Analysis of HEAT WAVE Over Nepal

A Dissertation Submitted to the Central Department of Hydrology and Meteorology

Institute of Science and Technology

Tribhuvan University

In Partial Fulfilment of the Requirement for the Master's Degree in Hydrology and Meteorology

SUBMITTED BY

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LETTER OF DECLARATION

I hereby declare that the work presented in this dissertation is my work and has not been submitted elsewhere for the award of any degree. All the reference sources of information have been properly and fully acknowledged.

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LETTER OF RECOMMENDATION

This is to certify that **Mr. Hira Prasad Bhattarai** has prepared the dissertation entitled, **"Analysis of HEAT WAVE Over Nepal"**. The research has been carried out under my supervision and guidance. Moreover, I recommend this dissertation for final approval and acceptance as partial fulfillment of the requirement for the Master's Degree in Hydrology and Meteorology at the Central Department of Hydrology and Meteorology, Tribhuvan University.

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Sincerely
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ABSTRACT

Climate change imposed negative impact on socio-economic sectors of the mountainous region like Nepal. The 21st century has brought many records breaking warm year. Such warm periods brought many health-related problems, heat wave is one among them. Daily maximum temperature data of 46 stations of DHM is used to calculate the heat wave (HW)patterns over the country. To better understand the regional pattern of HW all the stations are further classified into 6 different regions: East Terai, Central Terai, Western Terai, Eastern Mountain, Central Mountain and Western Mountain based on the 3 large river basins (Koshi, Gandaki and Karnali). The percentile-based method is used for the calculation of the HW. The 90th percentile values are used as the threshold and HW is declared after the daily maximum temperature on exceeding the threshold and the normal temperature of the station by 4° C for at least 3 consecutive days. Based on the criteria, HW's different characteristics like the total number of events, total days of HW, longest event, average days in HW, Maximum deviation of temperature in HW, the onset date of HW and the withdrawal date of HW are calculated using MATLAB and MS-Excel. The western region records the highest frequency and total heat wave days. The central and western mountain region shows the highest maximum temperature deviation than the Terai regions. Although the HW events are more severe in the mountain region but terai region shows consistent severe HW in these regions. The average days of heat wave event throughout the country is 2.6 days. Also, the monsoon event controls the heat wave events. The ElNino phenomena shows no significant relation with the heat wave but the peak of the heat wave is found at ElNino+1 year. The criteria used in this study is very easy to calculate and can be used for the national decision-making process.

LIST OF ACRONYMS AND ABBREVIATIONS

DHM	Department of Hydrology and Meteorology
DMT	Daily Maximum Temperature
HW	Heat Wave
IPCC	Intergovernmental Panel of Climate Change
IMD	Indian Meteorological Department
NDRRMA	National Disaster Risk Reduction and Management Authority
ETCCDI	Expert Team on Climate Change Detection and Indices
BMD	Bangladesh Meteorological Department
WMO	World Meteorological Organization
MATLAB	Mathematical Laboratory

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Nepal lying within $26^{0}22'$ and $30^{0}27'$N latitude and $80^{0}04'$ and $88^{0}12'$E longitude and has steep altitudinal variation from 60m to 8848m within the average breadth of 120 km. Such large variation of the altitude has divided the country into the 5 different physiographic regions: Terai, Siwalik, Middle Mountains, High Mountains, High Himalaya. Also, the altitudinal variation causes extreme climatic variation from subtropical in the south to alpine/arctic in the north[1]. The altitudinal variation also makes Nepal prone to the many natural hydro- meteorological disaster like landslide, thunderstorm, drought, floods, flash floods, cold waves HW, heavy rainfall etc.

In particular, Nepal has four seasons namely pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February). Monsoon season alone brings almost all the annual precipitation of the country (about 80%) [1] due to the moist laden air mass of the Bay of Bengal and Indian Ocean followed by winter precipitation caused by westerly disturbances. Temperature variation is highly influenced by the altitude and topography variation of the country[2]. Such variation makes the terai and lower plain areas sites of the high temperature. Altitude and topography variation along with large circular circulation mainly control and influence the climate of the Nepal.[3]

After the retreat of winter season from Nepal the land surface temperature has started to increase along with the northward movement of the sun and becomes maximum in the April and May month. Such increasing temperature remains until the month of September which causes both the pre-monsoon and the monsoon season highly hot and results in the heat stress condition mainly in the southern part of the country. continuous persistence of the sub-tropical high pressure over the Indian peninsular region during the summer season causes the rise in temperature in the Nepal which will lead to the HW condition. Previous studies had shown the increasing trend of the maximum temperature of 0.056 0C/yrs.[4] Such increasing trend accompanied by the climate change and green house emission enhances the heat stress and extreme temperature indices condition of the terai and lower mountain regions of the country.

The special report of IPCC on the impact of global warming based on the gas emission pathways found the increasing rate of temperature is 1.5°C above the pre-industrial levels.[5] IPCC's sixth assessment report[6] found that global surface temperature between 2001- 2020 was 0.84-1.10°C higher than 1850-1900 period. The land surface shows higher increasing trends (1.34-1.83°C) than the ocean (0.68-1.01°C). also, the rate of the temperature rises during the recent decade (2011-2020) period is much higher than the last 6500 years. Due to such increasing trends of the temperature the human induced climate change disasters like HW, heavy precipitation, droughts etc. will affect more parts of the world more vigorously in the future. Projected increases in the occurrence of extreme HW episodes incur huge socioeconomic costs. [5].

Some extreme HW of the past includes the 2010 Russian HW(killing around 54000 people) 2003 HW of the western Europe (killed around 70,000 people)[7], 2009 HW over South Eastern Australia(killed 374 people)[8].The HW is a "silent killer"[9] as the impact of the HW are not instantaneous. Its causes heat stokes and mainly affects the elderly, young ones and those who work outdoors and generally causes the death after a number of days after its impact. The physical processes contributing to the initiation and maintenance of the HW in different geographical locations, as well as the variations in the severity, longevity and frequency of these extreme events in the 20th and 21st centuries, are therefore research topics of strong societal relevance.

There is no standard definition for HW, but most studies have used a combination of temperature (intensity) and duration to define them. In addition to comparing heat-wave days with non-heat-wave days, a few studies have examined the effects of HW characteristics, such as intensity, duration, and timing during the year[10], [11]. For defining the HW, thermal tolerance capability of the persons of the nation's must be considered. Also, the effects of the HW are mainly determined by the societal features and the socio-economic status of the region and its people. These events of the extreme condition are a slow poison.

The WMO identifies a HW 'when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5°C, the normal period being 1961-90. Thus, the definition of a HW implies that it is an extended period of unusually high atmosphere-related heat stress. Appropriate thresholds must be established for the combination, considering both daytime high and overnight low values and being related to the climatic variability common to the area. The effect of duration must also be included in order to determine its severity.

Due to the variation in physiographic and the heat tolerance capacity of the person of the country, different countries modify the definition of the HW given by the WMO as according to their national suitable form. For eg: IMD has given the followings criteria for HW [12]:

- HW need not be considered till maximum temperature of a station reaches at least 40°C for Plains and at least 30°C for Hilly regions
- HW is a condition when departure of maximum temperature from normal is +4°C to 5°C or more for the regions where the normal maximum temperature is more than 40°C and departure of maximum temperature from normal is 5°C to 6° C for the regions where the normal temperature is 40°C or less.
- IMD defines severe HW condition as, 'a condition when departure of maximum temperature from normal is +6°C or more for the regions where normal maximum temperature is more than 40°C and +7°C or more for regions where the normal temperature is 40°C or less.
- When actual maximum temperature remains 45°C or more irrespective of normal maximum temperature, HW should be declared. Higher daily peak temperatures and longer, more intense HW are becomingly increasingly frequent globally due to climate change. India too is feeling the impact of climate change in terms of increased instances of HW which are more intense in nature with each passing year and have a devastating impact on human health thereby increasing the number of HW casualties.

Similarly the BMD declare the HW on fulfilling the following conditions [13]:

- Mild HW when maximum temperature is 36-38°C
- Moderate HW when maximum temperature is 38-40°C
- Severe HW when maximum temperature is 40-42°C
- Extreme HW when maximum temperature >42°C.

In the context of Nepal, the study of HW has not been carried out. Furthermore, the DHM, responsible for the services and meteorological analysis in Nepal, has not set the definition for HW for Nepal. In such a scenario, it becomes very crucial to carry out the study of HW occurrence for Nepal. Thus, this study, which focuses on the evaluation of HW occurrences in various regions of Nepal, provides valuable results and assists in developing a basic criterion to declare the HW condition in Nepal.

1.2 Scope of the Study

In this study I will analyze and explore the various characteristics of the HW and severe HW. Along that other major scopes of this study are listed below:

- Acquisition of daily maximum temperature data of 46 stations of Nepal from 1st February 1991 to 30th September, 2021 and preparation of data for analysis.
- Determining the best criteria for the HW for Nepal.
- Exploring the various characteristics of the HW like frequency (total annual count of the HW events), duration (total annual count of the HW days), length (maximum length of the longest HW event), intensity (deviation of the maximum temperature of the HW days' event from their mean) and onset and withdrawal of the HW.
- Annual and decadal variations of the features of the HW.
- Exploring the spatial and temporal variation of the HW and its characteristics across the country.
- Identify the synoptic situation favorable for the HW.

1.3 Objectives of the Study

This study will identify the HW regions in Nepal based on the past DMT data of various stations. Followings are the main objectives of this study:

- To establish criteria for the heatwave.
- Identification of location, duration, intensity and frequency of HW incidents based on the temperature data of the study area and duration.

1.4 Recommendations and Limitations.

The main recommendations are:

- Detailed analysis of the various atmospheric variables affecting the HW.
- Use of the gridded data set for the efficient and total spatial coverage of the all parts of the country.
- Continuous and homogenous data of long period.

The main limitations of the study are:

- Lack of spatial coverage of the stations mainly in the high mountainous and Himalayan region.
- Large quantities of the missing data of the stations.
- Effect of the other large-scale atmospheric circulations eg. Maiden Julian oscillation.

CHAPTER 2: LITERATURE REVIEW

It has been well discussed for some time in the climate science literature that a small change in average temperature results in abnormal change in the intensity and frequency of the disaster caused by extreme climate [14]. IPCC 2012 report also explained how extreme temperature changes due to the shift in mean temperature or due to change in variability of mean temperature [15]. The report explains that the character and severity of the impacts from climate extremes depends not only on the extremes themselves, but also on the vulnerability and exposure to such extreme conditions. The climate extremes, exposures and vulnerability are influenced by several factors like anthropogenic climate change, natural climate variability, and socio-economic development. Shrestha et. al.

According to a recent IPCC report [9-10], during the 100-year period (1906 to 2005), the mean annual global surface air temperature has increased by about 0.74 °C and during the same period, the global averaged annual land surface air temperatures have increased much faster than the global averaged annual sea surface temperatures. The report also noted significant changes in the frequency and intensity of extreme weather events like HW, droughts, floods and hurricanes over various parts of the world. According to the Fifth Assessment Report of the IPCC [11], south Asian countries will be at the greatest risk in the emerging HW. Based on the analysis of DMT, minimum temperature and average temperature for the period 1950-2011, found increasing global trends in the intensity, frequency and duration in the observed summer time HW and annually calculated warm spells [12].

Huges et al claimed that climate change has accelerated the number of HW along with its intense temperature during the HW all around the world [16]. Also, the degree of impact caused by the HW to the human beings, property and infrastructure has become more worse. Due to the shift in the climatic system more severe HW are seen around the world. A small increase in the average maximum temperature has caused a drastic change in the frequency, severity and duration of the HW. Due to the continuation in the increase greenhouse gases in the atmosphere at the present rate too results in the increase in the record hot days and warm nights throughout the 21st century.

Perkins et al 2012 [17], [18] using daily temperature data sets over1950-2011 had studied the global trends of the HW and warm spells. It is found that the increase in the intensity, frequency and duration is found all over the globe within the study periods. Among the different character of the HW total no. of days satisfying HW condition has large increasing trend than others mainly in the North America, Eurasia and Australia regions.

HW are anticipated to be more common, longer, and more intense in the future [15]. Over central and northwestern parts of the India, frequency, total duration and maximum duration of HW are increasing [16]. Northern, western, central and south-central parts of India experience HW during summer (NIUA, 2016). The hot and dry winds which blow from the Thar desert and Rajasthan state. Also, the anti-cyclone over the Rajasthan prevents western disturbances from entering into the Indian subcontinent, leading to clear skies and leads to increase in the temperature of the surrounding regions. The HW in central and south-central parts of India is partially due to the wind originating from hot and arid regions of western India, and partially due to the rugged and barren physiography of plateau in these parts of India. When the monsoon is delayed or weak, the incidence of HW is higher as the rainfall which brings down the temperature over the heated landmass is absent or deficient. Thus, the overheating reaches up to the plain areas of the Jammu region and in Himachal Pradesh. Nissan et. al. 2017 had found that increase in the maximum and minimum temperature over 95th percentile values for consecutives 3 days increases the death rates by 20% in Bangladesh [19].

Karki et. al. 2017,[20] on studying precipitation from the 210 stations had found that the less wet days in the terai and siwalik regions, also the decreasing trends of the monsoon rainfall un the central and eastern low regions of the Nepal[20]. Aarati et. al. 2020, on studying the 10 extreme temperature indices from the 25 stations, revealed the decreasing trends of the cold days and significant increasing trends of maximum temperature in the higher elevation. The summer months are getting hotter across the country [21]. Based on the analysis of precipitation data from the 220 stations found that more long and severe long-term drought. The high value in the spring and autumn droughts during the 1980s decade but after the 2000 decade the summer and winter drought were almost doubled after the 2000s [22]. Thakuri et. al. 2019 [23] on studying the maximum air temperature had found that the rate of rising maximum temperature is more than the rate of increasing minimum temperature. A higher trend of the maximum temperature was found mainly in the mountainous region and in the pre-monsoon season. Also, the higher increasing trends for warm days (13 days/decade) is much more than the trends of warm nights [24].

The study of extreme climatic indices in the context of Nepal is very limited. Baidhya et.al [25], on studying the climatic indices of ETCCDI using DMT of Nepal, found increasing trends in warm nights, higher elevations shows the increasing trends of the warm days and decreasing trends of the cool days, trend of the DMT and daily minimum temperature show positive trends at higher elevations. Annual maximum temperature trend was observed to be lower in the southern parts and higher in the northern parts of the country. Maximum temperature is in increasing trend in large magnitude than the minimum temperature in most of the places and almost all the seasons. Increasing trend in temperature in post monsoon and a general decreasing trend in minimum temperature in the northern mountainous regions and increasing trend in the southern hilly and plain regions of the country. On studying the DMT show high rates of warming in the Middle Mountains and Himalayan (0.06 to 0.12°C/yr.), while low warming (0.038°C/yr.) trends were found in the southern regions [13-14].

Maximum temperature is in increasing trend in large magnitude than the minimum temperature in almost all the seasons. The average trend of mean annual maximum temperature over Nepal is 0.037^{o}C/year whereas minimum temperature trend is only 0.012oC/year. The mean annual minimum temperature trend is higher in low altitude Terai and Siwalik range and lower in High altitude region while the trend pattern is reverse in mean annual maximum temperature with higher in high altitude region and lower in low lying Terai plains [4].

In ElNino and LaNino phenomena of the southern pacific region largely controls our monsoonal activities This south pacific oscillation phenomena between the Darwin and Tahiti delayed the monsoonal activity over the Indian sub-continent during the ElNino period but it enhances the monsoon during the LaNino periods. For the determination of these phenomenon Nino 3.4 index is used. The Niño 3.4 (5N-5S, 170W-120W): region's anomalies is the representation of the average equatorial SSTs across the Pacific from about the dateline to the South American coast. The Niño 3.4 index typically uses a 5-month running mean, and El Niño or La Niña events are defined when the Niño 3.4 SSTs exceed +/- 0.4C for a period of six months or more.

CHAPTER 3: METHOD AND METHODOLOGY

3.1 Data

Daily maximum temperature data set from 1991 to 2021 A.D. of the Department of Hydrology and Meteorology of the various stations of the country were used. Out of the 139 climatic stations of the country only 46 stations were used for this study as they have less than 5% of the missing data. The quality and homogeneity of the data is checked using RClimDex software as discussed in Alexander et al 2006 [26]. The missing values and the values lying outside the outliners are noted and corrected using mean of the previous and following days value. The abrupt changes in the values are considered to occur solely due to the natural process and exclusive of any instrumental and human error reason.

The terai region shows gradual increase in the maximum temperature whereas the mountainous region shows the steep rate of the temperature such unequal increasing trends of the terai and mountain region as revealed by Shrestha et al. (1999) [27] Baidhya et al (2008) [25] and DHM (2015) [4] helps to separate the selected stations based on their altitude variation as the terai and mountainous region station in order to explore the impact of the HW in these regions.. The 3 major river basins: Koshi Basin, Gandaki Basin and Karnali Basin also gives impact to the climate of the Nepal. Thus, the above stations were also separated as the eastern, central and western regions stations. Thus, all the stations were kept in the 6 different regions depending on their altitude and geographic position. The 6 different regions are: Eastern Terai (ET), Central Terai (CT), Western Terai (WT), Eastern Mountain (EM), Central Mountain (CM) and Western Mountain (WM). The geographical position of the stations is shown in the map of Nepal.

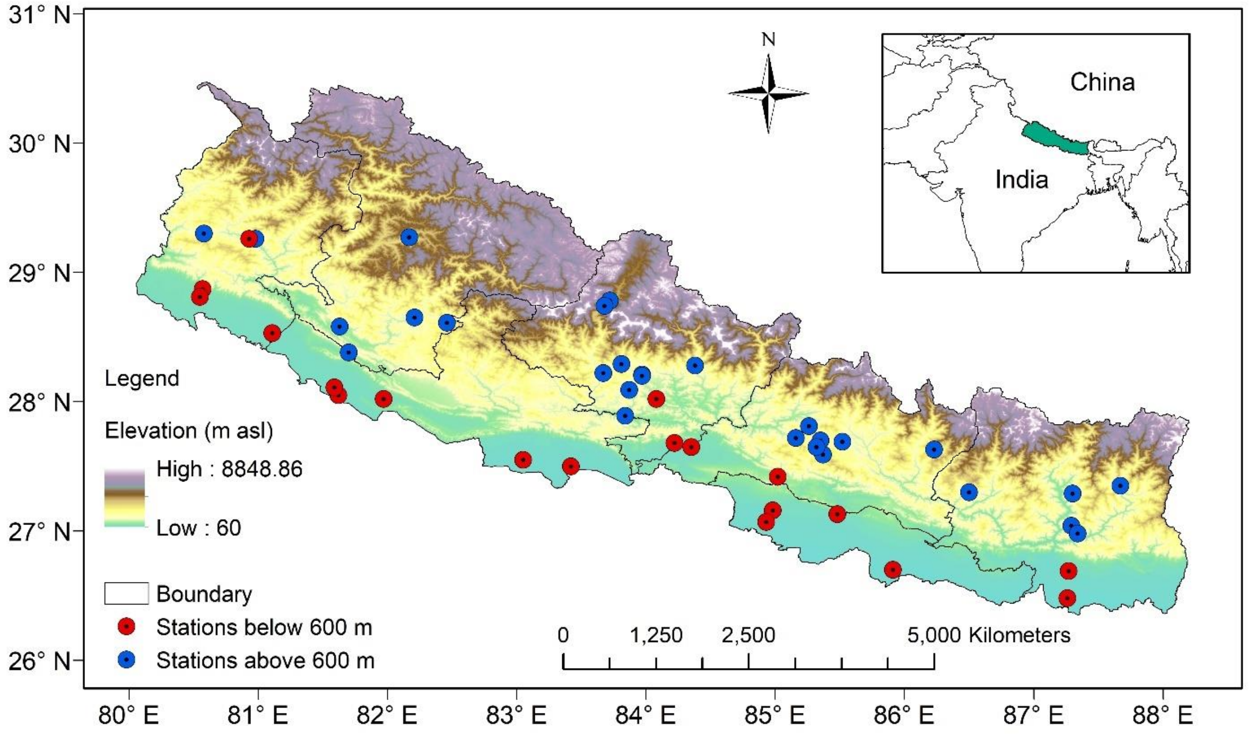


Figure 3-1: Geographical Position of the Stations.

The detailed metdata of the stations with their regions are given below.

Table 3-1: Metdata of the Station

S. N.	Regions	Stations Name	District	Elevation	Longitude	Latitude
1	ET	Biratnagar	Morang	72	87.26	26.48
2		Janakpur	Janakpur	76	85.91	26.7
3		Karmaiya	Sarlahi	121	85.48	27.13
4		Parwanipur	Bara	87	84.93	27.07
5		Simara	Bara	137	84.98	27.16
6		Tarahara	Sunsari	120	87.27	26.69
7	CT	Bhairahawa	Rupandehi	108	83.42	27.5
8		Dum kauli	Nawalpur	183	84.22	27.68
9		Hetauda	Hetauda	452	85.02	27.42
10		Khairini Tar	Tanahun	515	84.08	28.02
11		Rampur	Chitwan	189	84.35	27.65
12		Taulihawa	Kapilvastu	105	83.05	27.55
13	WT	Dipayal	Dipayal	563	80.93	29.26
14		Dhangadhi	Dhangadhi	184	80.55	28.81
15		Godawari (Weast)	Kailali	280	80.57	28.87
16		Khajura	Banke	129	81.59	28.11
17		Nepalgunj	Banke	141	81.62	28.05
18		Sikta	Banke	161	81.97	28.02
19		Tikapur	Kailali	149	81.11	28.53
20	EM	Taplejung	Taplejung	1744	87.67	27.35

S. N.	Regions	Stations Name	District	Elevation	Longitude	Latitude
21		Pakhribas	Dhankuta	1720	87.29	27.04
22		Okhaldhunga	Okhaldhunga	1731	86.5	27.3
23		Dhankuta	Dhankuta	1192	87.34	26.98
24		Chainpur (East)	Sankhuwasabha	1277	87.3	27.29
25	CM	Thakmarpha	Jomsom	2655	83.68	28.74
26		Lumle	Kaski	1738	83.81	28.29
27		Kushma	Baglung	900	83.67	28.22
28		Khumaltar	Lalitpur	1029	85.32	27.65
29		Malepatan	Kaski	859	83.97	28.21
30		Nagarkot	Bhaktapur	2147	85.52	27.69
31		Chapakot	Syangja	617	83.84	27.89
32		Pokhara	kaski	827	83.97	28.2
33		Syangja	Syangja	871	83.87	28.09
34		Kathmandu	Kathmandu	1337	85.35	27.7
35		Kakni	Nuwakot	1007	85.26	27.81
36		Jomsom	Jomsom	2741	83.72	28.78
37		Jiri	Jiri	1877	86.23	27.63
38		Godawari (East)	Lalitpur	1527	85.37	27.59
39		Khudi Bazar	Lamjung	838	84.38	28.28
40		Dhunibesi	Dhading	991	85.16	27.72
41		Musikot	Rukum (West)	1412	82.46	28.61
42		Jumla	Jumla	2363	82.17	29.27
43	WM	Dadeldhura	Dadeldhura	1879	80.58	29.3
44		Dailekh	Dailekh	1394	81.7	28.38
45		Surkhet	Surkhet	720	81.63	28.58
46		Chaur Jhari Tar	Rukum (West)	863	82.21	28.65
47		Silgadhi	Doti	1309	80.98	29.26

3.2 Methodology

Indices used for heatwave or warm spell measurement may involve either percentile or fixed thresholds, include maximum, minimum or apparent temperature, and may focus on either consecutive days where conditions above the threshold persist or single daily events [28][26]. Such metrics may vary in complexity, ranging from numerous pre-defined conditions to be satisfied [28] or meticulous calculations of apparent temperature [29], to simple counts of single days above a prescribed threshold [29].

Among the three different methods used for the study and analysis of the HW in this study I choose the percentile-based method. In this method, the 90th percentile value of the station during the summer season is calculated and used as the threshold value. For the stations lying below 800m altitude the threshold value is 39.5°C and for lying above 800m altitude it is 34°C. A HW event is declared on fulfilling the followings 3 conditions

1. The daily maximum temperature must exceed the threshold value.
2. The daily maximum temperature must exceed the mean value of the summer season of the station by 4°C or more.
3. The above-mentioned condition must occur continuously for at least 3 days.

The Mann-Kendell test is used to find the significance of the result. The spatial pattern and temporal trends of the result are done after the result are significant at the 0.05 significance level. The spatial coverage of the result is analyzed by the categorization into different regions as the eastern, central and western regions. For the calculation and analysis of the data MS- Excel and MATLAB software is used. For the detail analysis of the HW 8 followings parameters are analyzed.

i. HW Event (HWN): It represent the annual total frequency of the HW event occurred in the station. Its annual trends are analyzed. Unit Number/year
ii. Total HW Days (HWD): It represent the annual total days satisfying the HW conditions of the region. Its annual trends are analyzed. Unit days/year
iii. Longest HW Event (HWLD): It represent the longest event of the year satisfying the HW condition. Its annual trends are analyzed. Unit days/year
   Average HW Days (HWAD): It represent the average count of the days satisfying the HW condition. Its annual trends are analyzed. Unit days/year
   It is calculated as

   HWAD=HWD/HWN
iv. Maximum Temperature (HW Max): It represent the maximum temperature during the HW event. Its annual trends are analyzed. Unit (°C/year)
v. HW Onset (HW Onset): It shows the starting date of the HW event. Its unit is date of the year.
vi. HW Withdrawal (HW Withdrawal): It represent the last date of the HW event in a year. Its unit is date of the year.

CHAPTER 4: RESULTS AND DISCUSSIONS

Since HW are very much linked with the daily maximum temperature of a place or over a region during the pre-monsoon season, the analysis of maximum temperature has been made in different manners to find the patterns of HW.

4.1 Frequency of HW

It represents the total annual frequency of the HW. The general trends of the HW frequency are shown in the **Figure 4-1** and **Figure 4-2**. From these figures, decreasing trends of HW events are observed in the lower region of the country (terai) but slight increasing trends are observed in the higher region of the country (mountain). WT region shows the highest increasing rate (0.094events/year) of the HW frequency. However, the CM region shows the highest decreasing trend (-0.0617events/year) of the HW frequency. Baidhya et. al. 2009 and Shrestha et. al 1999 also found the similar results with the consideration of maximum and minimum temperature trends in terai and mountain region. CM and EM regions show almost of the zero HW events during 2001 to 2005 period [2], [25]. The scientific reason behind this finding should require rigorous synoptic scale analysis that could not be conduct during this study.

The overall analysis of the recent year shows the decreasing trends of HE frequency throughout the country except in the CM region. First decade of this century registers most of the HW events followed by the decade of 1991-2000 and by the 2011-2021 decade. The frequency of ElNino events during the early decade of the recent century (2000-2010) was found to be more frequent. The mild event of 2000-2002 and the severe events of 2005-2006. The following 2nd decades (2010-2020) the observed ElNino events is recorded to be severe by 2012-2016. Based on this observed fact, the corresponding HW events were highlighted in this study. In 2010, Dailekh and Surkhet stations of the WM register records the 5 events, the highest events of HW across the country. The western region (41.18%) records the highest of the total events followed by the central (37.84%) and eastern (20.96%) regions. The WM (26.15%) and WT (20.77%) holds the highest number of the events. The least (only 1) events is found in the EM region.

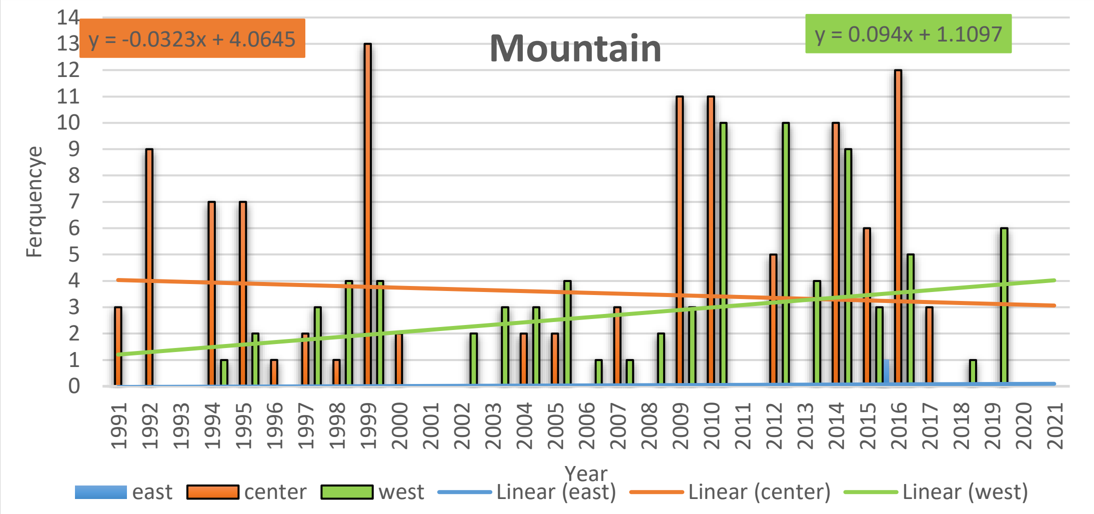


Figure 4-1: Temporal distribution of HW Events in Mountain Region

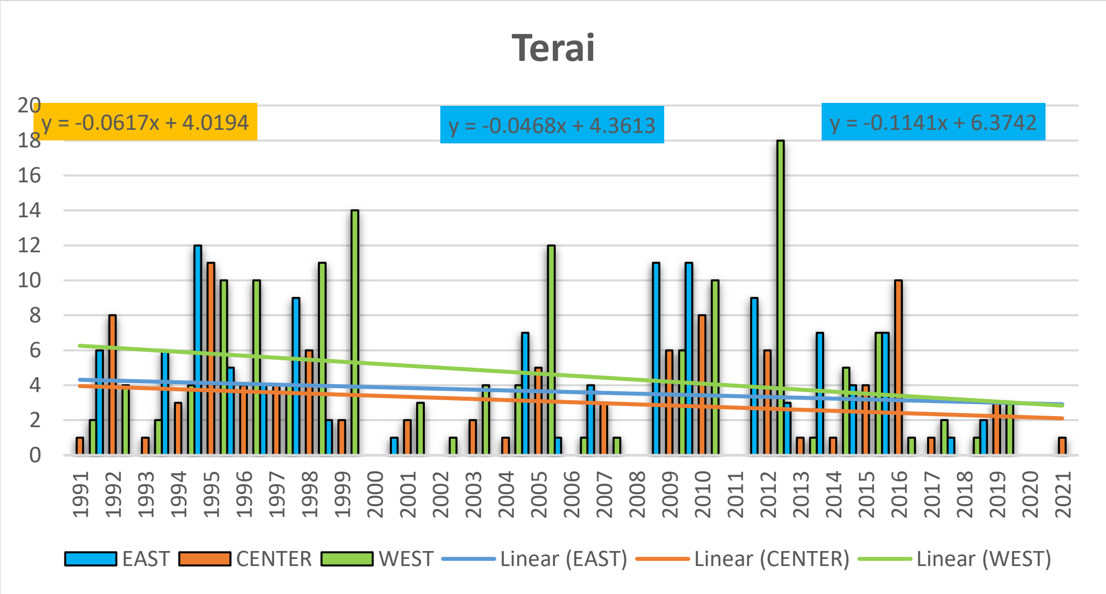


Figure 4-2: Temporal Distribution of HW Events in Terai Region

4.2 Total Heat Wave Days

It represents the annual total HW days of the regions. The trends of the total HW days are shown in figure 4-3. Most of the region shows the decreasing trends of the total HW days except the WM regions which shows the increasing trends (0.6302 days/yr). Highest decreasing trend (-0.1859 days/year) is found in the CT region. Only the WT region has the increasing trend (0.6302 days/year) of the HW days. Isolated peaks of total HW days are found in the CM and EM regions.

The western region registered the highest number of the HW days (64.58%) followed by the central (29.32%) and the eastern region (6.09%). The WT holds the highest value of THWD (37.62%) among the 6 regions. The Silgadhi station of WM had recorded highest values of THWD during 2012 (56) and 2013 (31). The highest of yearly heat wave day is found higher in the western region which coincides with the result of the Sigdel et. al 2010 and Chapagain et. al 2021[.

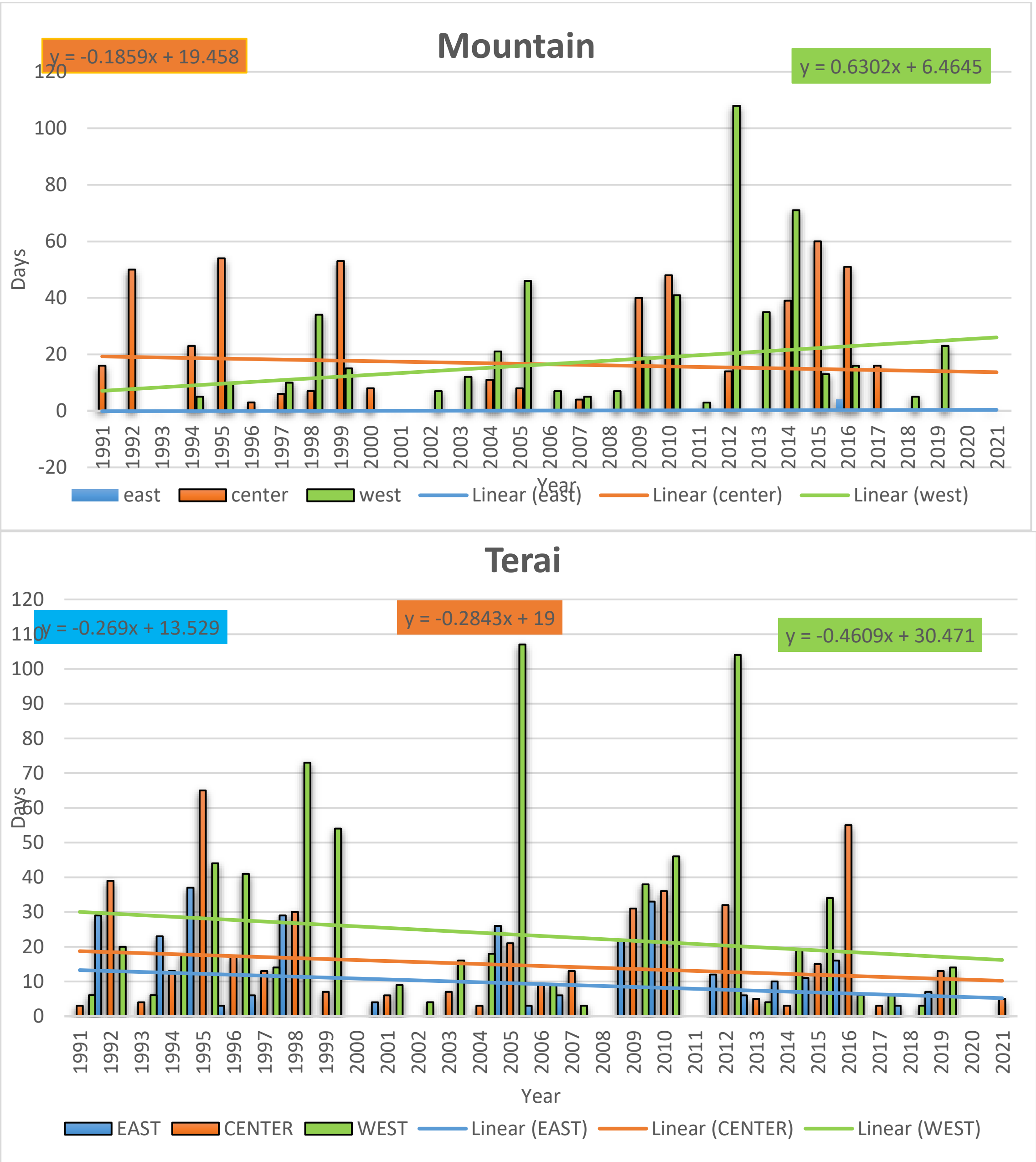
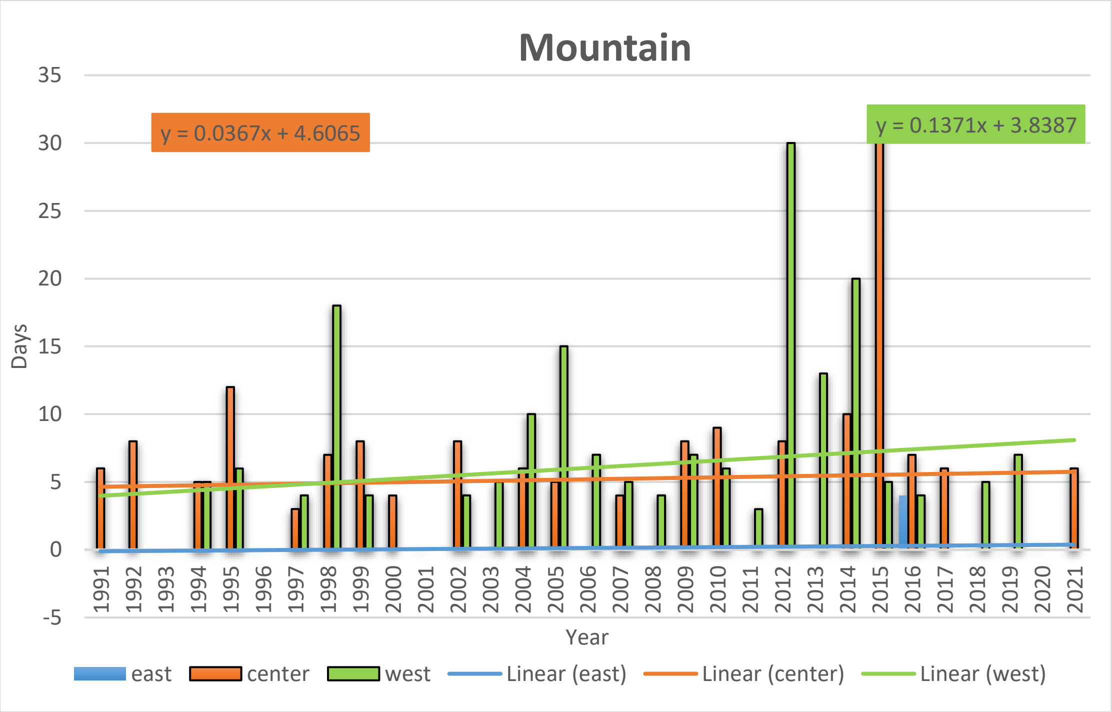


Figure 4-3: Temporal Distribution of Total HW Days in Mountain and Terai Region

4.3 Longest Heat Wave Event

The annual trends of longest HW event among the HW events of the year is shown in figure 4-4. From figure in an average the terai regions show the longest HW events throughout the study periods mainly the western and central region. Both the terai and CM region along with the WT region shows continuous longer waves of the HW in the recent years. Except the WT regions rest all the other station shows the decreasing trend of the longest HW event.

The CM (31) and WM (30) regions holds the longest events of the HW. The longer events are found in the mountainous regions than the terai regions which resembles with the Shrestha et. al 1999 [2] and the DHM report 2017 [20]. The table showing the top 9 longest HW events is shown below. From the table it is seen that the WM regions has longest HW events, especially in the Silgadhi station. Among the most longest HW the Silgadhi station holds the most of the longest HW events.



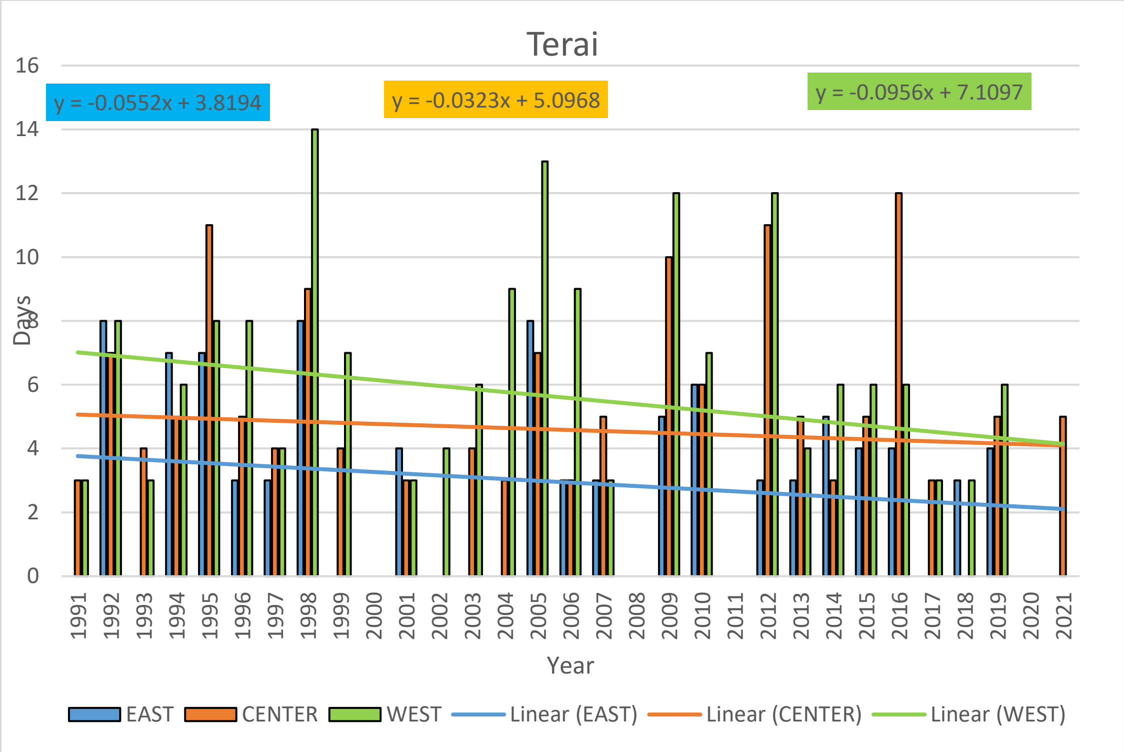


Figure 4-4: Temporal Distribution of Longest HW Event in Mountain and Terai Regions

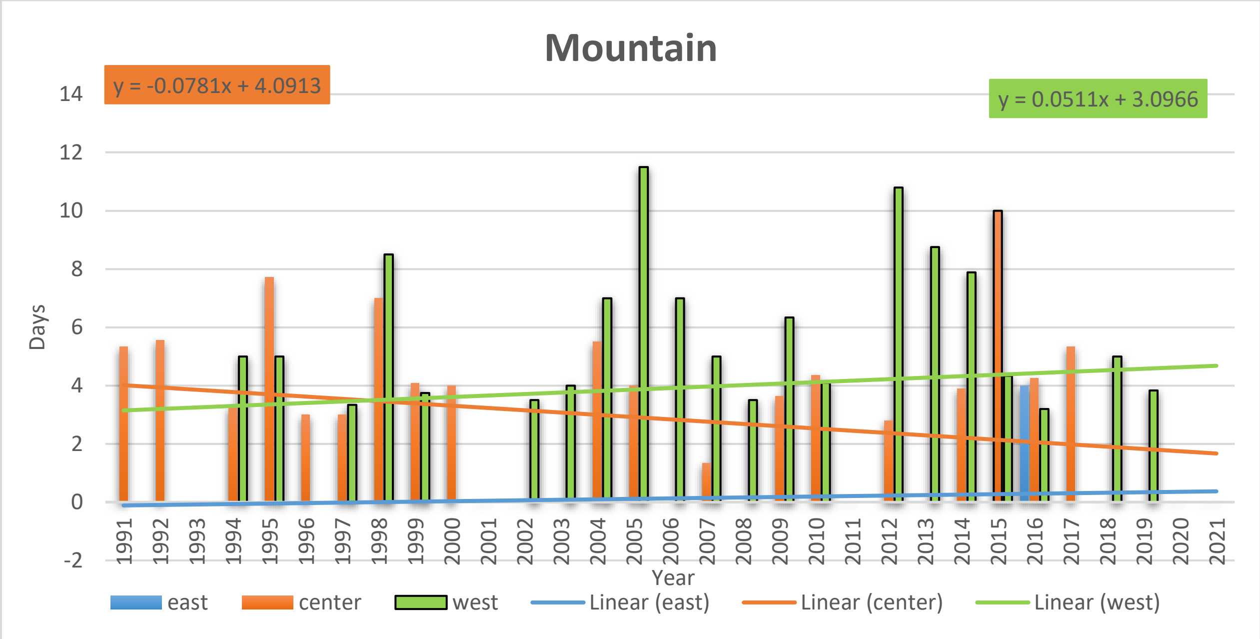
Table 4-1: Stations with Longest HW Days

S.NO	STATION	YEAR	DAYS	START DATE	END DATE
1	KHUDI BAZAR	2015	31	12-Apr	12-May
2	SILGADHI	2012	30	3-Jun	2-Jul
3	SILGADHI	2014	20	12-May	31-May
4	SILGADHI	1998	18	27-May	13-Jun
5	DAILEKH	2005	15	7-Jun	21-Jun
6	DIPAYAL	1998	14	28-May	10-Jun
7	DHANGADHI	2005	13	9-Jun	21-Jun
8	NEPALGUNJ	2005	13	9-Jun	21-Jun
9	SILGADHI	2013	13	30-Apr	12-May

4.4 Average Heat Wave Days

The annual trends of the average HW days are shown in the figure 4-5. All the regions show the decreasing trends of the average HW days except the high western region. Sharp decreasing rate is seen in the ET and CT regions. The average HW days of the WM region is much greater than the other regions of the country. Between 2005 to 2017 periods all the regions record their high values of the HW days.

The western regions exceed the other regions average days of the HWs and has the highest number of the average days. The average days of HW for the country is 2.6 days. The mountain region reports the isolated high average days of HW but the terai region shows continuous high value of the average HW days.



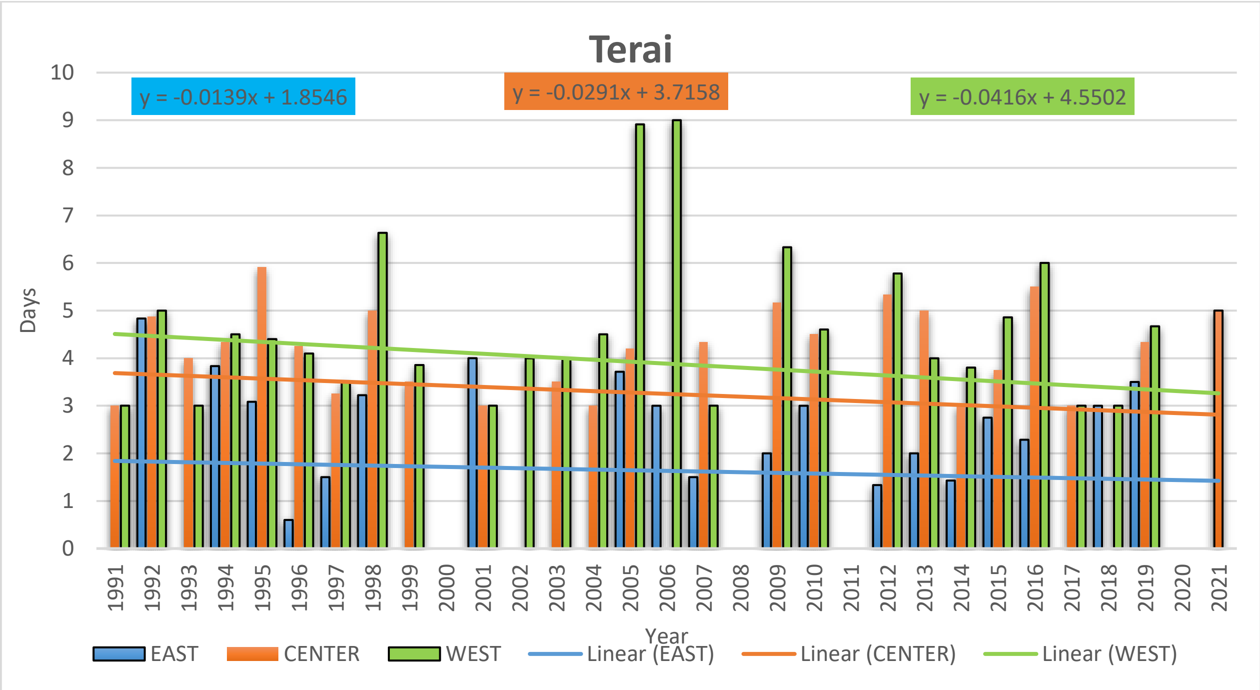
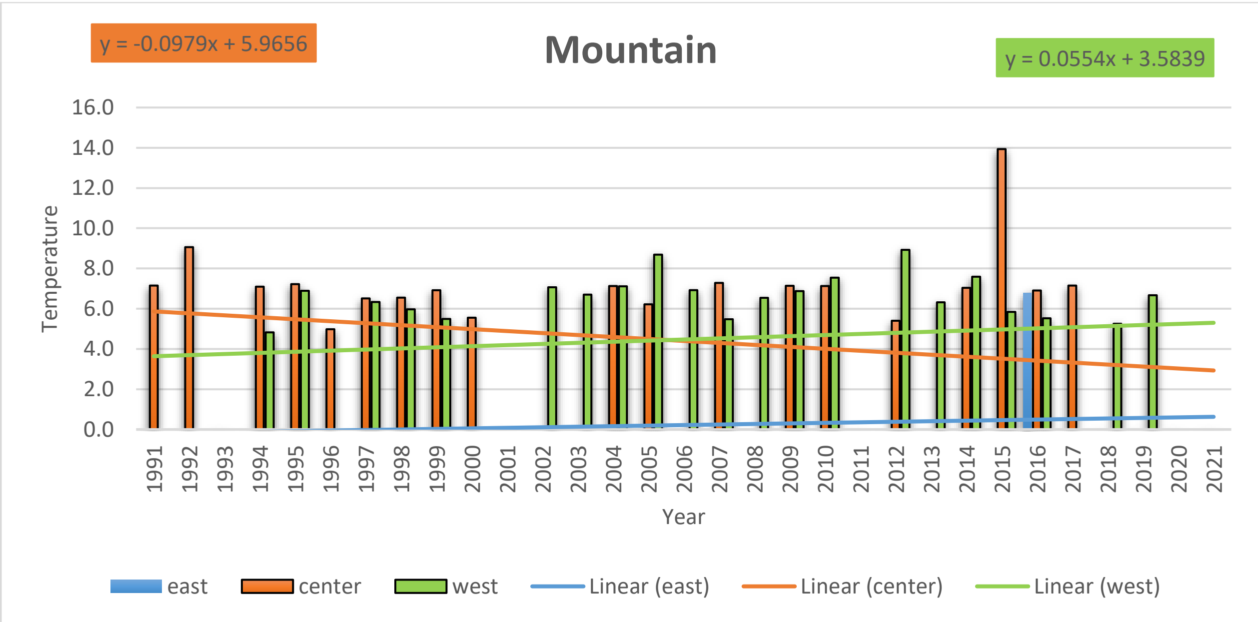


Figure 4-5: Temporal Distribution of Average HW Days in Mountain and Terai Regions

4.5 Maximum Temperature

The annual trends of maximum temperature is shown in the below figure4-6. The highest variation of the maximum temperature during the HW is found in the central mountain regions. The WM region shows the continuous high maximum temperature after the 2000s. In the terai region the ET shows the increasing trend than the other regions. After the 2010, all the regions of terai shows highest temperature during the HW days.The western region shows the highest decreasing trends of the maximum temperature during the HW period. Also the terai regions shows the more decreasing trends than the terai regions. Country wise highest temperature is found during the 2012 -2016 periods.

The western regions exceed the normal temperature by 6-8°C during the 2012-2016 time period. The highest deviation of 13.93°C is found in the terai regions in the 2015A.D.Usually the terai regions shows more high deviations in its temperature than the mountain region.



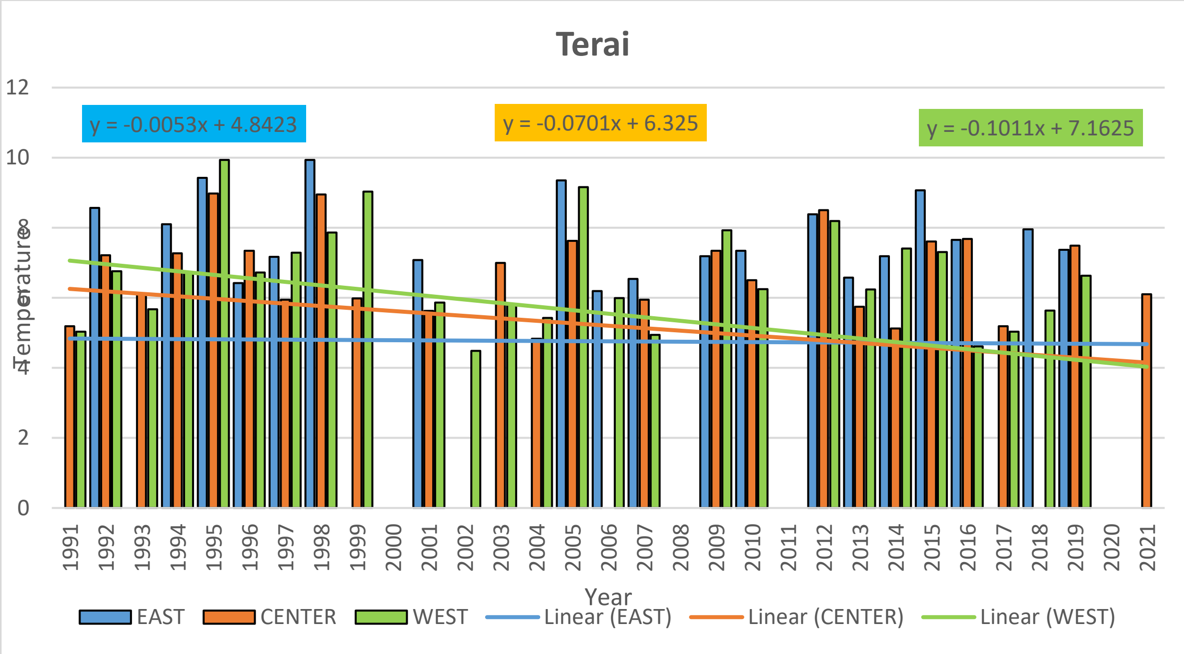
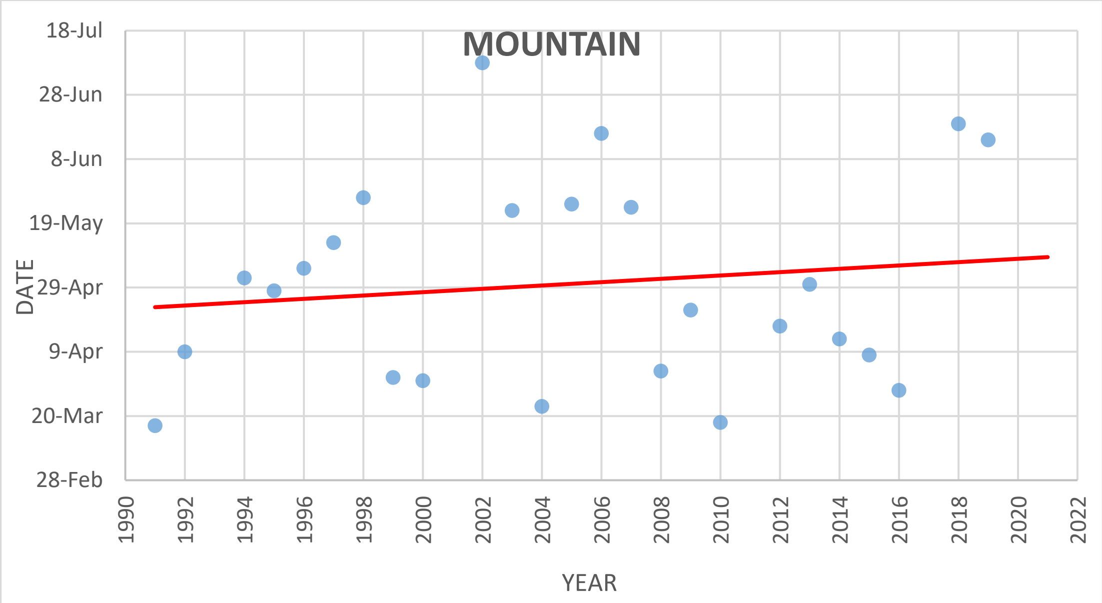


Figure 4-6: Temporal Distribution of Maximum Temperature in Terai and Mountain Region

4.6 Onset Dates

The scatter plot of the onset date of HW is shown in figure 4-7. The onset date of the HW marks the starting date of the event. From the scatter plots of the onset dates of the HW, it is seen that the terai regions shows more increasing trends of the onset dates of the HW which indicates the delay start of the HW events. HW occurs more lately after the 2000s throughout the country. The monthly distribution of the onset date of HW is shown in figure 4-8. Mostly the HW events occur during the month of April and May month. In the terai region all the month shows the large values of the HW throughout the months. The beginning of the HW is directly coupled with the movement of the sun in the Northern Hemisphere. In the mountain regions it starts in the March month. The May month, hold the records of highest onset of the HWs (86.5%), just before the monsoon activities.



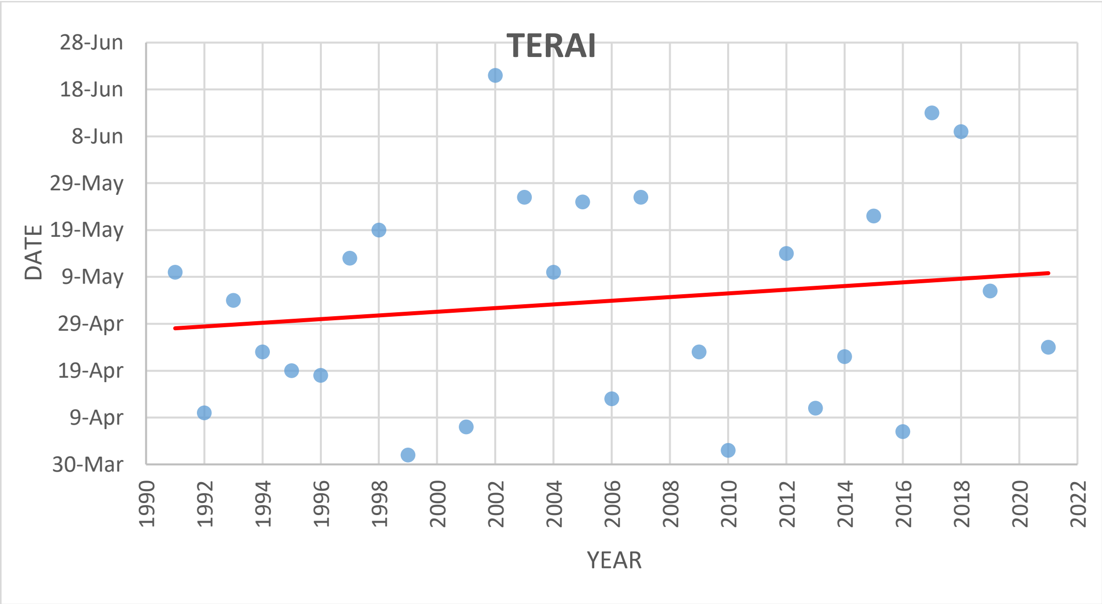


Figure 4-7: Scatter Plots of the Onset Dates of HW in Mountain and Terai Regio

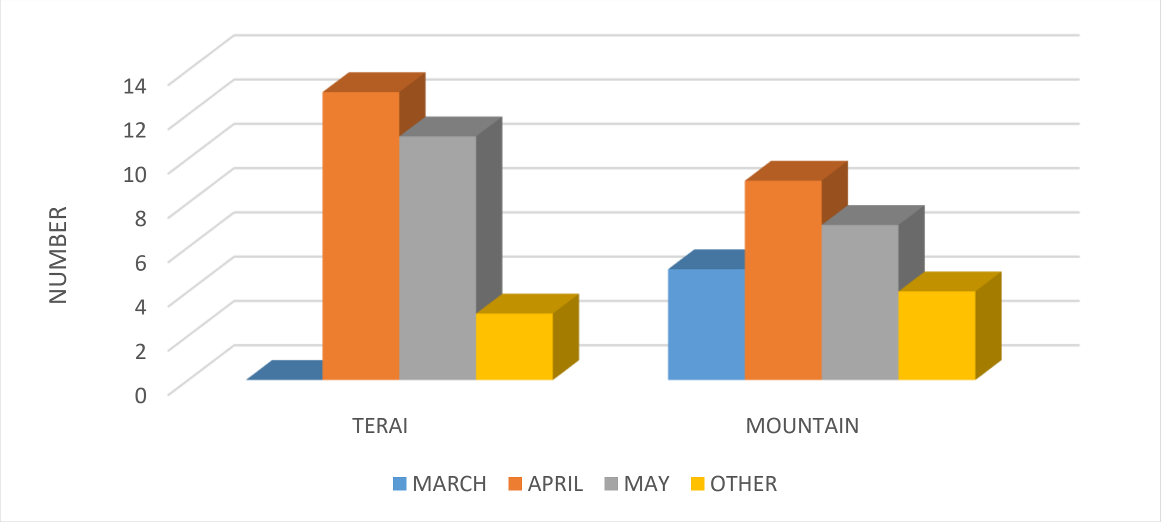
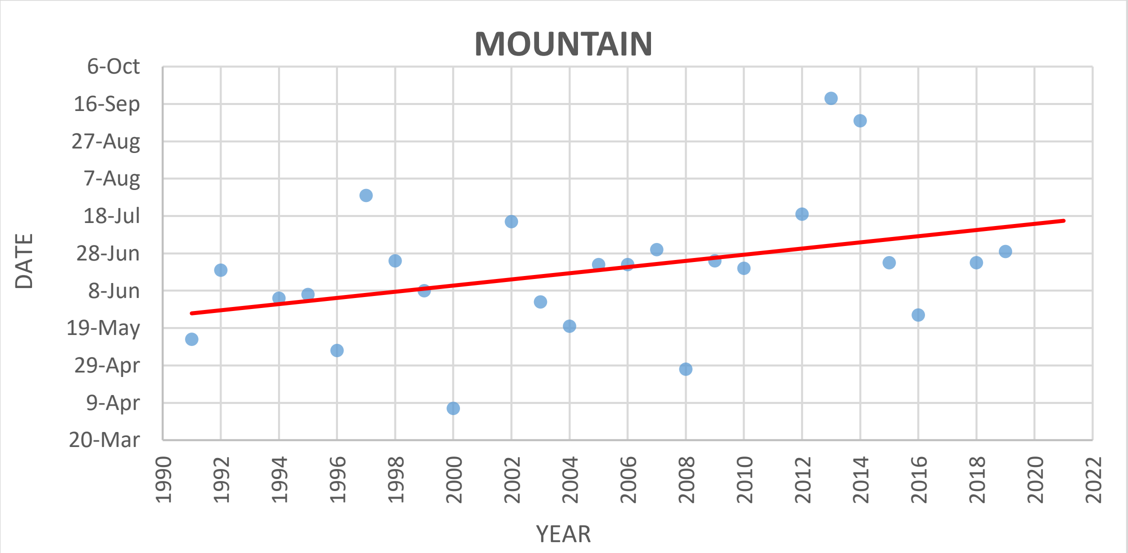


Figure 4-8: Monthly Distribution of the Onset Date of HW

4.7 Withdrawal Dates

The scatter plot of withdrawal dates of the HW is shown in figure4-9. The withdrawal date shows the end dates of the event of the year. The scatter plot diagram of the mountain regions shows more late end of the HW than terai regions. But the terai regions shows early end of the HW events. The monthly distribution is shown in the figure4-10. Mostly the June mark the end of the HW event throughout the country as the June months marks the start of the monsoon season in the country. The late delay of HWs is seen in the mountain regions during the 2012 and 2013 year at the month of september. The end date of the HW is found to be linked with the withdrawal dates of the monsoon. Also, the WM region shows late delay than other regions.



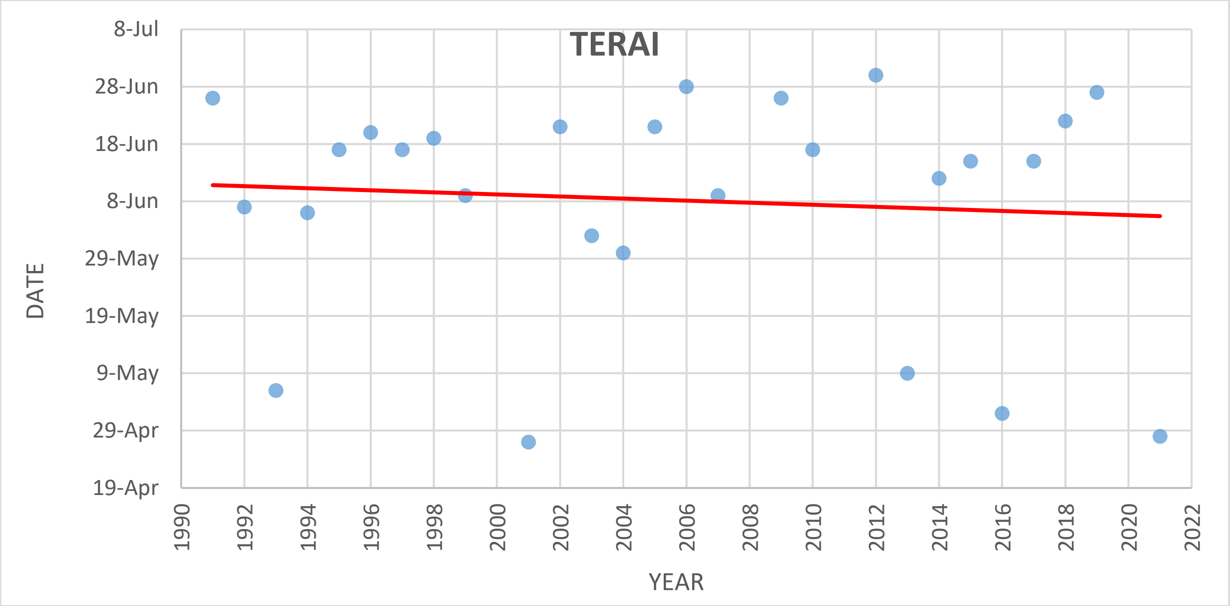


Figure 4-9: Scatter Plots of Withdrawal Dates of HW

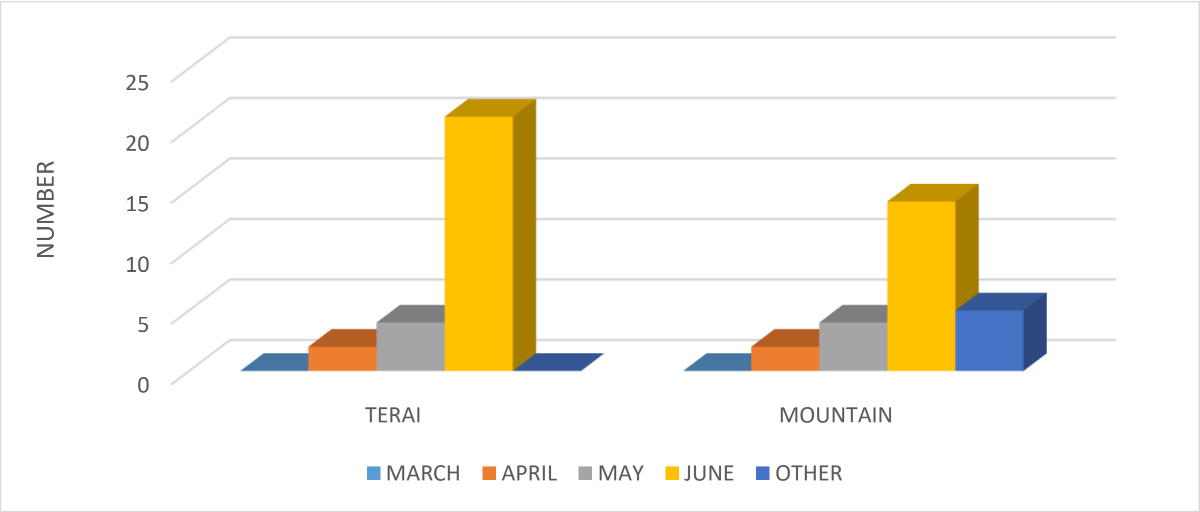


Figure 4-10: Monthly Distribution of the Withdrawal Date

4.8 Relationship with ElNino and LaNino

The relationship between ElNino and LaNino with the HW is shown in the figure4-11. The intra seasonal event ElNino and Lalino largely control the weather (mostly rainfall) pattern of the Nepal. The ElNina and the LaNino events usually control the monsoon pattern of the Indian sub continents. The relationship of the HW events with the ElNino and LaNino with the HW event of terai and mountain is shown belowfigure 4-12& 4-

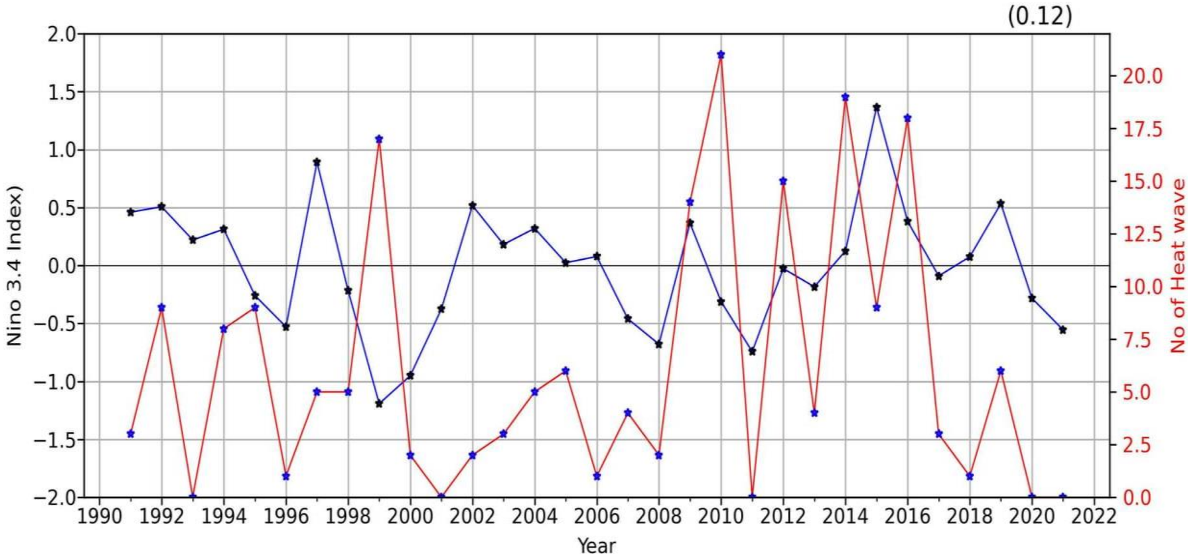


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Figure 4-11: Relationship of HW with the Nino 3.4 Index

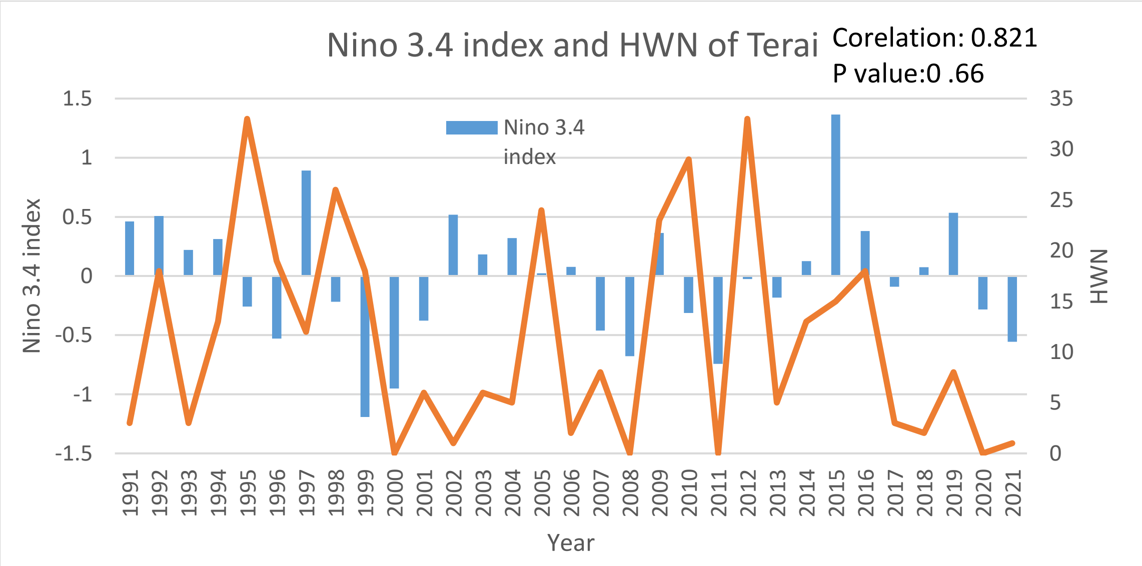

Figure 4-12: Relation between Nino 3.4 Index and HW events of Terai Region

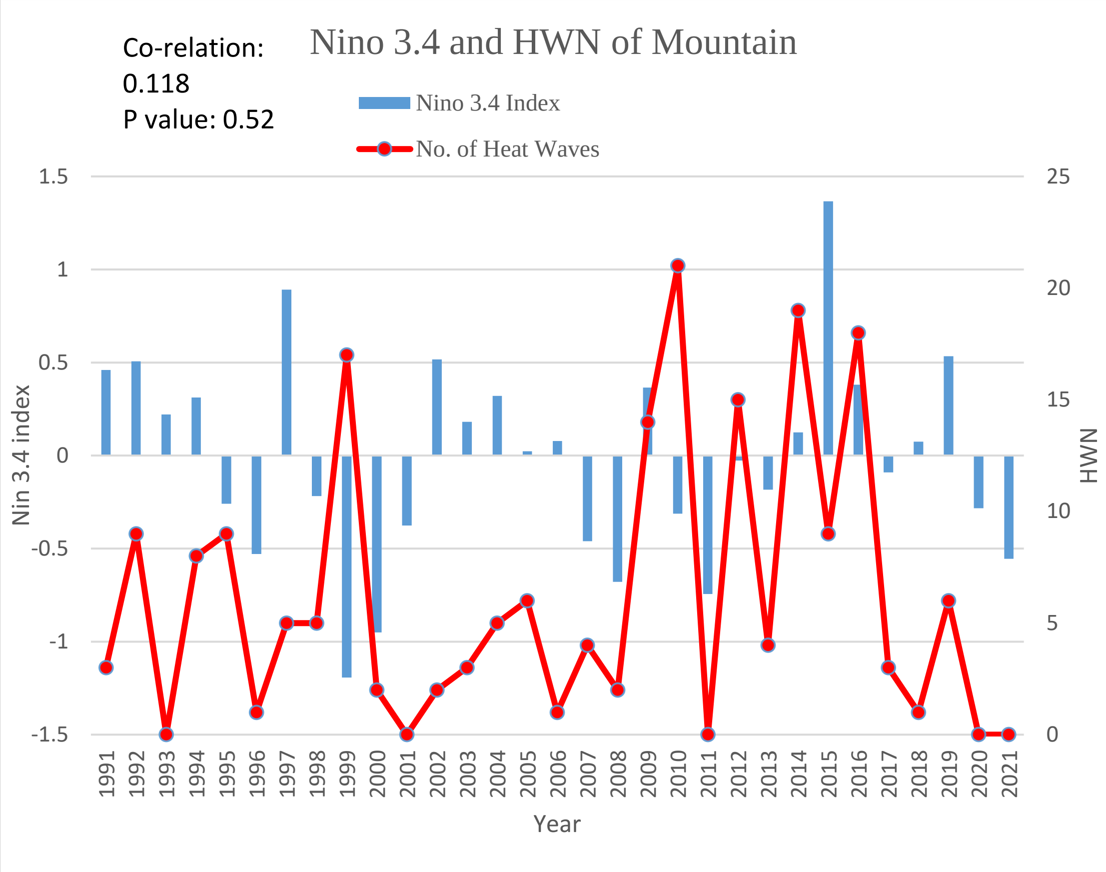

Figure 4-13: Relationship Between Nino 3.4 Index and HW Events of Mountain

As shown in the figure, the heatwave events of the number of HW of the nation has directly linked with the 2015-2017 ENino event. But as a whole it is significantly less significant throughout the study periods. Also the HW events of the are fund to be related with the ElNino+1 year.The obtained correlation value of 0.821 and the P value of 0.66 is for the Terai region but the values for the mountain regions are 0.118 and 0.52 respectively.Thus, the mountain region is more linked with the ElNino than the terai region.

4.9 Statistical Analysis

The highest mean and standard deviation of the total heat wave days is seen. It is also found that the mean deviation of the temperature is 6-7°C. Also, the average HW days is 2.6 days which is below the criteria of HW. The closeness of the standard deviation with the mean value reveals that if the HW events occur its mean value will be prevailed.

Table 4-2: Summary of HW indices

HW Indices	Mean	Standard Deviation	Maximum
HWN	17.3871	15.19906	50
THWD	61.29032	61.49335	258
AHWD	2.60843	1.422125	5.388492
MHW	7.315221	2.453663	13.93448
LHW	9.387097	7.115079	31

CHAPTER 5: CONCLUSIONS AND RECCOMMENDATIONS

This study proposed a definition of the HW events for Nepal. The use of percentile based statistical definition for defining HW is simple to use and calculate which uses the 90th percentile for 3 consecutive days. This method of calculating the HW can be used as a national threshold will be very useful for the prediction of the HW in the country.

Almost all HW occur during the hot pre-monsoon period (around 86%) and rest in the monsoon period. Such concentration of the HW during the pre- monsoon period are supported by the high-pressure area developed around the Indian continent. This study also supports the results of the previous studies which focused on that the more intense high temperature in the western part of the country. Also, the mountain region shows more intense and high increasing trends of the number of HW. It is worth noting that the peak Nino 3.4 index nearly coincidence with the corresponding peak of the HW events in Nepal.

This study will assist the policy maker for the accurate prediction of the events. Thus, it will also help to reduce the impact of the HW and its severity.

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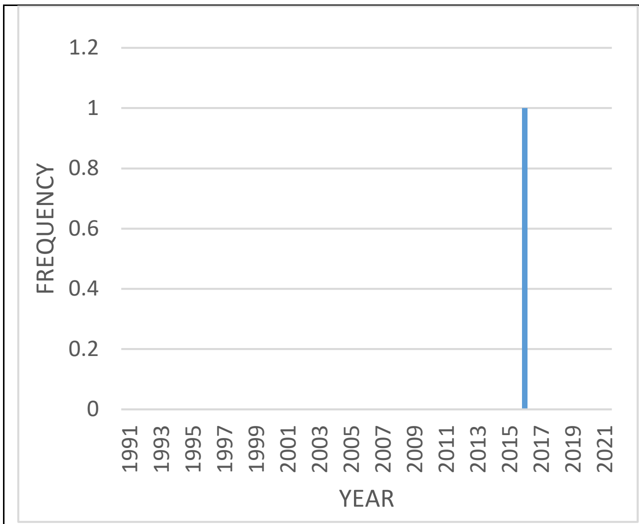
CHAPTER 6: APPENDIX

6.1 HW Events



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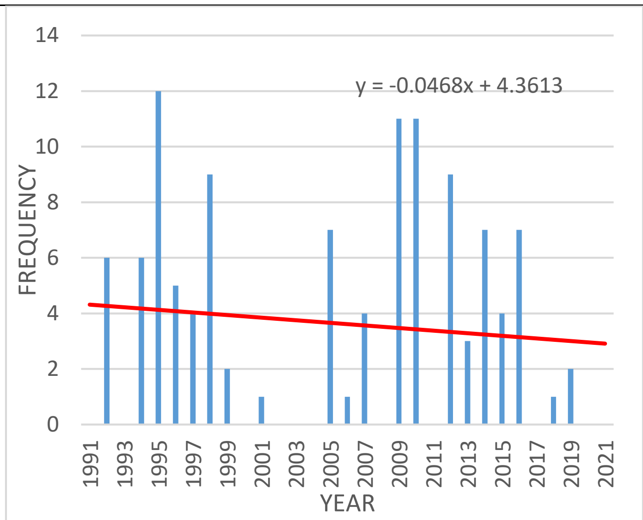

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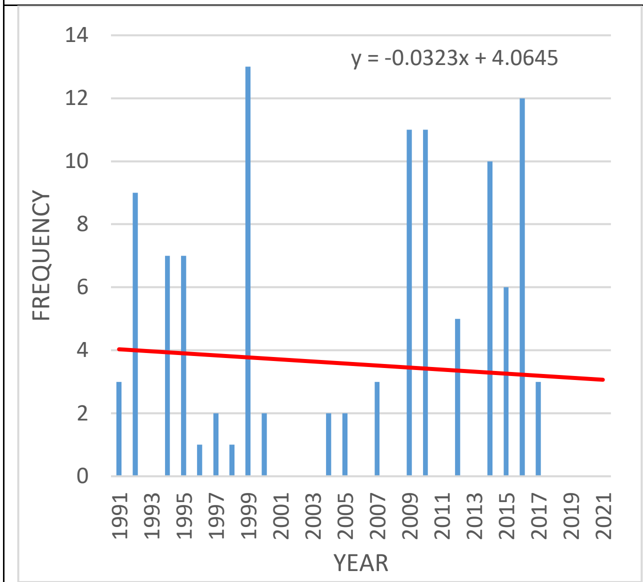

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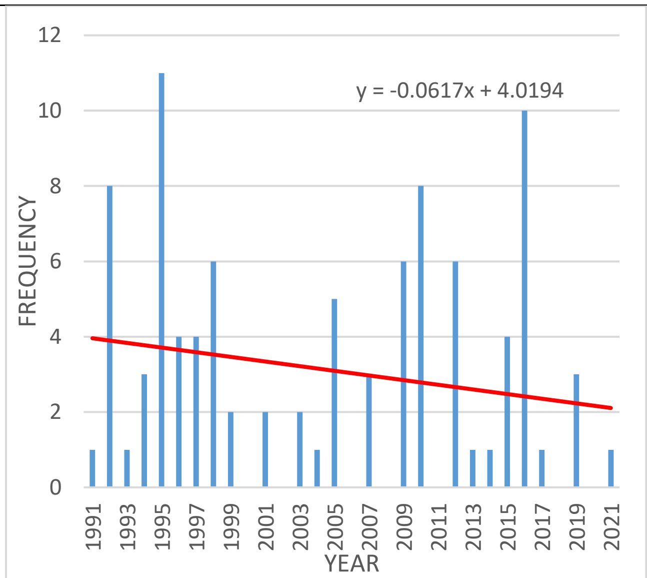

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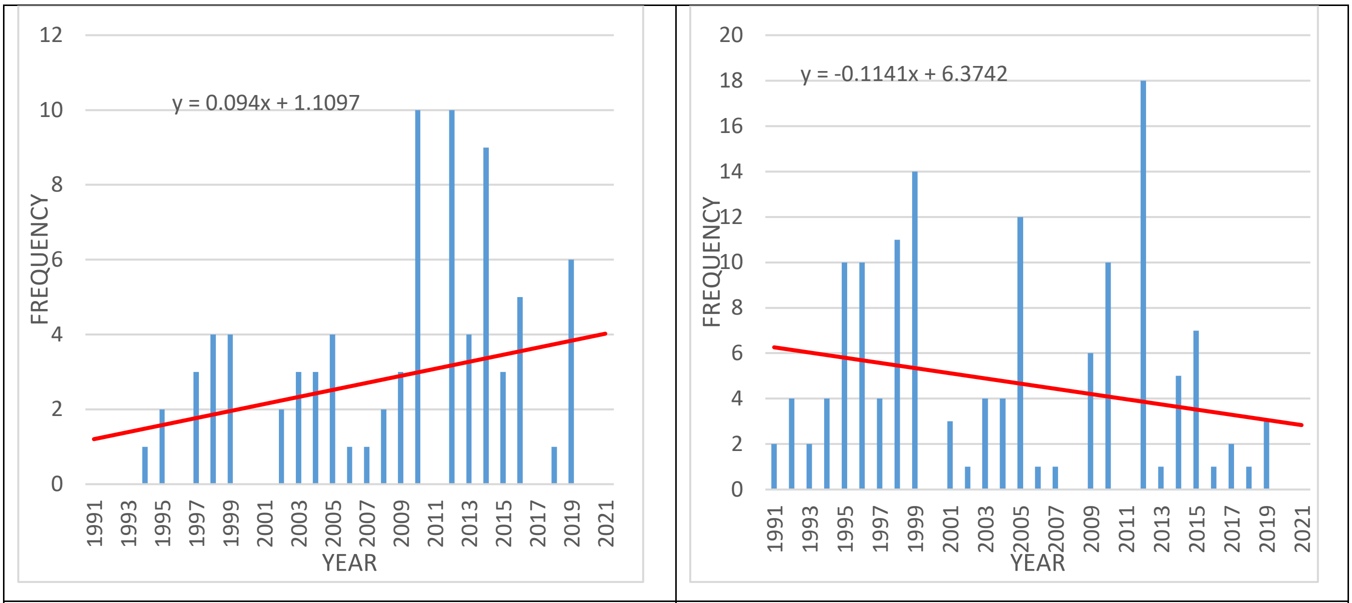
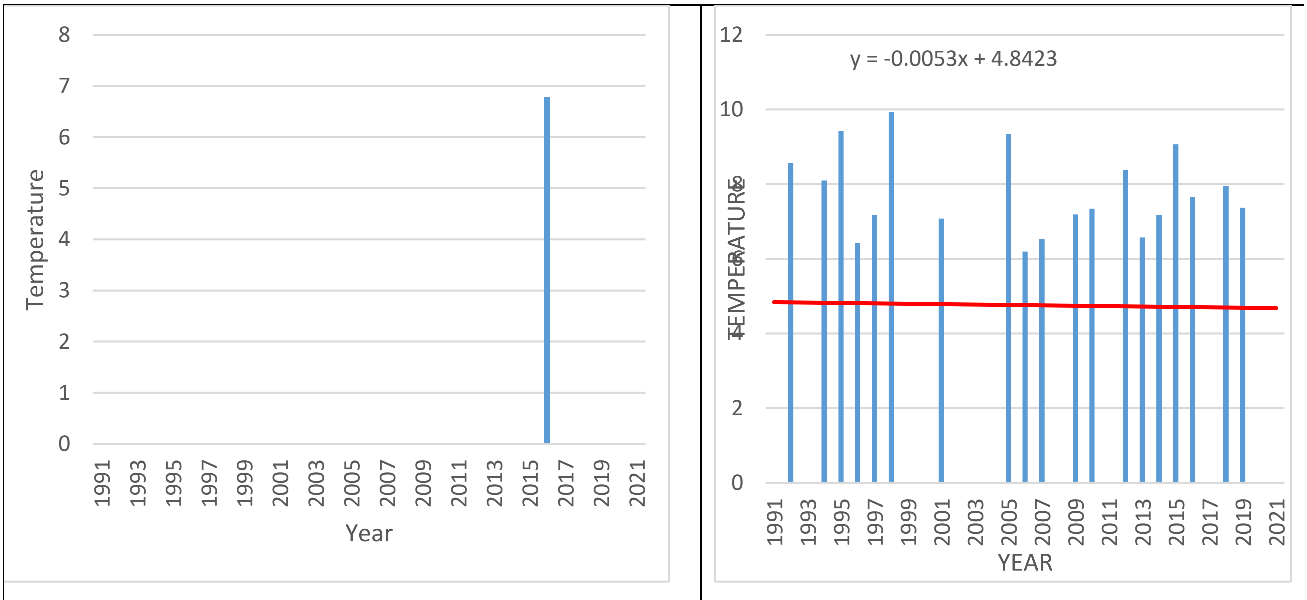


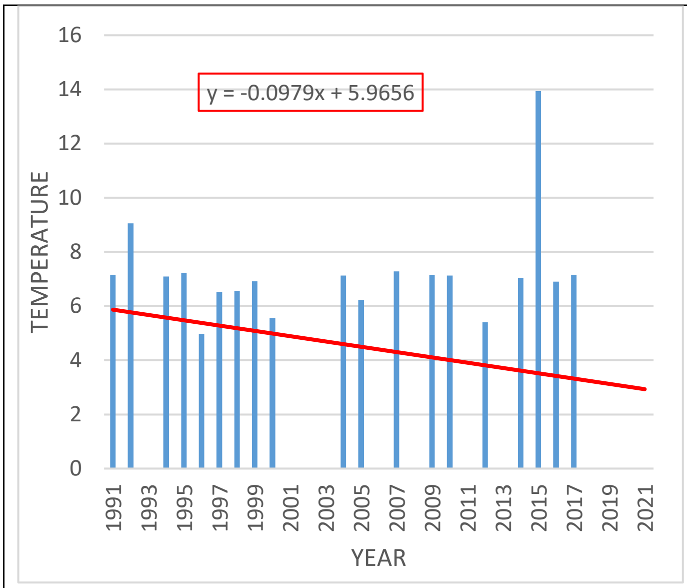
(e)	(f)

Figure 6-1: Total HW Events in eastern mountain(a), eastern terai(b), central mountain(c), central terai(d), western mountain(e) and western terai(f)

6.2 Maximum Temperature



(a)	(b)



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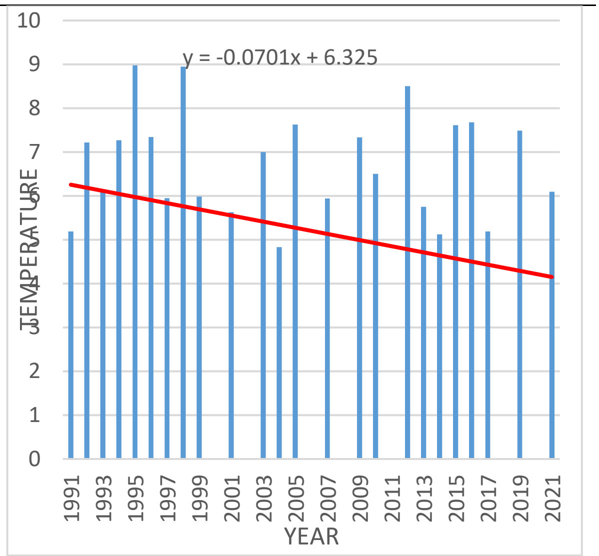

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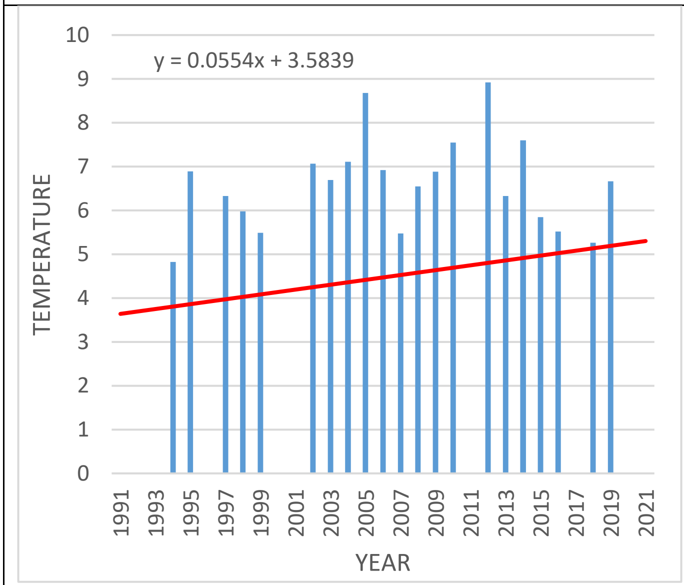

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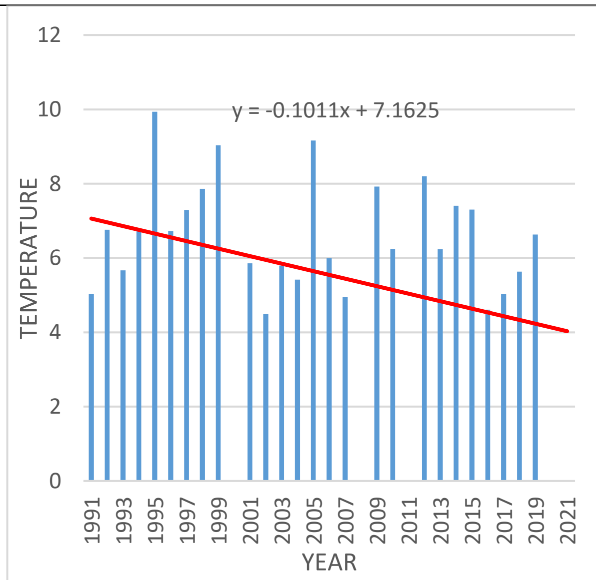
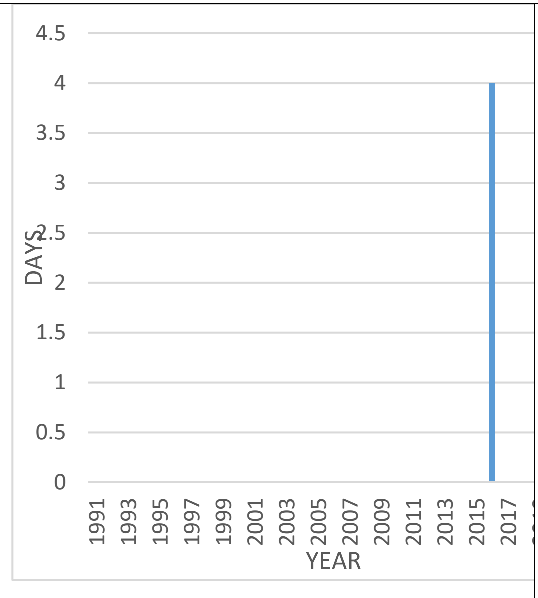


(f)

Figure 6-2: Trends of Maximum Temperature in eastern mountain(a), eastern terai(b), central mountain (c), central terai(d), western mountain(e), western terai(f) regions.

6.3 Total HW Days



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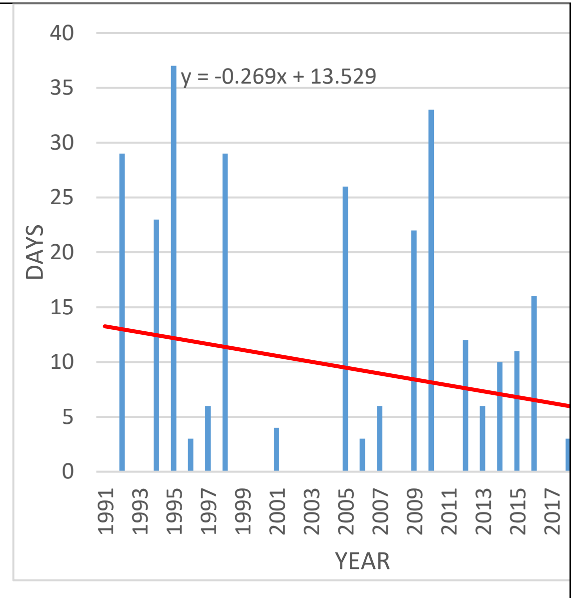

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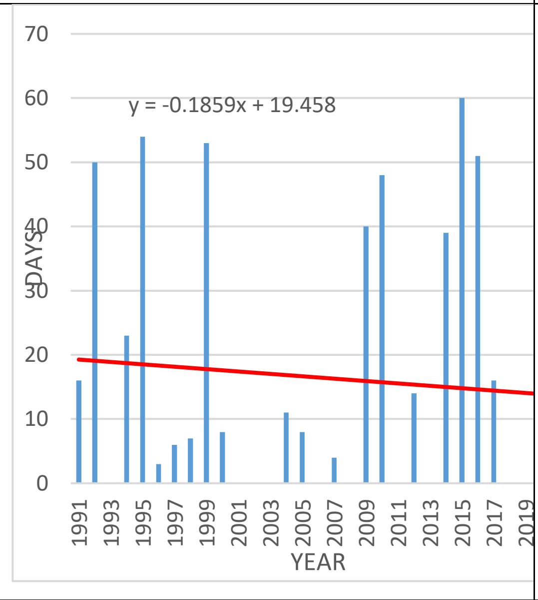

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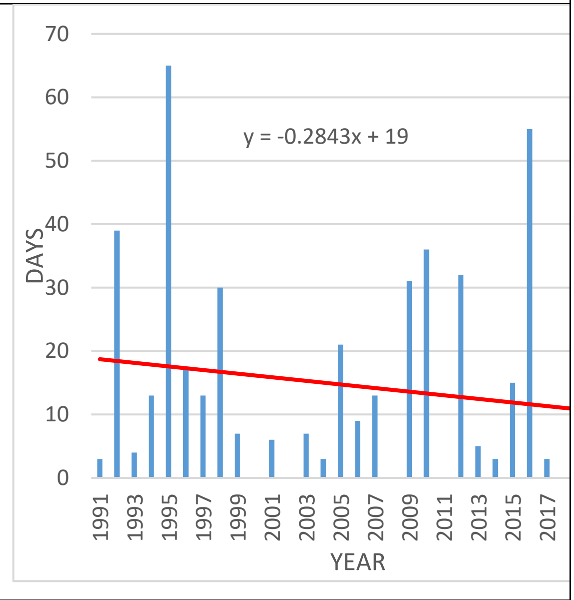

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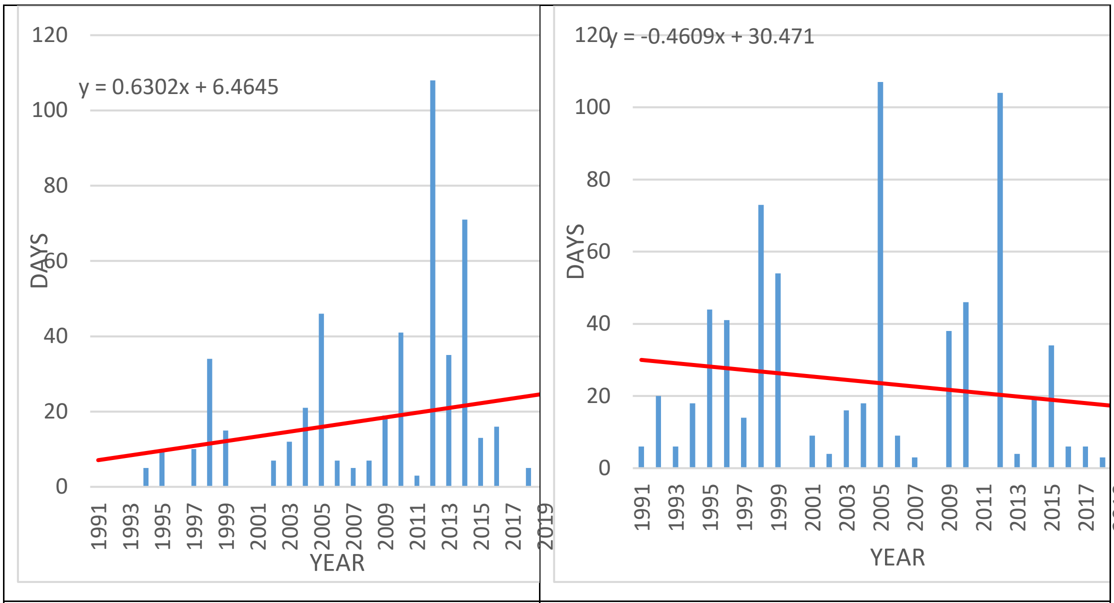
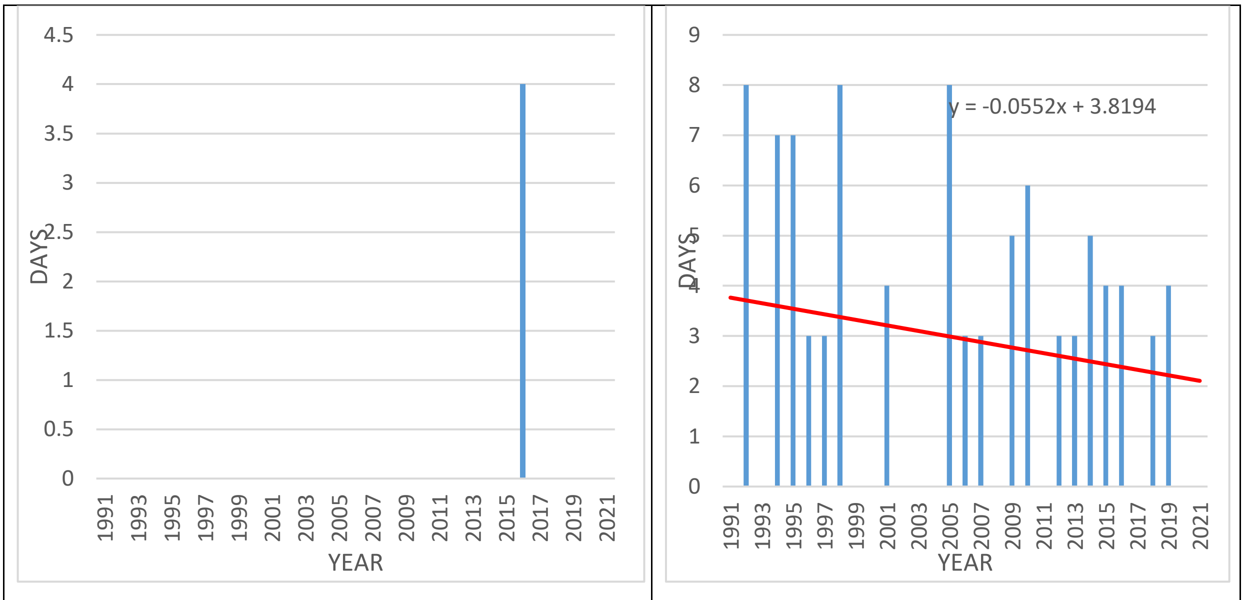


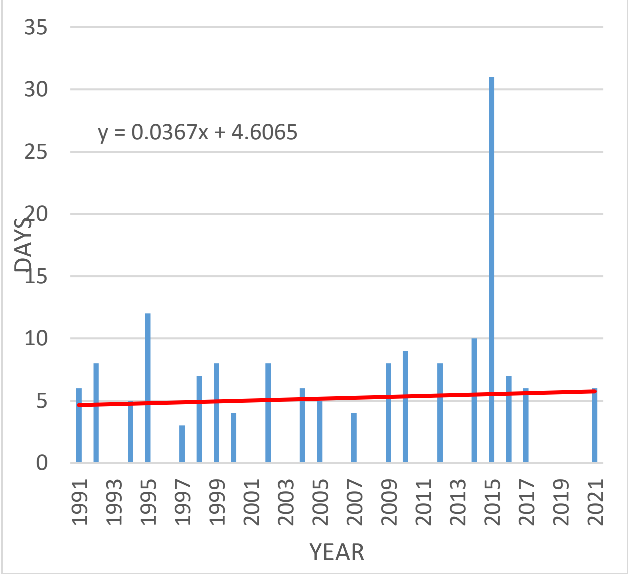
(e)	(f)

Figure 6-3: Distribution of Total HW Days in eastern mountain(a), eastern terai(b),central mountain(c), central terai(d),western mountain(e),western terai(f)

6.4 Longest HW Days



(a)	(b)



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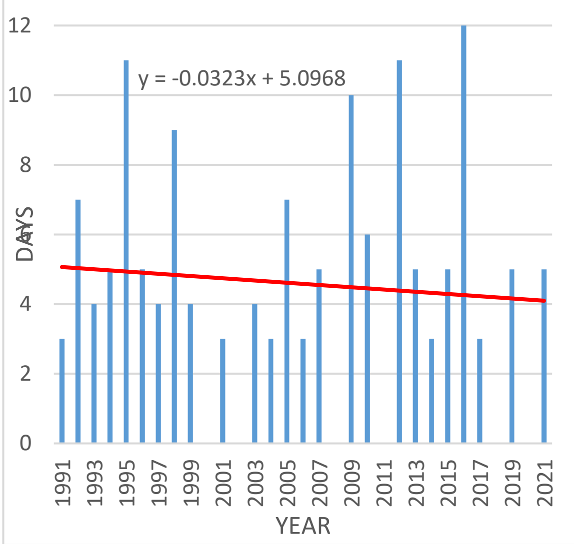

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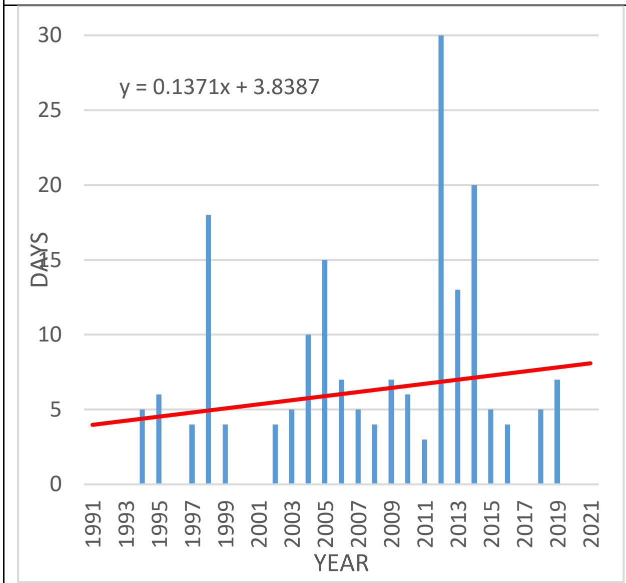

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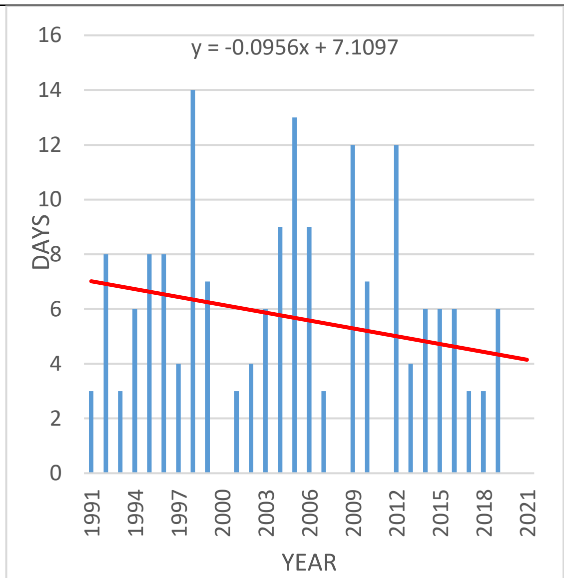
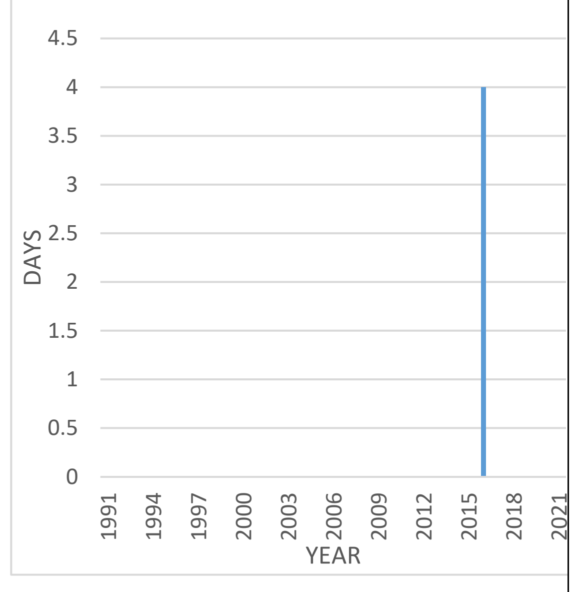


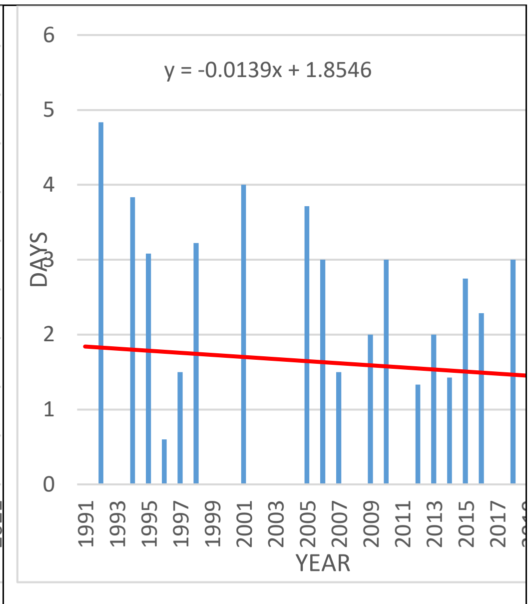
(f)

Figure 6-4: Distribution of Longest HW Events in eastern mountain(a), eastern terai(b),central mountain(c), central terai(d), western mountain(e)and western terai(f)

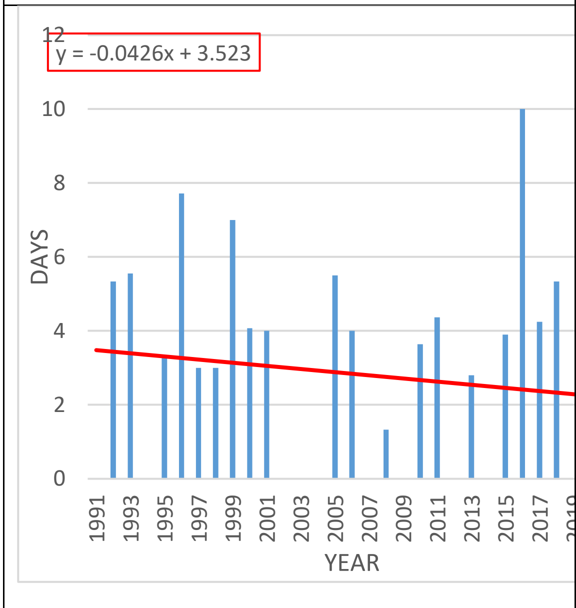
6.5 Average HW Days



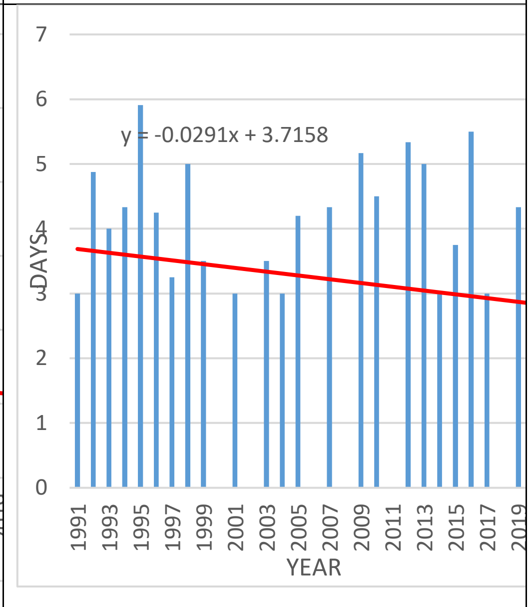
(a)



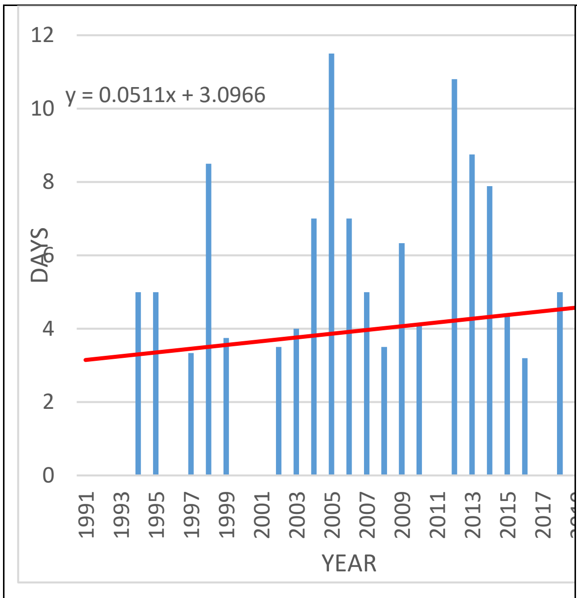
(b)



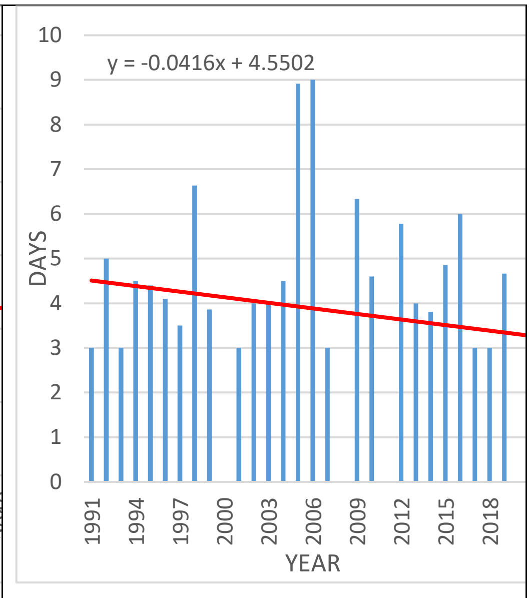
(c)



(d)



(e)



(f)

Figure 6-5:Temporal trends of Average HW Days in eastern mountain(a)eastern terai(b),central mountain(c), central terai(d), western mountain(e)and western terai(f)