STaTE OF THE CLImaTE 2021

NaTIONaL CENTRE FOR HYDROLOGY aND METEOROLOGY
ROYaL GOvERNmENT OF BHUTaN

PUBLISHED BY:
National Centre for Hydrology and Meteorology (NCHM)
Royal Government of Bhutan
PO Box: 207
Thimphu: Bhutan

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FOREWORD

The National Centre for Hydrology and Meteorology (NCHM) is the national focal agency responsible for studying, developing and providing services on meteorology, hydrology and the cryosphere. The hydro meteorological services play a major role in climate change, disaster risk reduction and sustainable development. The core mandate of the Centre is to provide early warning information that helps the nation to protect lives and properties from the impacts of climate change and variability.

Changes in climate and its variation presents both risks and opportunities and it affects all aspects of the domain. With precarious mountainous terrain topography, Bhutan is exposed to several hazards including flash floods, GLOF (Glacial Lake Outburst Flood), landslides, cyclone induced storms and erratic rainfall affecting the lives and livelihoods of the people. The planners and developers will require the information on various fields such as weather and climate, water resources and glaciers and glacial lakes for effective planning, management and making a sustainable approach to the changing climate patterns.

Therefore, NCHM strives to deepen the scientific understanding of weather and climate, hydrological and cryosphere services to improve public information about the impacts of a changing climate. NCHM will continue to provide a seamless suite of weather and climate services and facilitate efforts to identify and address the climate-related needs of planners and decision makers in various social and economic sectors.

(Karma Dupchu)
Director

1. Title	State of the Climate 2021
2. Volume no.	Volume I
3. Organisation Name and Address	National Centre for Hydrology and Meteorology Post Box: 207 Thimphu: Bhutan
4. Editorial Team	Mr. Karma Dupchu, Director, National Centre for Hydrology and Meteorology (NCHM) Mr. Karma Toeb, Chief, Cryosphere Services Division Mr. Singay Dorji, Chief, Weather and Climate Services Division Mr. Tayba Buddha Tamang, Chief, Hydrology and Water Resources Services Division
5. Preparation and Compilation	Mr. Phuntsho Tshering, Executive Geologist, Cryosphere Services Division Mr. Chimi Namgyel, Sr. Statistical Officer, Hydrology and Water Resources Services Division Ms. Phuntsho Wangmo, Asst. Environment Officer, Weather and Climate Services Division

Contents

SECTION A: CLIMATE

1. OVERVIEW

1.1 Global Scenario: WMO State of the Global Climate 2021

As per the World Meteorological Organization (WMO) State of Global Climate 2021, the global mean temperature for the year 2021 was 1.11± 0.13°C above the 1850–1900 baseline, used as an approximation of pre-industrial levels. The WMO assessment is based on six global temperature datasets as shown in figure below (Figure 1) and all of those datasets currently place the year 2021 between the 5th and 7th warmest years on record. The year 2021 is cooler than recent years due to the La Niña conditions at the beginning and end of the year.

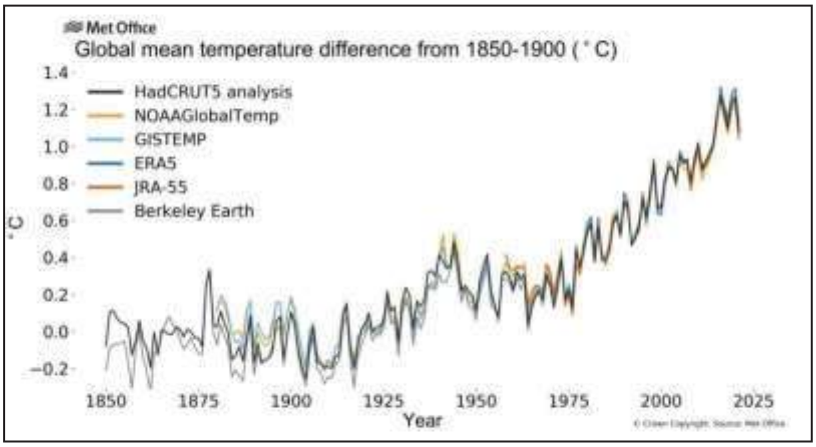


Figure 1: Global annual mean temperature difference from pre-industrial conditions 1850–1900 baseline for the six global temperature datasets. Source: UK Met Office Hadley Centre

As per the International Panel on Climate Change, sixth Assessment report for Summary for policymakers, the long-term assessments of changes in global mean temperature were assessed using a 20-year average. For the period 2001-2020 the average was estimated to be 0.99 [0.84-1.10] °C higher than the 1850-1900 industrial period. For the 20-year period for 2002-2021, the average of the six data sets was 1.01 ± 0.12 °C above the 1850-1900 average value. The overall warmth of variations in temperature anomalies across the globe is showed in Figure 2.

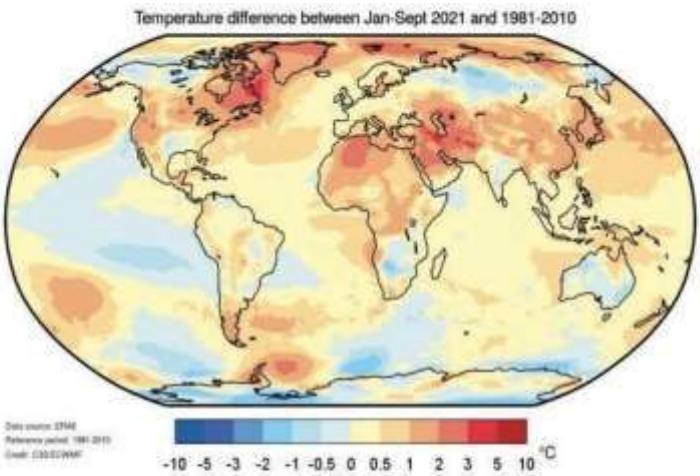


Figure 2: Near surface air temperature differences relative to the 1981-2010 long-term average from the ERA5 reanalysis for January to September 2021.

Source: European Centre for Medium-range Weather Forecasts (ECMWF), Copernicus Climate Change Service.

2. CLIMATE HIGHLIGHTS - 2021

2.1 Location of the Class A meteorological stations

The computation under this section is based on 20 Agrometeorological (Class A) stations located at each Dzongkhag or district.

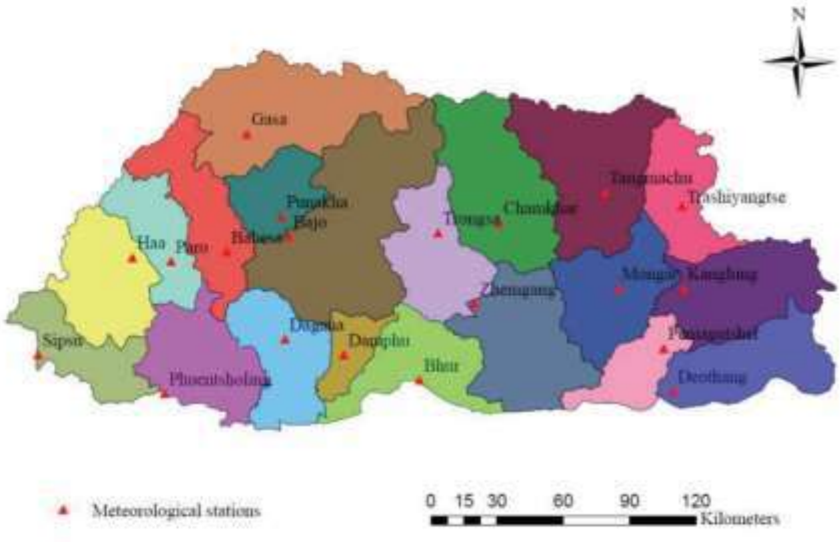


Figure 3: Location of Class A meteorological stations

2.2 Annual rainfall

The annual average rainfall (area average) was 1685.20 mm in 2021. The country as a whole received near normal to slightly below normal rainfall against the long-term average. The highest 24-hour rainfall was recorded at Sipsu with 283.8 mm. Gasa experienced the highest number of rainy days with 233 days (rainy days is defined as rainfall greater than or equal to 1 mm). It is to be noted that a greater number of rainy days does not translate to more accumulated rain. However, the highest total annual rainfall was recorded at Sipsu with 5991.30 mm followed by Bhur with 5024.8 mm.

2.3 Maximum and Minimum Temperature

The annual average maximum temperature was 22.54 ^{o}C and minimum temperature was 12.30^{o}C. The highest daily maximum temperature was recorded at Phuentsholing and Punakha met station with 37.0^{o}C and the lowest daily minimum temperature was recorded at Haa met station with -12.5^{o}C. Haa experienced a greater number of days with the minimum temperature below or equal to zero with 120 days (minimum temperature <=0).

2.4 Monsoon Monitoring

Bhutan experiences the summer monsoon from June to September. Bhutan receives most of its annual rainfall during summer monsoon so it is one of the predominant seasons of the year that influences much of the climate in Bhutan.

2.4.1 Rainfall

During the summer of 2021, the country as a whole received near normal to slightly below normal rainfall. However during the months of July, August and September, most of the stations received slightly below normal rainfall against the long-term average 1996-2020.

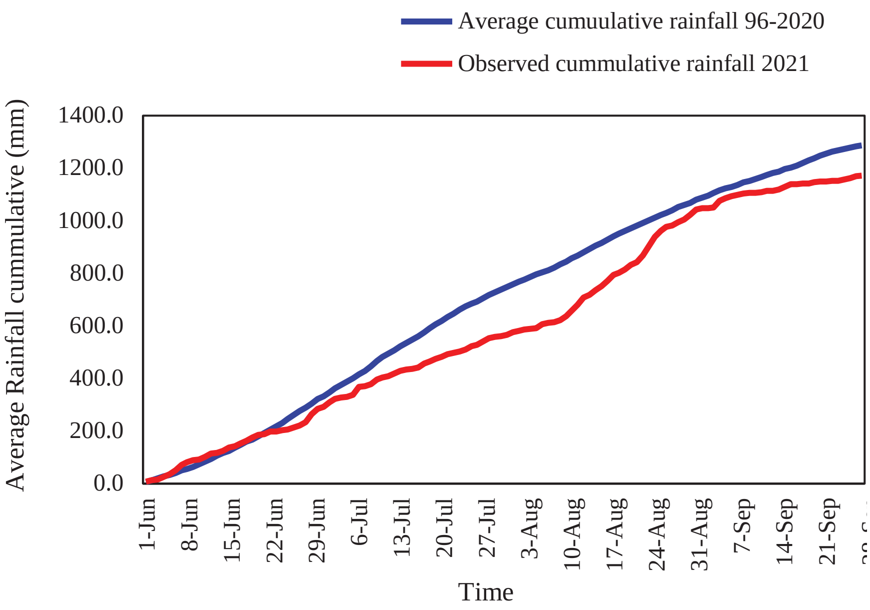


Figure 4: Observed rainfall of 2021 (JJAS) with long term average (1996-2020)

2.4.2 Temperature

During the summer of 2021, the country as a whole received near normal average temperature against the long-term average 1996-2020.

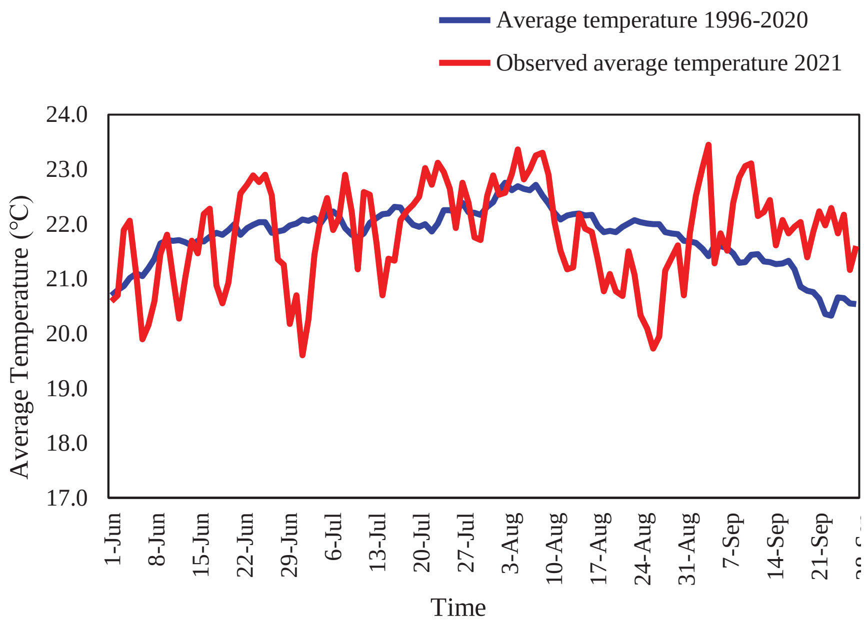


Figure 5: Observed average temperature of 2021 (JJAS) with long term average (1996-2020)

3. ANALYSIS OF TEMPERATURE - 2021

3.1 Maximum Temperature

A monthly climate monitoring report for the year 2021 is generated. The maps and extremes of monthly maximum temperature can be viewed and downloaded from the given website link http://www.nchm.gov.bt/. In this section, the spatial maps for annual average and seasonal variation of the average maximum temperature are included.

3.1.1 Annual average maximum temperature

The following map (Figure 6) shows the spatial distribution of annual average maximum temperature during the year 2021. Meteorological stations such as Sipsu, Phuentsholing, Bhur, Tangmachu, Punakha and Bajo experienced higher annual average maximum temperature. Conversely, Haa, Gasa, Paro and Chamkhar stations have recorded lower annual average maximum temperature.

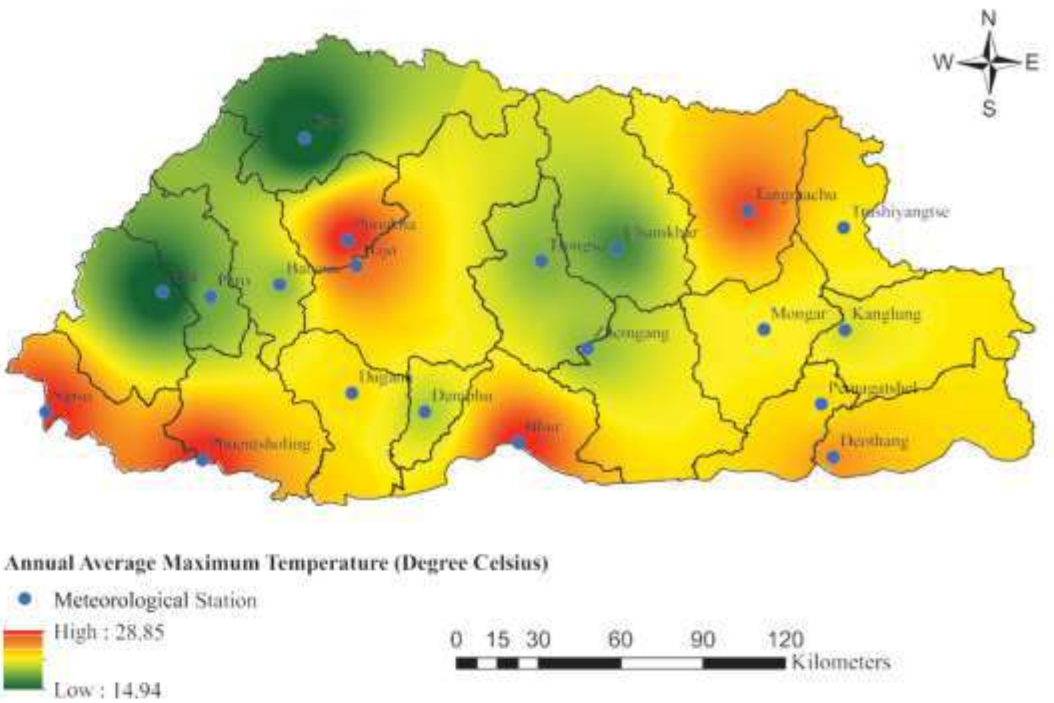


Figure 6: Spatial distribution of annual average maximum temperature for the year 2021

3.1.2 Seasonal average maximum temperature

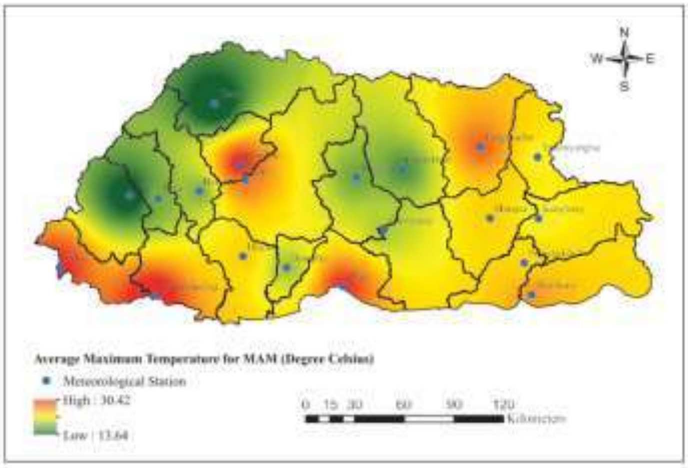
The spatial distribution for average maximum temperature across four seasons is mapped. In Bhutan based on the rainfall and temperature pattern, 12 months in a year are divided into four seasons.

i. Spring/ Pre-monsoon – March to May (MAM)
ii. Summer/Monsoon – June to September (JJAS)
iii. Autumn/Post-monsoon – October to November (ON)
iv. Winter/Monsoon – December to February (DJF)

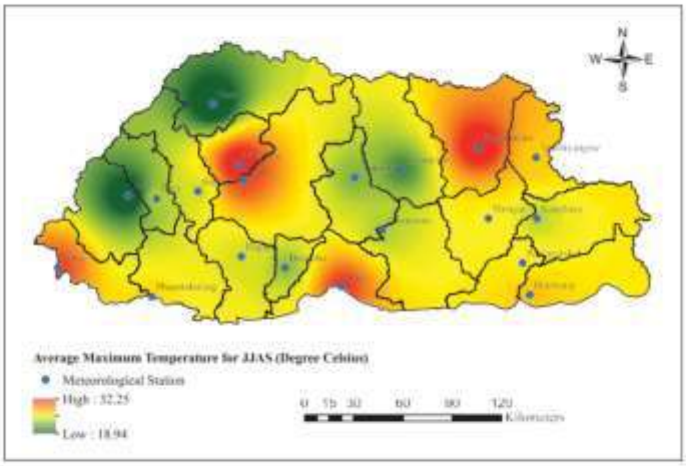
3.1.3 Seasonal spatial distribution average maximum temperature

The following maps (Figure 7) show the spatial distribution of seasonal average maximum temperature for the year 2021.

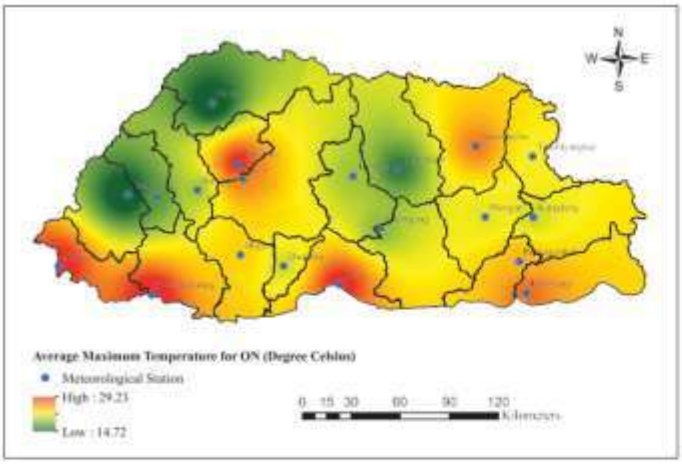
(a) Spring/Pre-monsoon (March-May)



(b) Summer/Monsoon (June-September)



(c) Autumn/Post-monsoon (October-November)



(d) Winter/Monsoon(December-February)

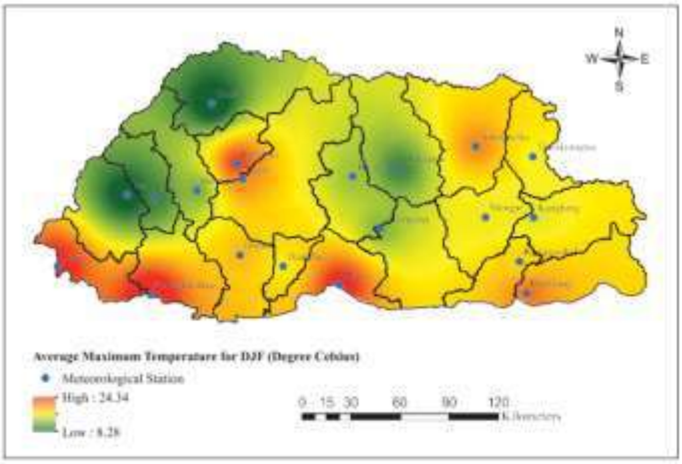


Figure 7: *Spatial distribution of seasonal average maximum temperature for the year 2021*

3.2 Minimum Temperature

A monthly climate monitoring report for the year 2021 is generated. The maps and extremes of monthly minimum temperature can be viewed and downloaded from the given website link *http://www.nchm.gov.bt/*. In this section, the spatial maps for annual average and seasonal variation of the average minimum temperature are included.

3.2.1 Annual average minimum temperature

The following map (Figure 8) shows the spatial distribution of annual average minimum temperature during the year 2021. Meteorological stations such as Sipsu, Bhur, Deothang, Punakha and Bajo experienced higher annual average minimum temperature. However, Haa, Paro, Babesa, Gasa and Chamkhar stations have experienced lower annual average minimum temperature.

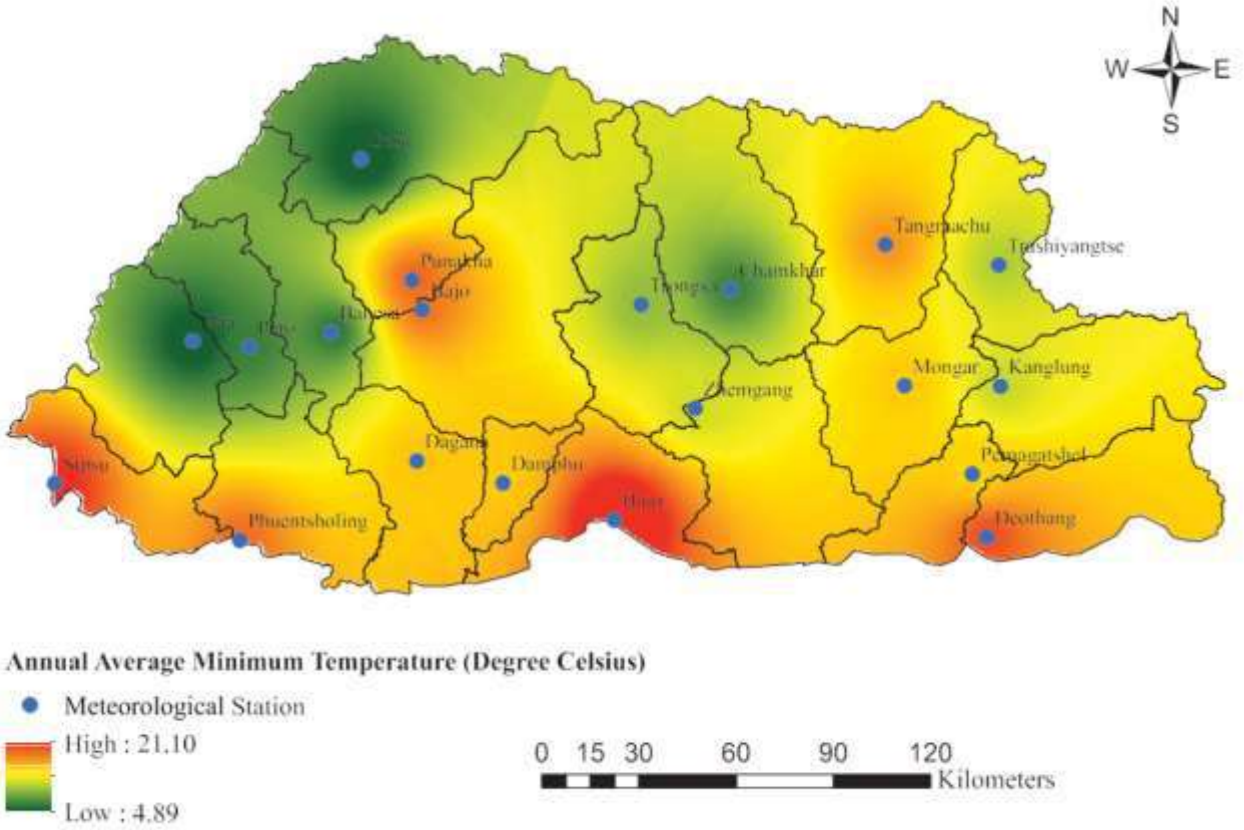
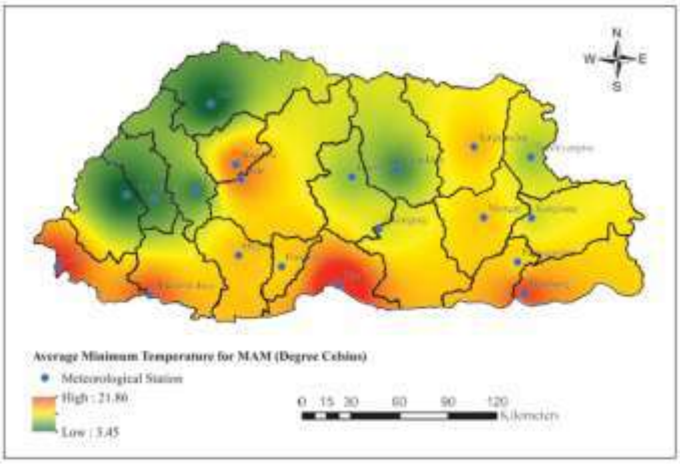


Figure 8: Spatial distribution of annual average minimum temperature for the year 2021

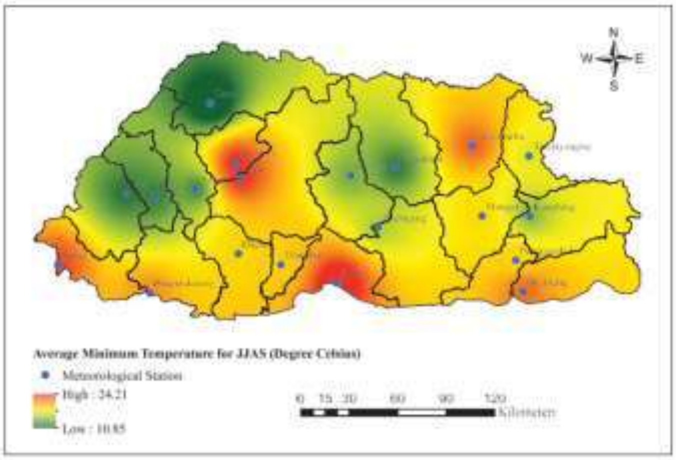
3.2.2 Seasonal spatial distribution of average minimum temperature

The following maps (Figure 9) show the spatial distribution of seasonal average minimum temperature for the year 2021.

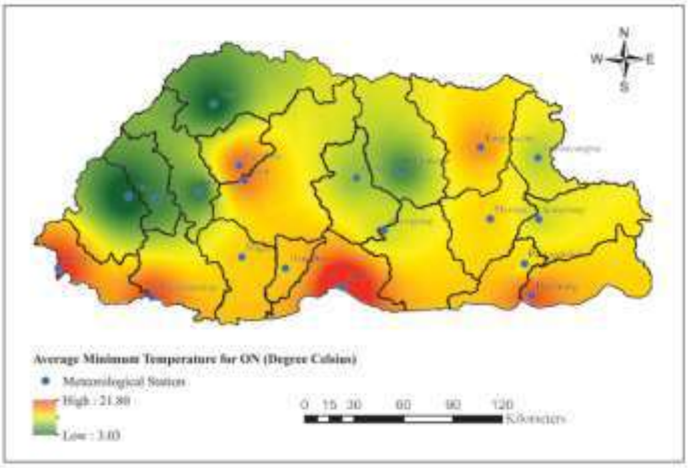
(a) Spring/Pre-monsoon (March-May)



(b) Summer/Monsoon (June-September)



(c) Autumn/Post Monsoon (October-November)



(d) Winter/Monsoon (December-February)

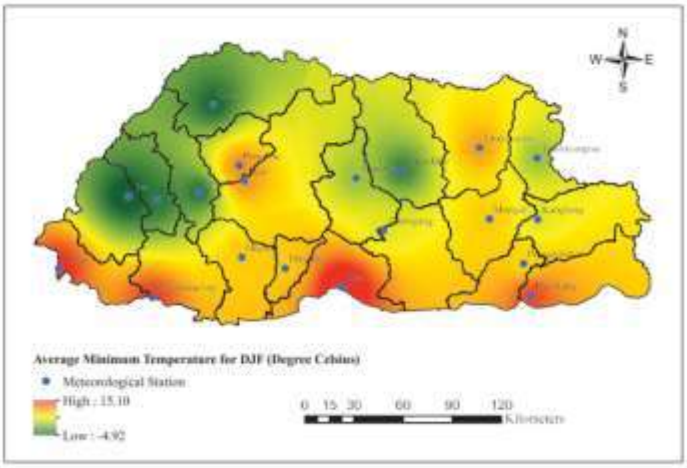


Figure 9: Spatial distribution of seasonal average minimum temperature for the year 2021

4. ANALYSIS OF RAINFALL - 2021

A monthly climate monitoring report for the year 2021 is generated. The maps and extremes of monthly accumulated rainfall can be viewed and downloaded from the given website link http://www.nchm.gov.bt/. In this section, annual and seasonal accumulated rainfall are included.

4.1 Annual Accumulated Rainfall

The following graph (Figure 10) shows the distribution of annual accumulated rainfall in the year 2021.

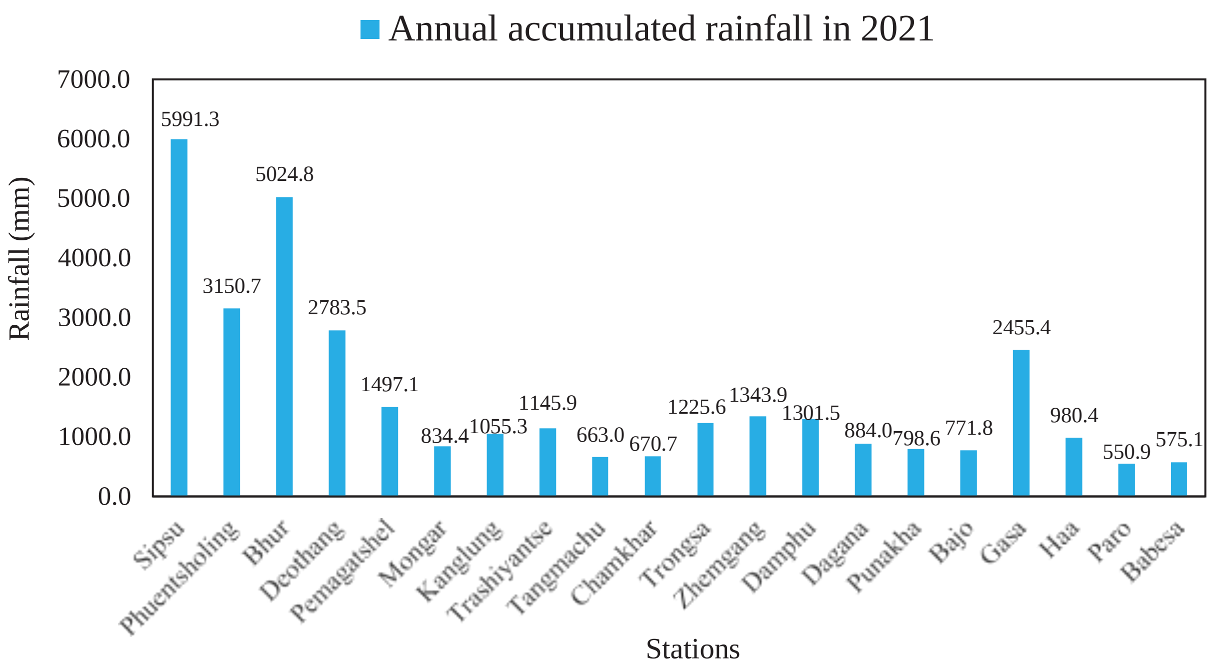
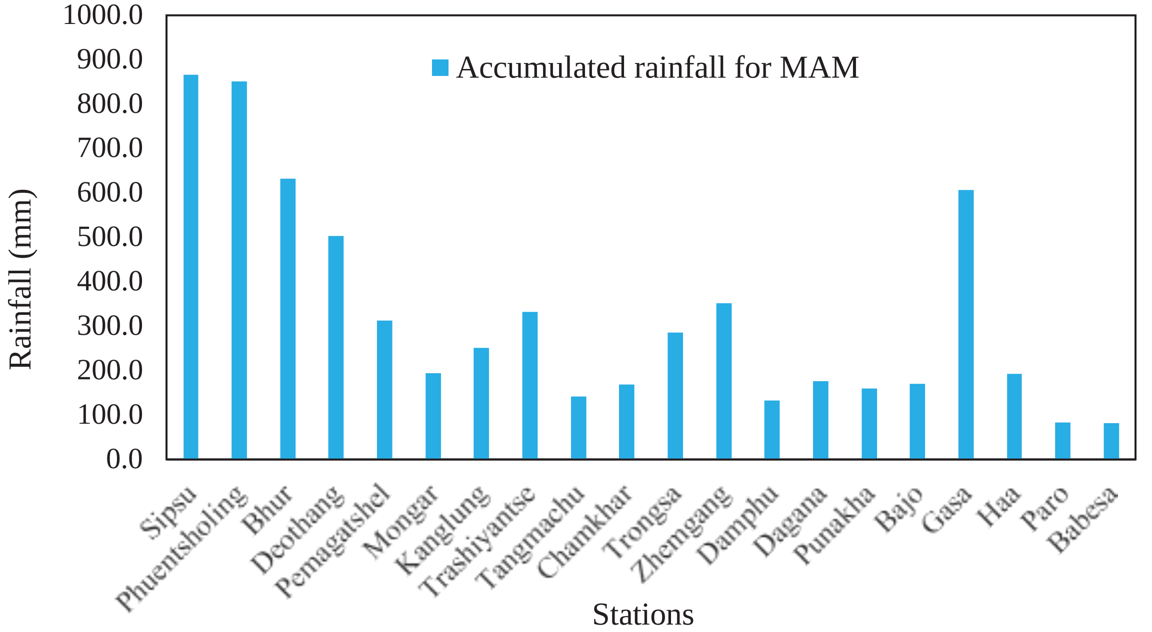


Figure 10: Annual accumulated rainfall for the year 2021

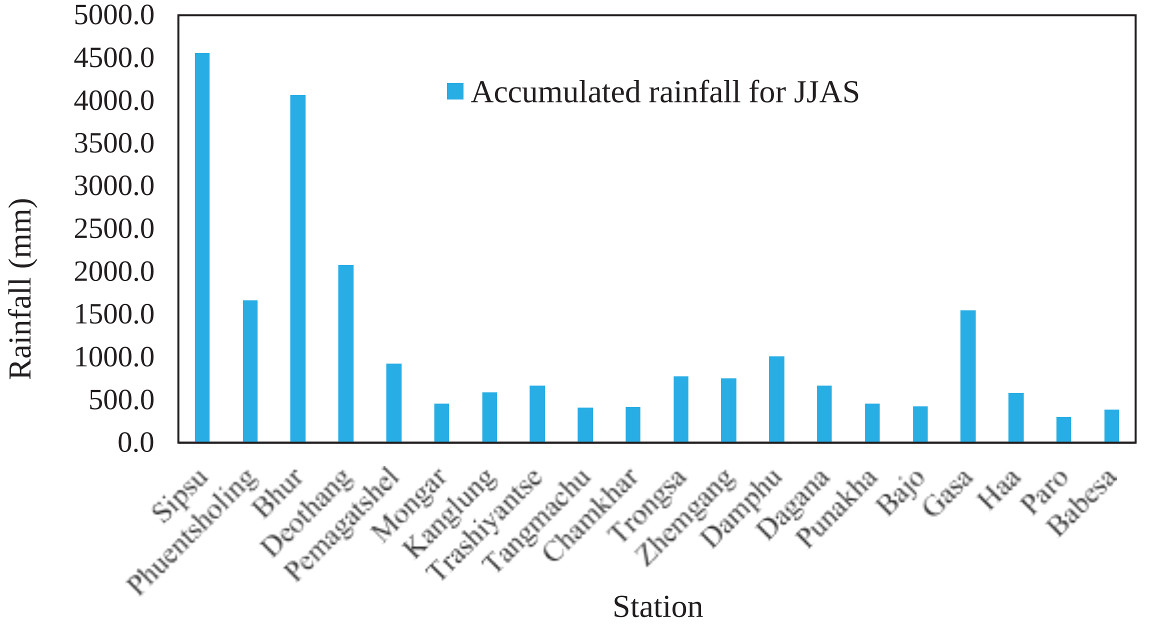
4.2 Seasonal spatial distribution of accumulated rainfall

The following graph (Figure 11) shows the distribution of seasonal accumulated rainfall.

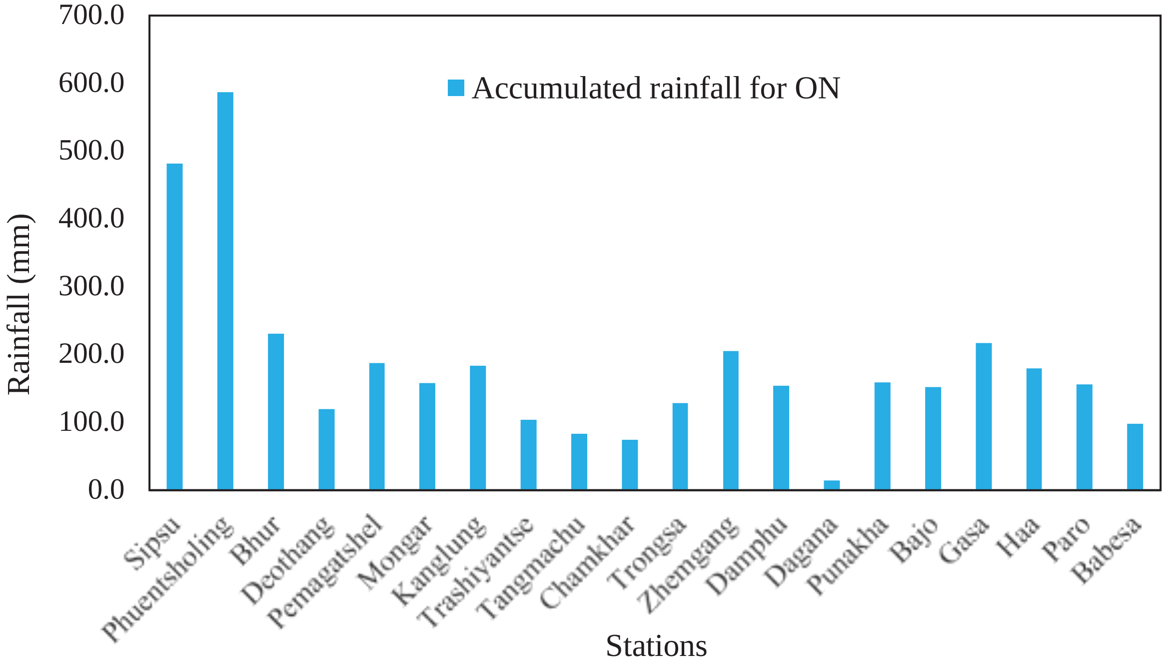
a. Spring/Pre-monsoon (March-May)



b. Summer/Monsoon (June-September)



c. Autumn/Post Monsoon (October-November)



d. Winter/Monsoon (December-February)

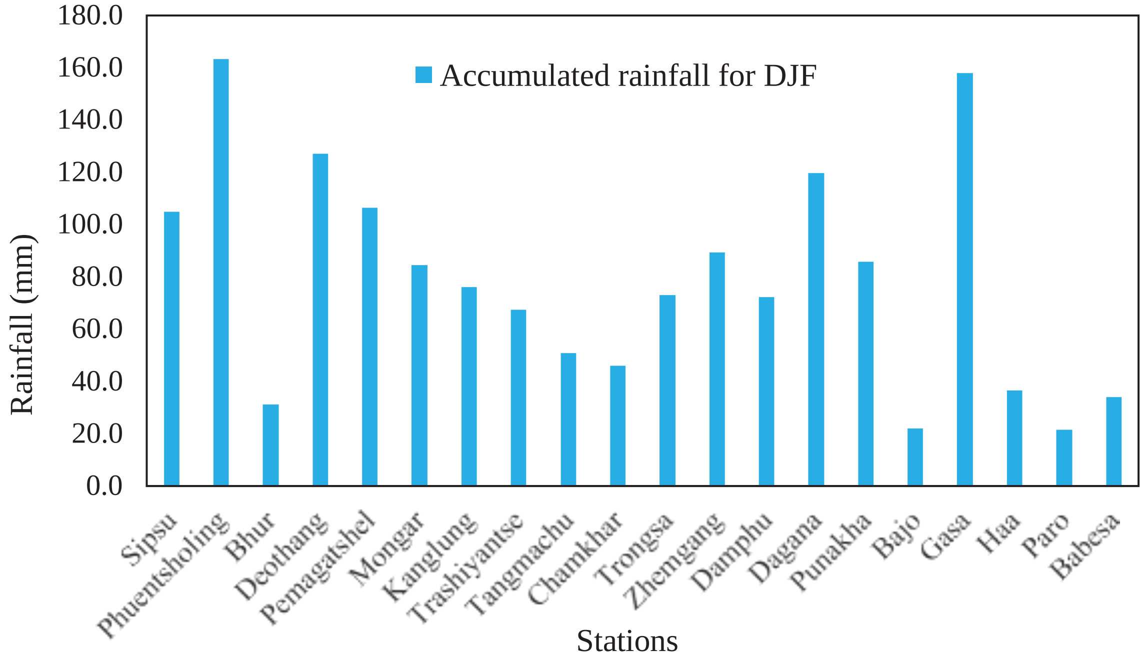
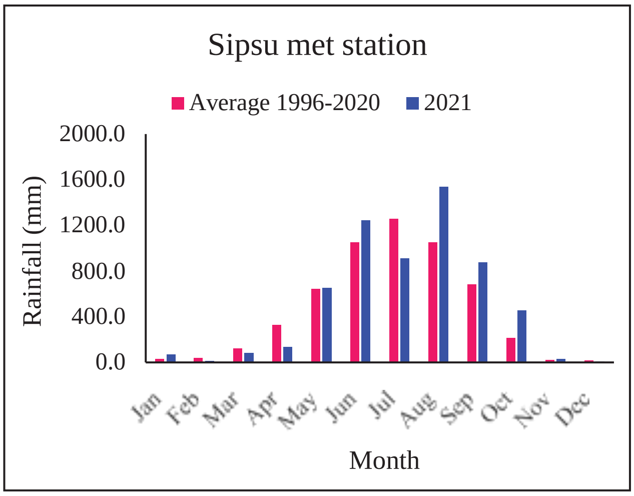
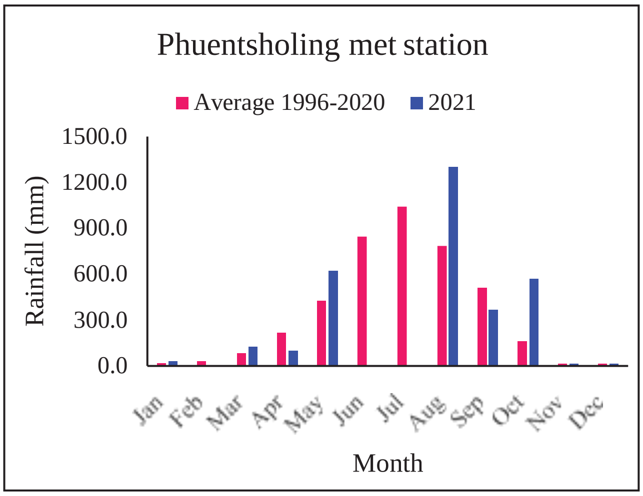


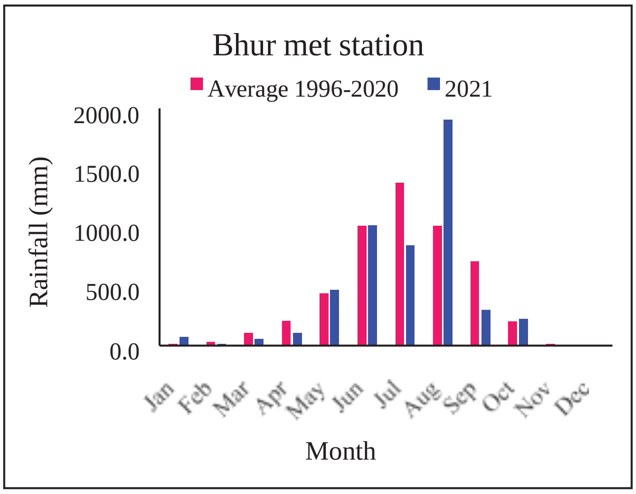
Figure 11: Distribution of seasonal accumulated rainfall for the year 2021

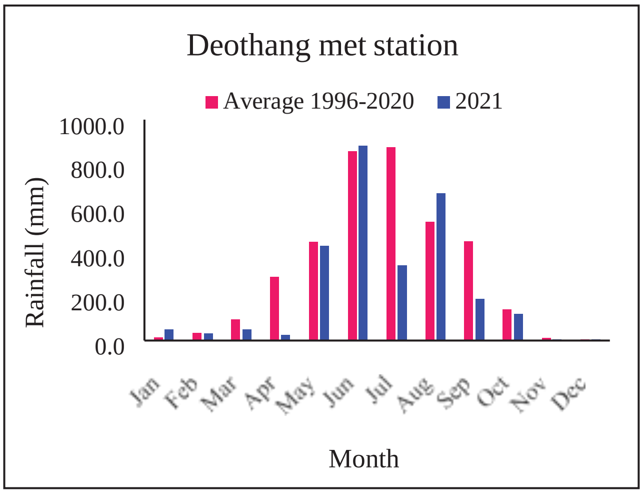
4.3 Comparison of monthly accumulated rainfall against long term average

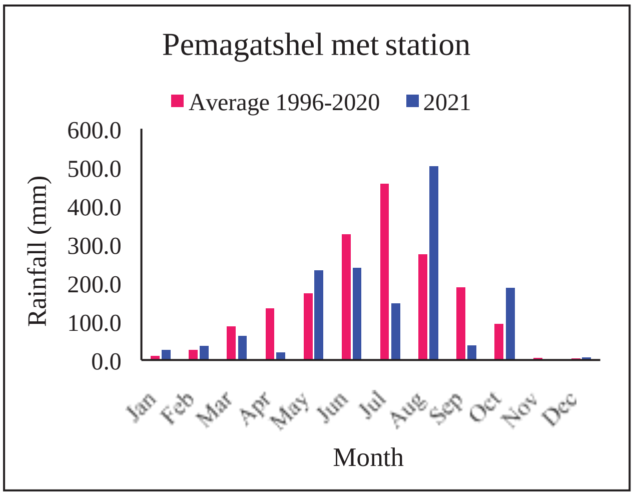
The following figures show the comparison of monthly accumulated rainfall of the year 2021 with their long term average. Please note that the long term averaging period in each station varies based on the data availability.

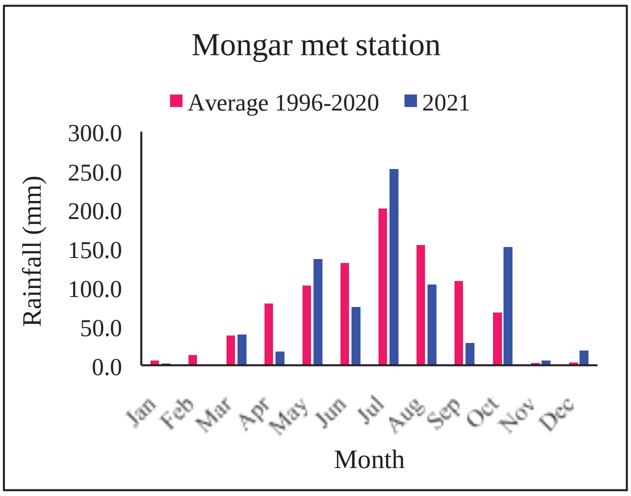


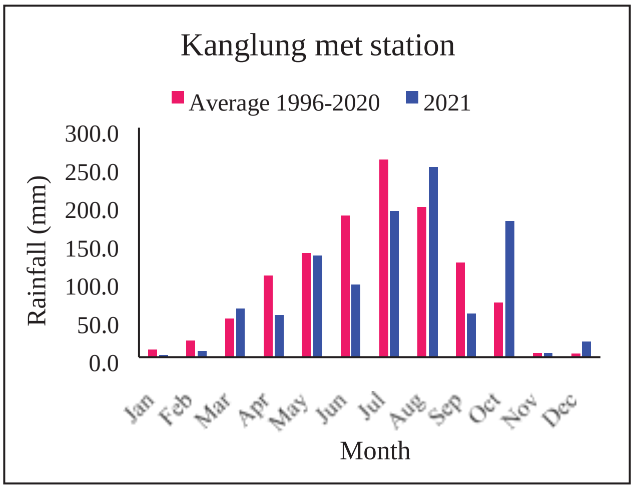


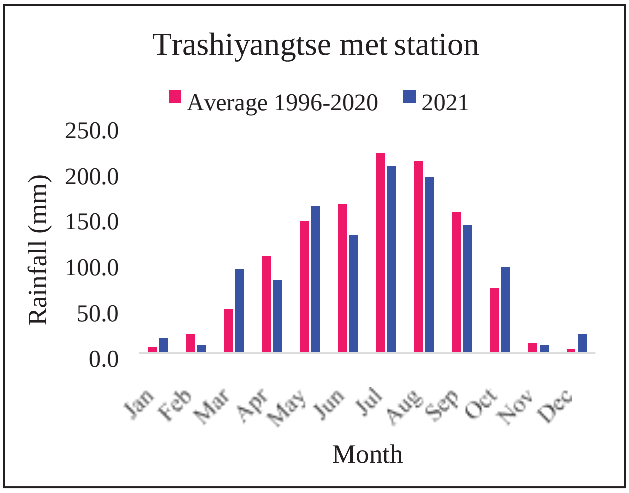


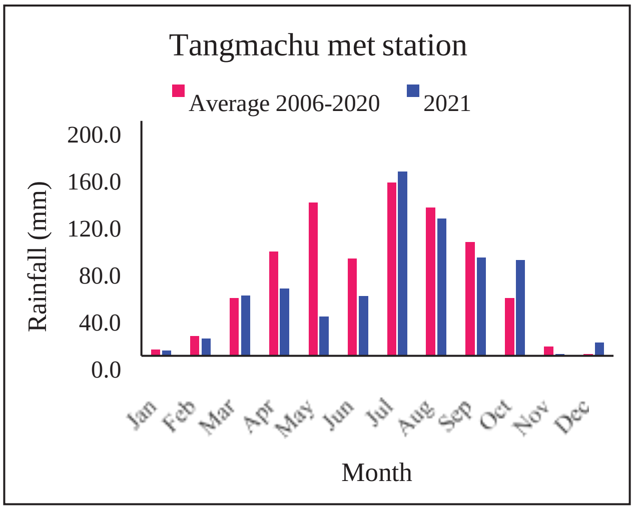


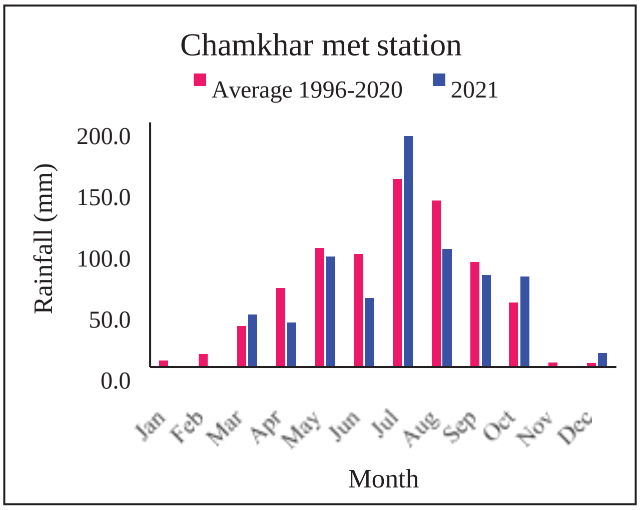

Pemagatshel met station
Average 1996-2020
2021
Rainfall (mm)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

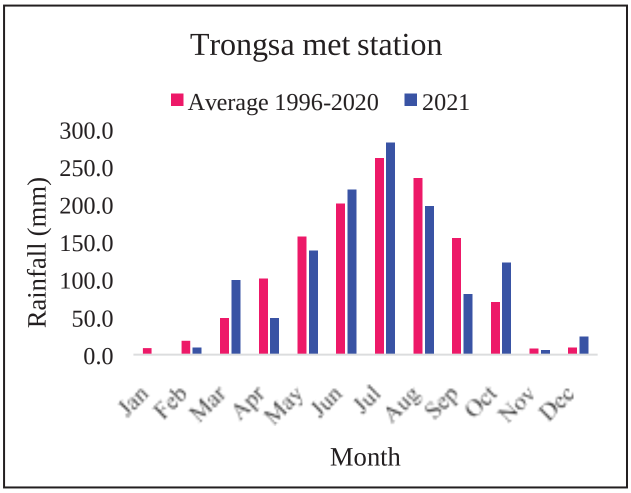

Mongar met station
Average 1996-2020
2021
Rainfall (mm)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

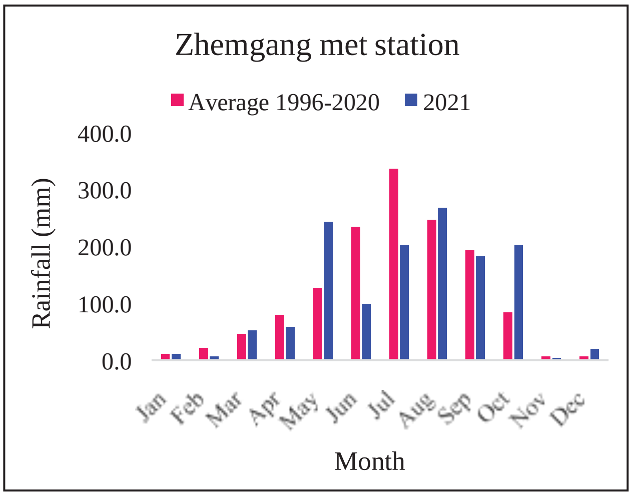

Kanglung met station
Average 1996-2020
2021
Rainfall (mm)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

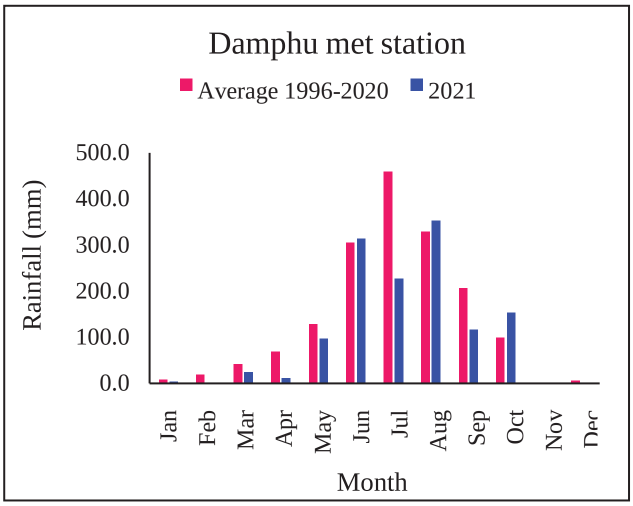

Trashiyangtse met station
Average 1996-2020
2021
Rainfall (mm)
250.0
200.0
150.0
100.0
50.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

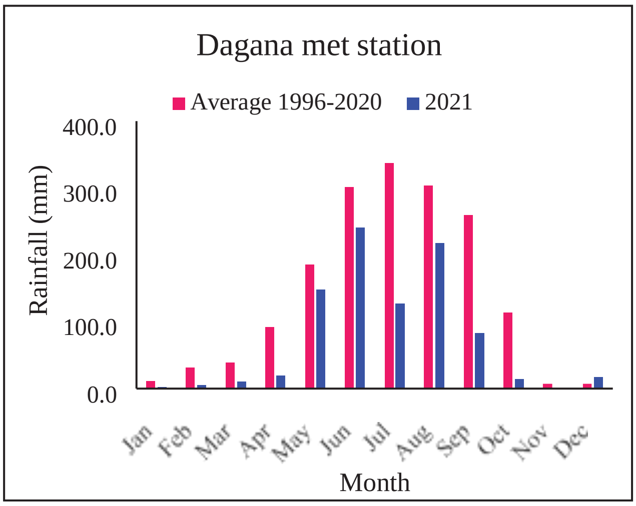

Tangmachu met station
Average 2006-2020
2021
Rainfall (mm)
200.0
160.0
120.0
80.0
40.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

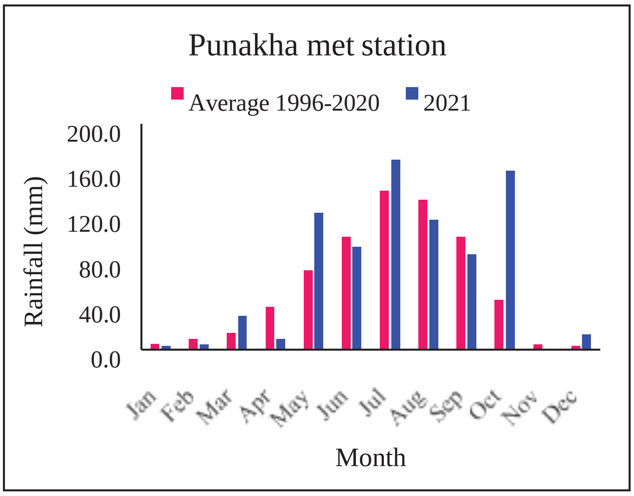

Chamkhar met station
Average 1996-2020
2021
Rainfall (mm)
200.0
150.0
100.0
50.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

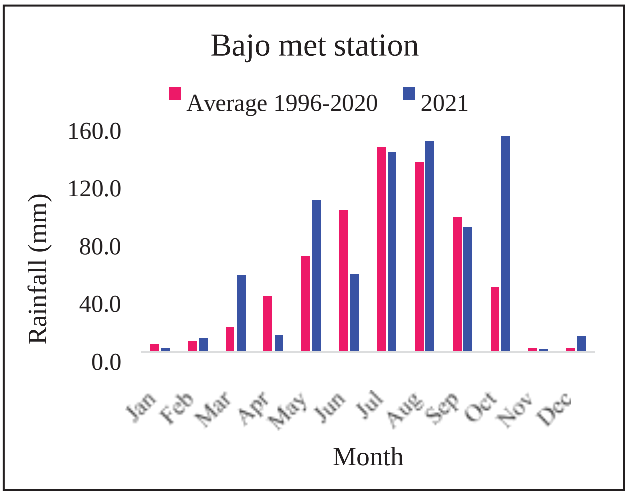

Trongsa met station
Average 1996-2020
2021
Rainfall (mm)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Zhemgang met station
Average 1996-2020
2021
Rainfall (mm)
400.0
300.0
200.0
100.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Damphu met station
Average 1996-2020
2021
Rainfall (mm)
500.0
400.0
300.0
200.0
100.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Dagana met station
Average 1996-2020
2021
Rainfall (mm)
400.0
300.0
200.0
100.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Punakha met station
Average 1996-2020
2021
Rainfall (mm)
200.0
160.0
120.0
80.0
40.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Bajo met station
Average 1996-2020
2021
Rainfall (mm)
160.0
120.0
80.0
40.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

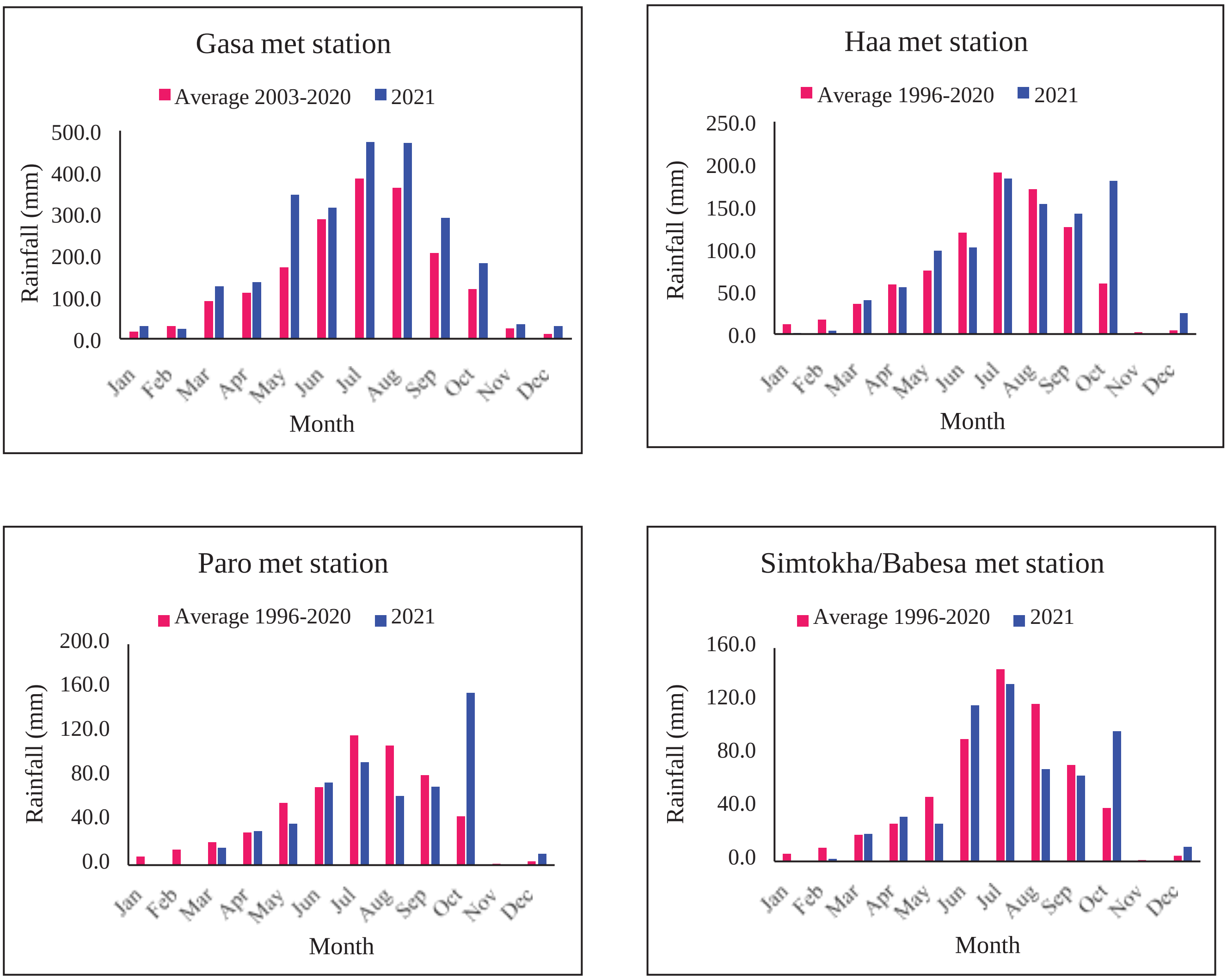
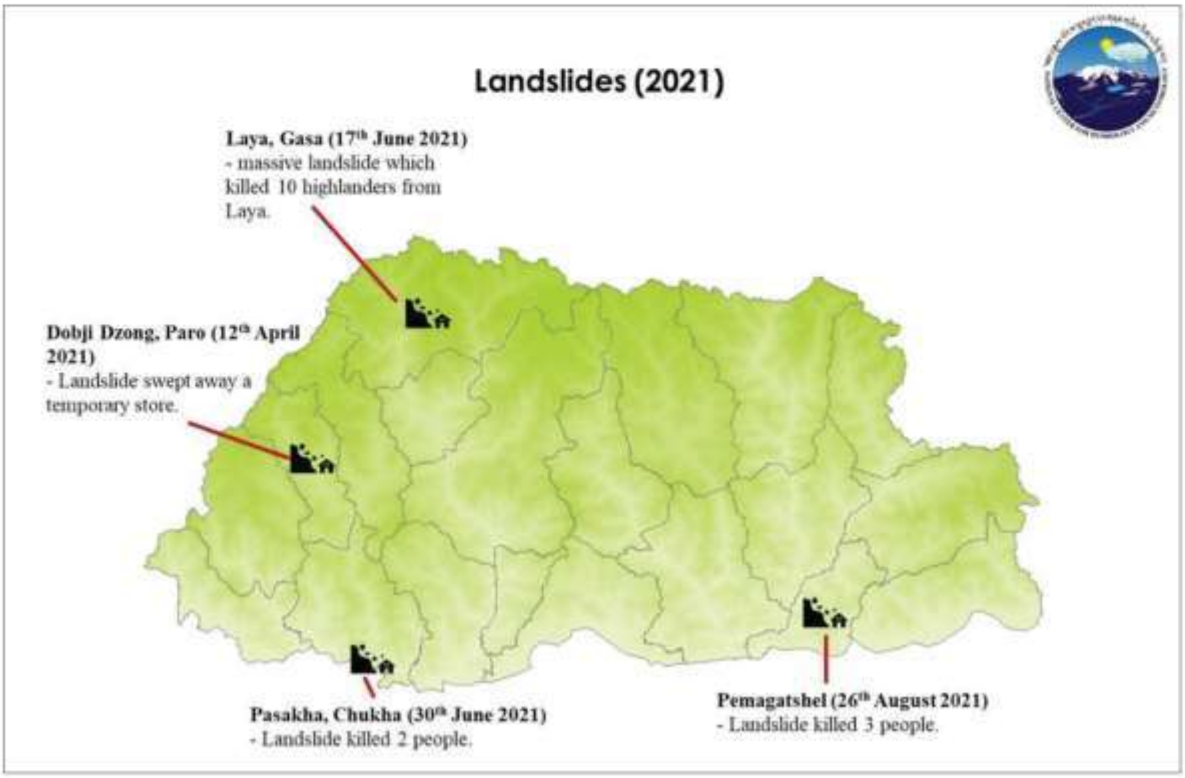
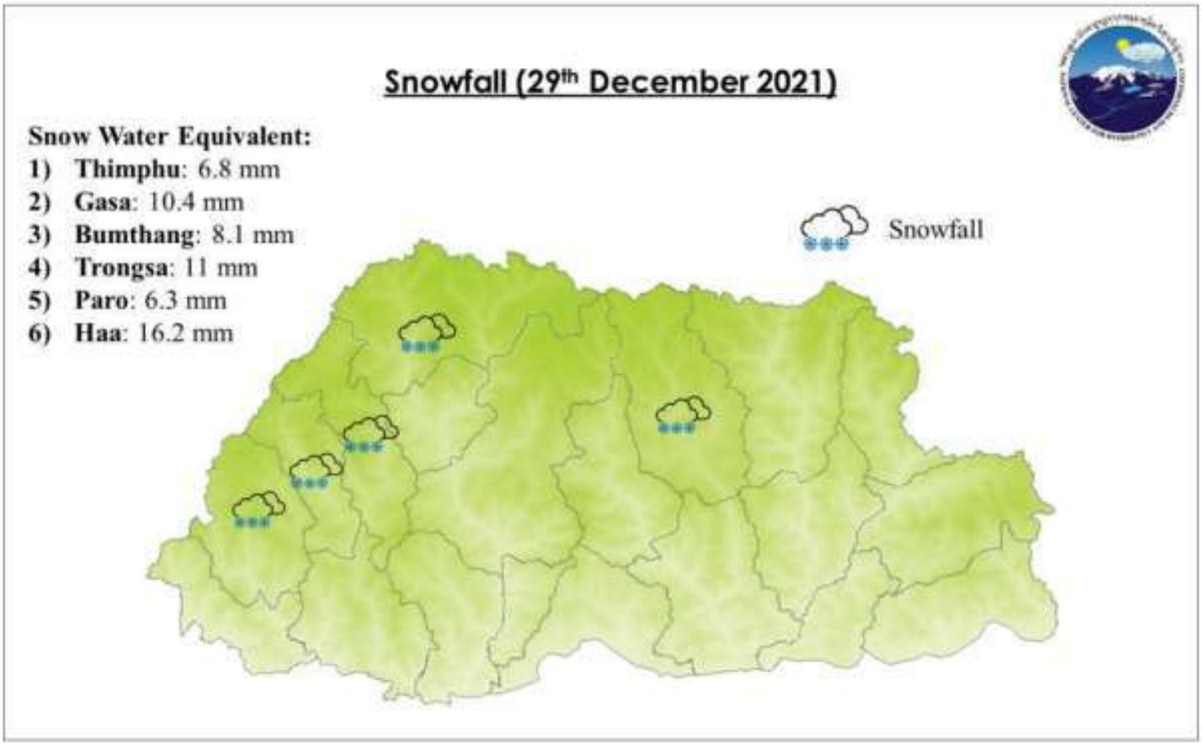


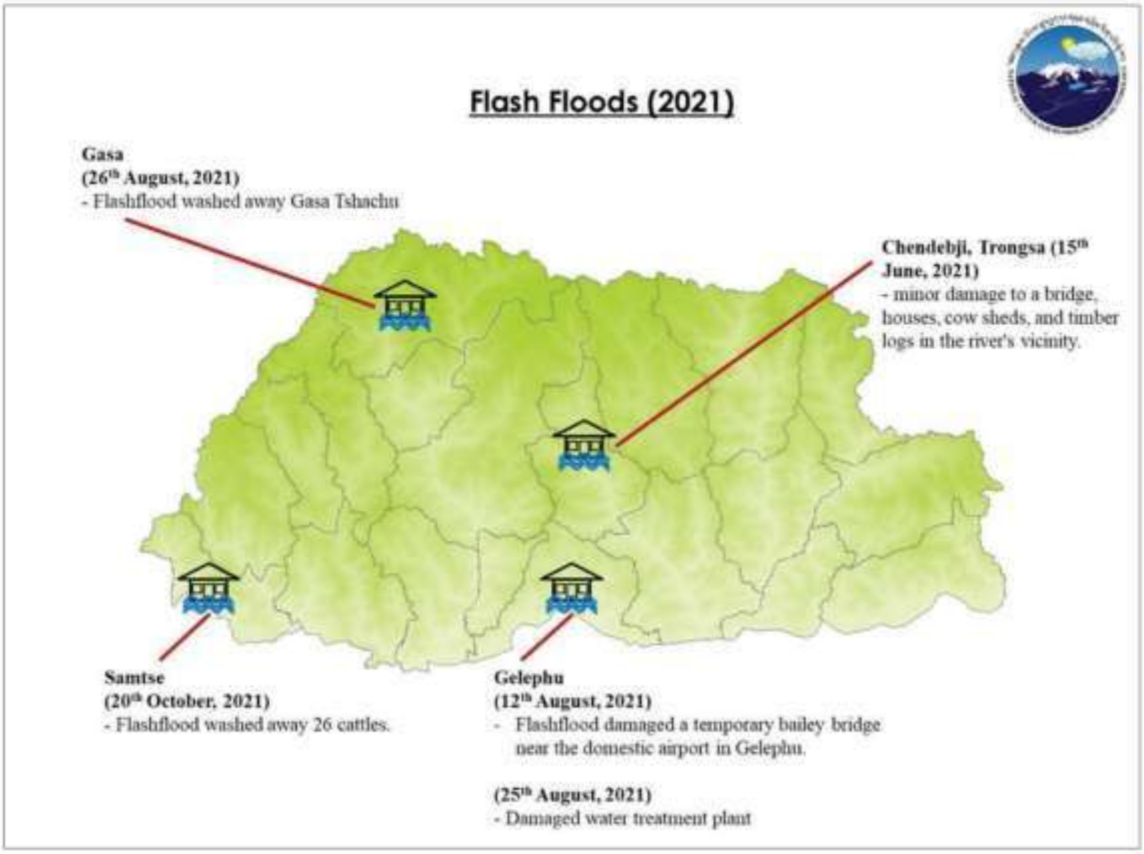
Figure 12: Comparison of total monthly rainfall of observed 2021 with long term average

5. EXTREME WEATHER EVENTS - 2021

The section includes lists of extreme meteorological events in the country from January to December 2021. The weather impact data and records relating to extreme weather and flooding are retrieved from Kuensel and BBS including the event occurrences, locations, causes, and impacts. The list of weather events that occurred during 2021 are presented below.







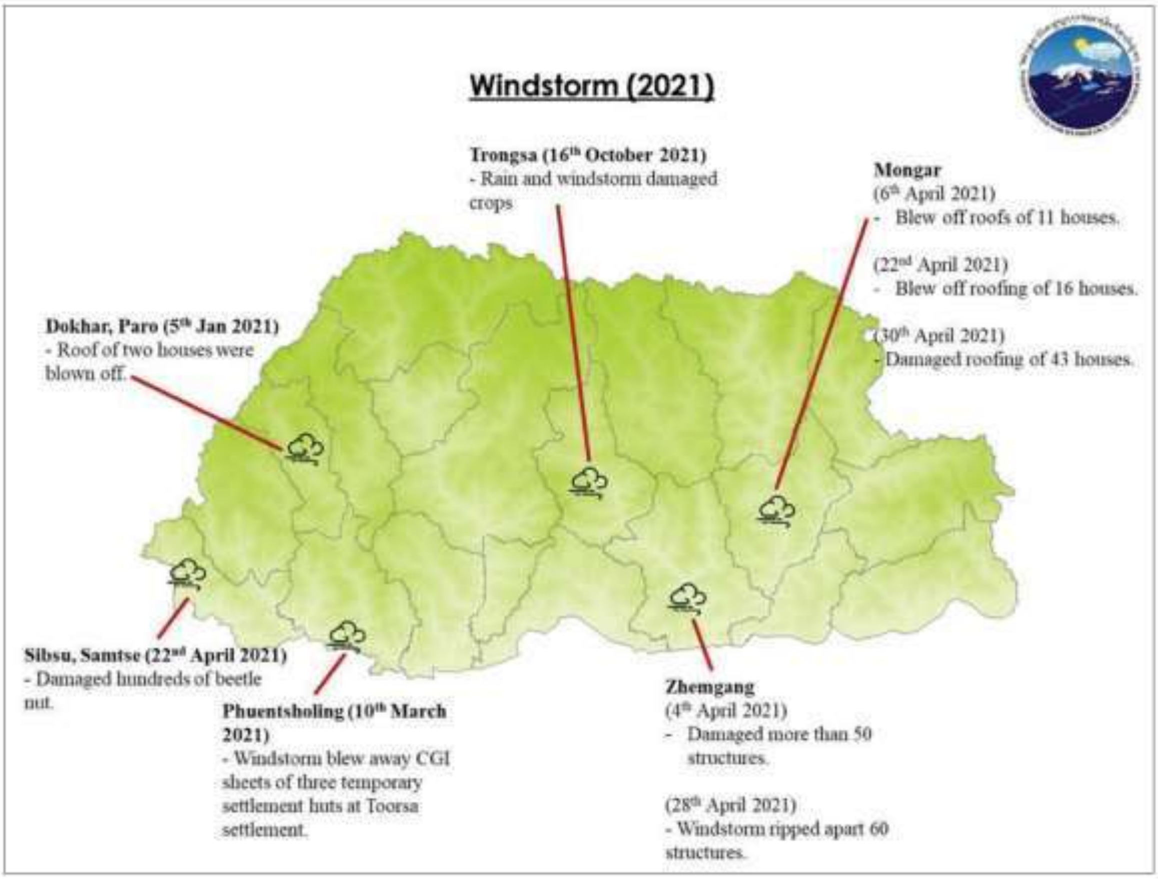


Figure 13: Extreme Weather Events during 2021

6. ANNUAL STATISTICS

6.1 Annual statistics for 20 Agrometeorological stations – 2021

Table 1. Annual statistics for 20 Agrometeorological stations

Station	*Annual average maximum temp (℃)*	*Annual average minimum temp (℃)*	*Annual total rainfall (mm)*	*Number of days with Tmax>=30*	*No. of days with Tmin<=0*	*Number of days with rainfall>=1mm*
Sipsu	27.87	18.27	5991.30	110	0	164
Phuentsholing	27.97	16.20	3150.70	120	0	89
Bhur	27.93	21.10	5024.80	108	0	153
Deothang	24.94	17.17	2783.50	29	0	130
Pemagatshel	22.91	13.12	1497.10	17	0	107
Mongar	22.45	13.52	834.40	14	0	87
Kanglung	21.46	10.62	1055.30	0	0	126
Trashiyangtse	22.63	10.16	1145.90	10	31	142
Tangmachu	26.94	15.09	663.00	123	0	102
Chamkhar	18.20	7.11	670.70	0	49	108
Trongsa	19.68	9.44	1225.60	0	21	132
Zhemgang	20.10	10.90	1343.90	0	0	123
Damphu	20.66	13.48	1301.50	0	0	101
Dagana	22.96	13.68	884.00	4	0	100
Punakha	28.85	16.58	798.60	182	0	102
Wangdue	25.64	16.10	771.80	76	0	100
Gasa	14.94	4.91	2455.40	0	83	233
Haa	15.00	4.89	980.40	0	120	120
Paro	19.51	7.03	550.90	0	54	81
Babesa	20.07	6.71	575.10	0	81	87

6.2 Extreme records for 20 Agrometeorological stations - 2021

Table 2. Annual extremes for 20 Agrometeorological stations

Station	***Maximum temperature (°C)***	***Date of occurrence***	***Minimum temperature (°C)***	***Date of occurrence***	***24 hour Rainfall (mm)***	***Date of occurrence***
Sipsu	35.00	27th Sept, 15th Oct, 2021	9.00	31st Jan, 2021	283.80	29th June, 2021
Phuentsholing	37.00	3rd April, 2021	9.00	31st Jan, 2021	215.40	20th Oct, 2021
Bhur	36.00	13th, 15th, 27th Sept, 2021	12.00	3rd Jan, 22nd Jan, 27th Jan, 2021	245.00	26th Aug, 2021
Deothang	32.50	27th Sept, 2021	8.50	22nd Jan, 2021	127.50	29th June, 2021
Pemagatshel	32.00	26th Sept, 2nd Oct, 2021	3.00	30th Jan, 31st Jan, 1st Feb, 23rd Dec, 26th Dec, 2021	97.20	13th Aug, 2021
Mongar	32.00	24th May, 2021	4.00	31st Jan, 24th Dec, 26th Dec, 31st Dec, 2021	72.80	26th May, 2021
Kanglung	29.00	24th May, 2021	0.50	26th Dec, 2021	71.80	19th Oct, 2021
Trashiyantse	30.50	24th May, 24th June, 6th Aug, 2021	-3.50	21st Dec, 2021	44.00	19th Oct, 2021
Tangmachu	36.50	22nd June, 2021	3.00	2nd Jan, 3rd Jan, 2021	35.00	18th Oct, 2021
Chamkhar	27.00	6th July, 2021	-9.50	21st Dec, 2021	32.70	26th May, 2021
Trongsa	28.00	13th Sept, 15th Oct, 2021	-2.50	23rd Dec, 2021	58.80	26th May, 2021
Zhemgang	28.50	22nd July, 10th Sept, 2021	0.50	31st Jan, 2021	85.20	19th Oct, 2021
Damphu	27.50	27th May, 2021	3.00	30th Jan, 31st Jan, 24th Dec, 2021	84.40	19th Aug, 2021
Dagana	31.00	24th May, 2021	4.00	26th Dec, 27th Dec, 28th Dec, 31st Dec, 2021	70.40	26th May, 2021
Punakha	37.00	23rd May, 2021	2.50	21st Dec, 2021	56.20	19th Oct, 2021
Wangdue	33.00	23rd May, 24th May, 6th Aug, 15th Oct, 2021	3.00	3rd Jan, 31st Jan, 21st Dec, 2021	66.20	18th Oct, 2021
Gasa	23.00	8th Aug, 2021	-6.50	31st Jan, 2021	53.40	20th Oct, 2021
Haa	23.00	10th Aug, 2021	-12.50	30th Jan, 2021	89.60	19th Oct, 2021
Paro	29.00	25th July, 2021	-6.00	23rd Dec, 24th Dec, 2021	83.20	19th Oct, 2021
Babesa	29.00	24th May, 16th Oct, 2021	-8.00	20th Dec, 2021	52.00	19th Oct, 2021

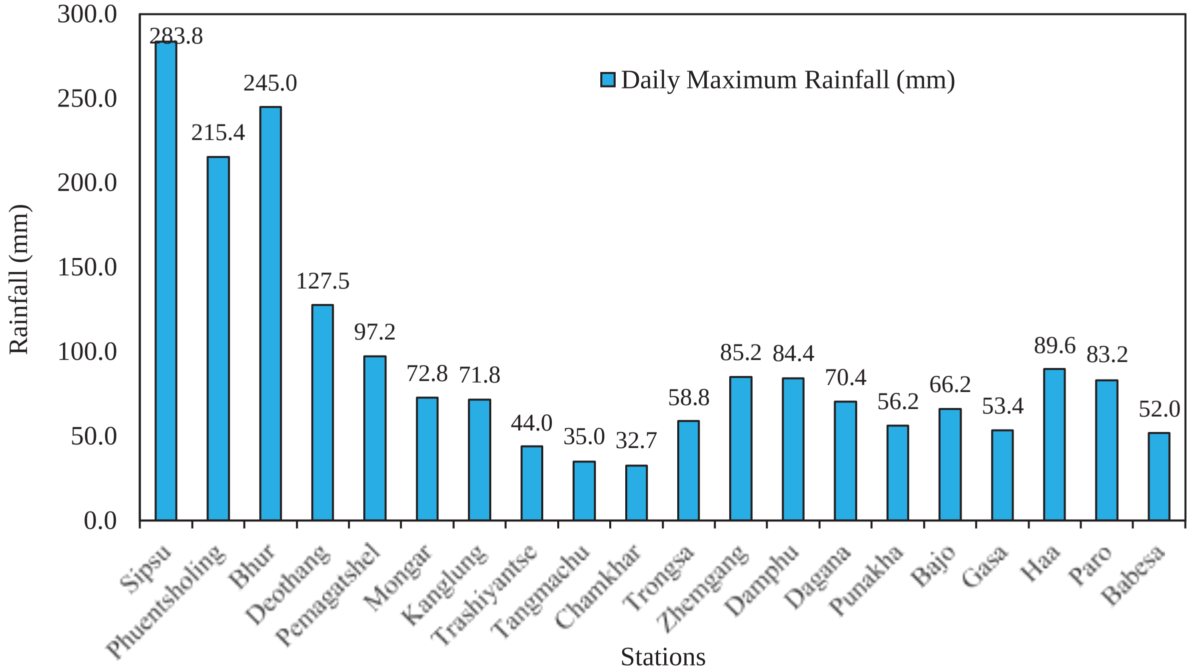


Figure 14: Daily maximum rainfall for 20 Class A stations

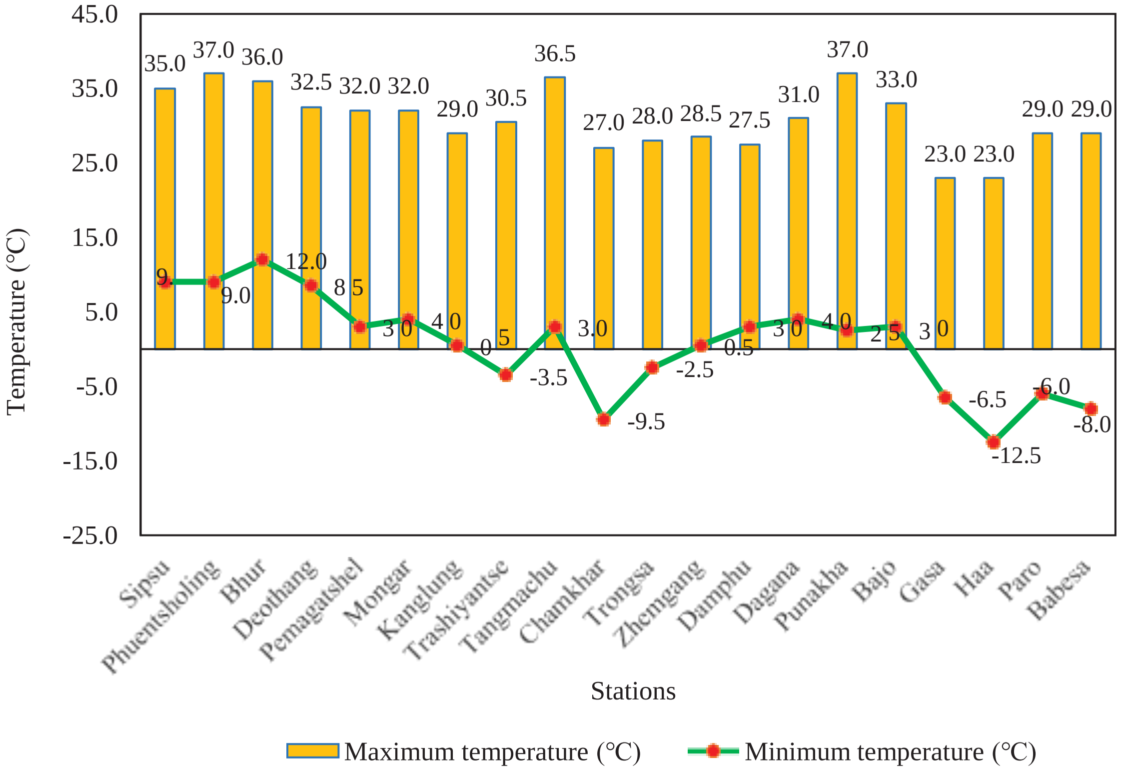


Figure 15: Daily maximum of maximum temperature (bar graph) and minimum of minimum temperature (line graph) for 20 Class A stations

SECTION B: HYDROLOGY

1. MAJOR FACTORS INFLUENCING RIVER FLOW VARIABILITIES IN BHUTAN

1.1 River Regimes

The river regime is the direct consequence of the climatic factors influencing the catchment runoff, which is derived or estimated from the climate knowledge of the region. The expected pattern of river flow during a year is known as the river regime. Flow records of 20-30 years are generally required to represent a pattern since there may be considerable variation in the seasonal discharge from year to year. The averages of the monthly mean discharges over the years of record calculated for each month, January to December, give the general or expected pattern: the regime of the river.

1.2 Temperature-dependent Regimes

Rivers with a dominant single source of supply, initially in the solid state (snow or ice), produce a simple maximum and minimum in the pattern of monthly mean discharges according to the seasonal temperatures.

- Glacial: When the catchment area is over 25-30 per cent covered by ice, the river flow is dominated by the melting conditions. Such rivers are found in the high mountain areas of the temperate regions. There is little variation in the pattern from year to year, but in the main melting season, July and August, there are great diurnal variations in the melt water flows.
- Mountain snowmelt: The seasonal peak from snowmelt is lower and earlier than in a glacial stream, but the pattern is also regular each year providing there has been adequate winter snowfall. The low winter flows are caused by freezing conditions.

1.3 Rainfall-dependent Regimes

In the equatorial and tropical regions of the world with no high mountains, the seasonal rainfall variations are the direct cause of the river regimes. Temperature effects in these areas are mostly related to evaporation losses, but with these being dependent on rainfall, the overall effect of evaporation is of secondary importance in influencing the river flow pattern. Drainage basins within the equatorial belt experience two rainfall seasons with the annual migration of the inter-tropical convergence zone, and these are reflected directly in the river regime.

2. ANNUAL FLOW OF 2021 COMPARED WITH THE HISTORICAL FLOW

The annual average flow of historical record is compared to the average flow of 2021 for stations located across Bhutan. The annual average flow from 1992-2020 is the historical annual average flow. The stations are selected based on basin representation (Figure 16) but does not necessarily represent the outflow of the entire basin. The following table shows the details of station with flow data comparison.

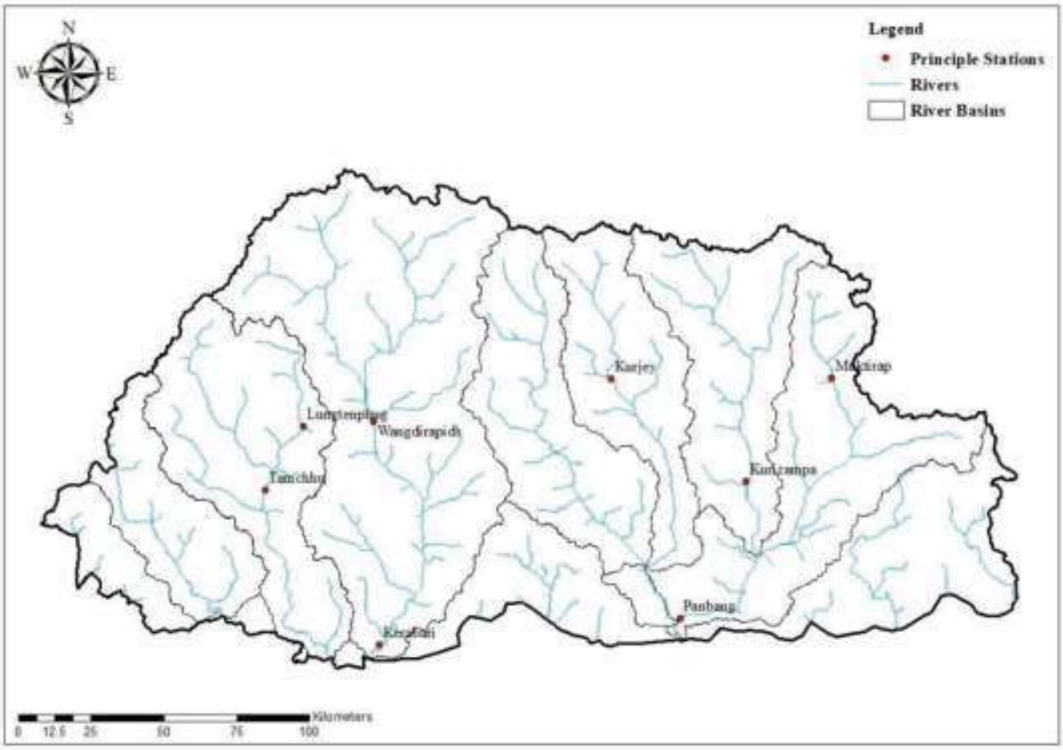


Figure 16: Selected stations based on Basin representation

Table 3. Comparison of historical annual average flow and 2021 average flow

Sl. No	Station Name	Basin	Historical annual Average flow m^3/s	2021 Average flow in m^3/s
1	Tamchhu	Wangchhu	60.0	57.8
2	Lungtenphu	Wangchhu	22.2	21.9
3	Kerabari	Punatsangchhu	455 0	433.8
4	Wangdirapids	Punatsangchhu	294.8	314.5
5	Kurjey	Manas	53.4	53.1
6	Muktitrap	Manas	64.2	61.4
7	Kurizampa	Manas	292.9	285.3
8	Panbang	Manas	779.5	804.3

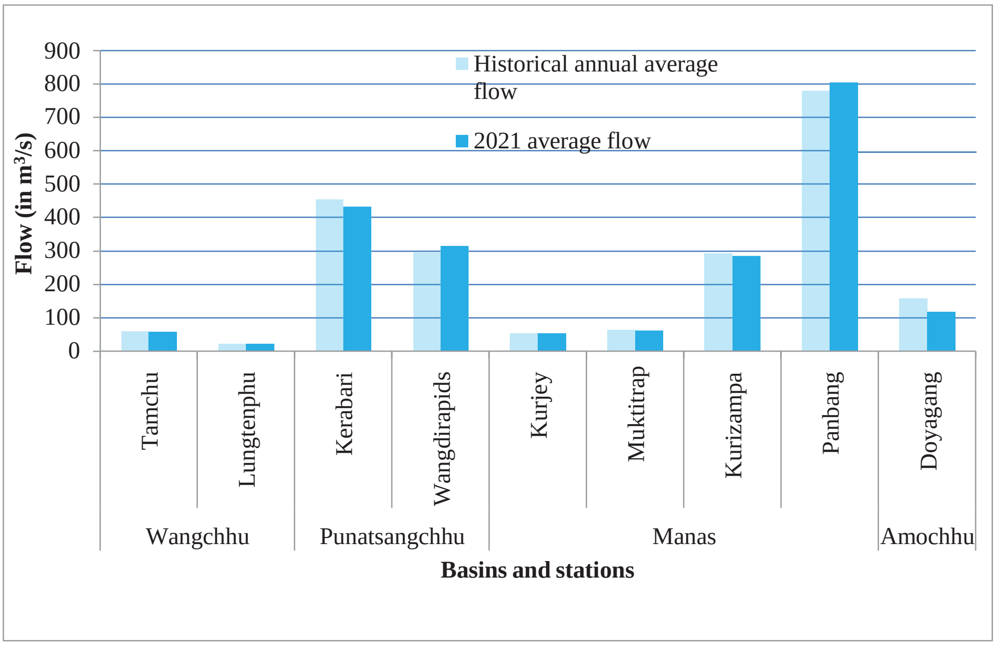


Figure 17: Bar graph for average flow comparison

3. MAXIMUM AND MINIMUM FLOW IN 2021

The maximum and minimum flow for the year 2021 for the respective stations is the observed highest and the lowest flow. The catchment areas shown here represent the watershed area in square kilometre (sq.km) at the observation station.

Table 4. Maximum and Minimum flows for 2021 with their date of occurrence

Sl. No	Station Name	Catchment area in sq.km	Max flow in m^3/s	Date of occurrence	Min flow in m^3/s	Date of occurrence
1	Tamchhu	2529.17	481.3	20th Oct	9.99	6th April
2	Lungtenphu	665.71	99.9	20th Oct	3.3	8th April
3	Kerabari	9627.237	1677.9	28th Aug	104.3	6th April
4	Wangdirapids	5647.62	1354	26th Aug	57.4	26th Feb
5	Kurjey	1354.97	195.3	27th May	9.6	20th Feb
6	Muktitrap	876.36	568.7	28th Aug	8.35	26th Feb
7	Kurizampa	8997.70	1263	9th Sept	61.9	25th Feb
8	Panbang	21006.1	4208.6	26th Aug	139.4	21st Feb

4. WANGCHU BASIN RIVER FLOW STATUS

4.1 Map showing annual average flow and river length for Wangchhu basin

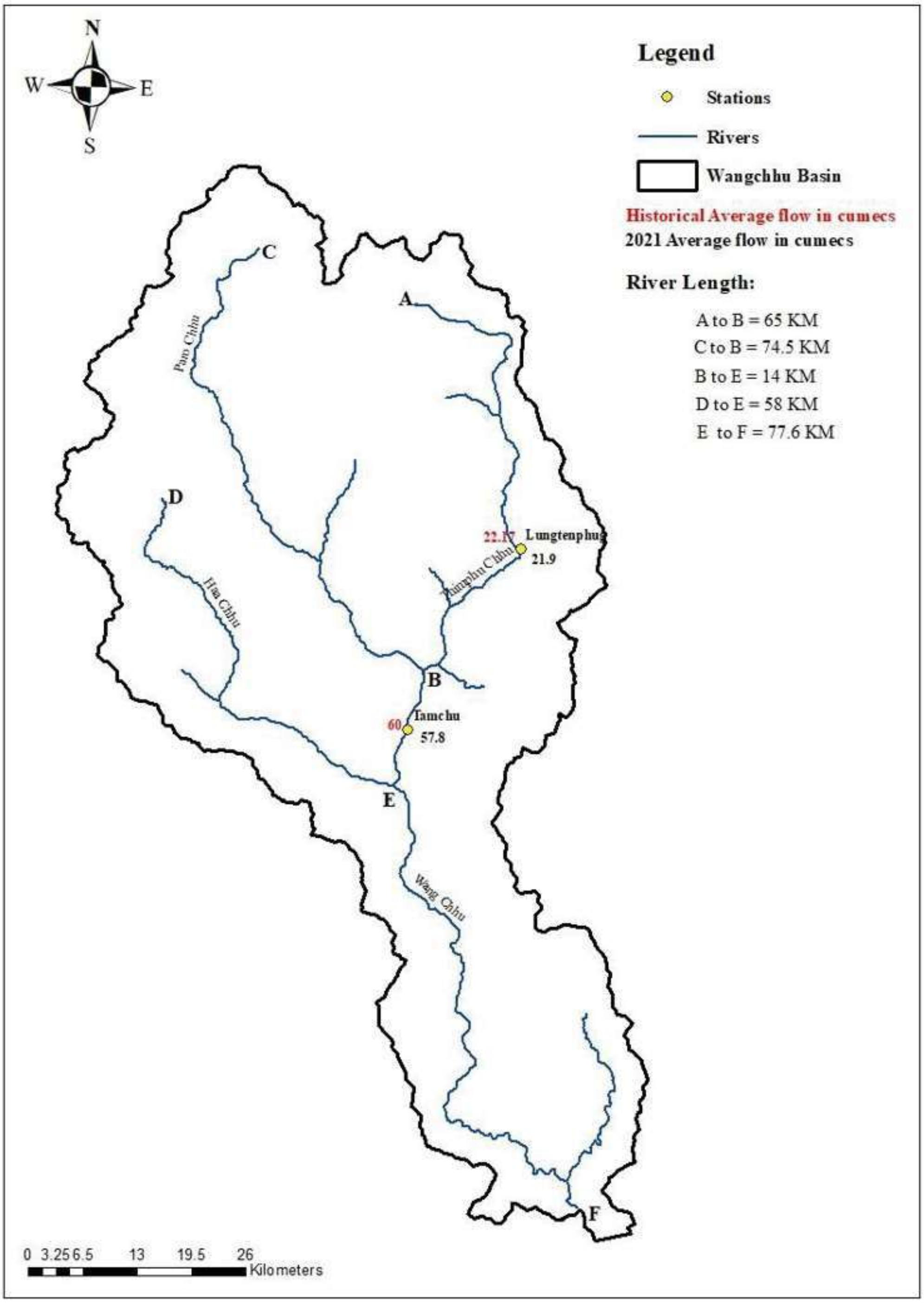


Figure 18: Annual average flow and river length for Wangchhu Basin

4.2 Station wise average monthly flow

The average monthly flow of 2021 is compared with the historical average monthly flow on Wangchhu basin from the observed data at Lungtenphu and Tamchhu observation stations. In general, the mean monthly flow of 2021 is observed to be below the historical mean monthly flow for Wangchhu basin during monsoon, while during post monsoon, the flow is observed to be above the historical mean monthly flow.

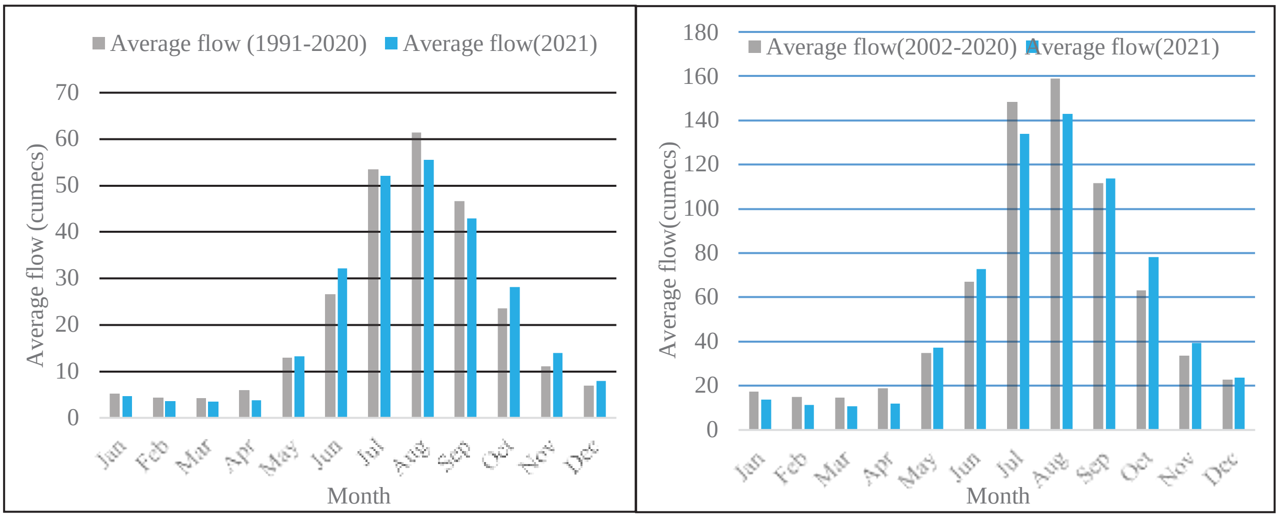


Figure 19: Monthly average flow comparison for Lungtenphu and Tamchhu stations in Wangchhu basin

4.3 Station wise JJAS flow

The daily flow of Lungtenphu and Tamchhu observation stations for the month of June, July, August and September (JJAS) were compared with the historical daily mean flow. The figure 20 below indicates general daily flow variability for the monsoon (JJAS) period.

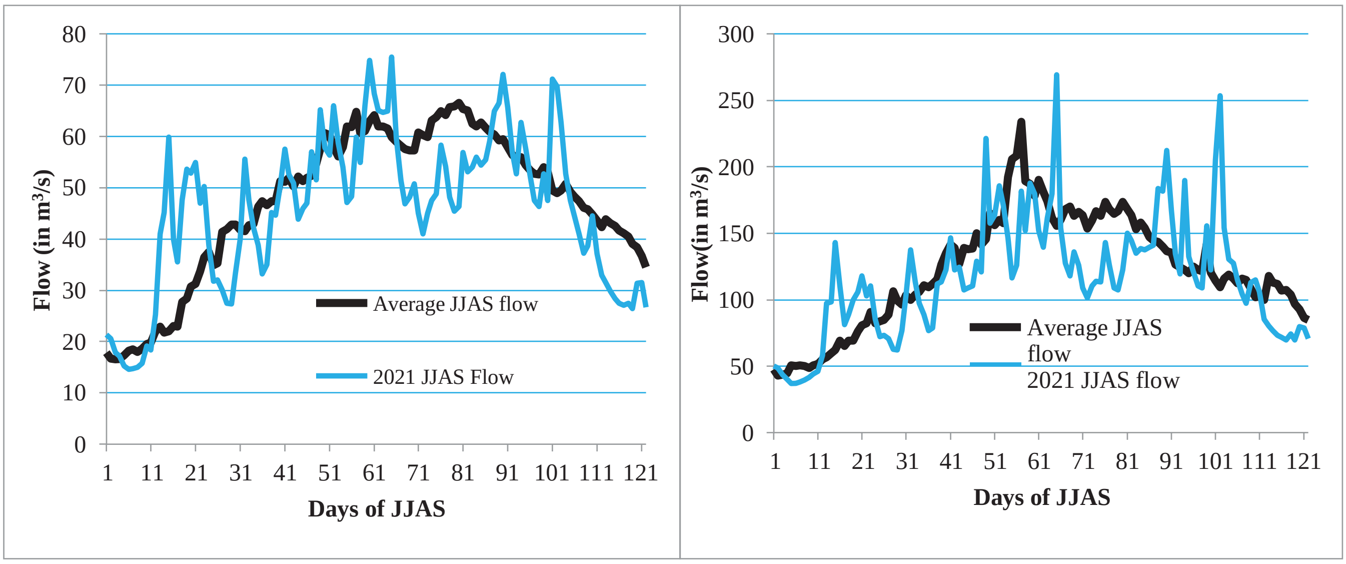


Figure 20: 2021 JJAS flow comparison with average JJAS flow for Lungtenphu and Tamchhu stations in Wangchhu basin

5. PUNATSANGCHU BASIN RIVER FLOW STATUS

5.1 Map showing annual average flow and river length for Punatsangchhu basin

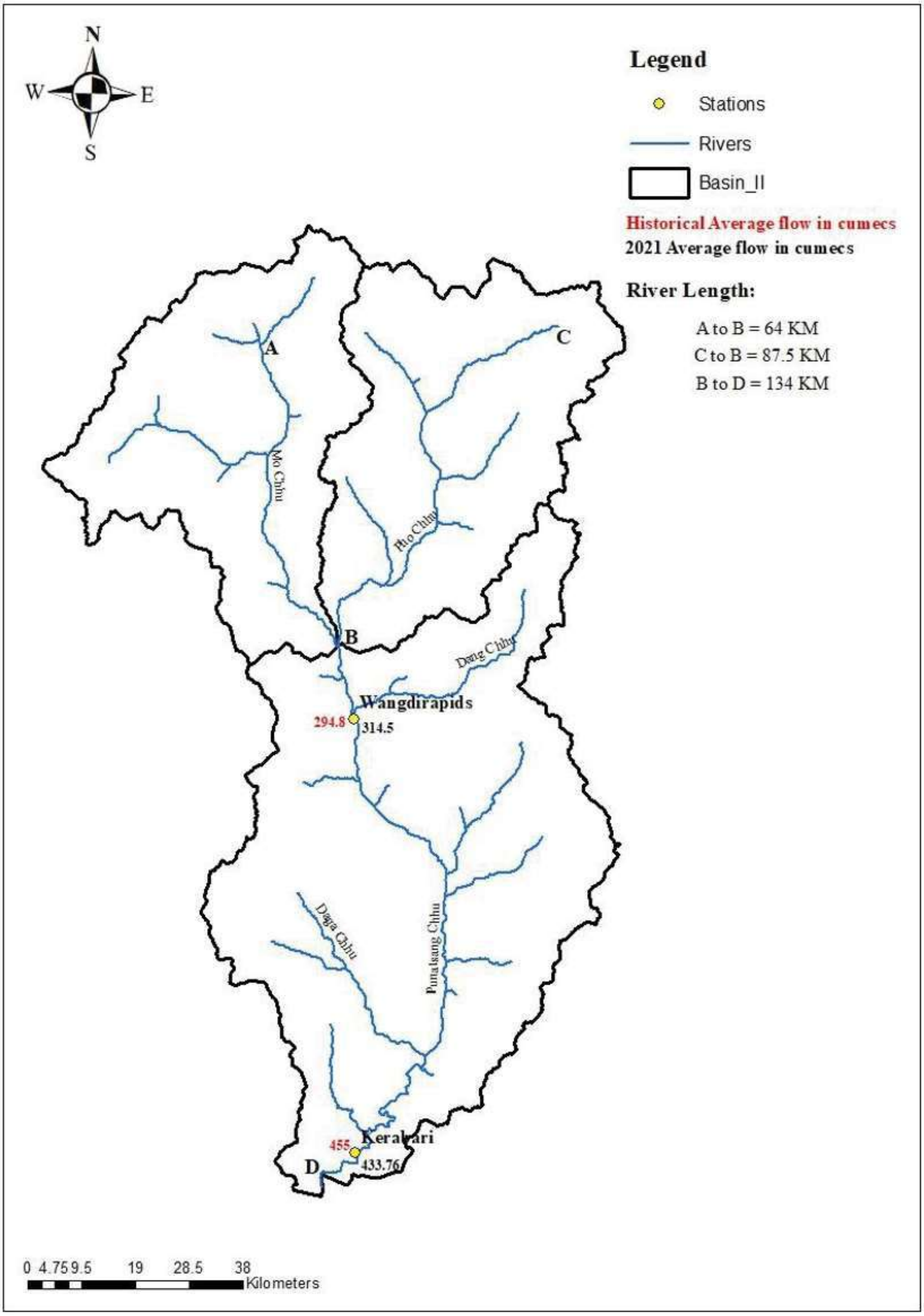


Figure 21: Annual average flow and river length for Punatsangchhu Basin

5.2 Station wise average monthly flow

The monthly average flow of 2021 is compared with the historical average monthly flow on Punatsangchhu basin from the observed data at Wangdirapids and Kerabari observation stations. In general, the average monthly flow of 2021 is observed to be below the historical average monthly flow for Punatsangchhu basin during pre monsoon (Jan-April), while during post monsoon (Oct-Dec), the flow is observed to be above the historical average monthly flow.

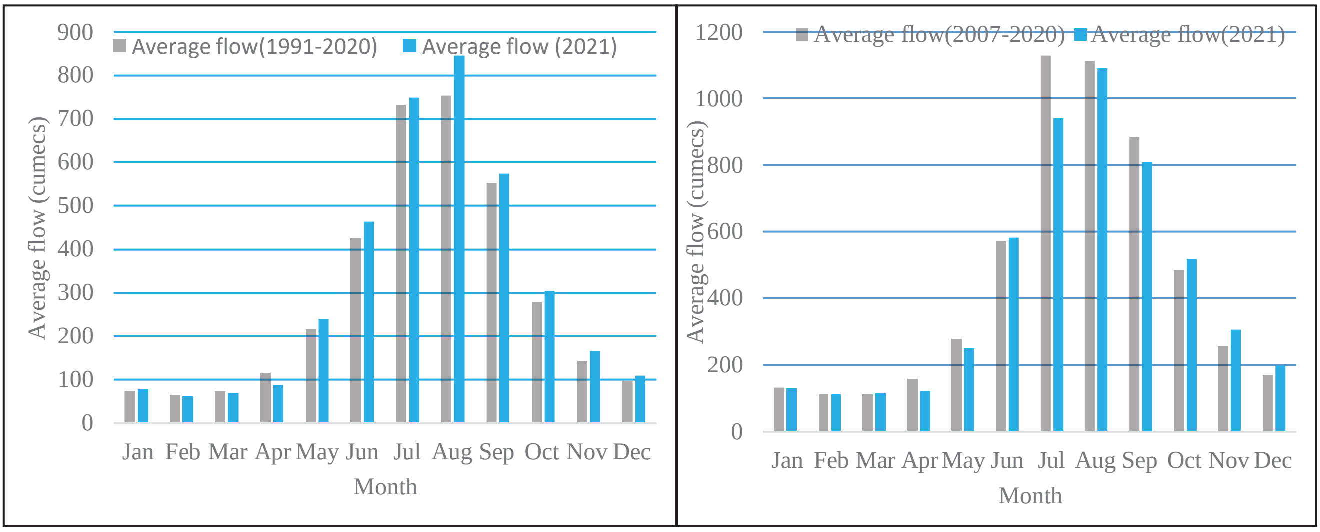


Figure 22: Monthly average flow comparison for Wangdirapids and Kerabari in Punatsangchhu basin

5.3 Station wise JJAS flow

The daily flow of Wangdirapids and Kerabari observation stations for the month of June, July, August and September (JJAS) were compared with the historical daily average flow. The figure 23 below indicates general daily flow variability for the monsoon (JJAS) period.

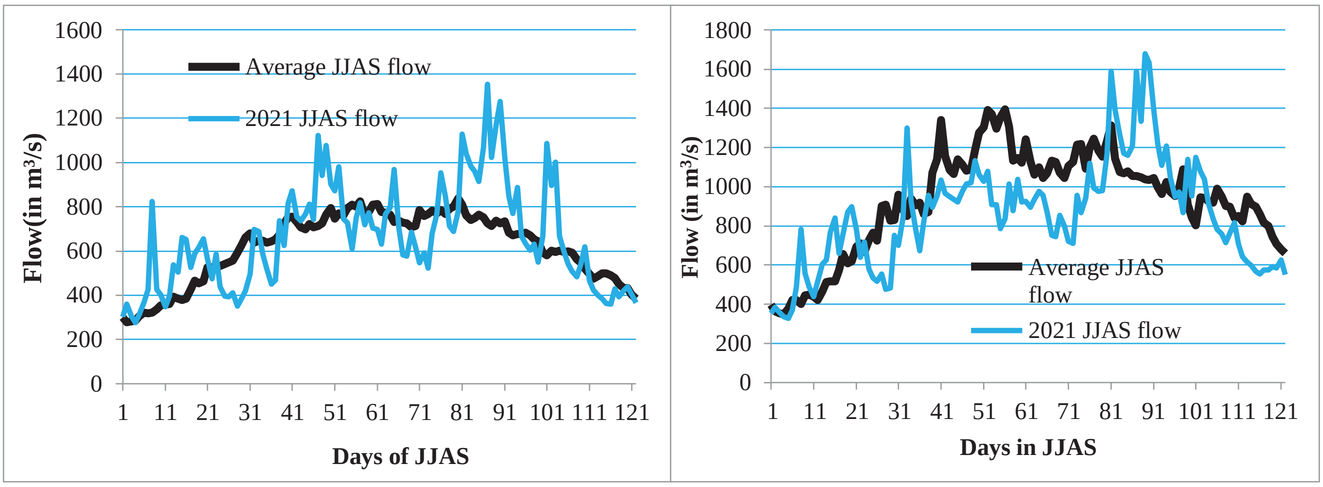


Figure 23: 2021 JJAS flow comparison with average JJAS flow for Wangdirapids and Kerabari stations in Punatsangchhu basin

6. MANAS BASIN RIVER FLOW STATUS

6.1 Map showing annual average flow and river length for Manas basin

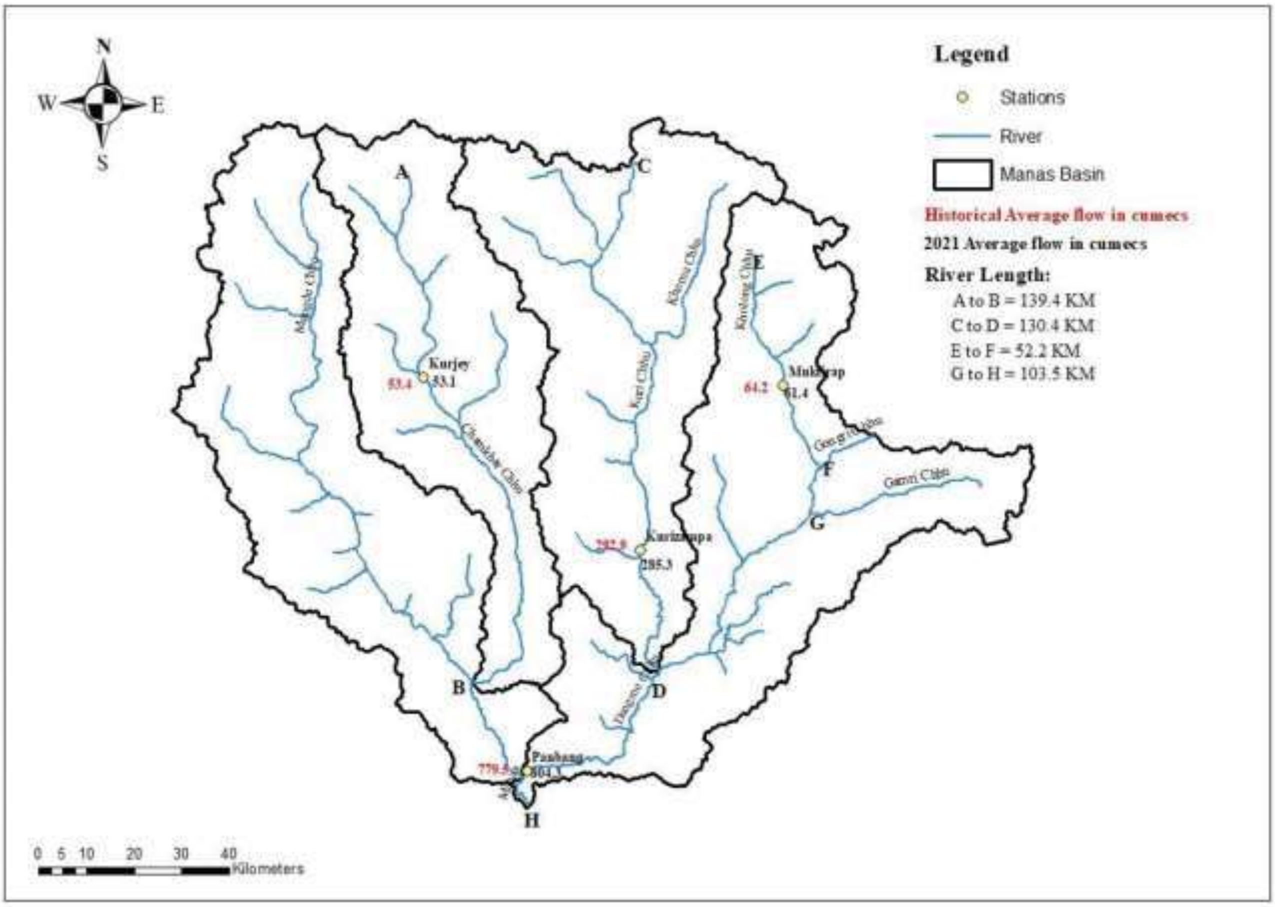


Figure 24: Annual average flow and river length for Manas Basin

6.2 Station wise average monthly flow

The monthly average flow of 2021 is compared with the historical average monthly flow on Manas basin from the observed data at Kurjey, Muktitrap, Kurizampa and Panbang observation stations. In general, the average monthly flow of 2021 is observed to be below the historical average monthly flow for Manas basin during pre monsoon (Jan-April), while during post monsoon (Oct-Dec), the flow is observed to be above the historical average monthly flow.

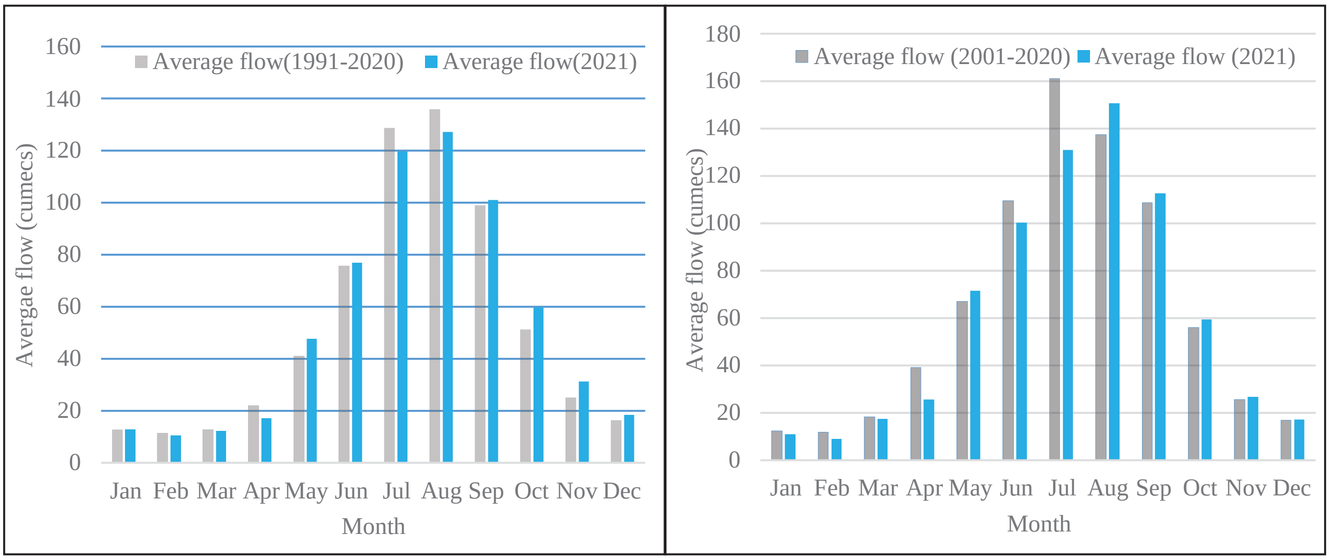


Figure 25: Monthly average flow comparison for Kurjey and Muktitrap stations in Manas basin

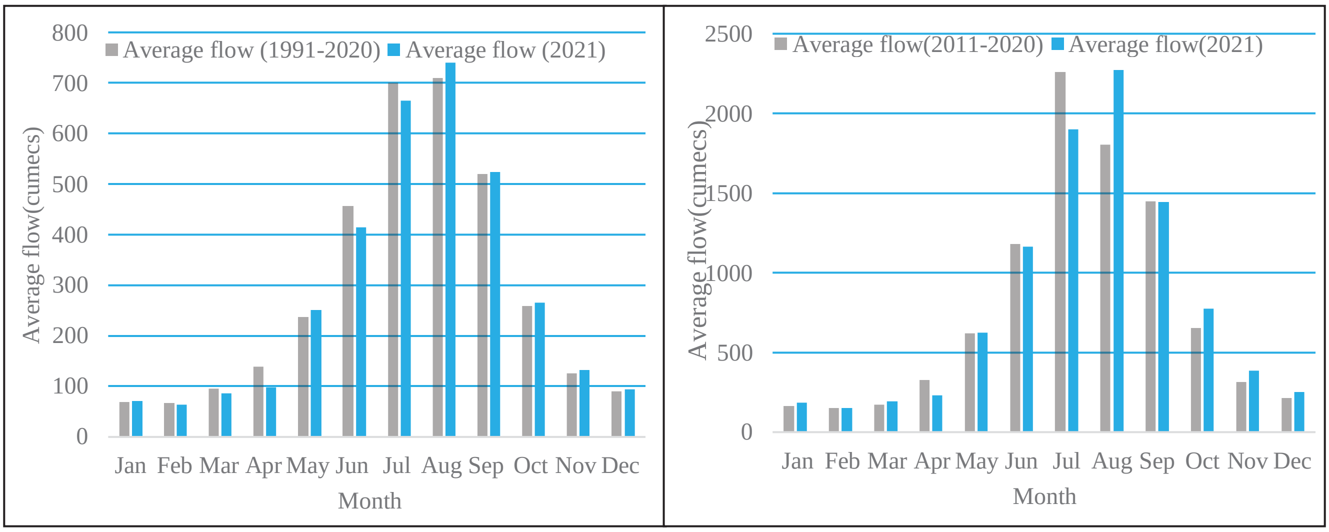


Figure 26: Monthly average flow comparison for Kurizampa and Panbang stations in Manas basin

6.3 Station wise JJAS flow

The daily flow of Kurjey, Muktitrap, Kurizampa and Panbang observation stations for the month of June, July, August and September (JJAS) were compared with the historical daily average flow. The figure 27 and 28 below indicate general daily flow variability for the monsoon (JJAS) period.

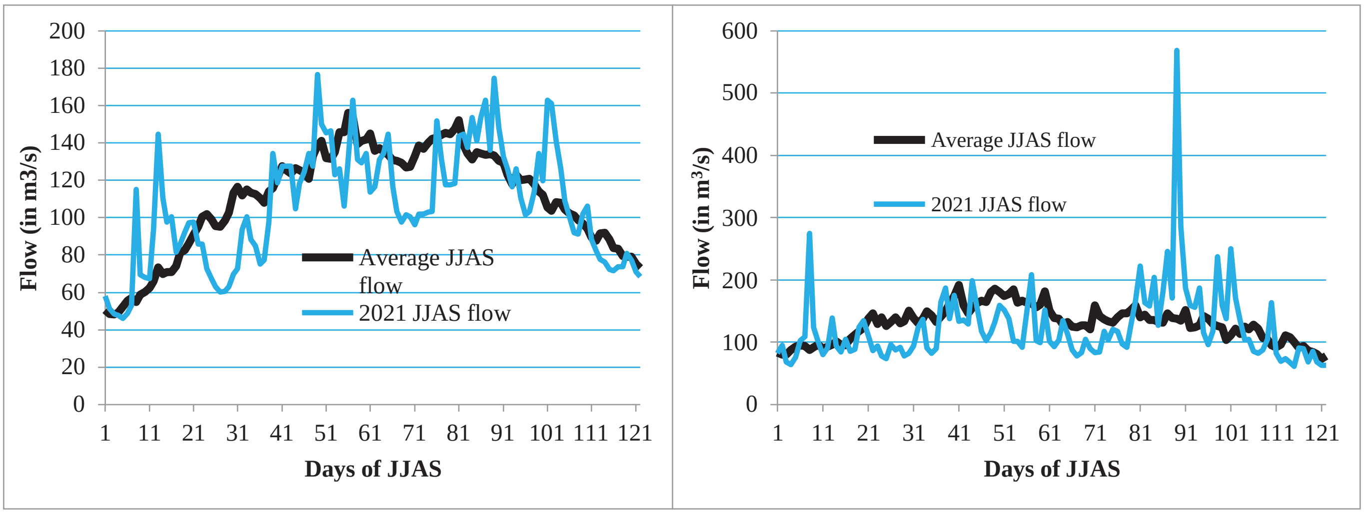


Figure 27: 2021 JJAS flow comparison with average JJAS flow for Kurjey and Muktitrap stations in Manas basin

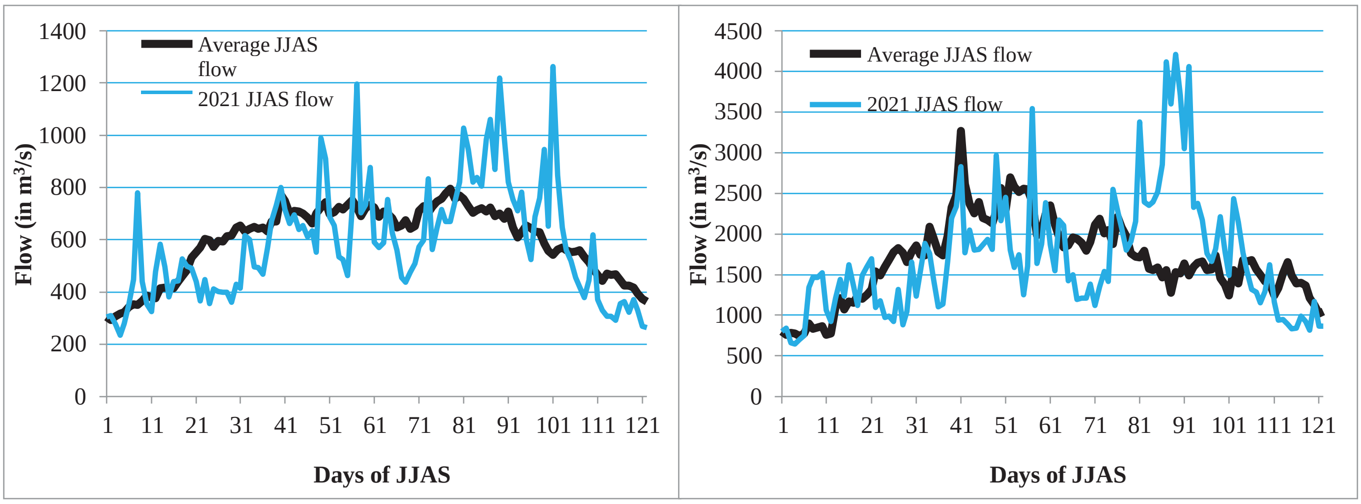


Figure 28: 2021 JJAS flow comparison with average JJAS flow for Kurizampa and Panbang stations in Manas basin

7. SUMMARY

Mean flow 2021:

In the Wangchhu basin, the Tamchhu and Lungtenphu stations observed slightly lower average flow in 2021 compared to historical average flow. In the Punatsangchhu basin, the Kerabari station observed lower average flow in 2021 compared to the historical flow, whereas Wangdirapids station observed slightly higher flow in 2021. While the Manas basin observed slightly lower flow in 2021 compared to the historical average flow.

JJAS flow 2021:

In the Wangchhu basin, the stations observed lower JJAS flow in 2021 compared to historical average flow of JJAS. In the Punatsangchhu, Wangdirapids station observed slightly higher JJAS flow in 2021 whereas the Kerabari Station observed lower JJAS flow in 2021. The Manas basin observed lower JJAS flow in 2021 compared to the historical average JJAS flow.

Maximum and minimum flow 2021:

In the year 2021, the maximum number of stations observed the occurrence of maximum flow in the month of August while most stations observed that the minimum flow occurred in the month of February.

SECTION C: CRYOSPHERE

1. GLACIERS

In 2018, the Cryosphere Services Division, National Centre for Hydrology and Meteorology started working on a special indigenous publication on Bhutan glacier inventory using recently available high-resolution satellite imageries such as Sentinel-2 (acquisition year: 2016) and was published in 2018. As per the publication (BGI, 2018), the glaciers with an area above or equal to 0.01 km^2 were considered, giving the total number of glaciers to be 700 covering an area of about 630 km^2. The status of glaciers given below are based on the BGI, 2018.

1.1 Basin-wise distribution

As per BGI, 2018 there are a total of 700 glaciers in Bhutan Himalaya covering a total area of 629.55 km^2. The highest number of glaciers are situated in Punatsang Chhu basin with 341 glaciers covering an area of 361.07 km^2 and the least is in Wang Chhu basin with 47 glaciers covering an area of 33.38 km^2. The glacier MMagr16_482 (G090443E28024) with a length of 15.56 km and having an area of 45.85 km^2 located in Mangde Chhu sub-basin is the largest glacier in Bhutan. Figure 29 and table 5 shows the glacier map and basin to sub-basin wise distribution of glaciers in Bhutan respectively.

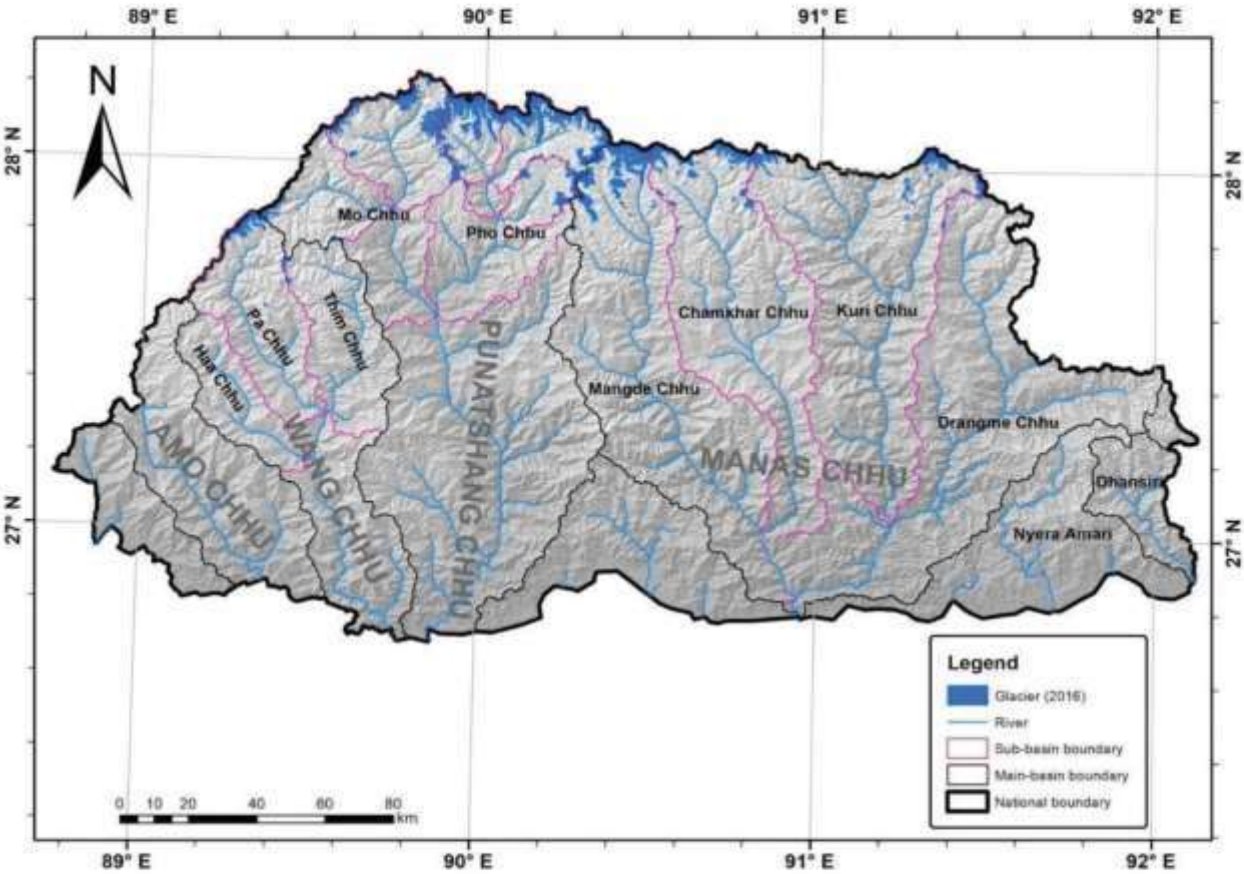


Figure 29: Sub-basin-wise distribution of glaciers of Bhutan. Pink polygons show the sub-basin boundary, dark blue polygons show the glaciers and light blue polygons are rivers of Bhutan

Table 5. Basin to sub-basin wise distribution of glaciers of Bhutan

Major Basin	Sub-basin	Glaciers (number)	Area (in km^2)
Wang Chhu	Ha Chhu	31	0.27
	Pa Chhu	13	28.39
	Thim Chhu	3	4.72
Punatsang Chhu	Mo Chhu	135	108.64
	Pho Chhu	206	252.42
Manas	Mangde Chhu	111	108.26
	Chamkhar Chhu	90	68.277
	Kuri Chhu	90	55.29
	Drangme Chhu	21	3.28
Total		**700**	**629.55**

2. GLACIAL LAKES

Cryosphere Services Division published an updated inventory on glacial lakes of Bhutan (BGLI, 2021). The study focused on semi-automated and manual delineation of glacial lake polygons using high-resolution satellite images referencing with polygons of other inventories. Among various criteria, BGLI, 2021 considered the area threshold of 0.01 km^2, elevation threshold of 3500 m a.s.l. and 2 km proximity threshold of lakes from the Little Ice Age moraine (Ukita et al., 2011). Total of 567 glacial lakes were identified covering an area of 55 km^2. Figure 30 shows the distribution of glacial lakes in Bhutan.

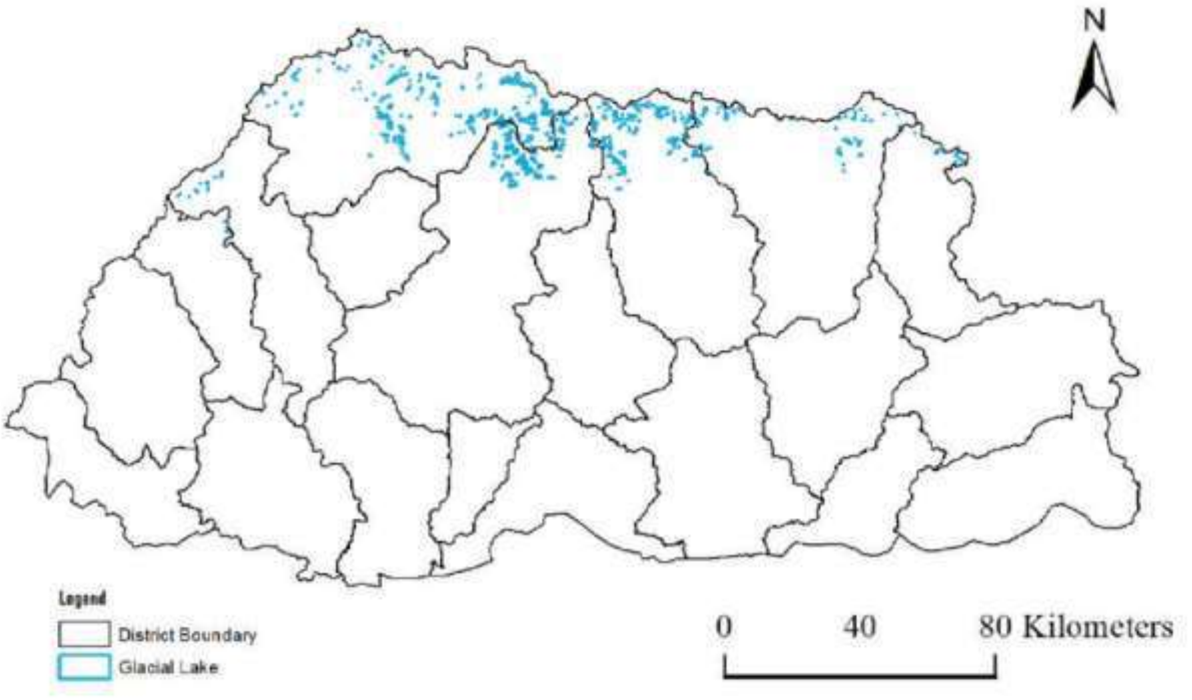


Figure 30: Distribution of glacial lakes in the northern frontiers of the country.
Blue polygons are the distribution of glacial lakes and the black polygons are district boundaries.

2.2 Basin-wise distribution

As per BGLI, 2021; there are a total of 567 glacial lakes in the Bhutan Himalayas covering a total area of 55.04 km^2. The highest number of glacial lakes are situated in Manas basin with 331 glacial lakes covering an area of 29.2 km^2 and the least in Wang Chhu basin covering an area of 0.6 km^2.

Table 6. Basin to sub-basin wise distribution of glacial Lakes of Bhutan

Major Basin	Sub-basin	Glacial lakes (number)	Area (in km^2)
Wang Chhu	Ha Chhu	0	0
	Pa Chhu	13	0.60456
	Thim Chhu	0	0
PunatsangChhu	Mo Chhu	66	4.254
	Pho Chhu	157	20.98
Manas	Mangde Chhu	130	11.8558
	Chamkhar Chhu	131	11.5627
	Kuri Chhu	61	5.00721
	Drangme Chhu	9	0.77262
Total		**567**	**55.0369**

3. POTENTIALLY DANGEROUS GLACIAL LAKES (PDGL)

The Cryosphere Services Division carried out field assessment on identified potentially dangerous glacial lakes on an annual basis and updated the list of potentially dangerous glacial lakes based on physical ground verification of the existing 25 potentially dangerous glacial lakes (NCHM, 2019). There were a few lakes which could not be ground verified due to accessibility issues and the status of those lakes remained as PGDL still and included in the updated list. According to the updated list, there are 17 PDGLs.

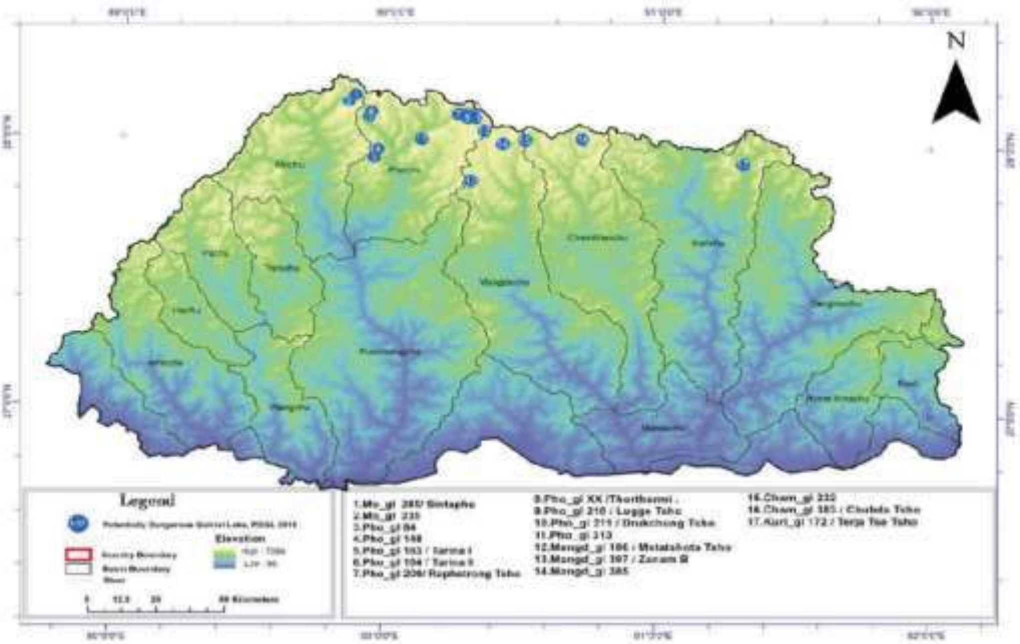


Figure 31: Sub-basin-wise distribution of potentially dangerous glacial lakes of Bhutan.

Table 7. Sub-basin wise distribution of potentially dangerous glacial lakes of Bhutan

Potentially Dangerous Glacial Lakes								
#	Lake Number	Local Name	Latitude	Longitude	Altitude	Area (m^2)	Volume (m^3)	Remarks
Mo Chu Sub-basin								
1	Mo_gl 37	Sintaphu	28° 10' 06.00	89° 51' 21.10	4480	238,314	6,410,000	PDGL
2	Mo_gl 39		28° 08' 35.40	89° 51' 21.10	4960	128,803	NA	PDGL
Pho Chhu Sub-basin								
3	Pho_gl 33	Tarina II	28° 06' 37.22	89° 54' 37.81	4338	446,325	13,000,000	PDGL
4	Pho_gl 32	Tarina I	28° 06' 06.43	89° 54' 11.83	4266	250,813	5,400,000	PDGL
5	Pho_gl 21		27° 58' 09.42	89° 56' 16.69	5072	637,422	26,310,000	PDGL
6	Pho_gl 8		27° 56' 48.53	89° 55' 14.03	4997	742,329	9,280,000	PDGL
7	Pho_gl 98		27° 59' 58.72	90° 07' 18.86	5049	211,705	NA	PDGL
8	Pho_gl 75	Raphstreng	28° 06' 43.56	90° 14' 03.65	4368	1,241,970	54,650,000	PDGL
9	Pho_gl 76	Thorthormi	28° 06' 19.90	90° 15' 48.46	4446	2,908,490	NA	PDGL
10	Pho_gl 77	Lugge	28° 05' 00.34	90° 18' 28.58	4570	1,460,870	65,190,000	PDGL
11	Pho_gl 78	Drukchung	28° 05' 40.45	90° 19' 11.95	4701	101,096	NA	PDGL
Mangdechhu Sub-basin								
12	Mang_gl 35	Metatshota	27° 53' 19.45	90° 17' 33.94	5065	1,203,880	41,740,000	PDGL
13	Mang_gl 81	Zanam B	28° 02' 21.01	90° 21' 58.87	5208	862,181	37,030,000	PDGL
14	Mang_gl 119		27° 58' 58.53	90° 26' 21.90	5089	248,574	NA	PDGL
Chamkhar Chhu Sub-basin								
15	Cham_gl 33		27° 59' 11.33	90° 30' 31.42	5205	188,550	NA	PDGL
16	Cham_gl 89	Chubda Tsho	28° 01' 25.91	90° 42' 31.77	4868	1,388,320	21,690,000	PDGL
Kurichhu Sub-basin								
17	Kuri_gl 140	Terja tse Tsho	27° 55' 47.56	91° 18' 08.77	4373	167,540	NA	PDGL

4. GLACIER MASS BALANCE

Bhutan has identified two benchmark glaciers for long-term monitoring for the understanding of glacier behaviors since 2003 and 2012 for Gangju La and Thana glaciers respectively. Over the observation periods, both the glaciers have exhibited negative mass balance indicating glacier ice mass loss. Table 8 shows the glacier mass balance data of Gangju La and Thana glacier over the observation periods.

Table 8. Glacier mass balance of Thana and Gangju La

Year	Gangju La (mm w.e. a^{-1})		Thana (mm w.e. a^{-1})	
	Direct	Geodetic	Direct	Geodetic
2003 – 04	-1230±230	–	–	–
2004 – 11	–	-1790±260	–	–
2011 – 12	–	-2040±460	–	–
2012 – 13	-1810±160	-2020±290	–	–
2013 – 14	-1110±160	-1120±310	–	–
2014 – 17	–	-1350	–	–
2016 – 17	–	–	-660	-930
2017 – 18	–	-2390	-1570	-1870
2018 – 19	–	1470	-1650	–
2019 – 20	–	1660	-2645	-2910

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