with precipitation ($r = 0.48$), indicating that inter-annual variability in rainfall influences total annual water supply. However, the negative annual correlation with temperature ($r = -0.31$) points to long-term warming progressively undermining discharge resilience, particularly outside the monsoon season.

Land cover changes have compounded the district's climatic pressures (Figure 8). Land use and land cover (LULC) data indicate that between 2000 and 2017, water bodies declined by 15% and riverbeds contracted by 68%, degrading natural hydrological infrastructure critical for groundwater recharge and dry-season flow regulation in Kaski. This landscape degradation aligns temporally with reductions in river discharge: 60% of low-discharge years occurred after 2001, and the sharpest losses in riverbed area between 2017 and 2021 coincided with diminished base flows. Water bodies that buffer rainfall variability shrank most rapidly after 2019, declining by 11.6% by 2022. Their loss has reduced the district's capacity to mitigate flow volatility, directly affecting the 10,316 hectares of irrigated farmland that depends on stable river conditions. The interaction between land cover degradation and discharge decline is particularly evident in 2002 to 2003, when, despite near-average precipitation, discharge fell to record lows in parallel with reductions in riverbed and water body areas.

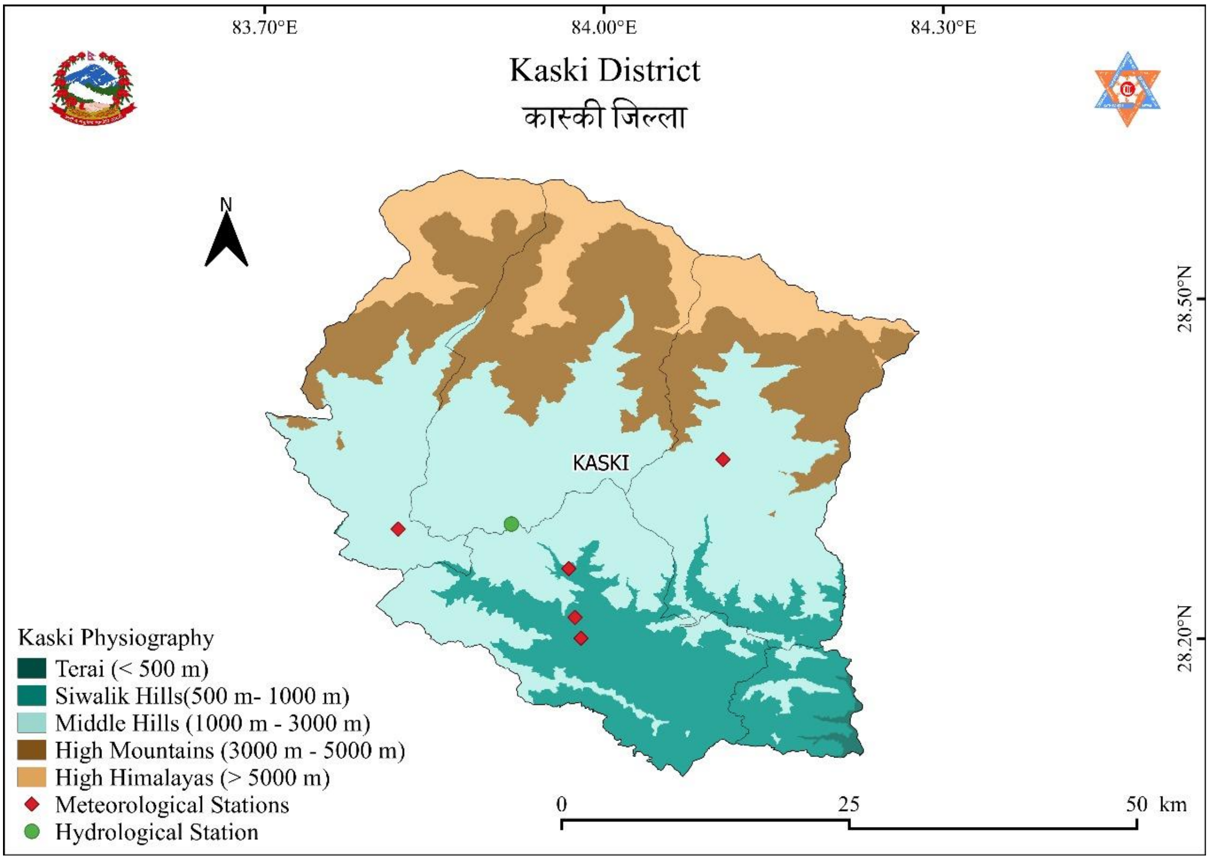

Figure 7 Map of Kaski District with the physiographic zones and the analyzed meteorological and hydrological stations

Demographic pressures are intensifying hydrological stress in Kaski. Since 2001, the district's population has increased by 57.7%, reaching 600,051 residents in 2021 with a density of 298 persons per square kilometer. This rapid growth has escalated water demand, while per capita water availability has declined to 5,019 cubic meters, the lowest in Gandaki Province. Agriculture, which supports over 60% of the population, is increasingly vulnerable. Rising temperatures raise crop water requirements by an estimated 7.6% per 1°C during dry seasons, while the decline of water bodies has reduced access to supplementary irrigation sources. Hydropower development, part of Gandaki's 45,610 MW potential, is also at risk due to discharge volatility. Low-flow years reduce generation efficiency, while high-intensity rainfall events increase sedimentation, causing wear and damage to infrastructure. The 2017 discharge surge to 22.03 cubic meters per second, triggered by extreme rainfall totaling 5,813 mm, illustrates the growing mismatch between current flow variability and infrastructure designed for historical conditions.

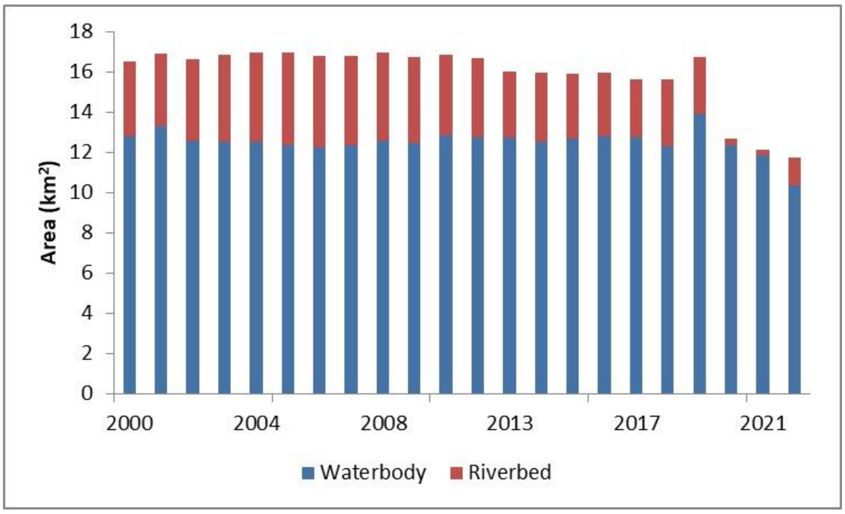

Figure 8 Annual variation in riverbed and water body land use/land cover (LULC) for the Kaski district from 2000 to 2022

The convergence of climate shifts, landscape degradation, and population growth signals systemic water stress in Kaski District. Rising temperatures accelerate evaporation, reducing renewable water supplies just as demand peaks. Increasing precipitation variability disrupts recharge cycles, while the continued loss of riverbeds and water bodies weakens natural storage capacity. For Gandaki Province, these changes threaten agricultural stability, as fluctuating flows undermine irrigation across 19,164 hectares of cultivable land; energy security, as hydropower output becomes increasingly sensitive to climatic extremes; and broader socioeconomic resilience, with rural water scarcity risking displacement and livelihood loss. The abrupt hydrological changes observed after 2019 suggest that critical climate thresholds may have already been crossed, beyond which natural systems struggle to recover.

Protecting remaining hydrological features is now essential to sustaining groundwater recharge and dry-season baseflows. Strategic interventions such as managed aquifer recharge, small reservoir expansion, and climate-resilient hydropower infrastructure can buffer future rainfall variability. However, these solutions require spatially differentiated approaches tailored to Kaski's complex topography that spans 387 masl valleys to peaks over 8,000 masl. Based on these findings, there is an urgent need for sector-specific, in-depth research to guide water management, infrastructure planning, and resource allocation. Without targeted adaptation strategies, the momentum of warming risks irreversible water loss, threatening Kaski's role as a key agricultural, educational, and economic center within Gandaki Province. The window for action is narrowing as climatic and demographic pressures intensify, making locally grounded, evidence-based planning more critical than ever.

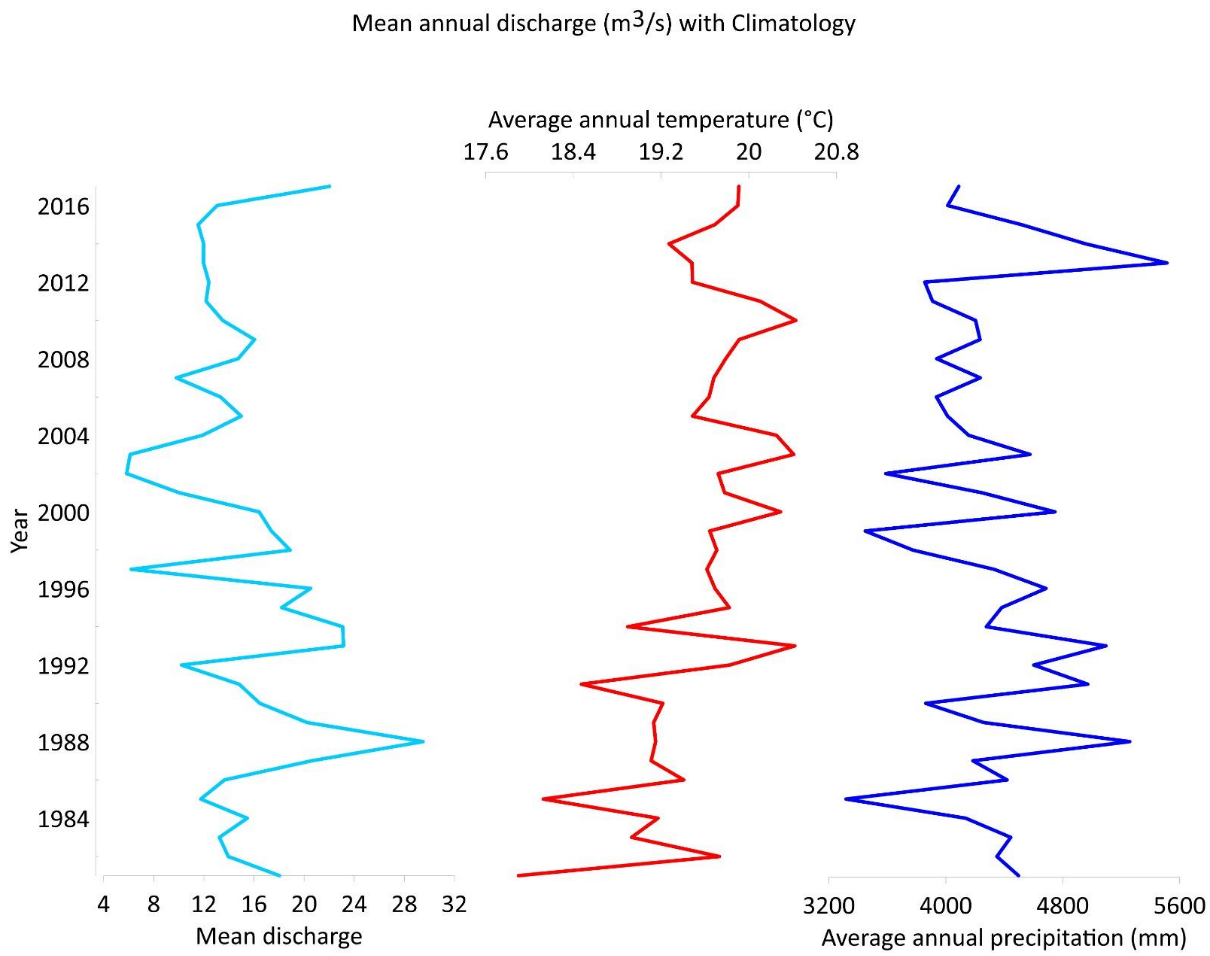

Figure 9 Annual discharge at Mardi Khola (Index 428) Vs Climatology

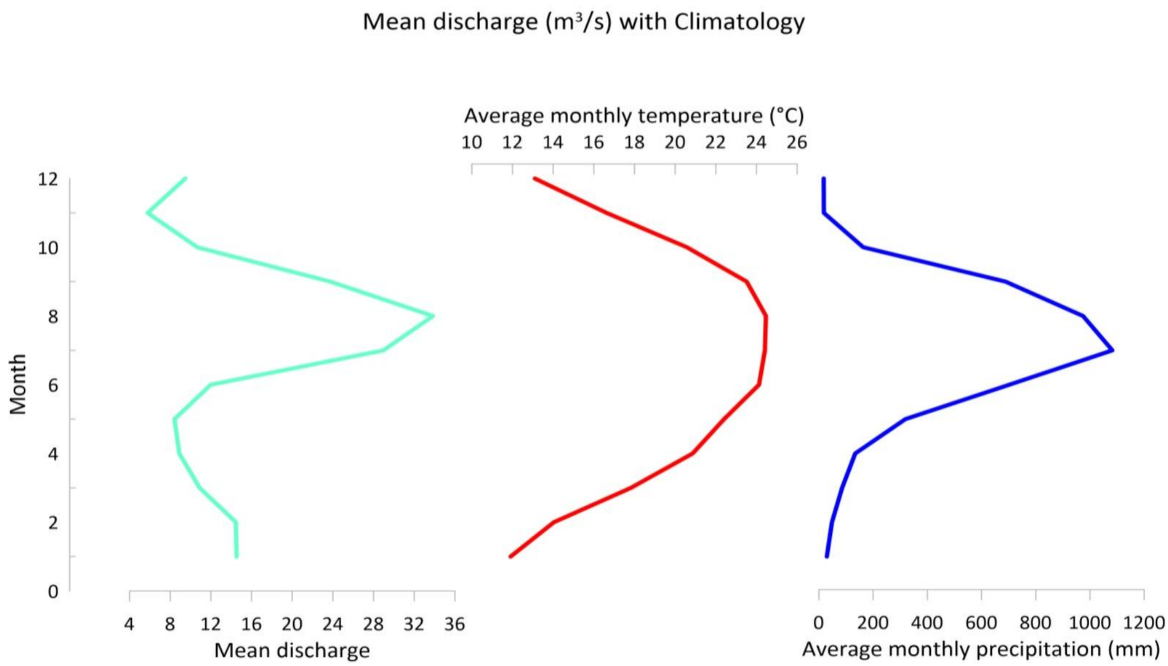

Figure 10 Monthly discharge at Mardi Khola (Index 428) Vs Climatology

Table 2 Correlation of River Discharge with Precipitation and Temperature for Kaski

Timescale	vs. pptn (r, p)	Implication	vs. temp (r, p)	Implication
Monthly	(0.92, p < 0.0001)	Precipitation directly controls river flows	(-0.81, p=0.0008)	Warming reduces dry-season base flow
Annual	(0.48, p=0.002)	Precipitation variability drives inter annual supply	(-0.31, p = 0.032)	Warming reduces long-term discharge resilience

4.2.3. Climate Change Impacts on Urban and Human Settlements in Gandaki Province

This section assesses the impacts of climate change on urban and human settlements in Gandaki Province by integrating long-term climate records (1981-2024), high-resolution land cover data (2000-2022), and population statistics from the 2021 National Census. Over the past two decades, the province has experienced significant climatic and land use transformations that directly influence the vulnerability of its urban and rural settlements.

Long-term temperature records reveal clear and persistent warming in Gandaki Province, with annual means rising by 0.92°C since 1981 to 2024, equivalent to 0.21°C per decade. This trend has intensified since 2015, with the most recent decade averaging 1.1°C warmer than the 1980s baseline. Precipitation patterns exhibit high inter-annual variability but no significant trend over the full period. However, a recent decline is notable, with average precipitation between 2021 and 2024 falling 8% below the preceding five-year period. These climatic changes coincide with major shifts in land cover across the province. Built-up areas have expanded by 101% since 2000, adding 48 square kilometers of urban surface, largely through the conversion of grasslands and croplands. Grasslands have declined by 59%, amounting to a loss of 2,842 square kilometers, while croplands have decreased by 21% or 821 square kilometers. In contrast, bare rock surfaces have expanded dramatically by 139% (a 3,583 square kilometer gain), suggesting increased geological exposure due to erosion or land degradation. Although forest cover has increased by 15%, largely due to conservation and afforestation initiatives at local and government levels, this modest gain provides limited compensation for the extensive loss of climate-regulating grasslands.

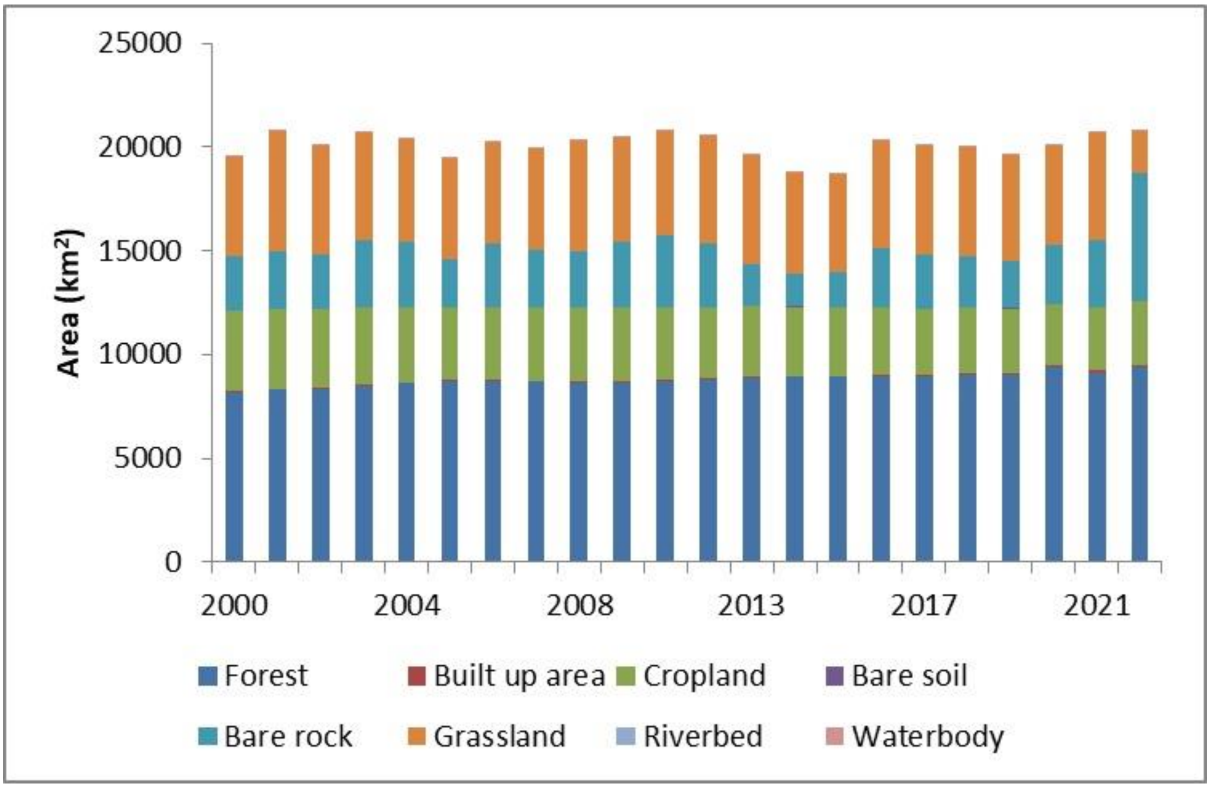

Figure 11 Annual distribution of land use/land cover (LULC) classes in Gandaki Province from 2000 to 2022

The convergence of climatic warming and land cover change amplifies risks to human settlements across Gandaki Province. Urban expansion contributes to the formation of heat islands, where built surfaces absorb and retain heat, raising local temperatures beyond broader regional trends. This effect intensifies when grasslands, which naturally provide evaporative cooling, are replaced with impervious materials such as concrete and asphalt. With a population density of 112.8 persons per square kilometer, increasingly concentrated in growing urban centers, heat exposure is becoming a public health concern, particularly during summer peaks.

Hydrological vulnerabilities further compound these risks. Urbanization accelerates surface runoff during rainfall events, increasing the likelihood of localized flooding. Simultaneously, the reduction in cropland diminishes the land's ability to retain soil moisture, weakening the buffer against both drought and flood extremes. The rapid expansion of bare rock areas indicates heightened erosion potential, especially on slopes where settlements are encroaching. These interconnected dynamics produce a dual effect, where climatic warming and landscape transformation reinforce each other, escalating the risk of both flooding and landslides.

For Gandaki Province, these findings underscore the urgent need to integrate climate resilience into settlement planning. The expansion of urban areas into former grasslands and erosion-prone zones has unintentionally increased community exposure to thermal stress and hydrological hazards. Preserving remaining green buffers, particularly grasslands that regulate microclimates and stabilize soils, must become a core priority in land use and urban policy. Future development should avoid geologically sensitive areas where bare rock expansion signals land degradation, and instead promote climate-sensitive designs and sustainable construction practices.

Reinforcing water management infrastructure is equally critical, given the dual pressures of erratic precipitation and reduced infiltration caused by cropland loss. Land use policies must explicitly account for climate projections, ensuring that present-day development decisions do not embed long-term vulnerability. Moreover, the establishment of localized climate monitoring stations in urban centers is necessary to quantify heat island effects and assess settlement-specific risks more accurately.

Based on these findings, there is a clear need for in-depth, sector-specific research to understand the evolving interactions between climate, land use, and settlement vulnerability. Such evidence is essential for designing adaptive urban strategies that ensure safety, livability, and long-term sustainability across Gandaki Province's rapidly transforming landscape.

4.2.4. Impact of climate extremes and people’s perception; a case study in Mustang district

This study employed a cross-sectional design to assess the impacts of climatic extremes and local perceptions in Mustang District, Nepal. Site selection focused on areas that have experienced frequent or severe extreme precipitation events (Figure 12). Selected locations included Gharapjhong Rural Municipality Ward 2 (Marpha) and Barhagaun Muktikhsetra Rural Municipality Ward 4 (Kagbeni) in Lower Mustang, as well as Lo-Manthang, New Samjong (Lo-Manthang Rural Municipality Ward 2), and Dhey Village (Lo-Ghekar Damodarkunda Rural Municipality Ward 5) in Upper Mustang. A total of 75 eligible respondents participated in the survey, with 60.2% male and 39.8% female representation.

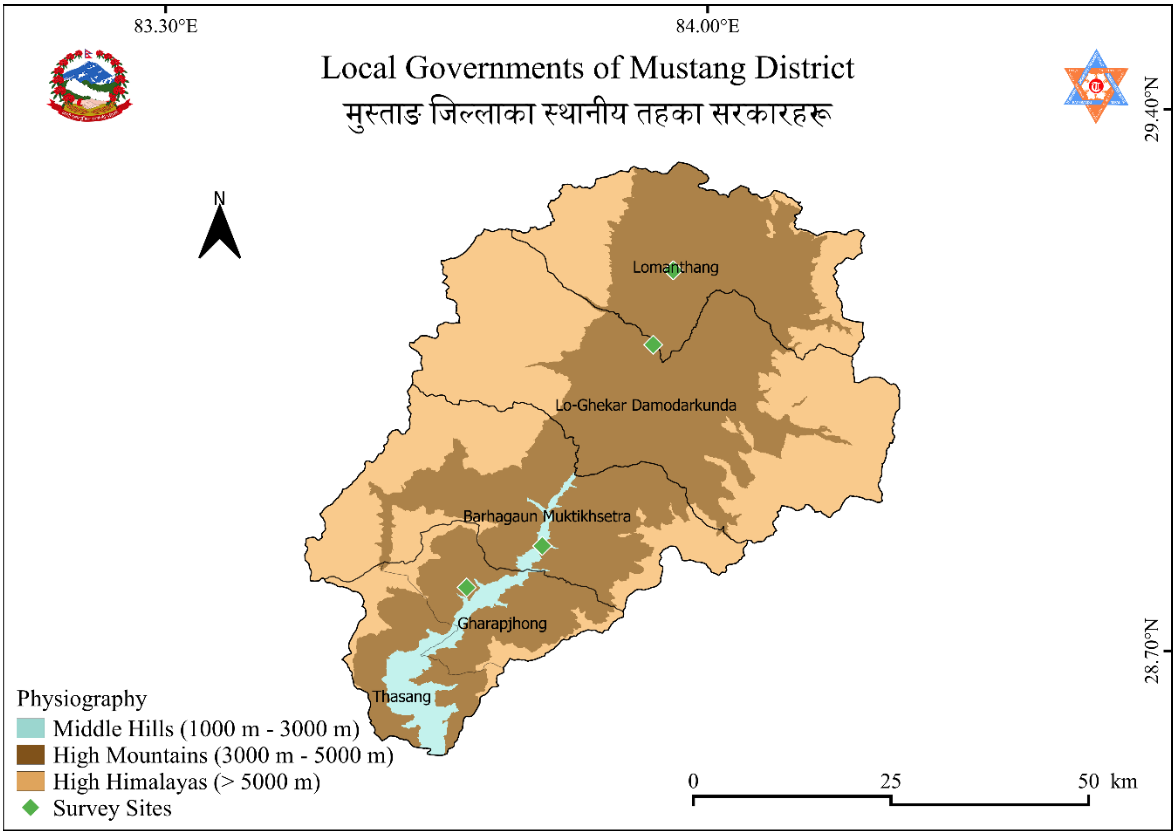

Figure 12 Mustang District, with physiology and Local Governments (green diamonds for where the surveys were conducted)

Respondents ranged in age from 18 to 89 years, with a median age of 43 years, allowing the study to capture diverse generational perspectives on property loss, health risks, and vulnerability. The average duration of residence in the study areas was over 27.8 years, reflecting strong local knowledge and lived experience of climatic impacts. Background information such as education level, religion, caste/ethnicity, and occupation was also collected, as these are key determinants of disaster vulnerability and adaptive capacity. A detailed summary of respondent demographics is provided in Table 3.

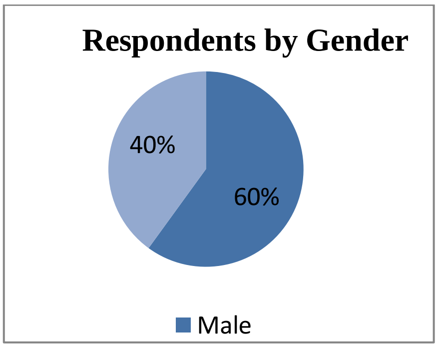

Figure 13 Distribution of survey respondents by gender (%)

Perceptions of Weather Changes and Disaster Impacts

All respondents (100%) reported experiencing noticeable changes in weather patterns over time. Irregular rainfall was identified as the most significant disaster risk, with direct impacts on agriculture, livestock, and overall farming systems. Other frequently reported concerns included shifting climate patterns (ranked 2nd), reduced snowfall (3rd), increased rain-induced flooding (4th), landslides (5th), and drought (6th). These rankings reflect a broad local awareness of both immediate and long-term climate-related challenges.

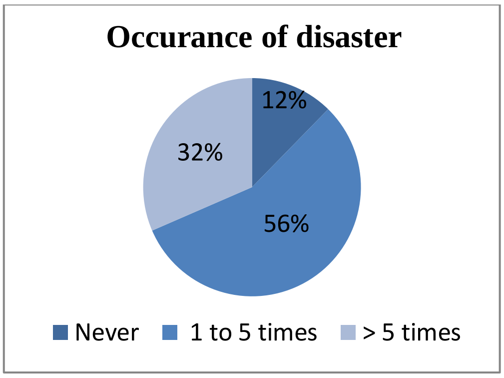

Figure 14 Frequency of disaster

Over the past five years, 32% of respondents reported experiencing disasters caused by heavy rainfall, floods, or landslides more than five times, while 56% experienced such events up to five times. Only 12% indicated they had not encountered any such disasters. Notably, 52% suffered damage to homes, gardens, vehicles, agricultural land, or businesses, and 32.4% reported losses of livestock and poultry. Temporal patterns revealed that 37% of disaster impacts occurred at night, 16% during evening hours, and 9% of respondents were unaware of the specific timing.

Monetary loss assessments were based on verified local government records, particularly for major events such as the Kagbeni flood of 2023. A detailed summary of reported economic losses is provided in Table 4.

Migration and Health Impacts

Climate-related vulnerability has compelled 39.2% of respondents or their family members to migrate, particularly from villages such as Samjong and Dhyee, which have been officially designated as climate refugee zones by the Government of Nepal. Additionally, 32.4% of respondents reported that family members experienced adverse health effects resulting from disasters such as heavy rainfall, floods, or landslides.

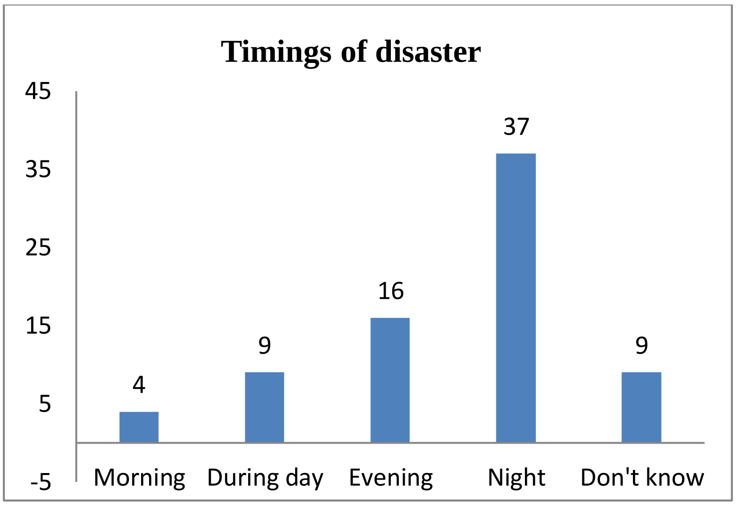

Figure 15 Timings of disaster

Awareness and Response Measures

A significant gap in disaster preparedness was identified. In Kagbeni, 71.43% of respondents reported never having participated in disaster awareness programs conducted by governmental or non-governmental organizations, largely due to accessibility challenges and limited awareness. Province-wide, 78.4% of respondents lacked insurance coverage for personal safety or asset protection.

Regarding early warning systems, 42.7% emphasized the importance of regular weather broadcasts, 10.7% advocated for the installation of local meteorological stations, and 46.6% stressed the need for more proactive government involvement. Despite the current gaps, 92.0% of participants expressed willingness to attend disaster preparedness training in the future.

Insurance knowledge was notably low: 81% of respondents were unfamiliar with insurance options. Among the 19% who were aware, common barriers to enrollment included the absence of land ownership certificates (Lalpurja) in villages such as Samjong and Dhyee, and unregistered housing in Kagbeni.

The Mustang case study reveals the profound and multifaceted impacts of climate extremes on local communities, highlighting widespread perceptions of shifting weather patterns and increasing disaster frequency. High rates of property damage, health issues, and climate-induced migration underscore the tangible vulnerabilities faced by residents. Significant gaps in preparedness, early warning systems, and insurance coverage further exacerbate these risks, despite strong community willingness to engage in adaptive training. These findings emphasize the urgent need for targeted, sector-specific in-depth research to better understand the socio-economic, health, and environmental dimensions of climate vulnerability in Mustang. Such research is critical to inform effective policy, improve disaster risk management, and develop locally appropriate adaptation strategies that enhance resilience in this climatically sensitive region.

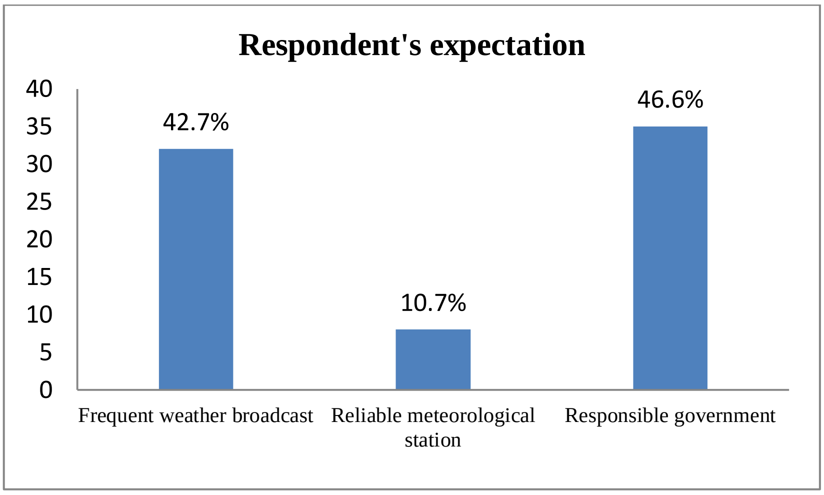

Figure 16 Respondent's expectation for weather information

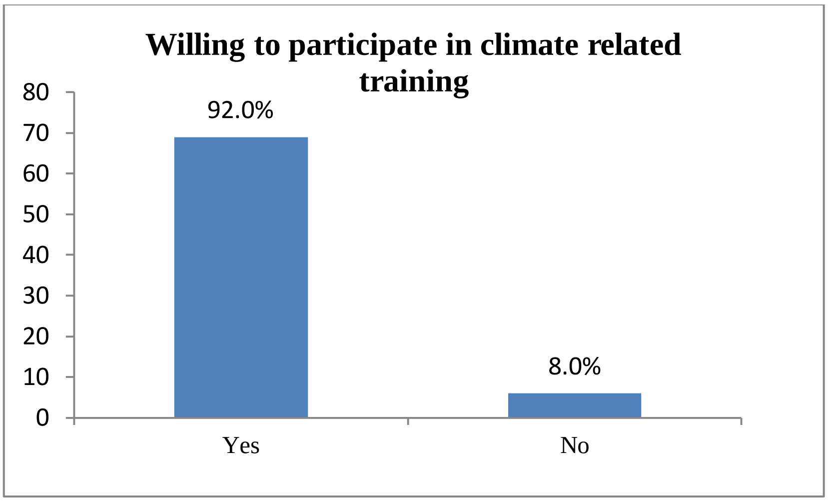

Figure 17 Respondent's will to participate in climate related training

5. Findings

5.1. Climatological Patterns Based on the Atlas

5.1.1. Temperature Patterns

Temperature in Gandaki Province shows a clear north-south gradient, with high-altitude areas like Manang and Mustang remaining the coldest year-round, while southern lowlands such as Nawalpur and Tanahun are the warmest. The annual temperature cycle peaks in July and reaches its lowest point in January, consistent across maximum, minimum, and mean temperatures. Seasonal patterns reflect this cycle, with winter being coldest and the monsoon warmest. Decadal data reveal a steady warming trend, particularly in maximum temperatures, with warming zones expanding from southern lowlands into higher elevations.

5.1.2. Precipitation Patterns

Precipitation follows a strong monsoonal pattern, with July as the wettest month and November the driest. Rainfall gradually increases from early in the year, peaks during the monsoon, and declines sharply post-monsoon. Central districts such as Kaski receive the highest rainfall, while northern mountainous areas like Mustang and upper Manang experience consistently low precipitation. Over the last four decades, precipitation patterns have remained largely stable with only minor localized increases, especially in northern highlands. This contrasts with the clear warming trend observed in temperature.

5.1.3. Extreme Precipitation Indices

The analysis of five key extreme precipitation indices provides valuable insights into the frequency, intensity, and duration of rainfall events across Gandaki Province. These indices include the number of wet days (R1mm), total rainfall from very heavy rain days (R99p), maximum rainfall accumulated over three consecutive days (Rx3day), longest wet spell duration (CWD), and longest dry spell duration (CDD).

Central Kaski consistently records the highest values in most indices, indicating frequent rainfall, intense precipitation events, and prolonged wet periods. This highlights the area’s vulnerability to flooding and related hazards. In contrast, northern high-altitude regions such as Mustang and upper Manang experience fewer wet days and less intense rainfall, but also endure long dry spells, which can contribute to drought stress and water scarcity.

Southern lowlands show a unique combination of intense short-duration rainfall and extended dry periods, emphasizing seasonal variability and challenges for agriculture and water management. Understanding these spatial patterns of extremes is critical for climate risk assessment, infrastructure planning, and designing targeted adaptation measures such as flood control, drought mitigation, and sustainable water resource management in different parts of the province.

5.2. Sectorial Implications

5.2.1. Agricultural Impacts in Nawalpur (East)

In Nawalpur (East) District, sustained warming has increased over the past four decades by about 1.5°C, accelerating notably after 2010, with seven of the nine hottest years occurring after 2015. Precipitation has been highly variable increasing challenges for rain irrigated agriculture. Cropland area declined by 9.4% from 2000 to 2022, while built-up areas expanded more than sevenfold to 6.16 km², directly consuming agricultural terrain. Critical water retention features such as riverbeds and grasslands also shrank, reducing natural buffers against rainfall variability. Paddy yields demonstrated strong temperature sensitivity despite low rainfall, though this heat tolerance remains uncertain under prolonged warming. Wheat showed moderate heat sensitivity with persistently low yields. Maize exhibited significant drought resilience nearly doubling yields in drier years despite shrinking cropland. Spring rice (Chaite dhan) maintained consistently high yields with moderate drought tolerance. Barley and buckwheat benefited modestly from warming, while millet remained unresponsive to climate shifts. These intersecting trends: rising temperatures, erratic rainfall, cropland loss, and degradation of water-retention features, accelerate soil moisture loss and increase irrigation demand heighten vulnerability to drought, erosion, and pest outbreaks. Although maize and spring rice show adaptive capacity, staple crops like paddy and wheat remain highly climate-vulnerable. Such findings show urgent need for localized adaptation strategies to ensure sustainable agricultural livelihoods.

5.2.2. Water Resource Impacts in Kaski District

In Kaski District, long-term warming has increased annual average temperatures by 1.36°C over 44 years, intensifying evaporation and moisture loss. Precipitation totals varied widely, complicating water recharge and irrigation planning. Water bodies declined by 19%, and riverbeds contracted by 63% between 2000 and 2022, diminishing groundwater recharge and natural water storage capacity. River discharge decreased by 22% between 1981 and 2016, reaching extreme lows in warmer years. Discharge correlates strongly with monsoon rainfall but is inversely linked to temperature confirming warming reduces dry-season flows. Land cover degradation compounds these stresses, declined water bodies and riverbeds contraction during 2000 and 2017 weakened the groundwater recharge and flow regulation. This aligns temporally with discharge declines: 60% of low-flow years occurred after 2001. The population surged by 57.7% from 2001 to 2021, leading to the lowest per capita water availability in Gandaki Province. These trends create systemic water stress, threatening agricultural productivity, hydropower generation, and socioeconomic stability through reduced dry-season flows and increasing sedimentation risks. The abrupt hydrological changes post-2019 suggest critical thresholds may be crossed, demanding urgent protection of remaining water-retention features to avert irreversible water loss.

5.2.3. Climate Change Impacts on Urban and Human Settlements

Across Gandaki Province’s urban and human settlements, mean temperatures have increased by 0.92°C since 1981, with faster warming since 2015. Built-up areas doubled since 2000, primarily at the expense of grasslands and croplands, while bare rock surfaces expanded dramatically, signaling increased erosion and land degradation. Urban expansion has intensified heat island effects, especially with rising population densities. Loss of natural land cover combined with altered precipitation patterns has elevated flood and landslide risks, exacerbating vulnerabilities in rapidly growing settlements.

5.2.4. Climate Extremes and Local Perception in Mustang

All surveyed respondents in Mustang District reported noticeable changes in weather patterns, identifying irregular rainfall as the primary disaster risk affecting agriculture and livelihoods. Nearly 90% experienced recurrent floods or landslides over the past five years, with over half incurring property or agricultural losses. Climate impacts have driven migration for nearly 40% of respondents or their relatives, while approximately one-third reported disaster-related adverse health effects. Disaster preparedness remains critically low: most respondents have never participated in awareness programs and lack insurance coverage. Respondents urgently requested province level government intervention to Formalize land ownership rights, and streamline insurance claim procedures (e.g., excessive administrative burdens where livestock compensation processes exceed the asset's value). This documentation deficit prevents effective disaster preparedness and limits livelihood diversification through land-based enterprises. Nevertheless, an overwhelming majority expressed willingness to engage in future preparedness training.

6. Conclusions and Recommendations

This project represents a major milestone in understanding regional climate dynamics in Gandaki Province. As the central output of this project, *Climate Atlas of Gandaki Province ("गण्डकी प्रदेशको जलवायु मानचित्र")* provides a foundational and spatially detailed overview of long-term temperature and precipitation patterns based on observational data from 1981 to 2024. It successfully compiles and visualizes key climate parameters across diverse physiographic zones, offering critical insights into broad climatic trends, including rising temperatures and evolving precipitation regimes. Additionally, integrated sectorial analyses highlight the varied and complex impacts of these climatic changes on agriculture, water resources, urban settlements, and local livelihoods, providing an important starting point for targeted adaptation and policy planning. While the analysis is intentionally simplified for accessibility, it marks an important step toward evidence-based climate information systems at the provincial scale.

The findings confirm a clear warming trend across the province, more pronounced in southern lowlands and mid-hills, though the high Himalayan regions are also affected, raising serious concerns for snow and glacier stability. Rainfall patterns remain highly variable, with extremely wet zones like Lumle contrasting sharply with chronically arid trans-Himalayan areas like Mustang. The high sensitivity to erratic rainfall, short-duration extremes, and extended dry spells, as captured by indices such as R99p, Rx3day, and CDD, reflect a growing risk of floods, droughts, and landslides.

Sector-specific analyses underscore urgent challenges. In Nawalpur (East), warming and erratic rainfall are aggravating soil moisture deficits and placing staple crops like paddy and wheat at risk. Kaski faces systemic water stress from reduced river discharge and water body loss, with implications for irrigation, hydropower, and overall water security. Urban areas are increasingly vulnerable to heat islands, erosion, and flooding due to land cover change and population growth. In Mustang, community perceptions corroborate scientific findings, highlighting disaster exposure, climate-driven migration, and severe gaps in preparedness and insurance access.

Despite data limitations, especially in remote mountainous areas, this atlas provides a vital spatial and temporal baseline. It can directly inform planning, risk management, and adaptation at local and provincial levels. Crucially, the relevance of climate information across sectors, from agriculture and water to energy, disaster risk reduction, and urban development, demands more detailed, sector-specific research.

In sum, this atlas is not an endpoint, but a foundation. Its true value lies in prompting sustained monitoring, stronger science-policy integration, and targeted resilience strategies for Gandaki Province’s diverse and climate-vulnerable landscapes.

To support long-term climate resilience in Gandaki Province, the atlas should be maintained as a living document that evolves over time. Periodic updates incorporating improved datasets, refined interpolation techniques, and changing climate conditions will ensure continued relevance and accuracy. These updates can build on growing data availability and improved modeling capacity at both national and provincial levels.

Expanding the climate observation network, especially in high-altitude and data-scarce areas, is crucial. Enhanced spatial and temporal coverage through additional monitoring stations, complemented by remote sensing and model integration, will improve the precision of future climate assessments and support more localized adaptation planning.

This report also highlights the importance of sector-specific climate analysis. Targeted studies on agriculture, water systems, infrastructure, health, and settlement planning should follow to translate general climate signals into concrete adaptation measures. For example, further research into hydrological changes in Kaski, crop-climate interactions in Nawalpur, and settlement vulnerability in Mustang would support more tailored policy development and investment.

The communication and accessibility of climate information should be improved through capacity-building programs, decision-support tools, and simplified products that make data usable for local governments, civil society, and at-risk communities. Building these bridges between science and practice will ensure that the insights gained from this atlas inform real-world decision-making.

Finally, institutional coordination remains vital. Stronger collaboration among academia, provincial agencies, development partners, and local stakeholders will be essential for mainstreaming climate data into risk reduction, infrastructure planning, and sustainable development efforts across Gandaki Province.

7. References

- Intergovernmental Panel On Climate Change (Ipcc). (2023). Climate Change 2021 - The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009157896
- Santer, B. D., Bonfils, C. J. W., Fu, Q., Fyfe, J. C., Hegerl, G. C., Mears, C., Painter, J. F., Po-Chedley, S., Wentz, F. J., Zelinka, M. D., & Zou, C.-Z. (2019). Celebrating the anniversary of three key events in climate change science. Nature Climate Change, 9(3), 180-182. https://doi.org/10.1038/s41558-019-0424-x
- Government of Nepal. (2022). *National climate change survey 2022*. Government of Nepal. https://giwmscdnone.gov.np/media/app/public/36/posts/1715605547_98.pdf
- DHM (2017) Observed Climate Trend Analysis of Nepal
- Central Bureau of Statistics (CBS). (2021). National Population and Housing Census 2021. Government of Nepal.
- Department of Hydrology and Meteorology (DHM). (2024). Historical Climate Data for Gandaki Province (1981-2024) [Unpublished dataset]. Government of Nepal.
- Eriksson, M., Xu, J., Shrestha, A. B., Vaidya, R. A., Nepal, S., & Sandström, K. (2009). The Changing Himalayas: Impact of Climate Change on Water Resources and Livelihoods in the Greater Himalayas. International Centre for Integrated Mountain Development (ICIMOD).
- Intergovernmental Panel on Climate Change (IPCC). (2007). Climate Change 2007: The Physical Science Basis. Cambridge University Press.
- Pacific Climate Impacts Consortium (PCIC). (2023). climdex.pcic: PCIC Implementation of Climdex Routines [R package]. Retrieved from https://github.com/pacificclimate/climdex.pcic
- Panday, S., Ghimire, B., & Prajapati, R. (2014). Climate change and adaptation in the Himalayas: A case study of Nepal. Mountain Research and Development, 34(3), 267-279. https://doi.org/10.1659/MRD-JOURNAL-D-13-00089.1
- QGIS Development Team. (2023). QGIS Geographic Information System (Version 3.34) [Computer software]. Open-Source Geospatial Foundation.
- R Core Team. (2023). R: A Language and Environment for Statistical Computing (Version 4.3.1) [Computer software]. R Foundation for Statistical Computing.

- Santer, B. D., et al. (2011). Separating signal and noise in atmospheric temperature changes: The importance of timescale. Journal of Geophysical Research: Atmospheres, 116(D22). https://doi.org/10.1029/2011JD016263
- Survey Department of Nepal. (2023). Administrative Boundary Maps of Gandaki Province [Geospatial dataset]. Government of Nepal.
- World Meteorological Organization (WMO). (2011). Guide to Climatological Practices (WMO-No. 100).
- Zhang, X., Alexander, L., Hegerl, G. C., Jones, P., Tank, A. K., Peterson, T. C.,... & Zwiers, F. W. (2011). Indices for monitoring changes in extremes based on daily temperature and precipitation data. Wiley Interdisciplinary Reviews: Climate Change, 2(6), 851-870. https://doi.org/10.1002/wcc.147
- Gauli, B. et al. (2021). Impact of Climate Change on Wheat Production in Nawalparasi District, Nepal. *Environment & Ecosystem Science*.
- Pokhrel, P. et al. (2021). Impact of climate change on rice production: an empirical study in Kaski and Nawalparasi, Nepal. *Journal of Agriculture and Natural Resources*.

8. List of Annex

1. Tables

Table 3 Survey respondent background information

Background characteristic	Gender			Percent
	Male	Female	Total	
Education				
SLC and above	9	3	12	16.00%
Some secondary (9-10)	6	2	8	10.70%
Basic (1-8)	17	8	25	33.30%
No education	13	17	30	40.00%
Religion				
Hindu	4	1	5	6.70%
Non-hindu	41	29	70	93.30%
Caste/ethnicity				
Brahmin/Chhetri	2	1	3	4.00%
Janajati	42	29	71	94.7%%
Dalit	1	0	1	1.30%
Occupation				
Agriculture/farming	19	18	37	49.33%
Business/industry	13	9	22	29.33%
Service	3	1	4	5.33%
Unemployed	10	2	12	16.00%

Table 4 Total estimated monitory loss due to Kagbeni Flood August 2023

Particular	Total estimated lost (NRs)
Individual Houses (72 Houses)	**19,03,70,000.00**
Irrigation and river embankment	**5,00, 00,000.00**
Kagbeni Hindu religious places temple and around	**3,50, 00,000.00**
Kagbeni Monasteries	**2,50, 00,000.00**
Janashkati Secondary School Kagbeni	**25,00,000.00**
Road to the village (1 Km)	**2,50, 00,000.00**
Varagung Muktichhetra Rural Municipality ward number -4 office building	**1,50,00,000.00**
Women's group community building	**1,50, 00,000.00**
Bridge at highway to upper Mustang	**1,25,00,000.**
Agricultural loss	**75,00,000.00**
Local police Station at Varagung Muktichhetra R.M-4	**75,00,000.00**
Club Building	**75,00,000.00**
Drainage System	**50,00,000.00**
Suspension bridge	**45,00,000.00**
Bridge linking Kagbeni-Tiri	**35,00,000.00**
Underground Electricity	**35,00,000.00**
Drinking Water purification System	**25,00,000.00**
2 Wooden Bridge (Local)	**10,00,000.00**
Total Loss	**1.50,36,53,70,005.00**

2. Survey Questionnaire

a. Informed consent

I …………………………………………………. of age ……….. years. I hereby confirm that I have clearly understood the aim of the study and happy to involve in the survey process. I have given my consent for this research being conducted by CDHM, IoST, T.U for Gandaki Province Policy and Planning Commission, I think, it is an opportunity to me to response the questions, which I am happy to contribute some of my experience in climate related disaster risk and its vulnerability in socio-economic condition of the local people.

I hereby declare that,

1. I understand that my participation in the study is voluntary and that I am permitted to withdraw my involvement at any time without giving a reason, and without my legal rights being affected.
2. I understand that my identity will not be revealed in any form that will be published or released to third parties.
3. I agree to allow the use of any data or results obtained from this study provided that such use is only for academic and scientific purposes.
4. I agree to participate in this study.

Signature of the research participant/ respondent

Signature: ………………………...	Investigator:
Name: ……………………….......................	Signature: …………………….
Mobile: ………………………….	Name: ………………………………………
Date: ……………………………..	Date:………………………………

b. Survey Questionnaire

Extreme Precipitation Impact on Socio-Economic Condition of People of Nepal

Respondent IDN: …………..

Section 1: Identification

1.1 Province ………………………………

1.2 District ………………………………

1.3 Rural municipality/municipality………………………………

1.4 Ward number ………………………………

1.5 Contact ………………………………

Section 2: General information

QN Question and filters Number & coding

2.1 Name of the respondent …………………….

2.2 Age of respondent ……………………….

2.3 Gender ……………………….

2.4 Education

- ☐ No education 1
- ☐ Basic education (1-8) 2
- ☐ Some secondary (9-10) 3
- ☐ SLC and above 4

2.5 Occupation

- ☐ Farming - livestock/crops 1
- ☐ Business/industry 2
- ☐ Self-employment 3
- ☐ Government service 4
- ☐ Private service 5
- ☐ Unemployed 6

2.6 Religion

- ☐ Hindu 1
- ☐ Buddhist 2
- ☐ Muslim 3
- ☐ Kirat 4
- ☐ Christian 5
- ☐ Other (specify): 6

2.7 Caste/ethnicity

- ☐ Brahmin/ Chhetri 1
- ☐ Janajati 2
- ☐ Dalit 3
- ☐ Musalman 4
- ☐ Other (specify): 5

Section 3: General environmental concerns

3.1 How long have you been living here? …………………………… Years

3.2 Do you feel the pattern of weather is generally changing?

- ☐ Yes
- ☐ No
- ☐ Don't know

3.3 In your view which of the following issues you frequently experienced in your life. Please mark the issues that concern you the most (1 = highest, 2=second highest and so on) .

- ☐ Irregular rainfall
- ☐ Flooding
- ☐ Landslide
- ☐ Heavy snowfall
- ☐ Drought
- ☐ Air pollution
- ☐ Pollution of rivers
- ☐ Wildfire
- ☐ Litter/poor waste management
- ☐ Climate change

3.4 Have you, in last 5 years, experienced any form of disaster occurred by rainfall or floods or landslides while living in this area?

- ☐ Never been
- ☐ One to five times
- ☐ More than five times

3.5 If you have experienced, which time you feel was more vulnerable?

- ☐ During morning time
- ☐ During day time
- ☐ During evening time
- ☐ During night time

3.6 Have you, in the last 5 years, experienced any form of damage caused by rainfall or floods or landslides (including to your home, garden or vehicle, agriculture land, business)?

- ☐ Yes
- ☐ No
- ☐ Not sure

3.7 Have you, in the last 5 years, experienced any form of damage to your livestock (including to your castles, poultry and pets etc.) caused by rainfall or floods or landslides?

- ☐ Yes
- ☐ No
- ☐ Not sure

3.8 If yes to he Q.3.6 & Q 3.7, could you tentatively calculate the total cost of damage?

NRs…………….

3.9 Has the disasters (unexpected rail fall, landside or floods) ever affected the health of any of your family or friends?

- ☐ Yes
- ☐ No
- ☐ Don’t know

3.10 Has the disasters (unexpected rail fall, landside or floods) ever cause the death of any of your family member or friends?

- ☐ Yes
- ☐ No
- ☐ Don’t know

3.11 Have you, in the last 5 years, witnessed of any of your family member or friends or relatives or neighbor migrated from this place due to the affect disasters (unexpected rail fall, landside or floods)?

- ☐ Yes
- ☐ No
- ☐ Don’t know

Section 4: Awareness and response measure

4.1 Have you ever been taken part in the disaster related awareness program provided by any of the reorganizations (including government or non-government or civil society)?

- ☐ Yes
- ☐ No

4.2 In the event of a major disruption or crisis, what measures do you have in place to ensure the safety and well-being of family and friends?

- ☐ Evacuation plans and designated safe place
- ☐ Emergency communication among family members
- ☐ Call security personal for help for the rescue
- ☐ Reserving some amount of money for emergency

4.3 Do you have any insurance coverage or risk transfer mechanisms to mitigate the financial impact of disruptions or crises caused by the disaster?

- ☐ Yes
- ☐ No

4.4 What would you expect to become you first aware that flood waters or landslide might reach to your areas just before the heavy rainfall?

- ☐ Frequent weather broadcast
- ☐ Reliable meteorological station
- ☐ Scientific research and development
- ☐ Responsible government

4.5 Would you be willing to participate in the awareness/orientation/training program related to disasters?

- ☐ Yes
- ☐ No
- ☐ Not sure

Section 5: Awareness and response measure (only applicable for Kagbeni study site)

5.1 Is your house or property located in a flood or landslide prone or other natural disaster area?

- ☐ Yes
- ☐ No

5.2 Have you or your household experienced any natural hazards (e.g., floods, landslides, erosion) in the past 5 years?

- ☐ Yes
- ☐ No
- ☐ Don't know

5.3 During monsoon season, how frequently does flooding or river overflow occur in your area in the last five years?

- ☐ Every year frequently
- ☐ Every year occasionally
- ☐ Rarely
- ☐ Never

5.4 Did the flooding or river overflow during monsoon season change direction in the last five years?

- ☐ Yes
- ☐ No

5.5 If yes, how frequently does flooding or river overflow change direction in the last 5 years?

- ☐ Many times
- ☐ Every year frequently
- ☐ Every year occasionally
- ☐ Rarely

5.6 Does your village have flood or other natural disaster protection structures (e.g., embankments, retaining walls, community buildings etc.)?

- ☐ Yes
- ☐ Limited
- ☐ No

5.7 Has your home or community infrastructure (e.g., roads, bridges, communication system) been damaged by recent floods or landslides or other natural disaster?

- ☐ Yes
- ☐ No
- ☐ Don't know

5.8 Has the flooding or river caused erosion or snowfall damaged agricultural land near your village?

- ☐ Yes
- ☐ No
- ☐ Don't know

5.9 Are you aware of any glacial lake outburst flood risks in the nearby region?

- ☐ Yes
- ☐ No
- ☐ Not applicable

5.10 Are evacuation routes or emergency shelters available in your community in case of a natural disaster?

- ☐ Yes
- ☐ No

5.11 To what extent are you satisfied with road accessibility during disasters or extreme weather?

- ☐ Highly satisfied
- ☐ Satisfies
- ☐ Moderately satisfied
- ☐ Not satisfied
- ☐ Not satisfied at all

5.12 Is your primary source of livelihood been impacted by natural hazards (e.g. extreme precipitation) ?

- ☐ Yes
- ☐ Yes, but marginally
- ☐ No

5.13 How much of your income or crops have you lost due to natural disasters (e.g. extreme precipitation) in recent years?

In NRs. ……………..(approximately)

5.14 How accessible is clean drinking water during and after disasters (e.g. extreme precipitation)?

- ☐ Easily accessible at all times
- ☐ Sometimes accessible
- ☐ Difficult to access
- ☐ Not accessible at all

5.15 Do you have access to fuel or energy sources (e.g., firewood, electricity, gas) during winter or rainy seasons?

- ☐ Easily accessible at all times
- ☐ Sometimes accessible
- ☐ Difficult to access
- ☐ Not accessible at all

5.16 Do you or your children have access to health care service or medication during winter or rainy seasons?

- ☐ Easily accessible at all times
- ☐ Sometimes accessible
- ☐ Difficult to access
- ☐ Not accessible at all

5.17 How accessible is children's school education during and after disasters (e.g. extreme precipitation)?

- ☐ Easily accessible at all times
- ☐ Sometimes accessible
- ☐ Difficult to access
- ☐ Not accessible at all

5.18 How accessible is road transportation during and after disasters (e.g. floods, landslide, snowfalls etc.)?

- ☐ Easily accessible at all times
- ☐ Sometimes accessible
- ☐ Difficult to access
- ☐ Not accessible at all

5.19 How accessible is road communication (telephone, news, T.V, Radio etc.) system during and after disasters (e.g. floods, landslide, snowfalls etc.)?

- ☐ Easily accessible at all times
- ☐ Sometimes accessible
- ☐ Difficult to access
- ☐ Not accessible at all

5.20 Do you have access to alternative income sources that reduce your dependency on extreme precipitation-sensitive livelihoods?

- ☐ Yes
- ☐ No

5.21 Have you or your community received any disaster risk education or early warning training?

- ☐ Yes
- ☐ No

5.22 Do you have knowledge about first aid, evacuation, or how to respond during a natural disaster (e.g. extreme precipitation)?

- ☐ Yes
- ☐ No

5.23 Is there a local disaster preparedness committee or plan in your village?

- ☐ Yes
- ☐ No

5.24 What coping strategies do you or your household use to deal with disaster risks management?

- ☐ Temporary or permanent migration to safer areas
- ☐ Use of savings during/after disasters
- ☐ Storing food and water in advance
- ☐ Reducing daily expenses during risky seasons
- ☐ Shifting livestock to safer places
- ☐ Seek government or NGO aid
- ☐ Other (please specify): ___________

5.25 Do you have anything to add in this study? Please feel to add.

……
……
…………………….

Thank you for your valuable time!

Figure 18 Some pictures taken during the people's perception survey