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Thresholds and Characteristics for Heatwaves and Coldwaves in Nepal Between 1981-2020

by

Adarsh Gupta

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " Thresholds and Characteristics for Heatwaves and Coldwaves in Nepal Between 1981-2020" submitted by Adarsh Gupta in partial fulfillment of the requirements for the degree of Master in Climate Change and Sustainable Development.

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ABSTRACT

With continuous climate change and global warming, temperature related hazards like: heatwave and coldwave must be monitored and studied, specially keeping in mind the geographical diverseness of Nepal where temperature related hazards can easily change into disasters. This study covers all the Nepal and with 40 years of statistical and climatological study of heatwaves and coldwaves unlike any other study of its kind. Also, this study attempts to provide nationalized standard criteria for monitoring heatwaves and coldwaves on district levels that has been severely lacking.

With aim to determine percentile thresholds for heatwaves and coldwaves respectively and to characterize the past behaviors of both of these waves, this study analyzed the climatology and differences of heatwaves and coldwaves by using percentile method recommended by WMO based on last 40 years (1981-2020) of climatic data from 96 stations widely spread across the country. This study uses percentile method for computation of daily thresholds for heatwaves and coldwaves. Giving emphasis on 95th and 5th percentile value thresholds for heatwaves and coldwaves, these waves were identified. Also, this study extends to examine magnitude, frequency, spatial distribution and statistical comparison of these events.

Study showed that heatwave and coldwave thresholds from percentile method is reliable for identification and analysis of heatwaves giving 89.3% match with heat indexes. Behavior of heatwave have changed dramatically in last decade and variation in magnitude of heatwaves have increased by 200% while average heatwaves frequency had lowered by almost 50% in last decade. Coldwave magnitude had remained unchanged but average coldwave frequency in Nepal in has dropped significantly by 67.03%.

Keywords: Heatwave, Coldwave, Percentile-based thresholds.

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
CSDI	Cold Spell Duration Index
CW	Coldwaves
DHM	Department of Hydrology and Meteorology
HW	Heatwaves
IPCC	Intergovernmental Panel on Climate Change
MA	Moving Average
Max	Maximum
Min	Minimum
NHRC	Nepal Health Research Council
NWS	National Weather Service
Temp	Temperature
THT	The Himalayan Times
UNIDSR	United Nations Office for Disaster Risk Reduction
WB	World Bank
WBGT	Wet-Bulb Globe Temperature
WHO	World Health Organization

WMO	World Meteorological Organization
WSDI	Warm Spell Duration Index

CHAPTER 1: INTRODUCTION

1.1 Background

Examples of extreme weather and climate events include, but are not limited to, heatwaves, cold waves, floods, extreme precipitation, drought, tornadoes and tropical cyclones. Human-induced climate change beyond natural climate variability, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people (Intergovernmental Panel on Climate, 2023). The IPCC's Fifth Assessment Report shows an increase in the frequency of hot days, nights, and heat waves worldwide in the last 50 years(Intergovernmental Panel on Climate, 2023). The occurrence of wet-bulb temperatures at or above certain thresholds has more than doubled in some regions, and extreme combinations of heat and humidity also increased in parts of India, Bangladesh, and Pakistan(Russo et al., 2014). In all populated places, the frequency of hot extremes will rise as a result of climate change, according to the IPCC's special report on global warming of 1.5°C (Intergovernmental Panel on Climate, 2023). Due to human-induced climate change, severe events have become more frequent and intense over the past few decades, and this trend is expected to continue(Chapman et al., 2017; Nath & Lau, 2014; Purich et al., 2014).

The concept of heatwaves (HW) is not universally defined, but generally understood as a prolonged period of excessive heat (WMO, 2023). The WHO defines HW as "*sustained periods of uncharacteristically high temperatures that increase morbidity and mortality"* and vice-versa for coldwave (WHO, 2004). The IPCC defines it as "*a continuous period of abnormally and uncomfortably hot weather"*. The World Meteorological Organization (WMO) defines HW as "*a period during which the daily maximum temperature exceeds for more than five consecutive days the maximum normal temperature by 9◦F (5◦C), the 'normal' period being defined as 1961–1990"* (WMO, 2023). Different countries in South Asia have developed their own criteria for defining HW based on their specific climatic conditions. As of March 2022, Bhutan, Maldives, Nepal, and Sri Lanka do not have an official definition for HW.

Heat waves were responsible for 4 of the 10 deadliest natural disasters in 2015, with South Asian heat waves ranking third and fourth by mortality(Climate Risk Country Profile: Nepal (2021):The World Bank Group and the Asian Development Bank., 2021). The speed of warming after 1970, which is significantly greater than the first half of the century (0.15°C/decade)(IPCC, 2014). Extremes can shift significantly while the mean and variability are just slightly altered(Baten et al., 2022). The current median probability of a heat wave (defined as a period of 3 or more days where the daily temperature is above the long-term 95th percentile of daily mean temperature) in Nepal is around 3%. The median estimated probability of cold wave also sits at around 3% (defined as a period of 3 or more days where the daily temperature is below the long-term 5th percentile of daily mean temperature(Climate Risk Country Profile: Nepal (2021):The World Bank Group and the Asian Development Bank., 2021).

Heatwaves have emerged as a serious concern in Nepal, posing significant risks to public health, agriculture, and the environment. The National Disaster Risk Reduction and Management Authority (NDRRMA) reported that around 1.25 million people in Nepal were likely to be affected by disasters in 2023, with heatwaves being a major contributing factor. The Figure 1-1 shows the mean annual temperature increment for South Asian countries. Nepal's temperature increase is concerning when compared to rest of South Asian countries.

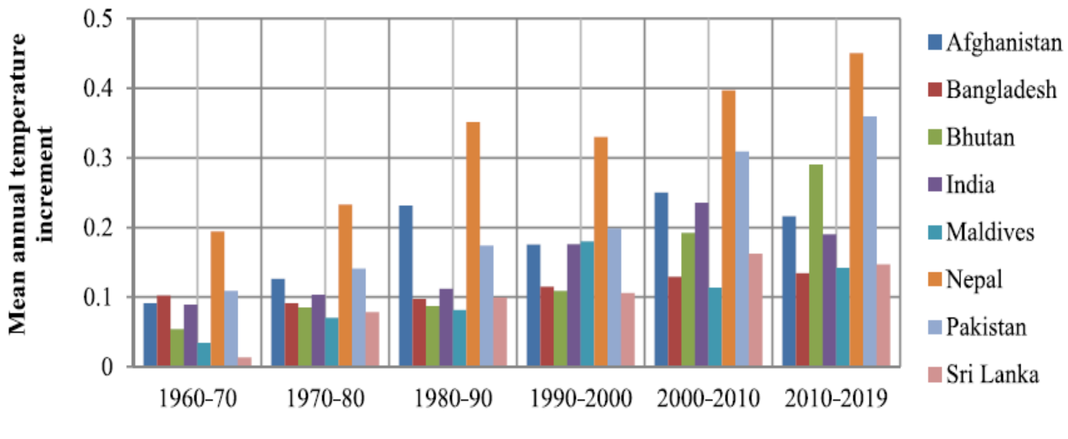

Figure 1-1: Decadal timeline showing rise in mean annual temperatures in SAARC countries.

Source: (Kotharkar & Ghosh, 2021)

Nepal is not alone in facing heatwave challenges, as evidenced by extreme heat events worldwide. Europe, Canada, the US Northwest, and the UK have experienced record-breaking heatwaves, further underscoring the global nature of this phenomenon (Press, 2019; Reuters, 2021). The United Nations has also warned about the growing climate crisis, with 2020 confirmed as one of the three hottest years on record (Pollitt, 2021). The frequency of dangerous heat events is predicted to rise in the future, necessitating urgent and coordinated efforts at both global and local levels to address the challenges posed by heatwaves(Press, 2019).

1.2 Statement of Problem

Heatwaves and coldwaves form some of the most challenging events for operational monitoring at the global scale, in all regions. This is due to the varying contexts and needs, making the characterization of these event dependent on local conditions (WMO, 2023). Many of these extreme events refer to heat and cold waves, heavy precipitation with flooding, and drought. As temperature and precipitation are the best-observed elements historically in most countries, extreme events related to temperature and precipitation benefit from the best available current and historical data, which allows use of robust statistical methodologies for characterizing these events in a consistent manner (*ClimPACT Software Manual (English)*, 2013). This study examines the potential changes in regional heatwaves, including their intensity, frequency, and duration, as global warming increases.

In Nepal, previous studies have provided limited information on heatwaves (HWs) and coldwaves (CWs) and have not established clear thresholds to identify and measure them with standard criteria (Baidya et al., 2008; Kotharkar & Ghosh, 2021). This lack of data has hampered our understanding of these phenomena, particularly in the diverse micro ecosystems of Nepal(Dhimal et al., 2018; Pollitt, 2021). Most of the study are limited or focused on certain parts of Nepal rather than studying all over the country(Pradhan et al., 2019; Pradhan et al., 2013). Not only this, but also very few studies have expanded temporally before 2000s(Bai et al., 2016; Kotharkar & Ghosh, 2021).

To address this gap, this study aims to provide reliable information on HWs and CWs, even without advanced heat and cold wave indices. The study provides district-wise thresholds that can used locally to monitor and warn from heatwaves and coldwaves. Additionally, it examines past vulnerabilities and patterns of heatwaves and coldwaves.

The findings of this study can be used to validate complex indices for heatwaves and cold waves in the future. It will also allow for the development of standardized warnings and monitoring systems for these hazards. Additionally, the study will enhance our understanding of the parameters of heatwaves and cold waves. As each district will have its own standards and thresholds for these events, this study will help establish important milestones in managing heatwaves and cold waves.

1.3 Objectives

The main objective of this study behavior and past occurrences of heatwaves and coldwaves using percentile thresholds.

The specific objectives are:

- To estimate the thresholds for Heatwaves for different districts in Nepal
- To characterize the behavior of these Heatwaves in Nepal
- To estimate the thresholds for Coldwaves for different districts in Nepal
- To characterize the behavior of these Coldwaves in Nepal

1.4 Significance and Limitations

This study builds a foundation for further advancements in the study of heatwaves and coldwaves. The generated thresholds in the results will provide standard base for decision making for further uses.

The limitation of this study includes:

- Use of basic parameter only without considering impact of humidity, thermal comfort etc.
- Unable to correlate the temperature impacts to health issues directly
- Unable to correlate the temperature impacts to deaths

CHAPTER 2: LITERATURE REVIEW

2.1 Heatwaves and Coldwaves

Heatwaves and coldwaves are extreme temperature events that can have significant impacts on human health, agriculture, ecosystems, and infrastructure. As the climate changes, heatwaves and coldwaves are projected to increase in frequency, intensity, and duration in many parts of the world.

Nepal has a highly variable climate ranging from subtropical in the south to alpine in the north. As a result, defining heatwaves and coldwaves in the Nepali context can be complex. This literature review summarizes various studies that have analyzed thresholds, frequency, intensity, and other characteristics of extreme temperature events across different countries and regions of Nepal. Understanding how heatwaves and coldwaves manifest and impact Nepali communities is increasingly urgent given projections that climate change will exacerbate many extreme weather events.

Compared to heatwaves, literature analyzing temperature minimums, cold spells and coldwaves in Nepal remains relatively limited. Part of the challenge lies in clearly defining a coldwave threshold given the already below freezing winter temperatures that persist for months across mountainous areas. However, extreme cold snaps do occur and cause excess winter mortality even among communities assumed to be resilient to cold (Acharya & Pathak, 2015).

2.2 Practices for Understanding, Measuring and Monitoring of Heatwaves and Coldwaves

Heatwaves

The Table 2-1 presents details from 6 studies on heatwaves in South Asia, including the location studied, indices used to quantify heatwaves, duration of the study period, and key metrics and findings examined in each study. Locations include Sri Lanka, Bangladesh, Afghanistan, Nepal, India, and Pakistan. Some of the common indices used include heatwave magnitude index (HWMI), excess heat factor (EHF), and various measures of apparent temperature. The table demonstrates the diversity of approaches used to monitor and analyze dangerous heat in South Asia and its impacts.

Table 2-1: Methods and parameters of SAARC countries for measuring heatwaves. Source: (Kotharkar & Ghosh, 2021)

Study	Geography	Indices used	Duration of study	Remarks
(Nianthi et al., 2018)	Sri Lanka	Human Comfort Index (HCI) and Human Heat Stress (HHS)	1931–1961 and 2006-2016	Intensity
(Nissan et al., 2017)	Bangladesh	NCEI (apparent temp index)	1989-2011	Frequency and intensity
(Aich et al., 2017)	Afghanistan	Heat Wave Magnitude Index (HWMI)	1958–1977	Frequency, intensity and duration
(Pradhananga et al., 2019)	Nepal	Percentile, Heat index, humidity index, and WBGT	2010	Frequency
(Rohini et al., 2016)	India	Excess Heat Factor (EHF) and percentile threshold	1981-2020	Frequency, threshold and intensity
(Zahid & Rasul, 2011)	Pakistan	Heat Index (HI)	1961–2007	Duration

For eg: Several studies have aimed to systematically define heatwave and coldwave thresholds for Nepal by analyzing historical observational data. (Pradhananga et al.,

2019) suggested that heatwaves occur when maximum temperatures exceed the 90th percentile of summertime means for at least three consecutive days. This translates to thresholds ranging from 31–34°C depending on the location and altitude. For coldwaves, they propose defining as at least seven consecutive days below the 10th percentile of wintertime means spanning -2° to 15°C across Nepal.

While these studies define some consistent baseline thresholds, Nepal still lacks nationally standardized criteria. (Baidya et al., 2008) argue for an integrated heat health warning system that better accounts for what different communities experience as extreme temperatures. They note that people acclimatized to cooler mountain areas perceive lower temperatures as “hot” compared to southern regions.

Coldwaves

This Table 2-2 summarizes key details from 4 studies analyzing coldwaves in South Asia, specifically in Bangladesh, Nepal, India, and Pakistan. Together, these studies demonstrate the range of metrics, indices, and methods used for monitoring and analyzing dangerous cold in South Asia. Key parameters examined include coldwave duration, intensity/severity, frequency, spatial patterns, variability, magnitude, and associated impacts on crops, health, etc.

Table 2-2: Methods and parameters of SAARC countries for measuring cold waves.

Source: (Kotharkar & Ghosh, 2021)

Study	Geography	Indices used	Duration of study	Remarks
(Mohammad & Mortuza, 2011)	Bangladesh	Cold Wave Duration Index (CWDI)	1988-2017	Duration and intensity
(Shrestha, S. K., Adhikari, B. R., & Adhikari, 2015)	Nepal	Cold Weather Severity Index (CWSI)	1981-2010	Intensity and spatial patterns
(Gupta, A. K., Kumar, A., &	India	Cold Wave Frequency	1971-2000	Frequency and variability

Singh, 2016)		Index (CWFI)		
(Khan, M. A., Ahmed, M., & Abbas, 2016)	Pakistan	Cold Wave Magnitude Index (CWMI)	1981-2010	Magnitude and impacts

Within South Asia, Nepal remains one of the countries with the least intensive heatwave and coldwave monitoring networks and forecast modelling capabilities. (Shrestha et al., 2017) call for improved fine scale meteorological data to capture microclimates unrepresented by existing stations clustered in valleys and urban areas. High elevation communities already experiencing climatic shifts may be most underserved by current systems (Feng et al., 2014). Translating data to timely heat alerts is also critical and will depend on integrating scientific and local knowledge of community vulnerabilities (Baidya et al., 2008).

2.3 Heatwave and Coldwave Metric Variability and Trends

On a global scale, heatwaves have become more frequent and intense since the 1950s, while coldwaves have become less frequent (IPCC, 2014). The IPCC Sixth Assessment report found that between 1850-1900 and 2001-2018, cold days and cold nights have become rarer, while warm days and warm nights have become more common(Intergovernmental Panel on Climate, 2023). Global climate models project these trends to continue, with continued warming leading to more intense, longer lasting heatwaves and fewer cold extremes.

Over the past three decades, Europe has experienced the highest number of heat waves, comprising 43% of the total 144 events globally, followed by Asia (33%), North America (13%), and Africa and Australia (4%). Europe and Asia showed an increasing trend in heat wave occurrences, particularly concentrated in the years 2000, 2003, 2006, and 2007 (Song et al., 2013).

The spatial distribution of heat waves and cold spells around the world, which is depicted below and, enabled a better understanding of the high-occurrence risk region of ETEs. India (17), the USA (15), Pakistan (9), Romania (7), and China (6) were the top five countries affected by heat waves, whereas India (23), Bangladesh

(19), the Russian Federation (15), Mexico (13), and Poland (12) experienced cold events more frequently than other parts of the globe(Song et al., 2013).

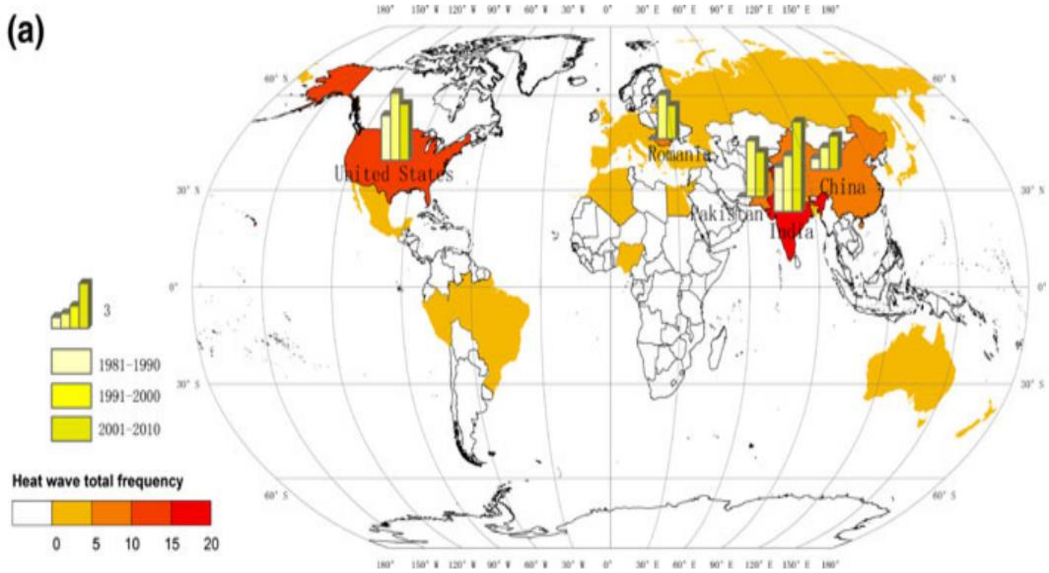

Figure 2-1: Global trend and distribution of heat waves for 3 decades starting 1981.

Source: (Song et al., 2013)

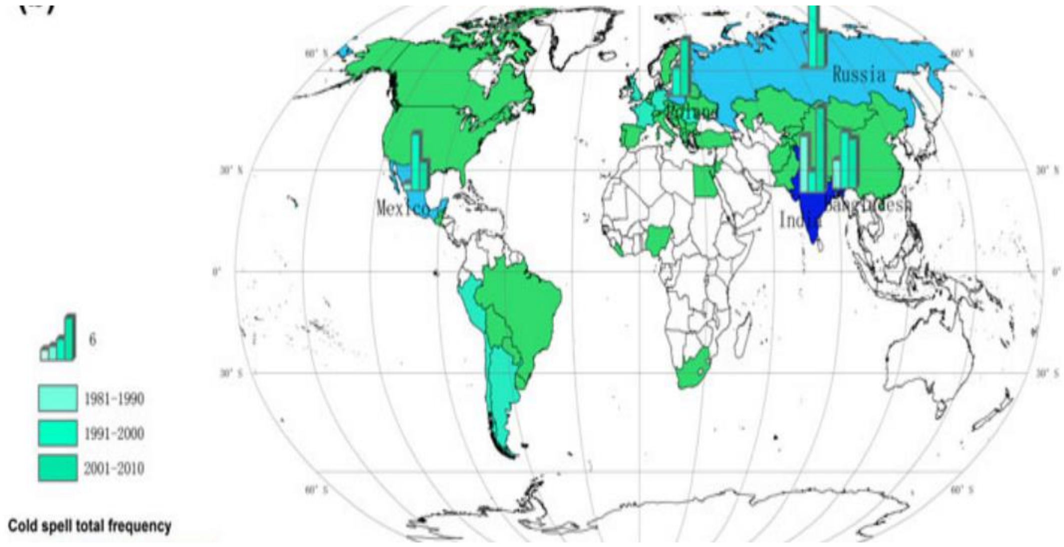

Figure 2-2: Global trend and distribution of cold waves for 3 decades starting 1981.

Source: (Song et al., 2013)

Also, middle and lower latitude countries tended to suffer more frequent extreme heatwaves, while high latitude countries were more prone to extreme cold events due to generally colder climates. However, the occurrence of heatwaves and cold spells did not show distinct spatial patterns globally, likely due to many complex factors affecting near-surface temperatures. Over the last decade, Asia accounted for almost half of the total fatalities from cold spells in the region over the three decades, while Europe had a proportion of approximately 64% (Song et al., 2013).

Regionally, heatwaves have increased substantially across Europe, East Asia, and Australia. Coldwaves such as the recent 2021 Texas cold snap have decreased in frequency and intensity across North America and Northern Asia. In the tropics, both heatwaves and coldwaves remain rare compared to other regions. South Asia faces major climate change-driven extreme heat risks with some of the hottest temperatures ever recorded, profoundly impacting urban populations, public health, infrastructure, and the built environment (Kotharkar & Ghosh, 2021).

Given Nepal’s climatic diversity, heatwaves manifest differently across the country. Several studies have found that northern mountain areas like Mustang and Manang rarely surpass 30°C even during extreme event (Karki et al., 2017; Pradhan et al., 2013). Heatwaves in low-lying southern plains near India, on the other hand, frequently result in maximum temperatures over 40°C (Revadekar et al., 2012). The influence of monsoons also leads to large intra-annual variability. Research on temperature extremes in Nepal is limited, but existing studies have found a rise in heatwave frequency and intensity, especially in the Terai plains, since the 2000s(Karki et al., 2017).

Analysis by found decreasing trends in both frequency and duration of cold spells across most of Nepal during the winter season from 1981-2010 (Shrestha et al., 2017). Declines were statistically significant in many western parts of the country. A study by (Karki et al., 2017) showed widespread cooling trends in minimum temperatures and cold wave severity in Nepal during 1982–2014. Cold wave severity increased only in some pockets of the Far-western and Mid-western Development Regions.

So, in summary, while few long-term widespread heatwave studies are available for Nepal, existing analyses suggest hot temperature extremes have become more frequent in recent decades, particularly in western parts of the country (Baidya et al., 2008). Also, while individual station trends vary, most studies suggest overall declining frequency, duration, and in some metrics intensity/severity of extreme cold events across Nepal over recent decades (Karki et al., 2017; Shrestha et al., 2017).

2.4 Needs and Research Gaps

Current literature reveals complex topographical and social factors underpin heatwave and coldwave variability across Nepal historically and today. Temperatures are already rising to amplify extreme impacts(Kotharkar & Ghosh, 2021). Key knowledge gaps remain regarding heatwaves and coldwaves, high elevation environments and vulnerable groups(Pradhan et al., 2013). Most study lack the spatial and temporal coverage to properly analyze trend in the country.

Also, almost none of the studies have tried to standardize the practice of monitoring of heatwaves and coldwaves (Baidya et al., 2008). Addressing these through interdisciplinary cooperation and research will allow developing threshold indices, forecasting capacity and adaptation strategies that account for diverse Nepali realities under climate change. (Pradhan et al., 2013). Quantifying heat mortality and morbidity remains a challenge, however, given insufficient reporting. (Baidya et al., 2008) note that "in Nepal, death registration data do not record heat wave as the cause of death." More research on how Nepalis are impacted physically and socially across geographic and demographic groups will be key for adaptation initiatives. This study tries to address all these research gaps by covering whole country as its spatial study area with temporal analysis dating back to 1980s. In addition, this study also provides percentile thresholds that can be used to standardize studying and monitoring practices of these heatwaves and coldwaves.

CHAPTER 3: STUDY AREA

Nepal is a mountainous country in the Himalayas, with an area of 147,560 sq.km. and elevations ranging from 60-8848.86 m above sea level. It can be grouped into three regions: Lowland, Mid-Mountains and Hills, and High Mountains. The country experiences a range of climates due to its altitude and aspect, with tropical/subtropical in the south and polar in the north within a short distance. The study area is shown in the Figure 3-1 with distribution of different temperature stations taken for this study.

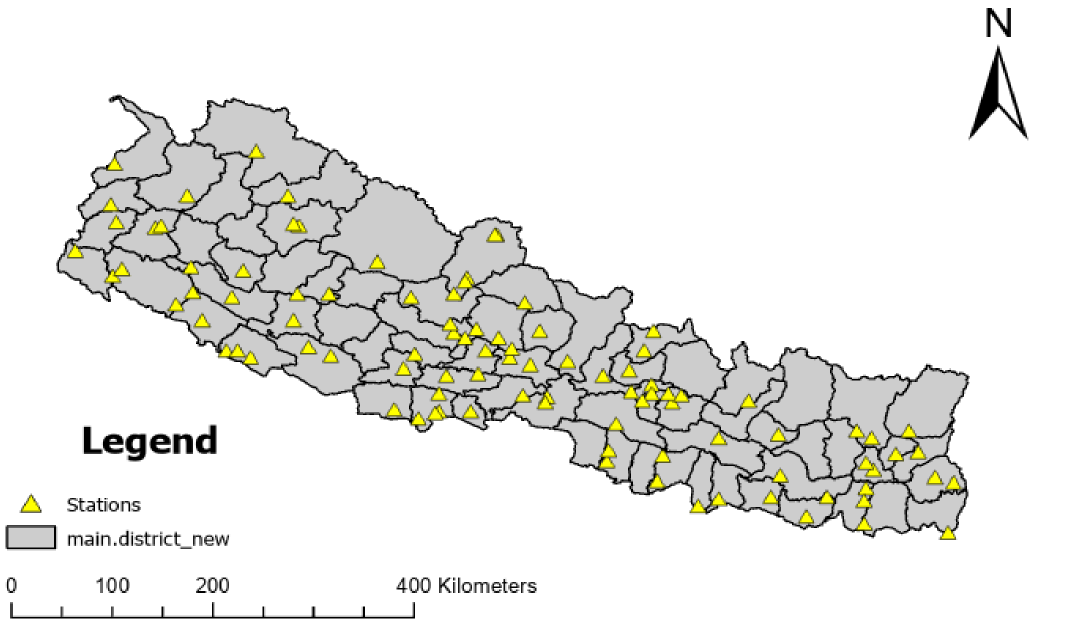

Figure 3-1: Location and distribution of 96 temperature stations all over Nepal taken for study.

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

Nepal has four typical climate seasons, namely, pre-monsoon (March- May), monsoon (June- September), post-monsoon (October-November) and winter (December-February)(Dhimal et al., 2018). Pre-monsoon season is characterized by hot, dry and westerly wind. Highest temperature of the year observed in late pre-monsoon and early monsoon (May-June) is resulted due to highest insolation. Day time temperature in southern plains reaches beyond 40°C in these months. Besides South-north gradient of temperature owing to elevation, west-east gradient of temperature in southern plains is also evident in the season, which is due to the closeness of western region from Indian deserts and relatively low moisture availability. In the season, precipitation usually observed in the evening hours is associated with localized convective instability with heating. Nevertheless, in the eastern region, considerable amount of precipitation of this season also occurs in May, when the moisture flow from Bay of Bengal starts to increase.

The maximum and minimum temperature distribution for different regions of Nepal obtained from our study data are plotted in Figure 3-2 and Figure 3-3 respectively to observe general temperature profile of maximum and minimum temperatures in Nepal.

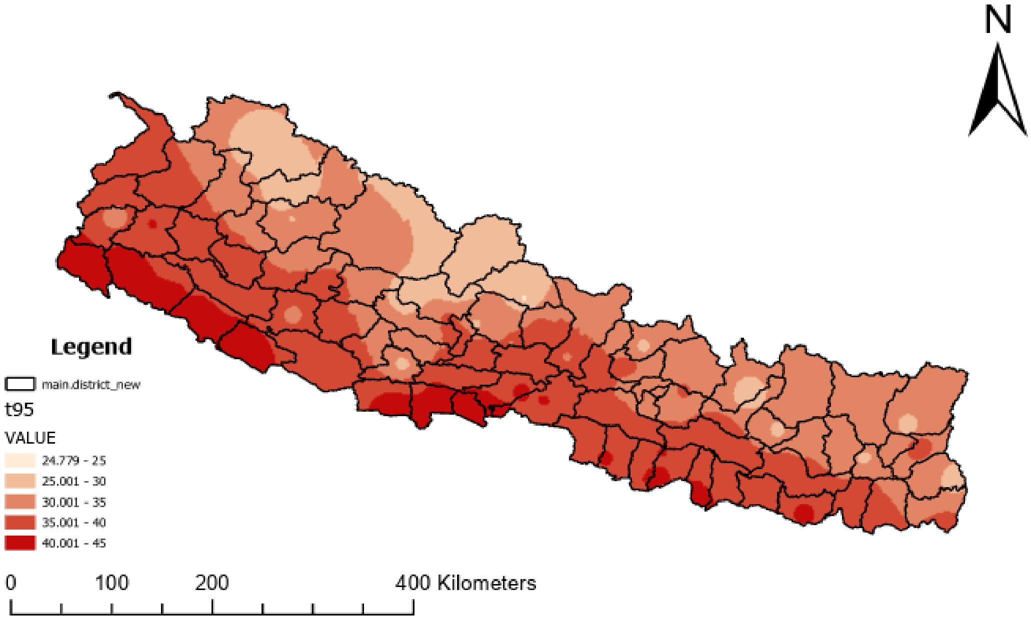

Figure 3-2: Maximum daily temperature distribution of Nepal during 1981-2010.

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

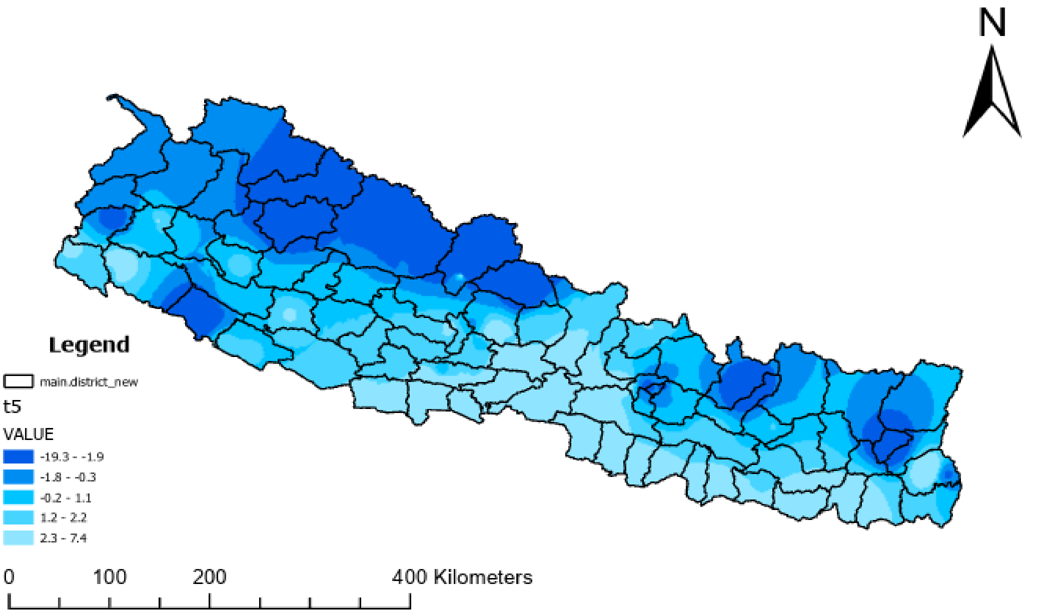

Figure 3-3: Minimum daily temperature distribution of Nepal during 1981-2010.

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

With the arrival of monsoon in mid-June, precipitation activity starts to increase from east towards west, leading to slight decrease of temperature. However, increasing amount of moisture (humidity) in the environment makes the feeling of warmness even higher. Post-monsoon is a dry season with pleasant weather and comfortable temperature, whereas winter is a coldest season. Therefore, heat stresses are the pre-monsoon and monsoon seasons feature and, especially southern Terai plains are more prone to these hazards (Dhimal et al., 2018).

CHAPTER 4: METHODOLOGY

This study analyzed the climatology and differences by using percentile method recommended by WMO based on last 40 years (1981-2020) of climatic data from 96 stations widely spread across the country. This study uses percentile method for computation of daily thresholds for heatwaves and coldwaves. Giving emphasis on 95th and 5th percentile value thresholds for heatwaves and coldwaves, these waves were identified. Also, this study extends to examine magnitude, frequency, spatial distribution and statistical comparison of these events. The overall methodology is depicted in the framework shown in Figure 4-1.

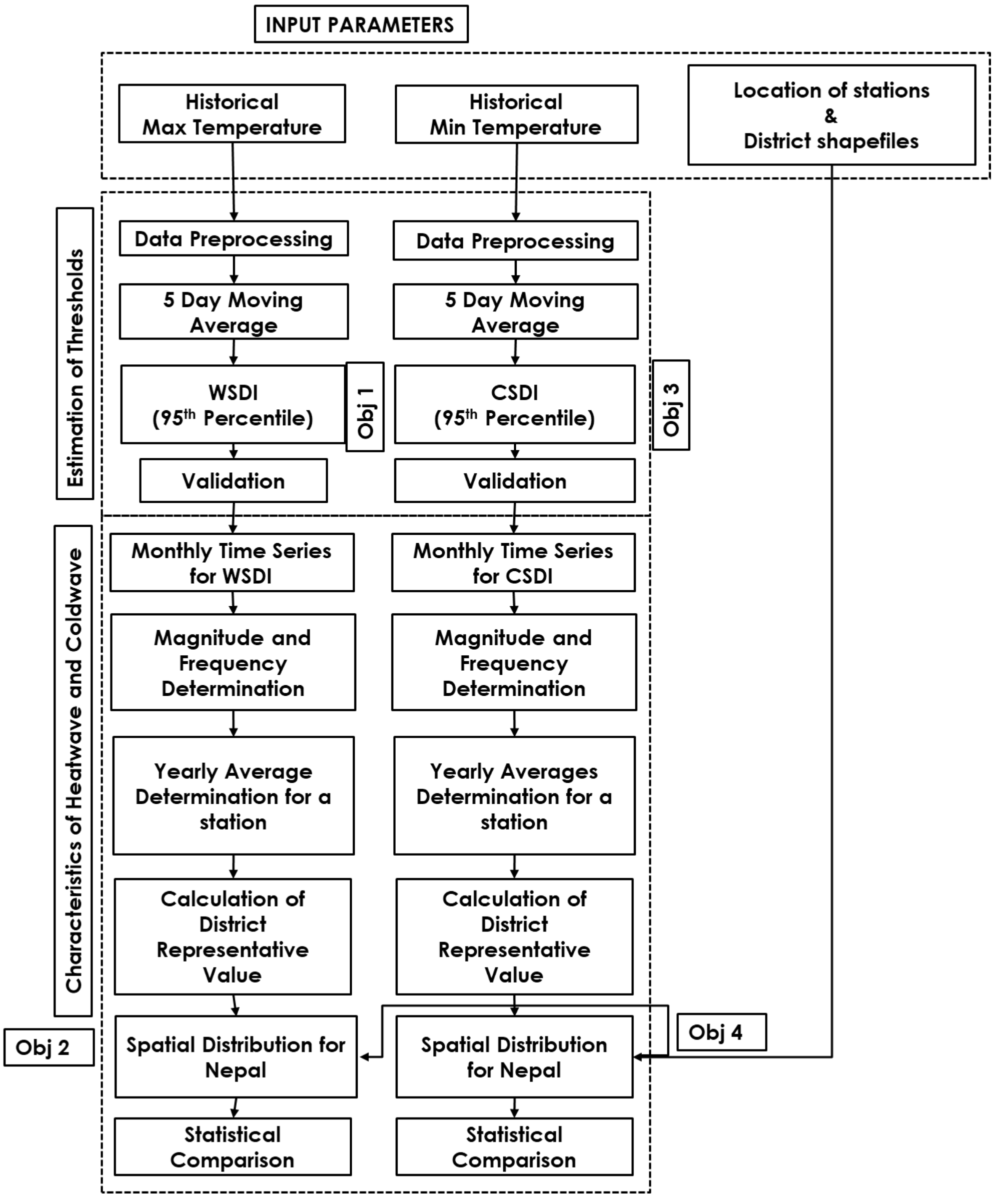

Figure 4-1: Framework of methodology

4.1 Estimation of Thresholds for Heatwave and Coldwave

The percentile method can be a straightforward and effective approach for examining climate extremes such as heatwaves and cold waves by utilizing basic parameters like daily maximum and minimum temperatures. This simplicity ensures a clear representation of the situation without delving into unnecessary complexities. Moreover, the method demonstrates flexibility in various scenarios, particularly in locations susceptible to heatwaves and cold waves, making it suitable for application in Nepal. Following steps are followed to generate percentile thresholds.

Selection of Reference Period:

For threshold estimation, 30 years' worth of data (1981-2010) were analyzed from 96 stations all over the Nepal (as shown in Figure 3-1) to estimate thresholds for every part of Nepal. Then again after validating these thresholds, further 10 years of data were studied from 2011-2020. The maximum and minimum temperature of is taken into consideration.

Data Preprocessing:

For preparing data for processing, steps recommended by WMO in its manual were followed (*ClimPACT Software Manual (English)*, 2013). Monthly indices are calculated if no more than 3 days are missing in a month, while annual values are calculated if no more than 15 days are missing in a year. No annual value is calculated if any one month's data are missing. For threshold indices, a threshold is calculated if at least 70% data are present. All these data manipulations were done during R-studio.

Threshold Estimation

The 5 day moving averages time series was generated from daily time series of minimum and maximum temperatures. Then 5^{th} and 95^{th} Percentile value as recommended by WMO in its indices like: Warm Spell Duration Index (WSDI) and Cold Spell Duration Index (CSDI) was determined by ranking these temperature values. The crossing of these threshold values is identified as heatwave and coldwaves events.

For example: A sample calculation of 15 days for Baglung heatwaves is shown in Table 4-1. Here, 15 days daily maximum temperature is taken and their 5-day moving average (MA) was calculated as shown in 2nd and 3rd column. These MA were then ranked in descending order and percentile value was calculated assuming maximum value in ranked MA as 100% and vice-versa as tabulated in 4th and 5th column. The 95th percentile value was then interpolated and used for further evaluation.

Whole 30 years of daily data was taken into account for actual account. The calculation process for coldwaves is similar to this where daily minimum temperature is taken in place of daily maximum temperature and 5-day MA was calculated, ranked and percentile value was calculated. Then 5th percentile value was used as percentile threshold for coldwave.

Table 4-1: 15 days sample calculation for threshold estimation of heatwave in Baglung.

Date	Daily Max Temp	5-day MA	Ranking MA	Percentile Value	95th Percentile Threshold
1/1/1990	22.4		21.32	0.995212569	20.558
1/2/1990	21.4		20.64	0.953789279	20.558
1/3/1990	21.8	21.32	19.92	0.92051756	20.558
1/4/1990	21	20.64	18.96	0.876155268	20.558
1/5/1990	20	19.92	18.02	0.83271719	20.558
1/6/1990	19	18.96	17.2	0.794824399	20.558
1/7/1990	17.8	18.02	17.12	0.791127542	20.558
1/8/1990	17	17.12	16.18	0.747689464	20.558
1/9/1990	16.3	16.18	15.72	0.726432532	20.558
1/10/1990	15.5	15.62	15.62	0.72181146	20.558
1/11/1990	14.3	15.02	15.02	0.694085028	20.558
1/12/1990	15	14.4			20.558
1/13/1990	14	14.1			20.558
1/14/1990	13.2				20.558
1/15/1990	14				20.558

A result obtained for Baglung's station is shown in Figure 4-2 and Figure 4-3 for better understanding of acquired results for a station.

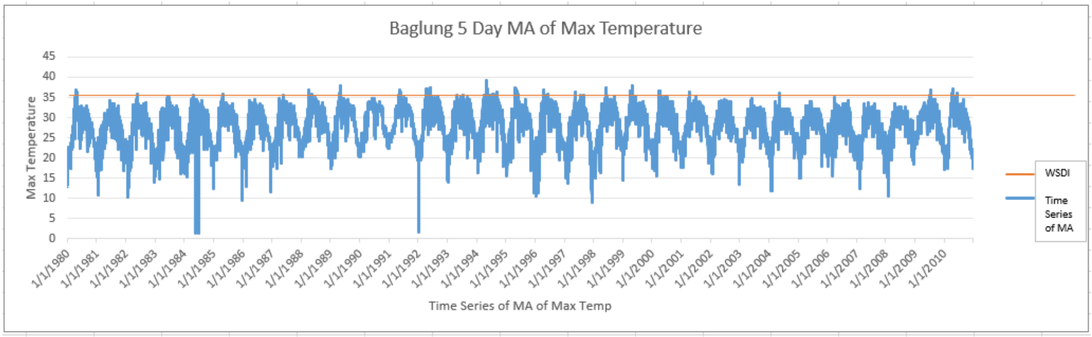

Figure 4-2 : Time series for 5-day MA of maximum temperature in Baglung with 95th percentile WSDI value for heatwave identification.

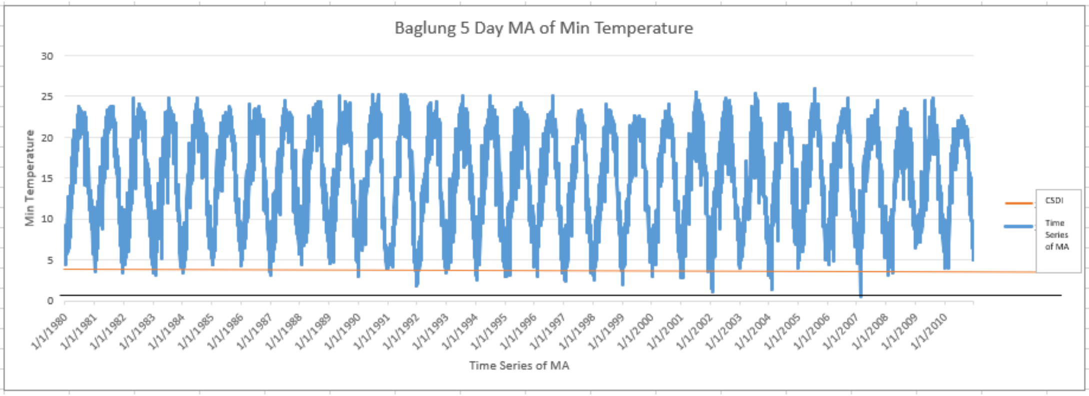

Figure 4-3: Time series for 5-day MA of minimum temperature in Baglung with 5th percentile CSDI value for coldwave identification.

Validation Analysis:

Although there is limited study in this field at the time in Nepal. There is study done by (NHRC) in 2018 related to heatwaves that takes into consideration of several parameters that are not taken in account in this study. Factors like: relative humidity, people's perception to rising temperature and correlation of temperatures on health is taken into account. It considers heatwaves in overlapping period with this study. 28 stations all over the Nepal is used in the report.

The study used National Weather Service (NWS) method for computation of daily, monthly and seasonal climatology of heat index. Using the outputs, the annual trend of heat index values was calculated for as shown in Table 4-2 given below. Since the study by NHRC and this study analyzed the heatwaves of almost similar and overlapping period, the outputs given by NHRC reports is used for validation of this study method as well. Here, yearly average magnitude is calculated by similar process shown in Table 4-1. Then Mann-Kendall test is done to find trend and its significance using R studio. The direction of trend (increasing or decreasing) and if its significant trend, then compared with annual heat index (HI) trend value to see whether the station trend obtained from percentile method is conforming to HI trend presented in NHRC report.

The annual HI for Taplejung is +0.18 which is significant (Dhimal et al., 2018) and positive trend, our results from Mann-Kendall also shows showed positive trend (Tau) and is significant trend ($p=0.002265<0.05$), thus conforming for Taplejung station.

Table 4-2: Sample calculation of trend of magnitude of heatwave in Taplejung station using Mann-Kendall test.

Year	Yearly avg. mag. (℃)
1981	0
1982	0
1983	0
1984	0
1985	0
1986	0
1987	0
1988	0
1989	0
1990	0
1991	0
1992	0.6
1993	0
1994	0
1995	0
1996	0
1997	0
1998	0
1999	0
2000	0
2001	0.4
2002	0
2003	0.7
2004	0
2005	0.4
2006	0.58
2007	0.3
2008	0.37
2009	0.3

2010	0.2		
z = 3.0531		n = 30	p-value = 0.002265
S = 139.00		VarS = 2043.00	Tau = 0.4462906

Since, the percentile method thresholds for heatwaves are reliable with 89.3% match with its comparative study done by NHRC as seen in our results, it can also be used to validate the coldwave thresholds as well. The assumption here is that if the same process of calculation is used for coldwaves, similar and reliable thresholds for coldwaves can be obtained. In other words, the statistical approach that proved effective in determining heatwave thresholds is expected to yield comparable and trustworthy results when applied to the calculation of thresholds for coldwaves, assuming consistency in the methodology.

4.2 Characterization of Heatwaves and Coldwaves

Heatwave and coldwave metric definition

In the dataset analysis, the goal is to compute several key metrics for each station and year. These events are characterized by extreme temperatures deviating from the climatological norms (thresholds).

<u>Magnitude</u>: The study assessed the maximum intensity of each event by examining the peak temperature anomaly from the climatology beyond threshold values.

<u>Frequency</u>: The number of heatwave and coldwave events was determined per month per year by the number of times thresholds were crossed.

<u>Duration</u>: Additionally, the analysis calculated the maximum duration of each heatwave or coldwave event, measuring the length of time these extreme temperature conditions persist.

Heatwave and coldwave metric calculation

In the dataset analysis, the goal is to compute several key metrics for each station and year. Firstly, the number of heatwave and coldwave events was determined annually. These events are characterized by extreme temperatures deviating from the climatological norms (thresholds). Additionally, the analysis calculated the maximum duration of each heatwave or coldwave event, measuring the length of time these extreme temperature conditions persist. Furthermore, the study assessed the maximum intensity of each event by examining the peak temperature anomaly from the climatology. This provides insights into the most extreme deviations from expected temperatures during these events.

For example: A sample calculation of 15 days sample calculation of magnitude, frequency and duration for heatwave in Baglung in Table 4-3. Here, 5-day MA of maximum temperature is subtracted from threshold calculated as shown in above Table 4-1 and presented in deviation from threshold column. This deviation is converted in magnitude of equal magnitude if the value is positive else magnitude is taken 0 for rest as shown in 6th column. The frequency is calculated by converting the magnitude column into binary by logic (if magnitude >0, 1 else 0) for each day. For duration of heatwaves, these binary frequency values are counted for consecutive 1s indicating the consecutive days Baglung was under heatwave.

Then, the average magnitude in these 15 day-period is calculated by adding magnitudes and dividing these by average number of days, heatwave occurred in Baglung. The maximum value of heatwaves was simply taken the maximum value appeared in magnitude column. For frequency, the number of clusters of 1s was calculated, meaning number of times heatwaves occurred in Baglung. Then, duration of each event is averaged for average duration of heatwaves in Baglung and maximum value in duration column was taken as maximum number of days Baglung was under heatwave attack.

Another 2-year result of calculation for Baglung station is presented in Annex A for better understanding of this process.

Table 4-3: 15 days sample calculation of magnitude, frequency and duration for heatwave in Baglung.

5-day MA	Ranking MA	Percentile Calculation	95th Percentile Threshold	Deviation from Thresholds	Magnitude of Heatwave (°C)	Frequency of Heat wave	Duration of Heat wave (Days

						(Days)	)
	21.32	0.985212569	20.558				
	20.64	0.953789279	20.558				
21.32	19.92	0.92051756	20.558	0.762	0.762	1	1
20.64	18.96	0.876155268	20.558	0.082	0.082	1	2
19.92	18.02	0.83271719	20.558	-0.638	0	0	0
18.96	17.2	0.794824399	20.558	-1.598	0	0	0
21	17.12	0.791127542	20.558	0.442	0.442	1	1
21.3	16.18	0.747689464	20.558	0.742	0.742	1	2
22	15.72	0.726432532	20.558	1.442	1.442	1	3
15.62	15.62	0.72181146	20.558	-4.938	0	0	0
15.02	15.02	0.694085028	20.558	-5.538	0	0	0
14.4	14.4	0.665434381	20.558	-6.158	0	0	0
14.1	14.1	0.651571165	20.558	-6.458	0	0	0
15.72		0	20.558	-4.838	0	0	0
17.2		0	20.558	-3.358	0	0	0
18.86	21.02	0.971349353			Average Magnitud	Frequency=	Average

					e=0.694	Twice in 15 days	Duration=2.5
20.88	21.02	0.971349353			Max Magnitude=1.442		Max Duration=3

Calculation of district representative value

Since there are multiple stations in some district, an average value that is representative for whole district was calculated by averaging these thresholds for a district.

Spatial distribution:

The table of heatwaves and coldwaves magnitude and frequencies were then assigned to the location of their respective stations in QGis. These discrete values were then interpolated using Gaussian interpolations (Talchabhadel et al., 2018) for smooth distribution all over the country to see the distribution pattern of heatwave and coldwave magnitude and occurrences in taken period.

Magnitude and frequency Analysis:

Magnitude of heatwaves and coldwaves were plotted for two distinct time division. The period between 1981-2010 and 2011-2020. These values of magnitudes and location of heatwaves and coldwaves hitting in these two distinct periods were seen in figurative outputs of QGis. Clear pattern of occurring and their changes were observed from the plot. For the statistical comparison (significance of change) of average changes in magnitudes of heatwaves and coldwaves, Z-Test was used.

Frequency of heatwaves and coldwaves were also plotted for two distinct time division. The period between 1981-2010 and 2011-2020. These values of frequency and location of heatwaves and coldwaves hitting in these two distinct periods were seen in figurative outputs of QGis. Clear pattern of occurring and their changes in duration were observed from the plot. For the statistical comparison (significance of change) of average changes in frequency of heatwaves and coldwaves, Z-Test was used.

4.3 Data and Sources:

For our study, the data, their sources, resolution, and processing tools are presented in Table 4-4.

Table 4-4: Data description

Type of Data	**Sources**	**Resolution**	**Length**	**Processing tools**
Max Temperature	DHM	Daily	1980-2020	R-tools (96 stations)
Min Temperature	DHM	Daily	1980-2020	R-tools (96 stations)
National GIS data	Survey Department	District-wise	77	QGis

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Estimated Thresholds for Heatwaves

Here, the goal is to determine how unusual or extreme current temperatures are compared to the historical record. For that purpose, a percentile-based threshold is generated according to our 1st objective as shown in Table 5-1.

These thresholds are basis by which for any day's temperature that may have occurred unusually compared to last 30 years can be detected. And if that deviation stands for 5 consecutive days, then it can be identified as start of heatwave event. Also, this percentile threshold information can then be used as heatwave early warning system's critical values to issue warnings and to implement heatwave mitigation measures. For example, if the 95th percentile of daily maximum temperatures in a city is 35 °C, then a heatwave would be declared if the daily maximum temperature exceeded 35°C for five or more consecutive days.

The percentile method is a relatively simple and straightforward way to define heatwaves, but it has some limitations. For example, the same percentile threshold may not be appropriate for all locations or regions. In some areas, the 95th percentile may be too high, while in other areas it may be too low. Additionally, the percentile method does not take into account the relative humidity, which can also play a role in heatwave severity.

Despite these limitations, the percentile method is a useful tool for defining heatwaves and can be used to track changes in heatwave frequency and intensity over time with limited data parameters. The percentile threshold should be calculated using a long-term dataset of daily maximum temperatures. This will help to ensure that the threshold is representative of the climate of the location or region. The percentile thresholds should be updated periodically to reflect changes in the climate. The percentile threshold should be used in conjunction with other metrics, such as relative humidity, to assess heatwave severity.

The percentile method is a valuable tool for defining heatwaves and can be used to develop heatwave early warning systems and to implement heatwave mitigation measures. However, it is important to be aware of the limitations of the method and to use it in conjunction with other metrics to assess heatwave severity.

Table 5-1: Heatwave thresholds for district representative stations

Index No.	**District**	**Region**	**95th P (°C)**
605	Baglung	Hilly	35.8
202	Bajhang	Hilly	35.3
402	Dadeldhura	Hilly	32.5
107	Dailekh	Hilly	35.9
1307, 1304	Dhading	Hilly	35.8
1103	Dhankuta	Hilly	29.8
218, 203	Dolakha	Hilly	27.7
809	Doti	Hilly	38.8
1407, 1416	Gorkha	Hilly	34.8
814, 804, 811	Ilam	Hilly	29
1124, 1136	Kaski	Hilly	32.5
802	Kavrepalanch	Hilly	34.9
609, 616	Lamjung	Hilly	35.8
1004	Myagdi	Hilly	31.5
1206	Nuwakot	Hilly	36.7
1419	Okhaldhunga	Hilly	29.4
614	Panchthar	Hilly	34.3
1055, 1001	Parbat	Hilly	37
1303, 1327	Salyan	Hilly	34
1043	Shankhuwasabha	Hilly	32.8
1071,	Bhaktapur	Hilly	29.4

1030, 1073			
103	Kathmandu	Hilly	33.3
1107	Lalitpur	Hilly	35.4
312	Sindhuli	Hilly	39
1111	Dang	Hilly	38.5
1319	Makwanpur	Hilly	38.3
1005, 1038	Darchula	Mountain	37.8
513, 514	Rasuwa	Mountain	29
511	Rukum	Mountain	36
311	Dolpa	Mountain	33.9
310, 303	Humla	Mountain	27.3
316	Jumla	Mountain	30.8
307	Manang	Mount	24.8

		ain	
633, 601, 604, 612, 607	Mugu	Mountain	26.6
409, 419	Mustang	Mountain	26.4
911, 909	Banke	Tarai	42.3
902, 927	Bara	Tarai	40.125
515, 508	Chitwan	Tarai	39.7
1422	Dhanusha	Tarai	40
207, 209, 215, 405	Jhapa	Tarai	41.4
105	Kailali	Tarai	41.8
1122	Kanchanpur	Tarai	41.9
906	Mahottari	Tarai	37.9
706	Morang	Tarai	39.3
7	Nawalparasi East	Tarai	40.7

728	Nawalparasi West	Tarai	40.6
112 1	Rupandehi	Tarai	41.8
703, 705, 707, 727	Rautahat	Tarai	40.2
121	Saptari	Tarai	38.37
5			5
131 1, 132 0	Siraha	Tarai	39
712	Sunsari	Tarai	36

Note: The multiple stations (multiple index numbers) for the same district are averaged out to find the district representative value. 1

Validation of heatwave thresholds

For the purpose of validation of this study, we use the previous study done on heatwaves by (Dhimal et al., 2018) under Nepal Health Research Council (NHRC) where trends and health risks of heatwaves were analyzed. In the study the trend of heatwaves was assessed using secondary analysis of retrospective meteorological data of last 30 years (1987-2016) and descriptive cross-sectional study was done to explore people's perception towards extreme heat exposure in a warming climate.

The study used National Weather Service (NWS) method for computation of daily, monthly and seasonal climatology of heat index. Using the outputs, the annual trend of heat index values was calculated for stations given below. Since the study by NHRC and this study analyzed the heatwaves of almost similar and overlapping period, the outputs given by NHRC reports is used for validation of this study method as well.

The outputs of NHRC report shows annual rate of change of heat index that represents trend of heatwaves in 5^{th} column in Table 5-2. The trend that is obtained by percentile method of the same stations were analyzed using Man-Kendall test and output is tabulated in the last column with their p-values with NHRC output for comparison.

The comparative outputs suggest percentile methods to be successfully predicting the trends same as NHRC reports. 25 out of 28 station's trends were matched in the study giving 89.3% match with NHRC reports. The three stations of different trends than that of NHRC outputs could be due to recent changes in the stations or their in-situ variation. The causes of the change need to be studied further. Since, the method for heatwave and coldwave is similar in nature, the results of coldwave can also be validated from this same study.

Table 5-2: Comparison of trends of this study and NHRC output

Index No	**Station Name**	**District**	**Annual Trend of Heat Index (HI)**	**Remarks**
104	Dadeldhura	Dadeldhura	0.1	Confirms trend (p-value = 0.008714)
207	Tikapur	Kailali	-0.01	**Reverse trend** (p-value = 0.2952)
209	Attariya	Kailali	0.04	Confirms trend (p-value = 0.7185)
215	Godawari (West)	Kailali	0.04	Confirms trend (p-value = 0.2012)
218	Dipayal	Doti	0.09	Confirms trend (p-value = 0.2581)
303	Jumla	Jumla	0.07	Confirms trend

				(p-value = 0.3049)
406	Surkhet	Surkhet	0.09	Confirms trend (p-value = 0.01573)
416	Nepalgunj (Irrigation)	Banke	0.03	Confirms trend (p-value = 0.8929)
419	Sikta	Bankey	0.03	Confirms trend (p-value = 0.6967)
513	Chaujhari	Rukum	0.06	Confirms trend (p-value = 0.1311)
705	Bhairahawa Airport	Rupandehi	-0.03	Confirms trend (p-value = 0.5182)
706	Dumkauli	Nawalparasi	0.04	Confirms trend (p-value = 0.4325)
707	Bhairahawa(Agric)	Rupandehi	0.06	Confirms trend (p-value = 0.05408)
805	Syangja	Syangia	0.1	Confirms trend (p-value = 0.2548)
814	Lumle	Kaski	0.04	Confirms trend (p-value = 0.02027)
815	Khairini Tar	Tanahun	0.11	Confirms trend (p-value = 0.5179)
902	Rampur	Chitwan	0.05	Confirms trend

				(p-value = 0.9944)
906	Hetaunda	Makwanpur	0.06	Confirms trend (p-value = 0.4861)
909	Simara	Bara	0.09	Confirms trend (p-value = 0.6459)
911	Parwanipur	Sarlahi	0.06	Confirms trend (p-value = 0.3741)
1030	Kathmandu Airport	Kathmandu	0.07	Confirms trend (p-value = 0.2131)
1038	Dhunibesi	Dhading	0.12	**Reverse trend** (p-value = 0.2222)
1111	Janakpur Airport	Dhanusa	0.08	Confirms trend (p-value = 0.1663)
1206	Okhaldhunga	Okhaldhunga	0.16	Confirms trend (p-value = 0.0008868)
1303	Chainpur(East)	Sankhuwasabha	-0.01	Confirms trend (p-value = 0.4048)
1307	Dhankuta	Dhankuta	0.07	Confirms trend (p-value = 0.002541)
1319	Biratnagar Airport	Morang	0.09	**Reverse trend** (p-value = 0.2368)
1405	Taplejung	Taplejung	0.18	Confirms trend

				(p-value = 0.002265)

5.2 Characteristics of Heatwaves

5.2.1 Magnitude of heatwaves

From 1981-2010 Magnitude Distribution:

With 95th percentile as the thresholds for tracking heatwaves, the distribution and magnitudes of heatwaves hitting Nepal from 1981-2010 was observed as shown in Figure 5-1. In this period higher magnitude heatwaves were hitting mid-hills of Nepal. Specially, western, mid-western and most of far western hills are getting hotter. Districts like: Gulmi, Kailali, Jajarkot, Bardiya e.t.c. had shown highest magnitude (beyond 5°C than threshold) of heatwaves in these 30years. Also, the Figure 5-1 indicates the rise of Himalayan temperatures at accelerated rate.

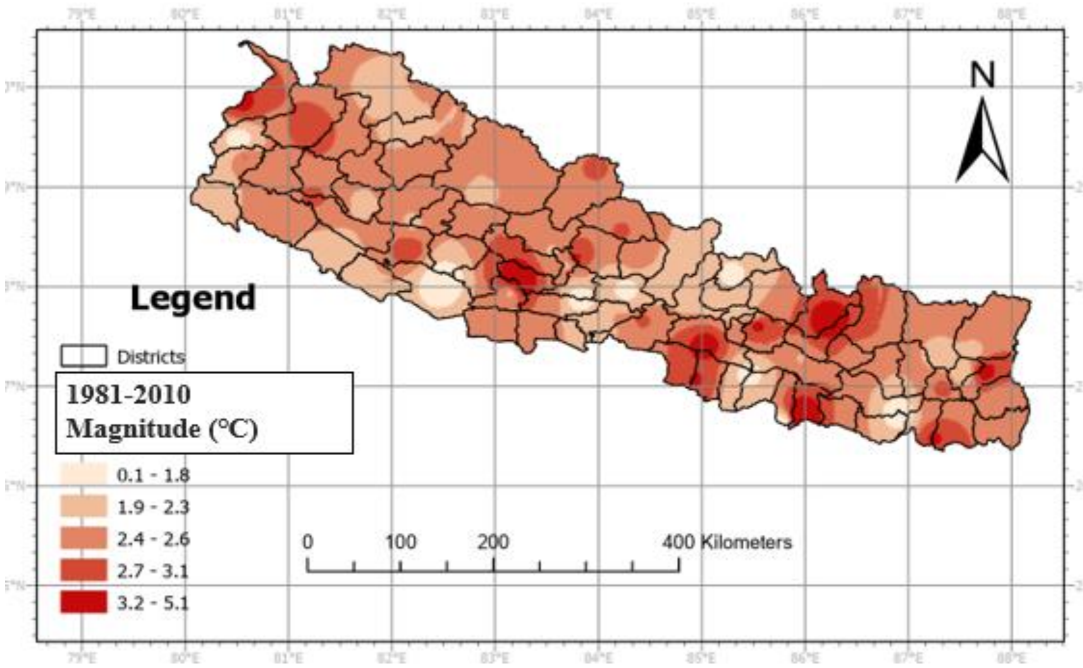

Figure 5-1: Magnitude of heatwaves occurred in 1981-2010 and their distribution (based on 95th percentile).

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

From 2011-2020:

But in the last decade, the heatwaves of higher magnitudes had shifted towards higher altitudes as can be seen in Figure 5-2. Most of the mountainous region had frequently crossed 95th percentile threshold mark (upto 7°C more than threshold). In this period higher magnitude heatwaves were hitting mountains of Nepal. These regions include: Udaypur, Saptari, Sindhuli, Lamjung, Banke, Mugu, Dadeldhura e.t.c.. Unlike the upper hilly regions, the temperature of Tarai had remained fairly under the 95th percentile value.

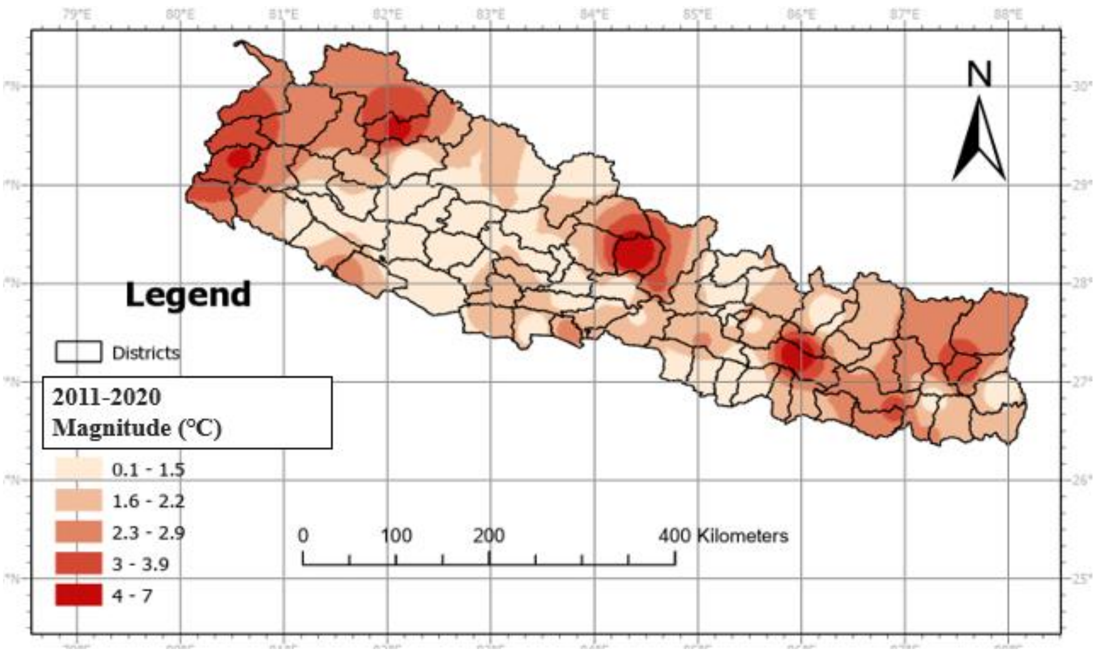

Figure 5-2: Magnitude of heatwaves occurred in 2011-2020 and their distribution (based on 95th percentile).

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

Statistical comparison of magnitude of heatwaves

From the above-mentioned results, the magnitude and distribution of extreme heatwaves can be seen. However, the changes in the magnitude of heatwaves needs to be quantified based on statistical methods to get concrete results as in whether the changes in magnitude are significant or not.

For this purpose, the statistical Z-Test(n>30) is done to compare the differences in magnitudes of heatwaves from period of 1981-2010 and 2011-2020.

Two-sample z-Test (Two tailed test)

Null hypothesis: True difference in means is equal to 0

Alternative hypothesis: Ture difference in means is not equal to 0

Data	**Mean**	**Std. Deviation**	**95% confidence interval**	**Remarks**
1981-2010 magnitude	2.608	0.859	(-1.9599, 1.9599)	Z = 0.785556 p-value = 0.783936
2011-2020 magnitude	2.212	1.515		

In the Z-Test for magnitude of heatwaves compared between the periods of 1981-2010 and 2011-2020, with the null hypothesis being of difference in true means is equal to 0. The average magnitude of heatwaves in the period of 1981-2010 is approximately 2.608℃ with the standard deviation of 0.859℃. The average magnitude of heatwaves in the period of 2011-2020 is approximately 2.212℃ with the standard deviation of 1.515℃.

In summary, the results suggest that there might be a difference in the magnitude of heatwaves between the two time periods (1981-2010 and 2011-2020), but the difference is not statistically significant based on the given p-value. The deviation in heatwave magnitudes has increased by almost 200% in the latter period, as indicated by the higher standard deviation.

From Figure 5-1 & Figure 5-2 it can be easily seen than the places where higher magnitudes of heatwaves were occurring have drastically changed in the last decade compared to previous decades. Results are in alignment with findings of Badiya saying while few long-term widespread heatwave studies are available for Nepal, existing analyses suggest hot temperature extremes have become more frequent in recent decades, particularly in western parts of the country (Baidya et al., 2008). Up to 2010 similar behavior was seen in our study as well.

The increase in the variability of heatwave magnitudes in Nepal over the last decade may be attributed to a combination of factors. Global climate change, stemming from heightened greenhouse gas emissions, is a key contributor, leading to shifts in temperature patterns and an increased likelihood of extreme weather events. Natural climate variability, including phenomena like the El Niño-Southern Oscillation, can also introduce fluctuations in temperature, contributing to the observed variability in heatwave magnitudes. Nepal's diverse topography and altitude variations may create localized climate conditions that influence the intensity and variability of heatwaves. Changes in land use, such as deforestation and urbanization, atmospheric circulation patterns, the urban heat island effect, and alterations in air pollution levels and aerosol concentrations all play roles in shaping the magnitude variability of heatwaves in the region.

A comprehensive understanding of these factors requires thorough analysis of regional climate data and trends, considering the complex interactions between natural and anthropogenic influences. The decadal rise of mean temperature of Nepal has been rapid as shown in Figure 1-1, these changes in historical temperature values could have resulted in these changes but further study must be done to evidently support these causes.

5.2.2 Frequency of heatwaves

From 1981-2010:

In terms of frequency of these heatwaves, Mid-western and western region of Nepal were most frequently hit by heatwaves. Mid-western hilly region of Nepal is the most prone (Figure 5-3). Heatwaves had occurred in these region for 2 to 3.7 days per month in the summer. It also indicates the frequent crossing and increasing of temperatures in mountains and Himalayas of mid-western region. Almost all the mountain region from central to far-western region shows consistent and frequent increase of temperatures across 95th percentile mark. In Central Nepal, Bara and Parsa are most frequently hit by heatwaves, while the farthest west terai of Nepal is also suffering the same.

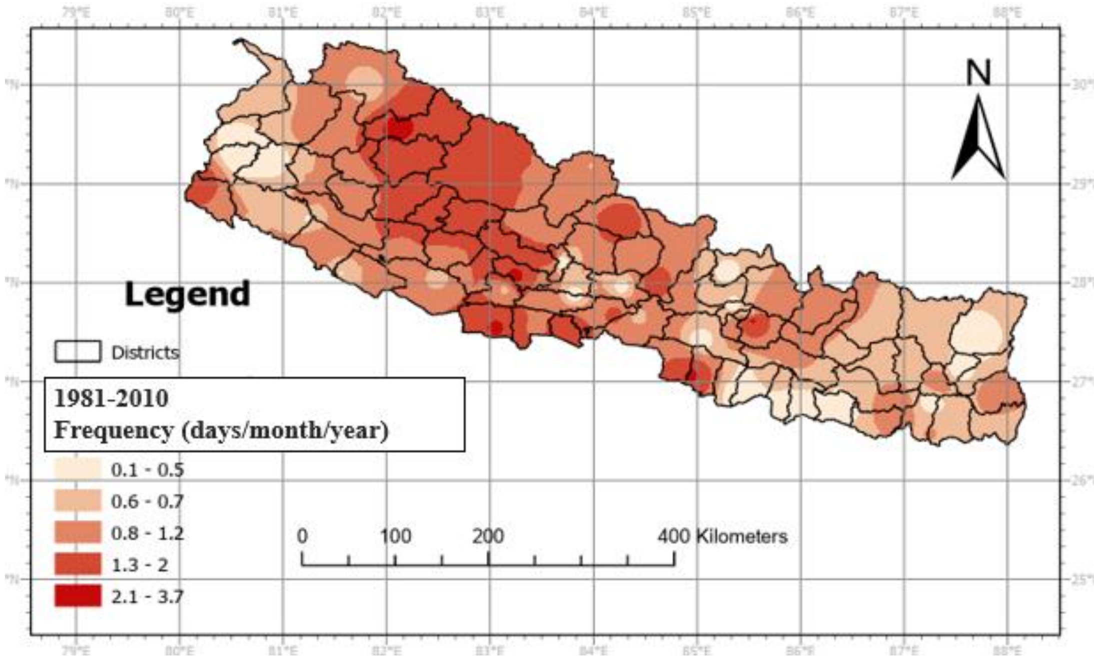

Figure 5-3: Frequency of heatwaves occurred in 1981-2010 and their distribution (based on 95th percentile).

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

From 2011-2020 Frequency of Occurrence's Distribution:

In last decade, western, central and eastern region of Nepal had been most frequently hit by heatwaves (Figure 5-4). Couple of most concentrated zones in central regions. Sindhuli, Ramechhap, Okhaldhunga, Dhanusa, Gorkha, Dhading, Chitwan, Parsa, Bara, Nawalparasi, Doti, Mugu, Banke e.t.c. are the most intense regions frequency-wise. The eastern and western Nepal is in the middle level of these frequencies. The mid-western region had remained safest during the last decade heatwaves. But the duration of heatwaves have somewhat reduced in these region to 2.4 days/month in last decade.

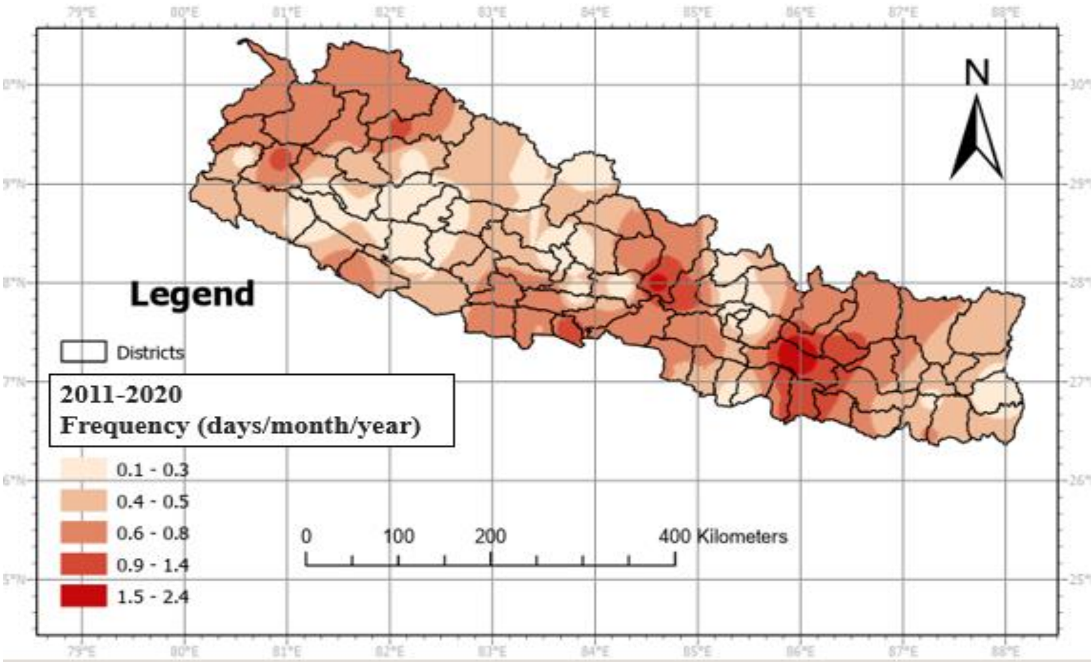

Figure 5-4: Frequency of heatwaves occurred in 2011-2020 and their distribution (based on 95th percentile).

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

Statistical comparison of frequency of heatwaves

From the above-mentioned results, the frequency distribution of extreme heatwaves can be seen. However, the changes in the frequency of heatwaves needs to be quantified based on statistical methods to get concrete results as in whether the changes in magnitude are significant or not.

For this purpose, the statistical Z-Test(n>30) is done to compare the differences in frequency of heatwaves from period of 1981-2010 and 2011-2020.

Two-sample z-Test (One tailed test)

Null hypothesis: True difference in means is not greater than 0

Alternative hypothesis: Ture difference in means is greater than 0

Data	**Mean**	**Std. Deviation**	**95% confidence interval**	**Remarks**

1981-2010 frequency	1.100	0.784	(-0.4171, 0.4171)	Z = 2.4905 p-value = 0.01276
2011-2020 frequency	0.570	0.498		

In the Z-Test for frequency of heatwaves compared between the periods of 1981-2010 and 2011-2020, with the null hypothesis being of difference in true means is not greater than 0.

The average frequency of heatwaves in the period of 1981-2010 is approximately 1.100 days per month in summer with the standard deviation of 0.784 days from mean value. The average frequency of heatwaves in the period of 2011-2020 is approximately 0.570 days per month in summer with the standard deviation of 0.498 days from mean value.

In summary, the results suggest that there is a significant difference in the frequency of heatwaves between the two time periods (1981-2010 and 2011-2020). The frequency of heatwaves in the later period is significantly lower (by almost 50%), as indicated by the p-value and the lower mean value. Additionally, the remarks and z-score for the first period suggest that the frequency of heatwaves in that period is significantly higher than the mean. This is in alignment with findings of (Baidya et al., 2008) in that time frame.

The decrease in the occurrence of heatwaves in Nepal over the past decade could be influenced by a combination of factors. Climate change, resulting from increased emissions of greenhouse gases, has the potential to cause lasting shifts in temperature patterns. Natural climate cycles, such as the El Niño-Southern Oscillation, may contribute to fluctuations in weather conditions. Nepal's varied topography, encompassing high-altitude regions, might exert a tempering influence on temperatures, while alterations in land use, urbanization, and concentrations of aerosols can also play a significant role in affecting temperature dynamics. A comprehensive understanding of these factors requires a collective consideration, and consulting the latest scientific research and climate assessments is crucial for a thorough grasp of the factors influencing heatwave frequency in Nepal.

5.3 Estimated Thresholds for Coldwaves

Here, the goal is to determine how unusual or extreme current minimum temperatures are compared to the historical record. For that purpose, a percentile-based threshold is generated according to our 3rd objective as shown in Table 5-3.

These thresholds are basis by which for any day's temperature that may have occurred unusually compared to last 30 years can be detected. And if that deviation stands for 5 consecutive days, then it can be identified as start of coldwave event. Also, this percentile threshold information can then be used as coldwave early warning system's critical values to issue warnings and to implement heatwave mitigation measures.

For instance, if the 10th percentile of daily minimum temperatures in a region is -5 °C, a coldwave would be identified if the daily minimum temperature falls below -5 °C for a duration of five or more consecutive days. This thresholds aids in objectively characterizing and quantifying the severity of coldwaves based on historical temperature patterns.

Table 5-3: Coldwaves thresholds for district representative station.

Index No.	**District**	**Region**	**5th P (°C)**
605	Baglung	Hilly	4
202	Bajhang	Hilly	0.9
402	Dadeldhura	Hilly	0.1
107	Dailekh	Hilly	2.8
1307, 1304	Dhading	Hilly	6
218, 203	Dolakha	Hilly	-4.3
809	Doti	Hilly	3.6
1407, 1416	Gorkha	Hilly	6

814, 804, 811	Ilam	Hilly	7
802	Kavrepalanchowk	Hilly	2.2
609, 616	Lamjung	Hilly	4.1
1419	Okhaldhunga	Hilly	3.5
1071, 1030, 1073	Bhaktapur	Hilly	0.2
103	Kathmandu	Hilly	-0.2
1107	Lalitpur	Hilly	1.5
1111	Dang	Hilly	4.1
1319	Makwanpur	Hilly	4.6
511	Rukum	Mountain	2.1
316	Jumla	Mountain	-7.8
307	Manang	Mountain	-5.2

633, 601, 604, 612, 607	Mugu	Mountain	-8.3
409, 419	Mustang	Mountain	-15
911, 909	Banke	Tarai	4.2
902, 927	Bara	Tarai	6.3
515, 508	Chitwan	Tarai	5.6
1422	Dhanusha	Tarai	6.2
207, 209, 215, 405	Jhapa	Tarai	4.2
1122	Kanchanpur	Tarai	4.3
706	Morang	Tarai	6.1
7	Nawalparasi East	Tarai	7
728	Nawalparasi West	Tarai	6.2
112	Rupandehi	Tarai	4.5

1			
121 5	Saptari	Tarai	4.1
131 1,	Siraha	Tarai	4.2

132 0			

Note: Note: The multiple stations (multiple index numbers) for the same district are averaged out to find the district representative value. 2

Validation of coldwave thresholds

Since, the percentile method thresholds for heatwaves are reliable with 89.3% match with its comparative study done by NHRC, it can also be used to validate the coldwave thresholds as well. The assumption here is that if the same process of calculation is used for coldwaves, similar and reliable thresholds for coldwaves can be obtained. In other words, the statistical approach that proved effective in determining heatwave thresholds is expected to yield comparable and trustworthy results when applied to the calculation of thresholds for coldwaves, assuming consistency in the methodology.

5.4 Characteristics of Coldwaves

5.4.1 Magnitude of coldwaves

From 1981-2010: Magnitude distribution for coldwaves

Based on the 5th percentile thresholds (as depicted in Figure 5-5), minimum temperatures remained relatively constant throughout the country from 1981 to 2010. Only a handful of locations exhibited notable breaches of the threshold. Over the 30-year span, Salyan, Lamjung, and Terathum experienced a more substantial deviation from the threshold, and these particular cold spots endured coldwaves with temperatures falling below 8℃ during this period.

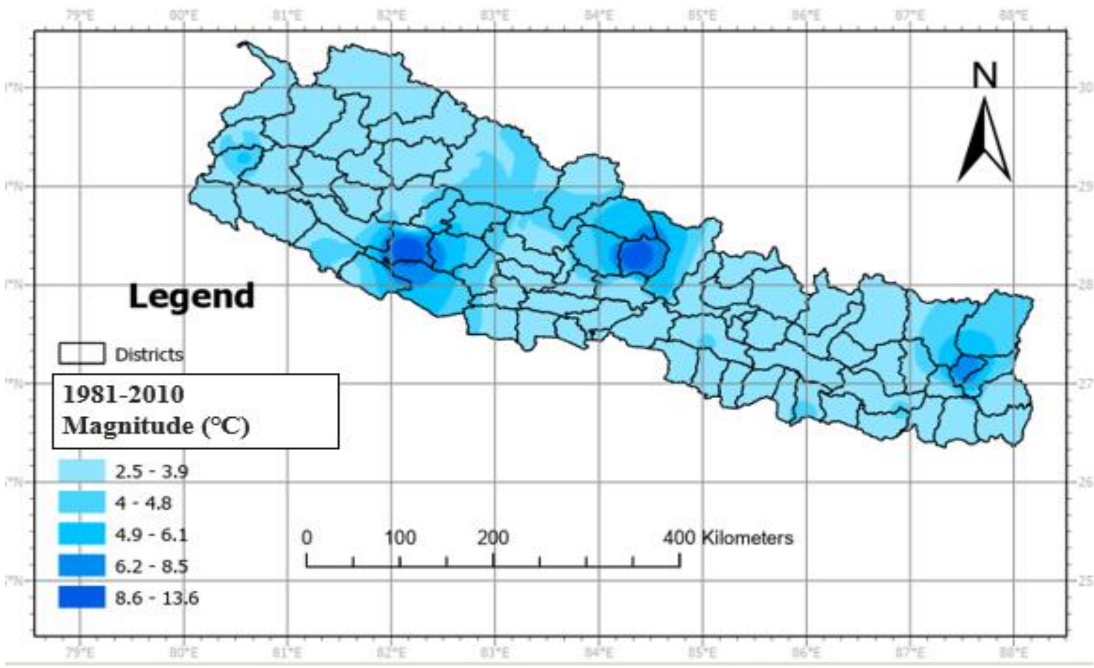

Figure 5-5 :Magnitude of cold waves occurred in 1981-2010 and their distribution (based on 5th percentile).

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

From 2011-2020: Magnitude distribution for coldwaves

Over the past ten years, the lower Tarai region of Nepal, as illustrated in the Figure 5-6, has been experiencing the most severe cold waves. These waves have been particularly intense in locations such as Dhanusa, Mahottari, Siraha, Saptari, Sindhuli, Dolakha, Ramechhap, Tanahun, East and West Nawalparasi, Dang, Salyan, Surkhet, Kailali, and others. In contrast, the rest of Nepal has maintained a relatively consistent pattern in terms of the higher magnitude cold waves.

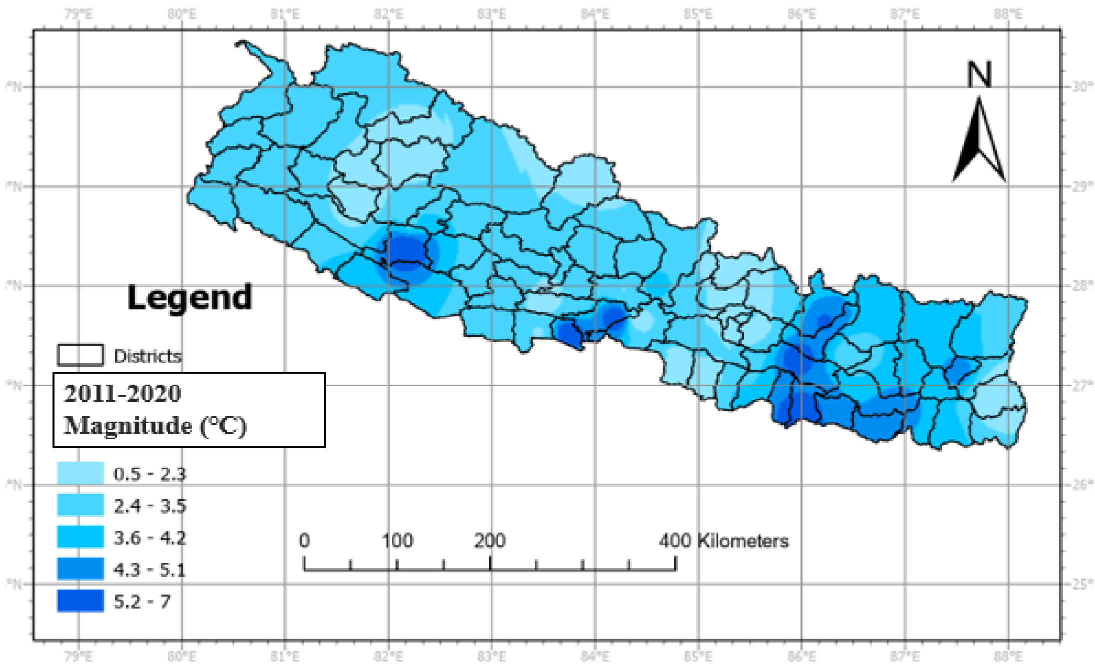

Figure 5-6 : Magnitude of coldwaves occurred in 2011-2020 and their distribution (based on 5th percentile).

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

Statistical comparison of magnitude of coldwaves

From the above-mentioned results, the magnitude and distribution of extreme coldwaves can be seen. However, the changes in the magnitude of coldwaves needs to be quantified based on statistical methods to get concrete results as in whether the changes in magnitude are significant or not.

For this purpose, the statistical Z-Test(n>30) is done to compare the differences in magnitudes of coldwaves from period of 1981-2010 and 2011-2020.

Two-sample z-Test (Two tailed test)

Null hypothesis: True difference in means is equal to 0

Alternative hypothesis: Ture difference in means is not equal to 0

Data	**Mean**	**Std. Deviation**	**95% confidence interval**	**Remarks**
1981-2010 magnitude	3.842	1.557	(-1.2205, 1.2205)	Z = 0.334 p-value = 0.7384
2011-2020 magnitude	3.634	1.752		

In the Z-Test for magnitude of coldwaves compared between the periods of 1981-2010 and 2011-2020, with the null hypothesis being of difference in true means is equal to 0.

The average magnitude of coldwaves in the period of 1981-2010 is approximately 3.842℃ with the standard deviation of 1.557℃ from mean value. The average magnitude of coldwaves in the period of 2011-2020 is approximately 3.634℃ with the standard deviation of 1.752℃ from mean value.

In summary, the analysis suggests a potential difference in the magnitude of coldwaves between the two time periods (1981-2010 and 2011-2020), but this difference lacks statistical significance based on the provided p-value. The magnitude and variation in magnitude of coldwaves are fairly similar in last decade compared to previous decades. This has also been supported with findings of (Karki et al., 2017; Shrestha et al., 2017) saying overall declining frequency, duration, and in some metrics intensity/severity of extreme cold events across Nepal over recent decades.

Figure 5-5and Figure 5-6 illustrate a notable shift in locations experiencing higher magnitudes of coldwaves over the last decade compared to previous periods. The heightened variability in coldwave magnitudes in Nepal during the last decade may be attributed to a combination of factors. Global climate change, driven by increased greenhouse gas emissions, contributes to temperature pattern shifts and an elevated likelihood of extreme weather events. Natural climate variability introduces temperature fluctuations, impacting observed coldwave variability. Nepal's diverse topography and altitude variations create localized climate conditions influencing coldwave intensity and variability. Changes in land use, urbanization, atmospheric circulation patterns, and alterations in air pollution and aerosol levels from our neighboring country India all contribute to shaping the variability in coldwave magnitudes but further studies are needed for conclusive evidence supporting these causal relationships.

5.4.1 Frequency of coldwaves

From 1981-2010: Frequency distribution for coldwaves

Using 5^{th} percentile as thresholds, the frequency of coldewaves in the period of 1981-2010 were observed. Eastern, central and western Nepal were getting hit by majority of coldwaves. These coldwaves were focused majorly on Tarai and mid-hills of these region. They were suffering beyond 4 days/month of coldwaves in winter in that period.

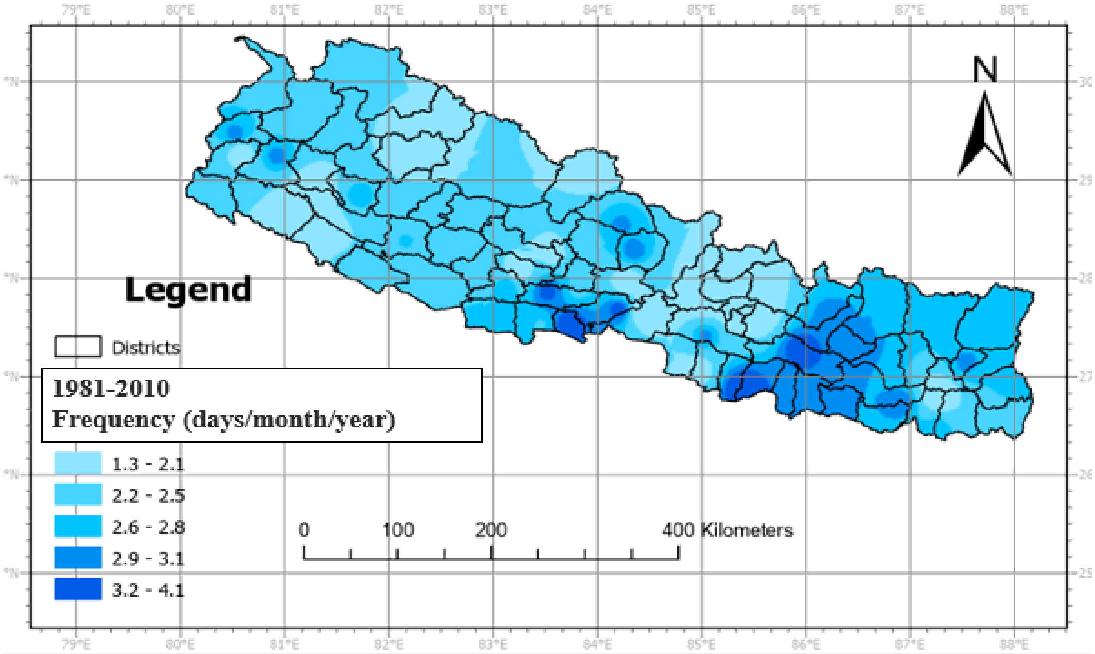

Figure 5-7: Frequency of cold waves occurred in 1981-2010 and their distribution (based on 5th percentile).

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

From 2011-2020: Frequency distribution for coldwaves

In terms of frequency of occurrences of cold waves in last decade, they overlap with the previous decades frequency distribution of coldwaves. They have been limited in the Tarai and mid hills of Nepal, and had remained constant in all the other parts of Nepal. But the number of days of occurrences have been limited to about 2.5 days/month in last decade.

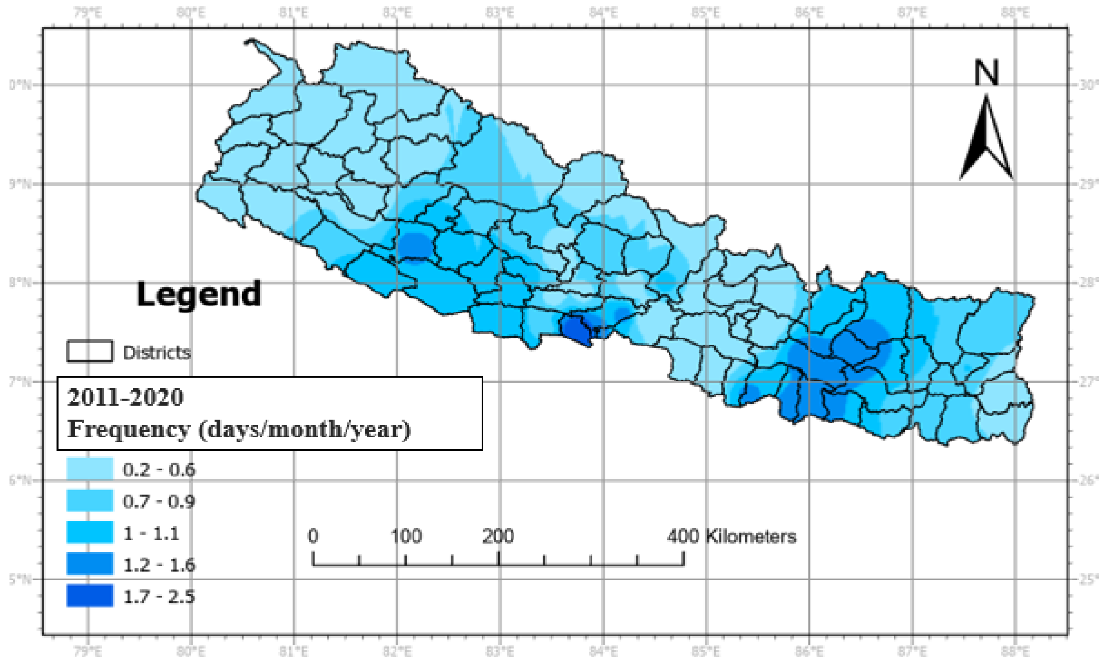

Figure 5-8: Frequency of cold waves occurred in 2011-2020 and their distribution (based on 5th percentile).

Source: Prepared by author with shape file of districts of Nepal from Survey Department, Government of Nepal (2020)

Statistical comparison frequency of coldwaves

From the above-mentioned results, the frequency distribution of extreme coldwaves can be seen. However, the changes in the frequency of coldwaves needs to be quantified based on statistical methods to get concrete results as in whether the changes in frequency are significant or not.

For this purpose, the statistical Z-Test(n>30) is done to compare the differences in frequency of coldwaves from period of 1981-2010 and 2011-2020.

Two-sample z-Test (One tailed test)

Null hypothesis: True difference in means is not greater than 0

Alternative hypothesis: Ture difference in means is greater than 0

Data	Mean	Std. Deviation	95% confidence interval	Remarks
1981-2010 frequency	2.739	0.588	(-0.4096, 0.4096)	Z = 8.7854 p-value < 0.00001
2011-2020 frequency	0.903	0.567		

In the Z-Test for frequency of coldwaves compared between the periods of 1981-2010 and 2011-2020, with the null hypothesis being of difference in true means is not greater than 0.

The average frequency of coldwaves in the period of 1981-2010 is approximately 2.739 days/month in winter with the standard deviation of 0.588 days from mean value. The average frequency of coldwaves in the period of 2011-2020 is approximately 0.903 days/month in winter with the standard deviation of 0.567 days from mean value.

In summary, the results suggest that there is a significant difference in the frequency of coldwaves between the two time periods (1981-2010 and 2011-2020). The frequency of coldwaves in the later period is significantly lower, as indicated by the p-value and the lower mean value. The remarks and z-score for the first period suggest that the frequency of coldwaves in that period is significantly higher than the mean, and the comparison is consistent with the extremely low p-value.

In summary, the analysis indicates a potential difference in the frequency of coldwaves between the two time periods (1981-2010 and 2011-2020), and this difference is statistical significant based on the provided p-value The frequency of coldwaves in the later period is significantly lower, as indicated by the p-value and the lower mean value. . This has also been supported with findings of (Karki et al., 2017; Shrestha et al., 2017) saying overall declining frequency, duration, and in some metrics intensity/severity of extreme cold events across Nepal over recent decades.

Figure 5-7 and Figure 5-8 highlight a minor shift in locations experiencing higher magnitudes of coldwaves over the last decade compared to earlier periods. The increased variability in coldwave frequency in Nepal during the last decade may be attributed to various factors. Global climate change, propelled by heightened greenhouse gas emissions, contributes to shifts in temperature patterns and an increased likelihood of extreme weather events. Natural climate variability introduces fluctuations in temperatures, affecting observed coldwave frequency. The diverse topography and altitude variations in Nepal create localized climate conditions influencing coldwave intensity and variability. Changes in land use, urbanization, atmospheric circulation patterns, and alterations in air pollution and aerosol levels from neighboring countries, such as India, all contribute to shaping the variability in coldwave magnitudes. However, further studies are necessary to provide conclusive evidence supporting these complex causal relationships.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

With continuous climate change and global warming, temperature related hazards like: heatwave and coldwave must be monitored and studied, specially keeping in mind the geographical diverseness of Nepal where temperature related hazards can easily change into disasters. In the context of frequent reporting's of heatwaves and coldwaves related incidents in Nepal, this study analyzed the climatology and differences by using percentile method recommended by WMO based on last 40 years (1981-2020) of climatic data from 96 stations widely spread across the country. This study uses percentile method for computation of daily thresholds for heatwaves and coldwaves. Giving emphasis on 95^{th} and 5^{th} percentile value thresholds for heatwaves and coldwaves, these waves were identified. Also, this study extends to examine magnitude, frequency, spatial distribution and statistical comparison of these events.

6.1 Conclusion

- The heatwave threshold outcome emphasizes unique temperature criteria in different regions. In hilly terrain, temperatures vary from 39℃ in Sindhuli to 27.7℃ in Dolakha. Mountainous areas show thresholds ranging from 33.9℃ in Dolpa to 24.8℃ in Manang, and the Tarai region exhibits varying thresholds from 42.3℃ in Banke to 36℃ in Sunsari district.
- Hilly heatwaves showed steady magnitude in last decade but 50% drop in frequency, though exceptional events exceed historical levels by 2°C. Mountain heatwaves declined 50% in magnitude, with a small frequency drop. And Tarai saw 1°C magnitude drop in average magnitude and 67% average frequency drop, but extreme heatwaves got 2°C hotter.
- The estimation of coldwave thresholds highlights distinct temperature criteria in different regions. In hilly areas, temperatures range from 7℃ in Illam to -4.3℃ in Dolakha. Mountainous regions exhibit varying thresholds, ranging from -5.2℃ in Manang to -15℃ in Mustang. The Tarai region experiences different thresholds, from 7℃ in Nawalparasi East to 4.1℃ in Saptari district.
- Hilly region coldwaves show steady magnitude over the last decade, but frequency has dropped by 70%. In mountainous areas, coldwave magnitude

declined 1°C as average frequency dropped by almost 50% in the last ten years. Though Tarai region magnitude was unchanged, average frequency declined by 67%; additionally, the magnitude of extreme coldwaves was 4°C lower than historical levels in this region over the past decade.

6.2 Recommendations

The following things can be recommended based on this study and for further study:

- Use other advanced parameters like: thermal comfort, relative humidity etc.
- Find a way to directly correlate heatwaves and coldwaves impacts on health and deaths because it will allow us to take into account of severity of these heatwaves and coldwaves as well.
- Practitioners on these matters can use thresholds like mentioned in this study to further build on this matter like: Early warning systems, heatwave-coldwave monitoring basis etc.
- Policy makers on different levels can take precautionary measures on places where these waves are intense or more frequent.

REFERENCES

Acharya, S., & Pathak, M. (2015). Analysis of cold wave over Nepal during winter season. *Journal of Hydrology and Meteorology*.

Aich, V., Akhundzadah, N., Knuerr, A., Khoshbeen, A., Hattermann, F., Paeth, H., Scanlon, A., & Paton, E. (2017). Climate Change in Afghanistan Deduced from Reanalysis and Coordinated Regional Climate Downscaling Experiment (CORDEX)—South Asia Simulations. *Climate*, *5*(2). https://doi.org/10.3390/cli5020038

Bai, L., Cirendunzhu, W., A., Dawa, J., Zhaxi, D., Yong, S., & Liu, X. (2016). Temperature, hospital admissions and emergency room visits in Lhasa, Tibet: A time-series analysis. *Science of the Total Environment*.

Baidya, S. K., Shrestha, M. L., & Sheikh, M. M. (2008). Trends in daily climatic extremes of temperature and precipitation in Nepal. *Journal of Hydrology and Meteorology*.

Baten, N., , M. A. H., Md. Habibur Rahman, & Rahman, a. M. A. (2022). Cold wave condition over Bangladesh for the period of 1988-2017. (Bangladesh Meteorological Department)

Chapman, S., Watson, J. E. M., Salazar, A., Thatcher, M., & McAlpine, C. A. (2017). The impact of urbanization and climate change on urban temperatures: a systematic review. *Landscape Ecology*, *32*(10), 1921-1935. https://doi.org/10.1007/s10980-017-0561-4

Climate Risk Country Profile: Nepal (2021):The World Bank Group and the Asian Development Bank. (2021).

ClimPACT Software Manual (English). (2013). World Climate Services Programme.

Dhimal, A. M., Nepal, B., Bista, B., Neupane, T., Dahal, S., Raj Pandey, A., & Kumar Jha, A. (2018). *Assessing Trends of Heat Waves and Perception of People about Health Risks of Heat Wave in Nepal*.

Feng, S., Hu, Q., Huang, W., Ho, C. H., Li, R., & Tang, Z. (2014). Projected climate regime shift under future global warming from multi-model, multi-scenario CMIP5 simulations. *Global and planetary change*.

Intergovernmental Panel on Climate, C. (2023). *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. https://doi.org/10.1017/9781009325844

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]*. G. IPCC, Switzerland.

Karki, R., Hasson, S. U., Gerlitz, L., Schickhoff, U., Scholten, T., & Böhner, J. (2017). Quantifying the added value of convection-permitting climate simulations in complex terrain: a systematic evaluation of WRF over the Himalayas. *Earth's Future*.

Kotharkar, R., & Ghosh, A. (2021). Review of heat wave studies and related urban policies in South Asia. *Urban Climate*, *36*. https://doi.org/10.1016/j.uclim.2021.100777

Mohammad, A. R., & Mortuza, M. R., Selmi. Saranah , Ankur. Asif Khan , Rahman. Md. Mujibur (2011). Increase of Heat Index over Bangladesh: Impact of Climate Change. *World Academy of Science, Engineering and Technology*.

Nath, M. J., & Lau, N.-C. (2014). Model Simulation and Projection of European Heat Waves in Present-Day and Future Climates. *Journal of Climate*, *27*(10), 3713-3730. https://doi.org/10.1175/jcli-d-13-00284.1

Nianthi, K. W. G., Nanayakkara, R., & Srimalee, N. W. (2018). Analysis of Human Heat Stress in Sri Lanka: Using Temperature Humidity Index (THI). *International Journal of Scientific and Research Publications (IJSRP)*, *8*(9). https://doi.org/10.29322/IJSRP.8.9.2018.p8184

Nissan, H., Burkart, K., Coughlan de Perez, E., Van Aalst, M., & Mason, S. (2017). Defining and Predicting Heat Waves in Bangladesh. *Journal of Applied Meteorology and Climatology*, *56*(10), 2653-2670. https://doi.org/10.1175/jamc-d-17-0035.1

Pollitt, N. (2021). Climate code red: Nepal at the frontline. https://kathmandupost.com/columns/2021/08/24/climate-code-red-nepal-at-the-frontline

Pradhan, B., Sharma, P., & K. Pradhan, P. (2019). Impact of Cold Wave on Vulnerable People of Tarai Region, Nepal. In *Climate Change and Global Warming*. https://doi.org/10.5772/intechopen.82201

Pradhan, B., Shrestha, S., Shrestha, R., Pradhanang, S., Kayastha, B., & Pradhan, P. (2013). Assessing Climate Change and Heat Stress Responses in the Tarai Region of Nepal.

Pradhananga, D., Mishra, A. R., Kristjánsson, J. E., Rai, S., & Olafsson, H. (2019). Observed snow and temperature trends across provinces in Afghanistan and Nepal. *Weather and Climate Extremes*.

Press, A. (2019). Europe heat wave breaks records, mercury set to go higher. https://myrepublica.nagariknetwork.com/news/europe-heat-wave-breaks-records-mercury-set-to-go-higher/

Purich, A., Cowan, T., Perkins, S., Pezza, A., Boschat, G., & Sadler, K. (2014). More Frequent, Longer, and Hotter Heat Waves for Australia in the Twenty-First Century. *Journal of Climate*, *27*(15), 5851-5871. https://doi.org/10.1175/jcli-d-14-00092.1

Reuters. (2021). UN warns of climate 'abyss' as 2020 confirmed as one of 3 hottest years on record. https://kathmandupost.com/35/2021/04/20/un-warns-of-climate-abyss-as-2020-confirmed-as-one-of-3-hottest-years-on-record

Revadekar, J. V., Patwardhan, S. K., Rupa Kumar, K., & Pant, G. B. (2012). Characteristic features of winter precipitation and temperature over India in the context of global warming. *International Journal of Climatology*.

Rohini, P., Rajeevan, M., & Srivastava, A. K. (2016). On the Variability and Increasing Trends of Heat Waves over India. *Sci Rep*, *6*, 26153. https://doi.org/10.1038/srep26153

Russo, S., Dosio, A., Graversen, R. G., Sillmann, J., Carrao, H., Dunbar, M. B., Singleton, A., Montagna, P., Barbola, P., & Vogt, J. V. (2014). Magnitude of extreme heat waves in present climate and their projection in a warming world. *Journal of Geophysical Research: Atmospheres*, *119*(22). https://doi.org/10.1002/2014jd022098

Shrestha, A. B., Aryal, R., & Kulkarni, A. (2017). *The Water-Energy-Food Nexus: Principles and Practices*. American Geophysical Union (AGU).

Song, X., Zhang, Z., Chen, Y., Wang, P., Xiang, M., Shi, P., & Tao, F. (2013). Spatiotemporal changes of global extreme temperature events (ETEs) since 1981 and the meteorological causes. *Natural Hazards*, *70*(2), 975-994. https://doi.org/10.1007/s11069-013-0856-y

Talchabhadel, R., Karki, R., Thapa, B. R., Maharjan, M., & Parajuli, B. (2018). Spatio-temporal variability of extreme precipitation in Nepal. *International Journal of Climatology*, *38*(11), 4296-4313. https://doi.org/10.1002/joc.5669

WHO. (2004). *Heat-waves: risks and responses[Christina Koppe, Sari Kovats, Gerd Jendritzky and Bettina Menne]*. WHO.

WMO. (2023). *Guidelines on the Definition and Characterization of Extreme Weather and Climate Events*. G. World Meteorological Organization, Switzerland.

ANNEXES

Annex A

Table A-1: 2 years sample result for magnitude, frequency and duration for heatwave in Baglung.

Date	Daily Min Temp	CSDI Threshold	Magnitude of Coldwave (°C)	Frequency of Coldwave (Days)	Duration of Coldwave (Days)
1/1/1991	4.8	4	0	0	
1/2/1991	5	4	0	0	0
1/3/1991	5.5	4	0	0	0
1/4/1991	6	4	0	0	0
1/5/1991	4	4	0	0	0
1/6/1991	4.2	4	0	0	0
1/7/1991	4.5	4	0	0	0
1/8/1991	4.8	4	0	0	0
1/9/1991	4.5	4	0	0	0
1/10/1991	5.9	4	0	0	0
1/11/1991	5	4	0	0	0
1/12/1991	6	4	0	0	0
1/13/1991	5.6	4	0	0	0
1/14/1991	5.6	4	0	0	0
1/15/1991	5	4	0	0	0
1/16/1991	5.5	4	0	0	0
1/17/1991	5.7	4	0	0	0
1/18/1991	5	4	0	0	0
1/19/1991	4.9	4	0	0	0
1/20/1991	5.5	4	0	0	0
1/21/1991	5.8	4	0	0	0
1/22/1991	5.8	4	0	0	0
1/23/1991	6.5	4	0	0	0
1/24/1991	5.5	4	0	0	0
1/25/1991	6	4	0	0	0
1/26/1991	4.9	4	0	0	0
1/27/1991	4.4	4	0	0	0
1/28/1991	5.5	4	0	0	0
1/29/1991	6	4	0	0	0
1/30/1991	6.8	4	0	0	0
1/31/1991	7	4	0	0	0
2/1/1991	4.8	4	0	0	0
2/2/1991	4.5	4	0	0	0
2/3/1991	5.1	4	0	0	0
2/4/1991	5	4	0	0	0

2/5/1991	4.4	4	0	0	0
2/6/1991	6	4	0	0	0
2/7/1991	5.3	4	0	0	0
2/8/1991	4.8	4	0	0	0
2/9/1991	5.1	4	0	0	0
2/10/1991	5	4	0	0	0
2/11/1991	4.9	4	0	0	0
2/12/1991	4.8	4	0	0	0
2/13/1991	5.4	4	0	0	0
2/14/1991	5.5	4	0	0	0
2/15/1991	5.2	4	0	0	0
2/16/1991	6	4	0	0	0
2/17/1991	5.8	4	0	0	0
2/18/1991	6	4	0	0	0
2/19/1991	6	4	0	0	0
2/20/1991	5.8	4	0	0	0
2/21/1991	5.5	4	0	0	0
2/22/1991	5.8	4	0	0	0
2/23/1991	6	4	0	0	0
2/24/1991	6.6	4	0	0	0
2/25/1991	5.5	4	0	0	0
2/26/1991	5.8	4	0	0	0
2/27/1991	6	4	0	0	0
2/28/1991	7	4	0	0	0
3/1/1991	9	4	0	0	0
3/2/1991	4.2	4	0	0	0
3/3/1991	7	4	0	0	0
3/4/1991	8	4	0	0	0
3/5/1991	9	4	0	0	0
3/6/1991	8.2	4	0	0	0
3/7/1991	6	4	0	0	0
3/8/1991	7	4	0	0	0
3/9/1991	6.5	4	0	0	0
3/10/1991	8.8	4	0	0	0
3/11/1991	8.4	4	0	0	0
3/12/1991	6.2	4	0	0	0
3/13/1991	6	4	0	0	0
3/14/1991	9	4	0	0	0
3/15/1991	7	4	0	0	0
3/16/1991	8	4	0	0	0
3/17/1991	6.8	4	0	0	0
3/18/1991	8	4	0	0	0
3/19/1991	8.2	4	0	0	0
3/20/1991	10	4	0	0	0

3/21/1991	9.4	4	0	0	0
3/22/1991	9.5	4	0	0	0
3/23/1991	9.4	4	0	0	0
3/24/1991	8.8	4	0	0	0
3/25/1991	8	4	0	0	0
3/26/1991	10.5	4	0	0	0
3/27/1991	11	4	0	0	0
3/28/1991	10.2	4	0	0	0
3/29/1991	11.4	4	0	0	0
3/30/1991	13.8	4	0	0	0
3/31/1991	15	4	0	0	0
4/1/1991	12.5	4	0	0	0
4/2/1991	10.2	4	0	0	0
4/3/1991	12	4	0	0	0
4/4/1991	12.5	4	0	0	0
4/5/1991	10.5	4	0	0	0
4/6/1991	10.2	4	0	0	0
4/7/1991	13.1	4	0	0	0
4/8/1991	9.4	4	0	0	0
4/9/1991	11.8	4	0	0	0
4/10/1991	12.8	4	0	0	0
4/11/1991	12.4	4	0	0	0
4/12/1991	12	4	0	0	0
4/13/1991	10.8	4	0	0	0
4/14/1991	12.8	4	0	0	0
4/15/1991	11.5	4	0	0	0
4/16/1991	11	4	0	0	0
4/17/1991	12.5	4	0	0	0
4/18/1991	11.5	4	0	0	0
4/19/1991	12.8	4	0	0	0
4/20/1991	10.5	4	0	0	0
4/21/1991	11.4	4	0	0	0
4/22/1991	12.5	4	0	0	0
4/23/1991	11.8	4	0	0	0
4/24/1991	12	4	0	0	0
4/25/1991	10.2	4	0	0	0
4/26/1991	12	4	0	0	0
4/27/1991	13	4	0	0	0
4/28/1991	14.4	4	0	0	0
4/29/1991	14	4	0	0	0
4/30/1991	13	4	0	0	0
5/1/1991	15	4	0	0	0
5/2/1991	15.6	4	0	0	0
5/3/1991	15.4	4	0	0	0

5/4/1991	16.3	4	0	0	0
5/5/1991	18.2	4	0	0	0
5/6/1991	17.8	4	0	0	0
5/7/1991	18.8	4	0	0	0
5/8/1991	17.4	4	0	0	0
5/9/1991	19.4	4	0	0	0
5/10/1991	19.2	4	0	0	0
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5/13/1991	18.6	4	0	0	0
5/14/1991	18.8	4	0	0	0
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5/18/1991	18.8	4	0	0	0
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12/15/1991	5.2	4	0	0	0
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12/17/1991	3.8	4	0.2	1	1
12/18/1991	4.4	4	0	0	0
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12/24/1991	5.2	4	0	0	0
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12/26/1991	3.2	4	0.8	1	1
12/27/1991	2.4	4	1.6	1	2
12/28/1991	2.6	4	1.4	1	3
12/29/1991	2	4	2	1	4
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7/7/1992	18.8	4	0	0	0
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7/21/1992	22.3	4	0	0	0
7/22/1992	22	4	0	0	0
7/23/1992	21.4	4	0	0	0
7/24/1992	21.4	4	0	0	0
7/25/1992	22.5	4	0	0	0
7/26/1992	21.8	4	0	0	0
7/27/1992	21.9	4	0	0	0
7/28/1992	22.3	4	0	0	0
7/29/1992	22.5	4	0	0	0
7/30/1992	22.4	4	0	0	0
7/31/1992	22	4	0	0	0
8/1/1992	20.8	4	0	0	0
8/2/1992	21.5	4	0	0	0
8/3/1992	21.2	4	0	0	0
8/4/1992	21.5	4	0	0	0
8/5/1992	22.2	4	0	0	0
8/6/1992	20	4	0	0	0
8/7/1992	21.3	4	0	0	0
8/8/1992	20.4	4	0	0	0
8/9/1992	21.4	4	0	0	0
8/10/1992	22.3	4	0	0	0
8/11/1992	21.8	4	0	0	0
8/12/1992	21.7	4	0	0	0
8/13/1992	22	4	0	0	0
8/14/1992	23.2	4	0	0	0
8/15/1992	21.4	4	0	0	0
8/16/1992	21.3	4	0	0	0
8/17/1992	22.2	4	0	0	0
8/18/1992	21.8	4	0	0	0
8/19/1992	21.3	4	0	0	0
8/20/1992	20.8	4	0	0	0
8/21/1992	21.2	4	0	0	0
8/22/1992	21.9	4	0	0	0
8/23/1992	21.9	4	0	0	0
8/24/1992	21.2	4	0	0	0
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8/26/1992	21	4	0	0	0
8/27/1992	20.4	4	0	0	0
8/28/1992	24.4	4	0	0	0
8/29/1992	22.4	4	0	0	0

8/30/1992	22.4	4	0	0	0
8/31/1992	22.8	4	0	0	0
9/1/1992	22.8	4	0	0	0
9/2/1992	23.7	4	0	0	0
9/3/1992	20	4	0	0	0
9/4/1992	22.2	4	0	0	0
9/5/1992	22.8	4	0	0	0
9/6/1992	21.4	4	0	0	0
9/7/1992	21.2	4	0	0	0
9/8/1992	21.2	4	0	0	0
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9/10/1992	21.4	4	0	0	0
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9/14/1992	21.6	4	0	0	0
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9/16/1992	21	4	0	0	0
9/17/1992	21.2	4	0	0	0
9/18/1992	19.4	4	0	0	0
9/19/1992	19	4	0	0	0
9/20/1992	16.7	4	0	0	0
9/21/1992	16.7	4	0	0	0
9/22/1992	16.7	4	0	0	0
9/23/1992	16.8	4	0	0	0
9/24/1992	19.2	4	0	0	0
9/25/1992	19	4	0	0	0
9/26/1992	18.8	4	0	0	0
9/27/1992	20	4	0	0	0
9/28/1992	20	4	0	0	0
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9/30/1992	19.6	4	0	0	0
10/1/1992	21.4	4	0	0	0
10/2/1992	19.8	4	0	0	0
10/3/1992	20	4	0	0	0
10/4/1992	18	4	0	0	0
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10/7/1992	21	4	0	0	0
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10/10/1992	22.2	4	0	0	0
10/11/1992	21.4	4	0	0	0
10/12/1992	21.8	4	0	0	0

10/13/1992	15	4	0	0	0
10/14/1992	18.4	4	0	0	0
10/15/1992	20.1	4	0	0	0
10/16/1992	20	4	0	0	0
10/17/1992	18.8	4	0	0	0
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11/17/1992	9.4	4	0	0	0
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11/24/1992	8.2	4	0	0	0
11/25/1992	7.4	4	0	0	0

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11/27/1992	7.2	4	0	0	0
11/28/1992	7.4	4	0	0	0
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11/30/1992	7.6	4	0	0	0
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12/2/1992	8.4	4	0	0	0
12/3/1992	7.2	4	0	0	0
12/4/1992	7	4	0	0	0
12/5/1992	8	4	0	0	0
12/6/1992	6.6	4	0	0	0
12/7/1992	5.2	4	0	0	0
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12/10/1992	6.6	4	0	0	0
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12/14/1992	8.5	4	0	0	0
12/15/1992	6.9	4	0	0	0
12/16/1992	7.2	4	0	0	0
12/17/1992	5.2	4	0	0	0
12/18/1992	5.4	4	0	0	0
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12/22/1992	6.8	4	0	0	0
12/23/1992	5	4	0	0	0
12/24/1992	3.4	4	0.6	1	1
12/25/1992	5	4	0	0	0
12/26/1992	8.4	4	0	0	0
12/27/1992	7.8	4	0	0	0
12/28/1992	5.4	4	0	0	0
12/29/1992	7.1	4	0	0	0
12/30/1992	7.4	4	0	0	0
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Date: November 26, 2023

To Whom It May Concern:

This is to certify that the paper titled "***Thresholds and Characteristics of Heatwaves and Coldwaves in Nepal over the period of 1981-2020***" (Submission# **170**) submitted by **Adarsh Gupta** as the first author has been accepted after the peer-review process for presentation in the 14th IOE Graduate Conference being held during Nov 29 to Dec 1, 2023. Kindly note that the publication of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon the author's presence for presentation during the conference and timely response to further edits during the publication process.

Bhim Kumar Dahal, PhD
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14th IOE Graduate Conference

Paper ID: H1-4

Thresholds and Characteristics of Heatwaves and Coldwaves in Nepal over the period of 1981-2020

Adarsh Gupta [a], *Suraj Lamichane* [b]

Abstract:

With continuous climate change and global warming, temperature related hazards like: heatwave and coldwave must be monitored and studied, specially keeping in mind the geographical diverseness of Nepal where temperature related hazards can easily change into disasters. This study uses percentile method to identify and analyze events like heatwave and coldwave. Also, this study extends to examine magnitude, frequency, spatial distribution and trends of these events. Study shows that the magnitude of heatwaves remained overall similar with small dip in frequency of occurrence. Magnitude of exceptional heatwaves has increased by 2°C in last decade. Also, variation of magnitude of heatwaves have doubled in last decade indicating serious extreme cases. The magnitude of coldwave remained similar in last decade and the variation in magnitude also remained similar. Average coldwave occurrences in Nepal in last decade has dropped to third of previous values while remaining same in variation.

Keywords:

Heatwave, Coldwave, Percentile-based thresholds,

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