State of Climate Report 2024

National Centre for Hydrology and Meteorology
Royal Government of Bhutan
2025

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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

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Content

SECTION A: CLIMATE

1. OVERVIEW

Global Scenario: WMO State of the Global Climate 2024

As per the World Meteorological Organization (WMO) State of the Global Climate 2024, the global mean near-surface temperature for the year 2024 was around 1.60°C above the 1850–1900 baseline, used as an approximation of pre-industrial levels making it the first year to exceed 1.5°C above that level. The WMO evaluation is based on six global temperature datasets, as shown in Figure 1 below. 2024 surpassed the previous warmest year, 2023 by 0.12 °C.

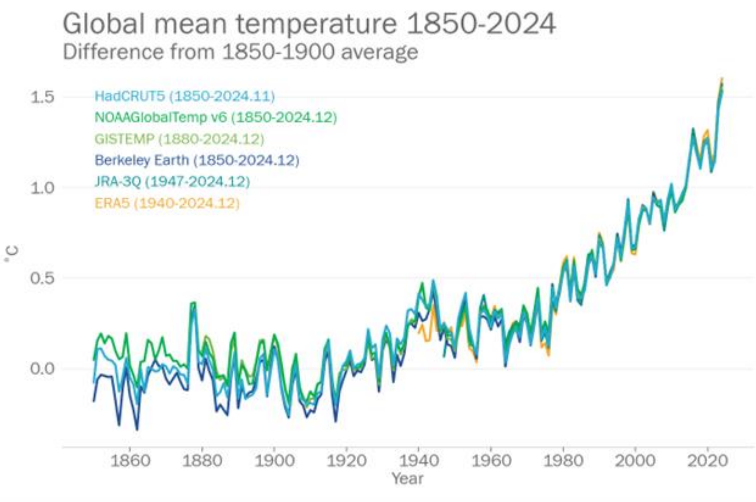


Figure 1: Global annual mean temperature difference from pre- industrial conditions 1850–1900 baseline for the six global temperature datasets 1850–2024.

The International Panel on Climate Change's sixth Assessment report states that a multi-year average was used to evaluate the long-term assessments of changes in the global mean temperature. The average for the years 2011 - 2020 was predicted to be 1.09 [0.95 - 1.20] °C warmer than the average for the industrial era between 1850 - 1900. The average is predicted to be 1.19 [1.07 - 1.31] °C for the 10-year period from 2014 - 2023, showing continued warming. The overall warmth of variations in temperature anomalies across the globe is shown in Figure 2.

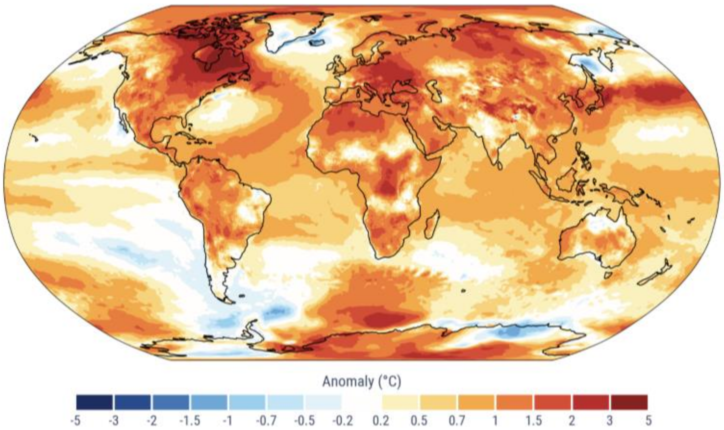


Figure 2: Near surface temperature differences between 2024 relative to the 1991-2020 long- term average.

2. CLIMATE HIGHLIGHTS - 2024

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.

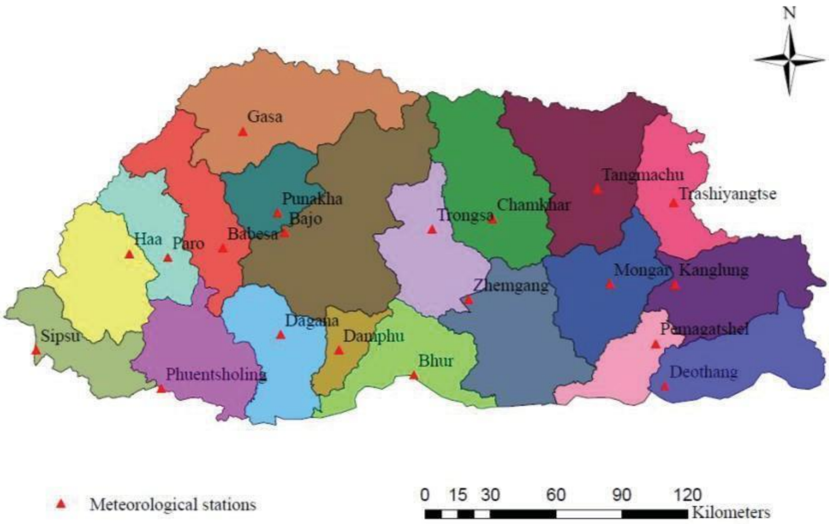


Figure 3: Location of Class A meteorological stations

2.2 Annual rainfall

The annual average rainfall (area average) was 1802.37 mm in 2024. The country as a whole received normal rainfall against the long-term average. The highest 24-hour rainfall was recorded at Phuntsholing with 210.6 mm. Gasa experienced the highest number of rainy days with 218 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 Phuentsholing with 6713.60 mm, Sipsu with 5040.90 mm followed by Bhur with 4539.80 mm.

2.3 Maximum and Minimum Temperature

The annual average maximum temperature was 23.31°C and minimum temperature was 12.51°C across the country. The highest daily maximum temperature was recorded at Bhur met station with 40.0°C and the lowest daily minimum temperature was recorded at Haa met station with -9.0°C. Haa experienced a greater number of days with the minimum temperature below or equal to zero with 131 days (minimum temperature <=0).

The annual average temperature for 2024 is the highest on record, surpassing the previous warmest year 2023 by 0.1 °C.

2.4 Monsoon Monitoring

Bhutan experiences the summer monsoon from June to September (JJAS). 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 2024, the country as a whole received normal rainfall against the long-term average 1996-2023. The peak was felt on July and mid-August and the drop was during mid September . The accumulated rainfall for the season (JJAS) was equivalent though.

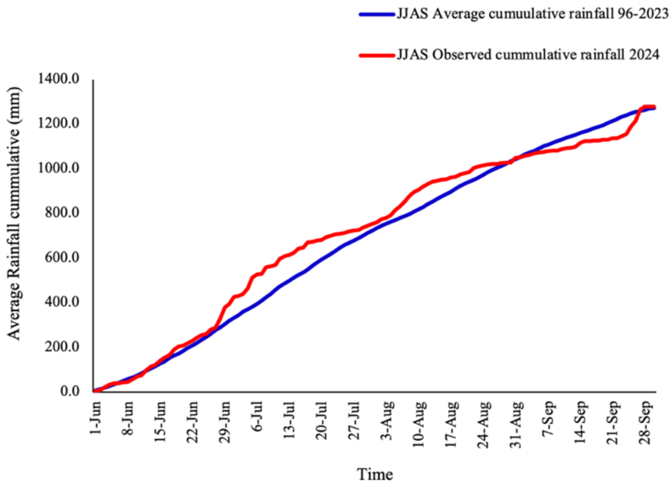


Figure 4: Observed rainfall of 2024 (JJAS) with long term average (1996-2023)

2.4.2 Temperature

During the summer of 2024, the country as a whole observed normal average temperature against the long-term average 1996-2023. The average temperature for JJAS 2024 was recorded 20.97 ^{o}C, 0.79 ^{o}C lesser than the normal average temperature for the summer.

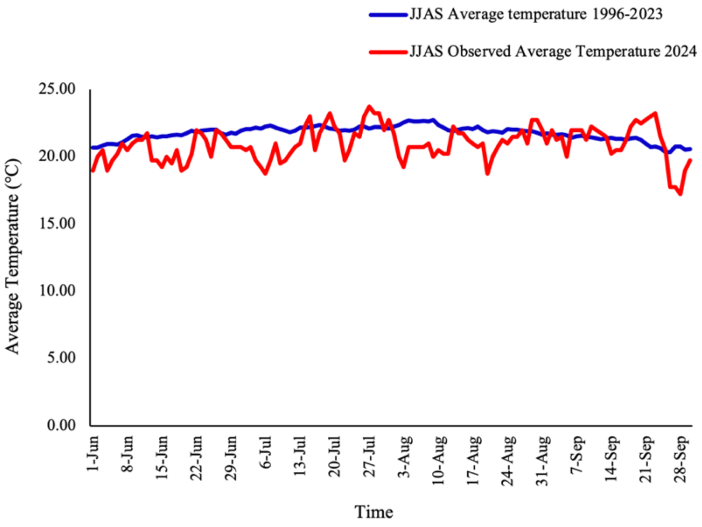


Figure 5: Observed average temperature of 2024 (JJAS) with long term average (1996-2023)

3. ANALYSIS OF TEMPERATURE - 2024

3.1 Maximum Temperature

A monthly climate monitoring report for the year 2024 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 2024. Meteorological stations such as Sipsu, Phuentsholing, Bhur, Punakha and Bajo experienced higher annual average maximum temperatures. Conversely, Haa, Gasa, Paro and Chamkhar stations have recorded lower annual average maximum temperatures.

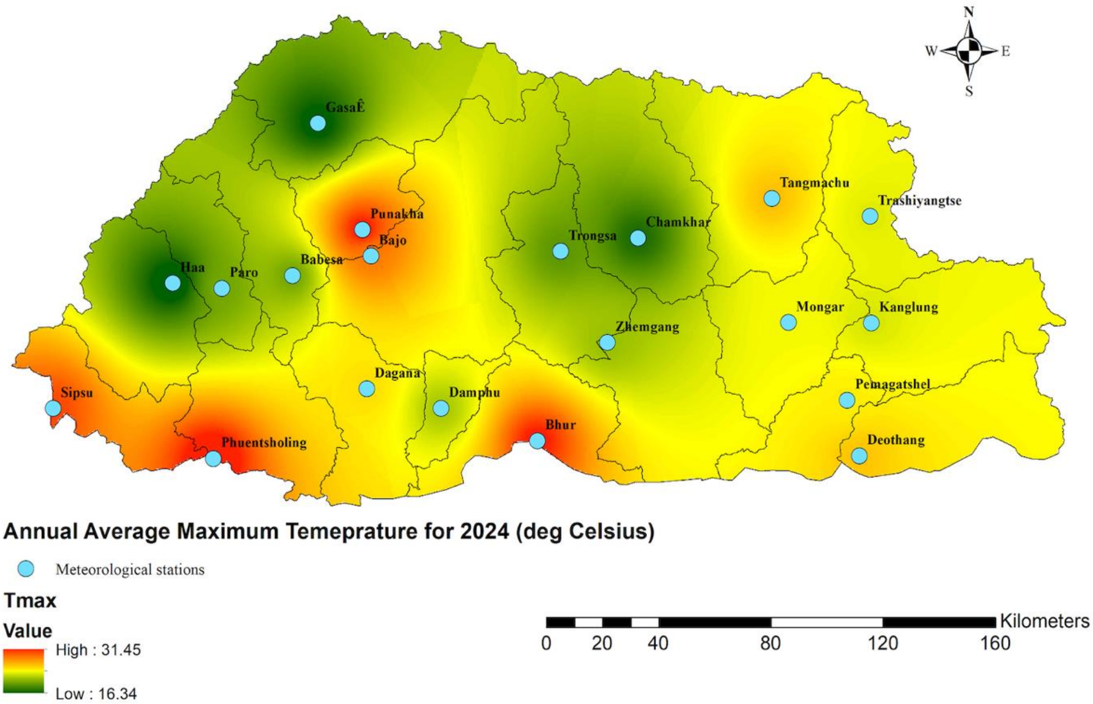


Figure 6: Spatial distribution of annual average maximum temperature for the year 2024

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.

3.1.2.1 Spring/ Pre-monsoon – March to May (MAM)

3.1.2.2 Summer/Monsoon – June to September (JJAS)

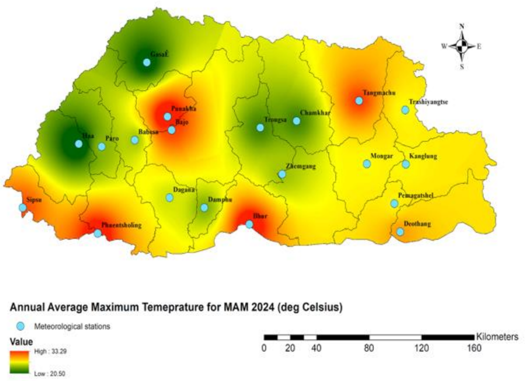
3.1.2.3 Autumn/Post-monsoon – October to November (ON)

3.1.2.4 Winter/Monsoon – December to February (DJF)

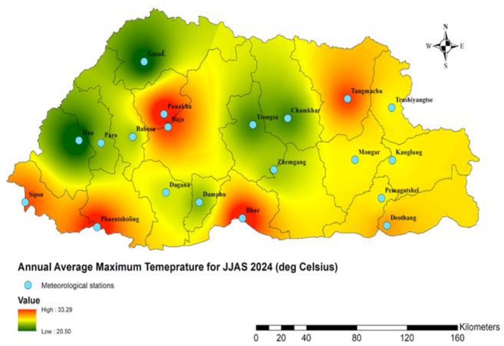
3.1.3 Seasonal spatial distribution average maximum temperature

The following maps (Figure 7) show the spatial distribution of seasonal average maximum temperature for the year 2024.

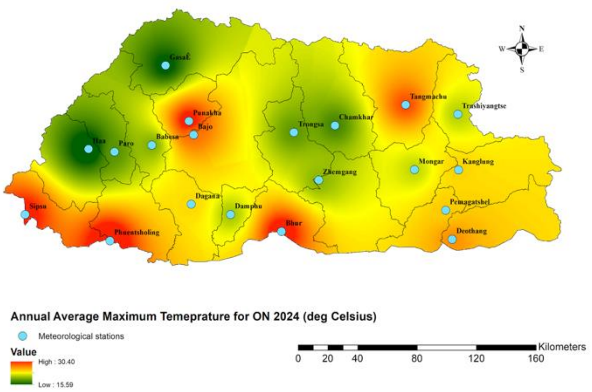
(a) Spring/Pre-monsoon (March-May)



(b) Summer/Monsoon (June-September)



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



(d) Winter/Monsoon (December-February)

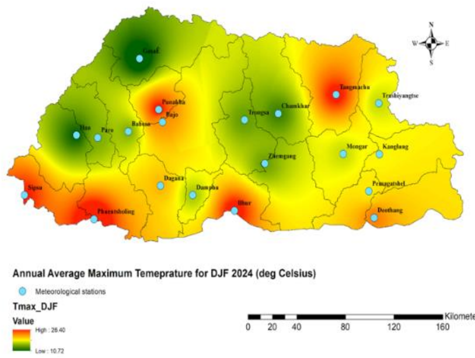


Figure 7: Spatial distribution of seasonal average maximum temperature for the year 2024

3.2 Minimum Temperature

A monthly climate monitoring report for the year 2024 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 2024. Meteorological stations such as Sipsu, Phuntsholing, Bhur, Deothang, Punakha, Bajo and Tangmachu experienced higher annual average minimum temperatures. However, Haa, Paro, Babesa, Gasa and Chamkhar stations have experienced lower annual average minimum temperatures.

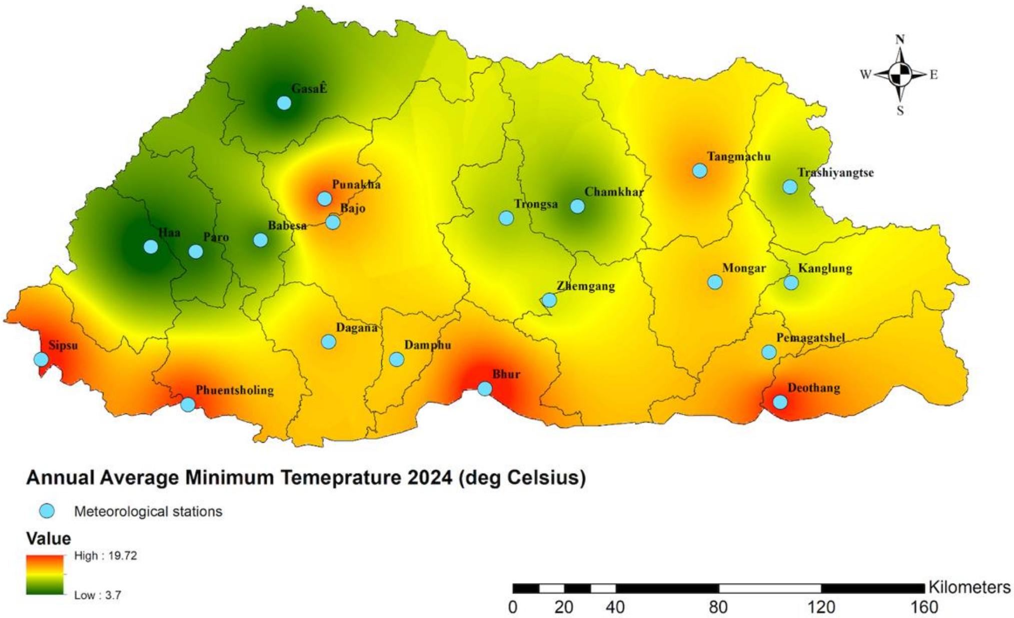
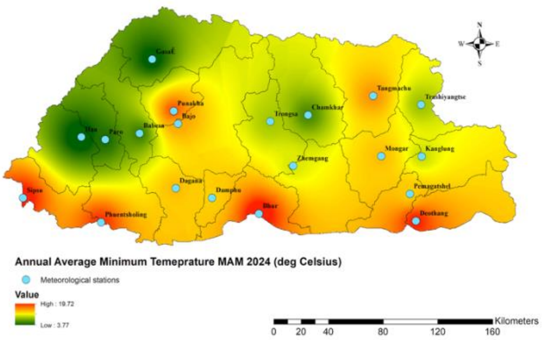


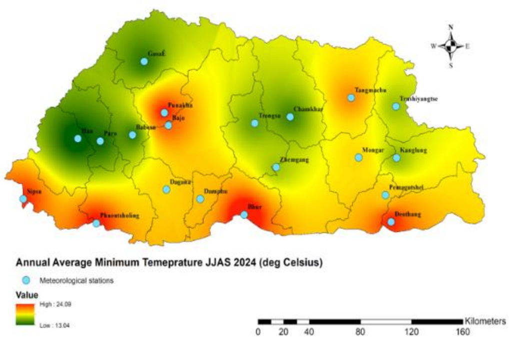
Figure 8: Spatial distribution of annual average minimum temperature for the year 2024

3.2.2 Seasonal spatial distribution of average minimum temperature

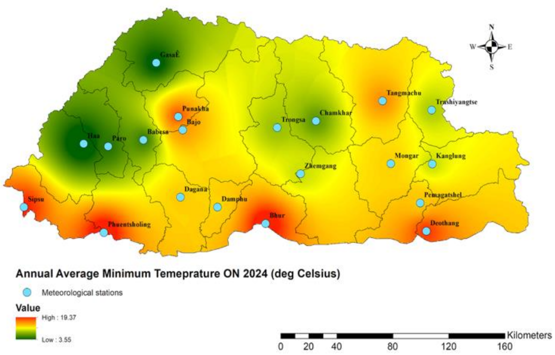
The following maps (Figure 9) show the spatial distribution of seasonal average minimum temperature for the year 2023.

(a) Spring/Pre-monsoon (March-May) (b) Summer/Monsoon (June-September)





(c) Autumn/Post Monsoon (October-November) (d) Winter/Monsoon (Dec-February)



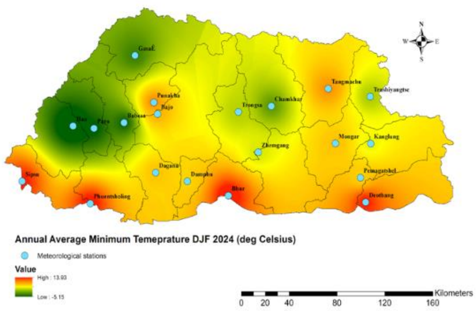


Figure 9: Spatial distribution of seasonal average minimum temperature for the year 2024

4. ANALYSIS OF RAINFALL - 2024

A monthly climate monitoring report for the year 2024 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 2024.

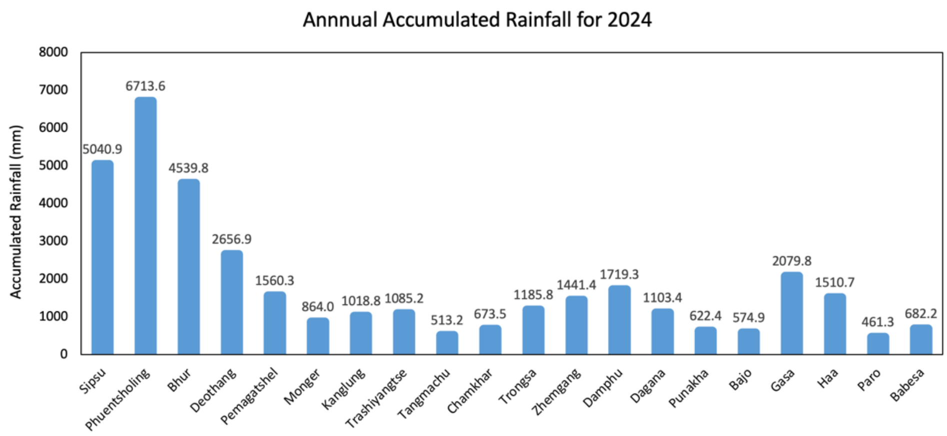
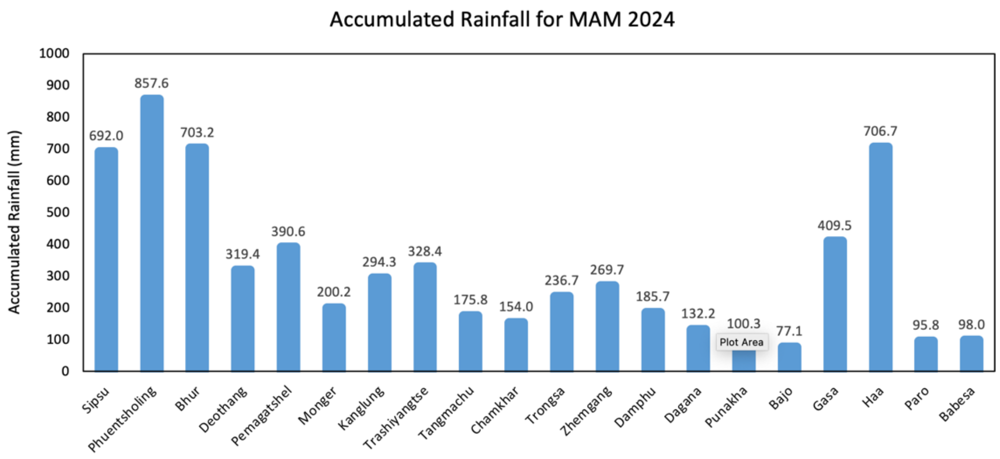


Figure 10: Annual accumulated rainfall for the year 2024

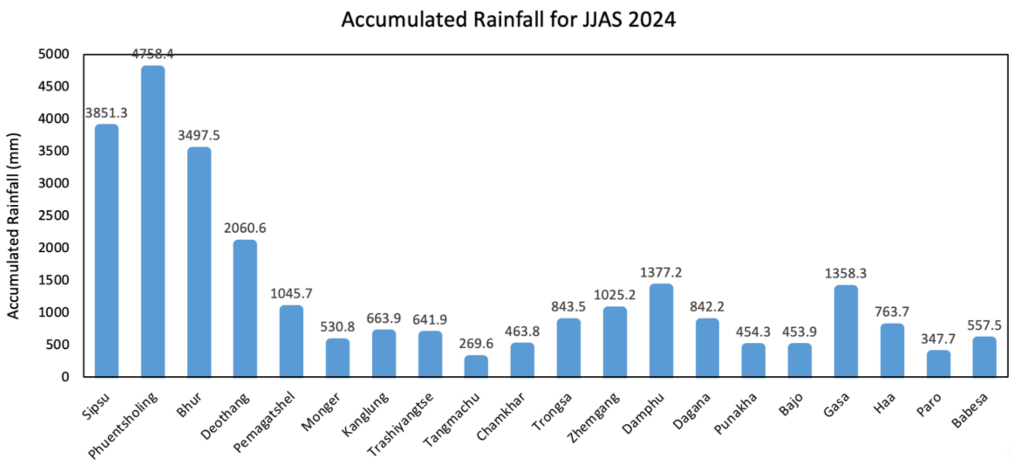
4.2 Seasonal spatial distribution of accumulated rainfall

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

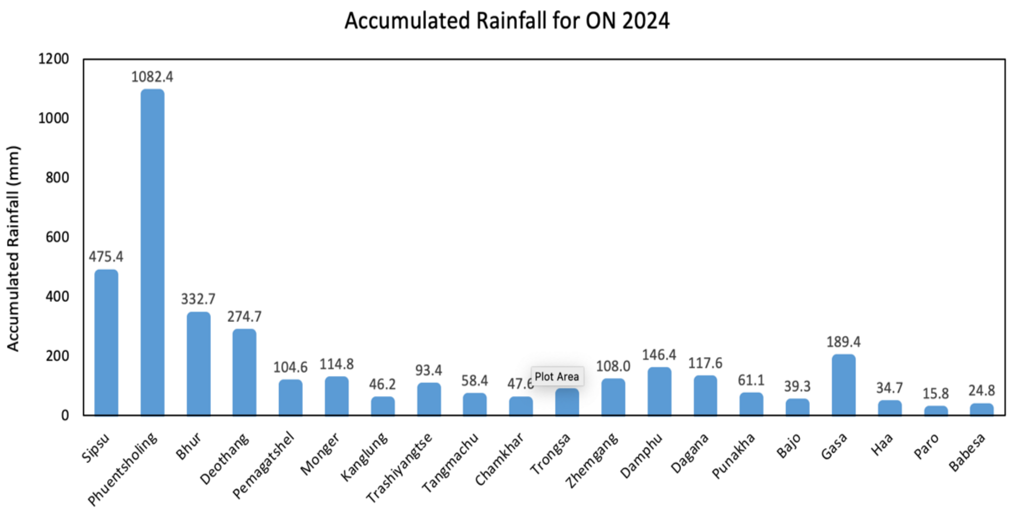
a. Spring/Pre-monsoon (March-May)



b. Summer/Monsoon (June-September)



c. Autumn/Post Monsoon (October-November)



d. Winter/Monsoon (December)

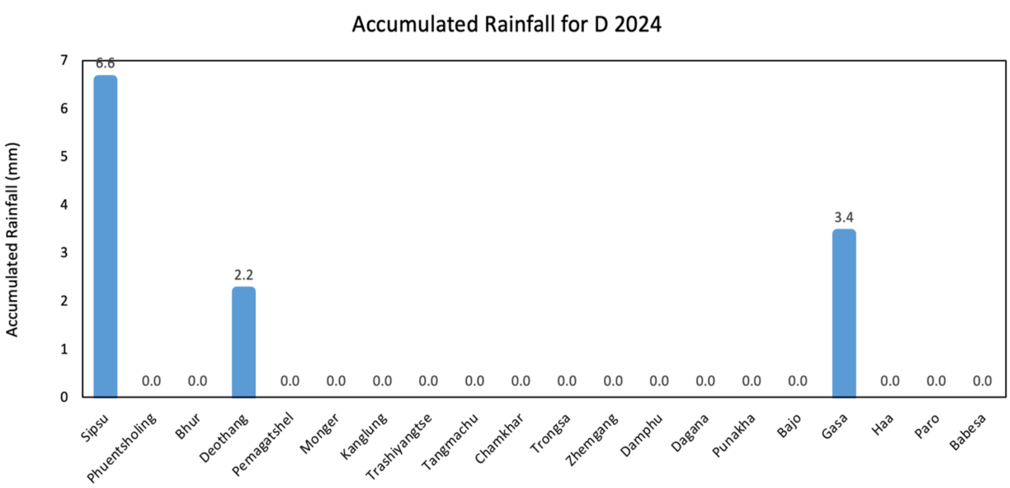
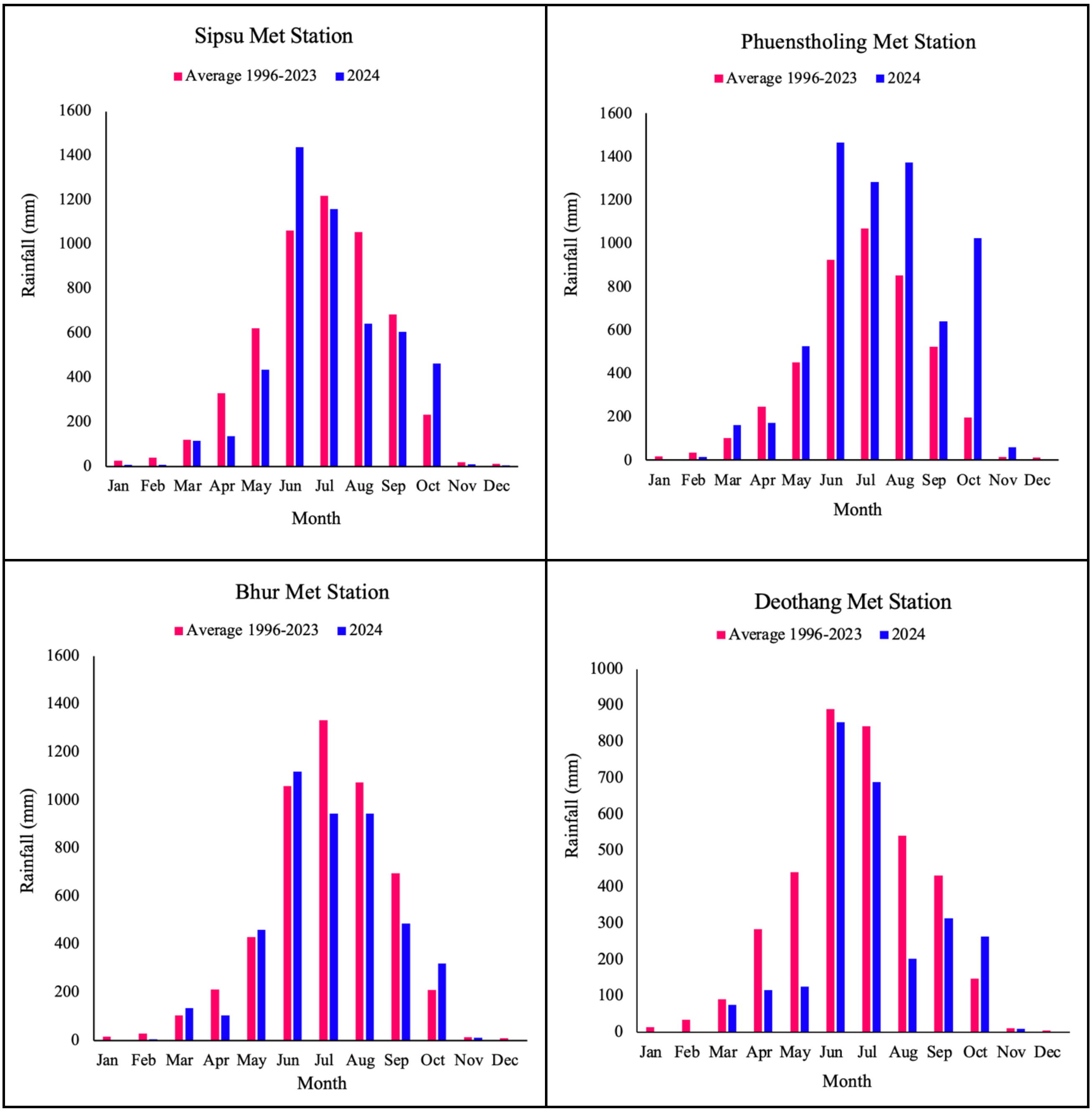
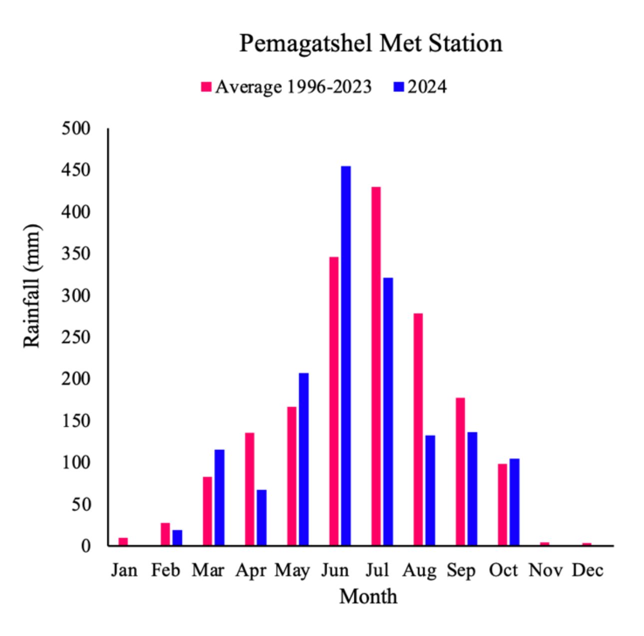


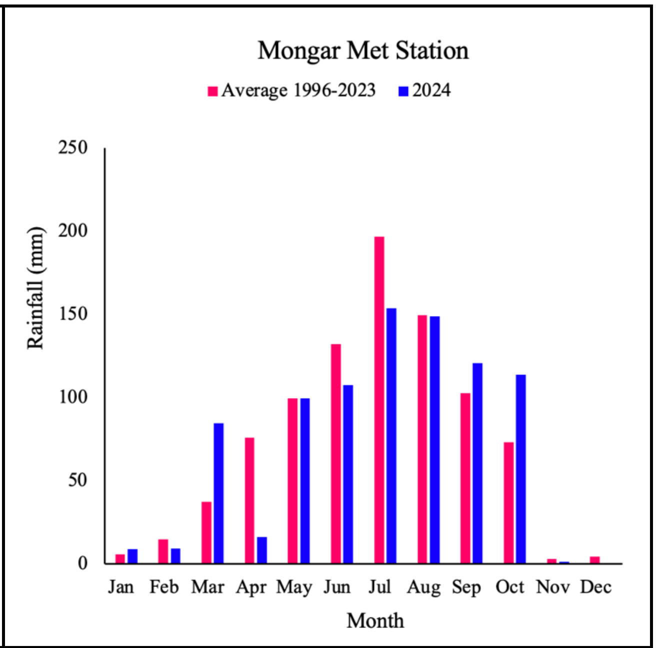
Figure 11: Spatial distribution of seasonal accumulated rainfall for the year 2024

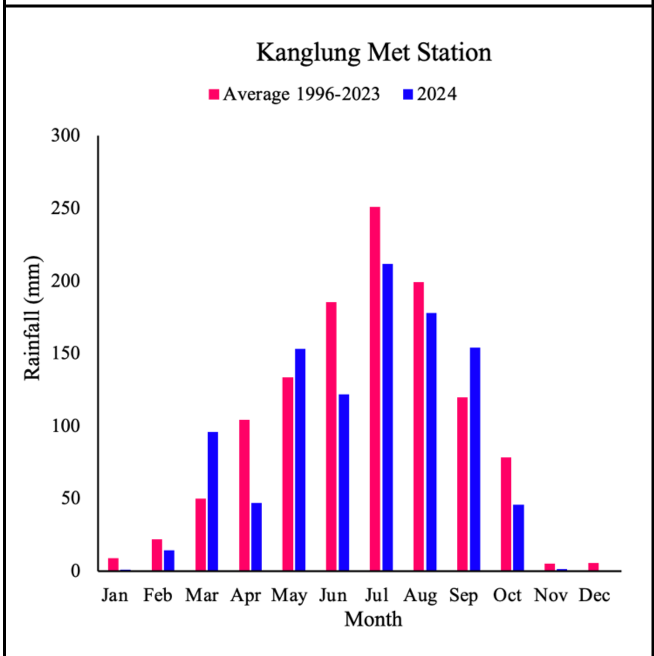
4.3 Comparison of monthly accumulated rainfall against long term average

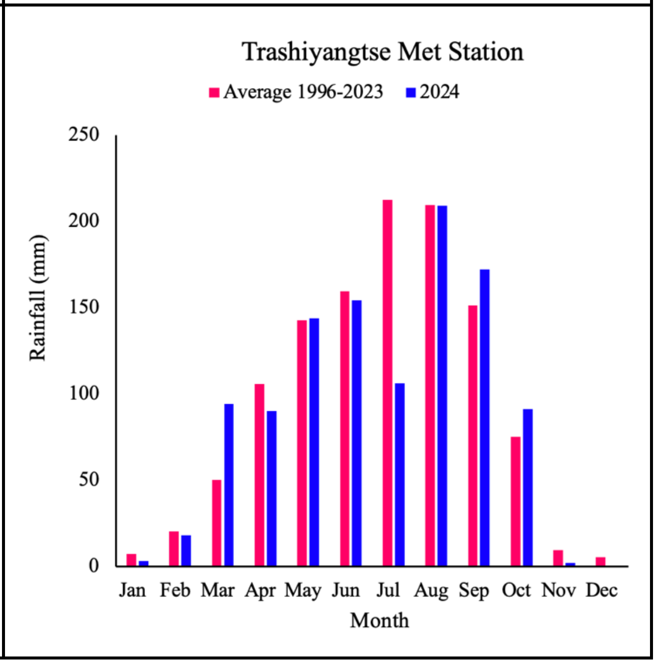
The following figures show the comparison of monthly accumulated rainfall of the year 2024 with their long-term average. Please note that the long-term averaging period in each station varies based on the data availability.

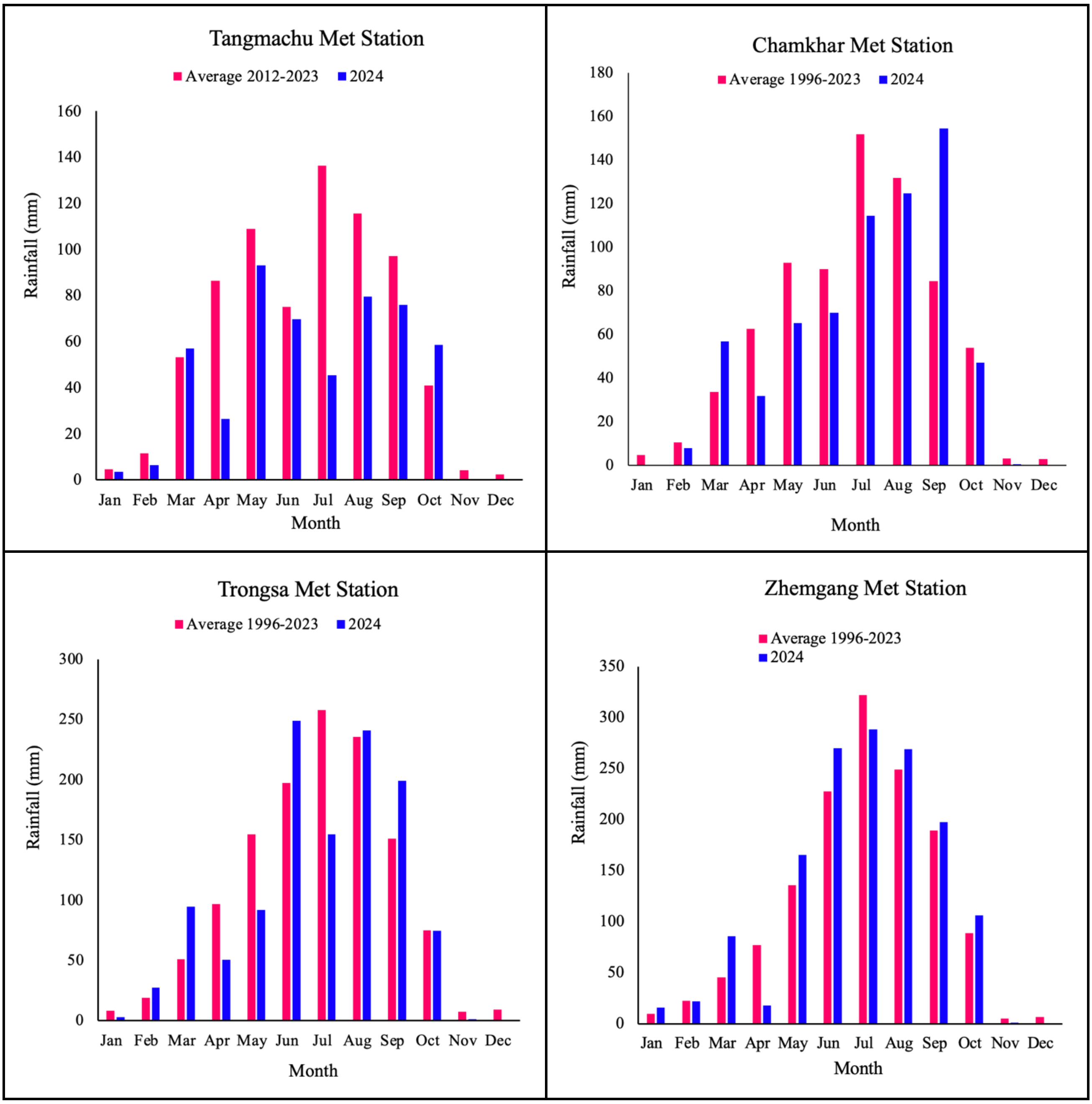


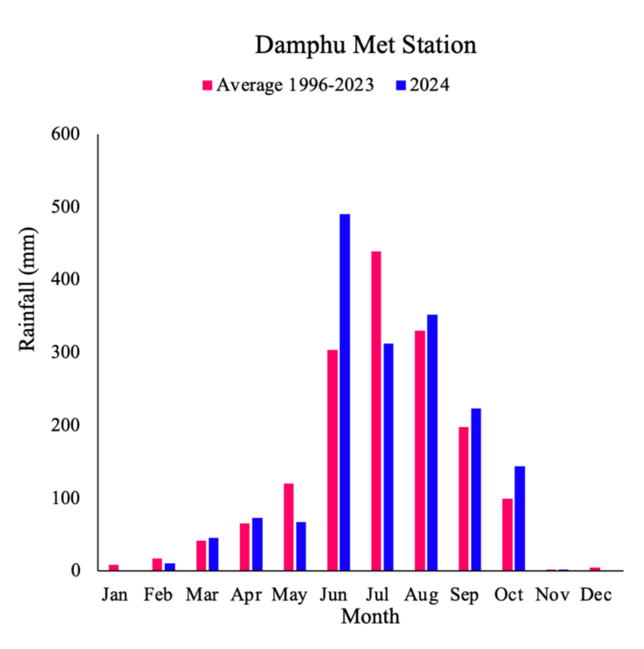

Pemagatshel Met Station
Average 1996-2023
2024
500
450
400
350
300
250
200
150
100
50
0
Rainfall (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

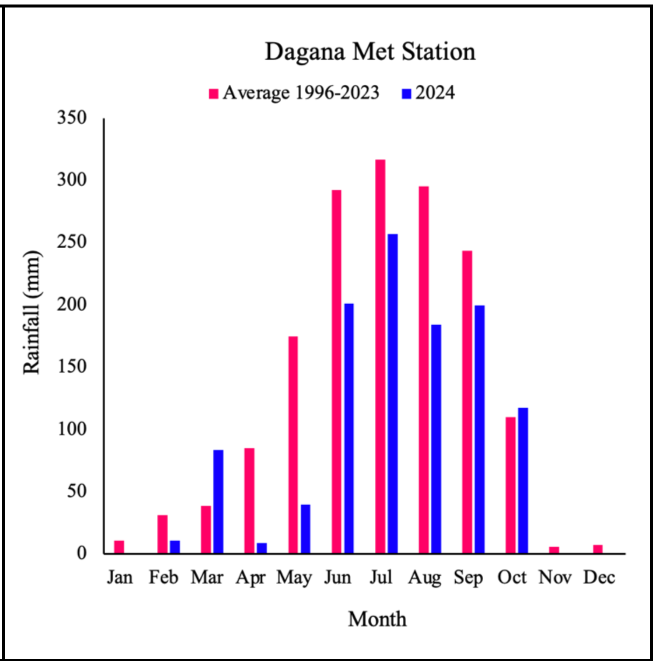

Mongar Met Station
Average 1996-2023
2024
250
200
150
100
50
0
Rainfall (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

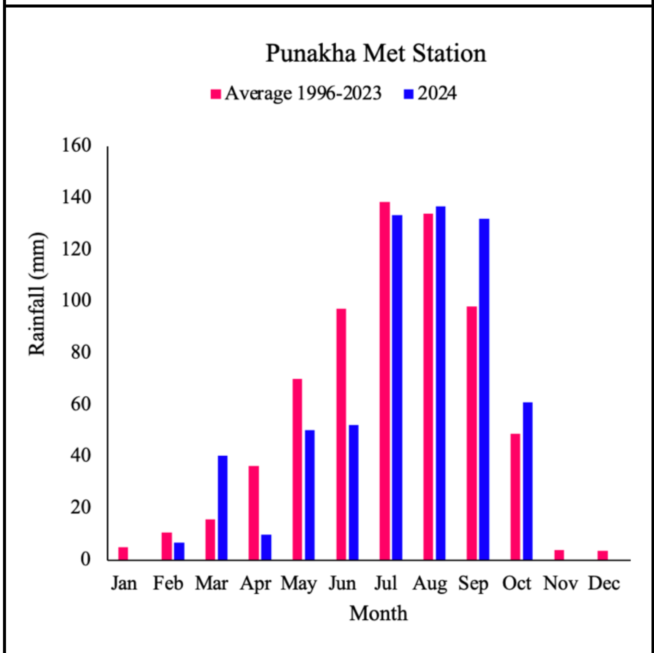

Kanglung Met Station
Average 1996-2023
2024
300
250
200
150
100
50
0
Rainfall (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

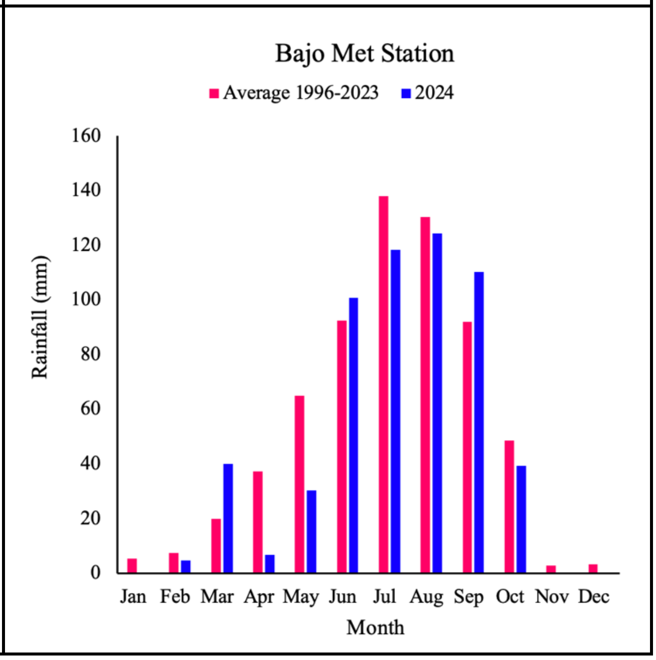

Trashiyangtse Met Station
Average 1996-2023
2024
250
200
150
100
50
0
Rainfall (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Tangmachu Met Station
Average 2012-2023
2024
Rainfall (mm)
0
20
40
60
80
100
120
140
160
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Chamkhar Met Station
Average 1996-2023
2024
Rainfall (mm)
0
20
40
60
80
100
120
140
160
180
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Trongsa Met Station
Average 1996-2023
2024
Rainfall (mm)
0
50
100
150
200
250
300
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Zhemgang Met Station
Average 1996-2023
2024
Rainfall (mm)
0
50
100
150
200
250
300
350
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Damphu Met Station
Average 1996-2023
2024
Rainfall (mm)
0
100
200
300
400
500
600
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Dagana Met Station
Average 1996-2023
2024
Rainfall (mm)
0
50
100
150
200
250
300
350
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Punakha Met Station
Average 1996-2023
2024
Rainfall (mm)
0
20
40
60
80
100
120
140
160
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Bajo Met Station
Average 1996-2023
2024
Rainfall (mm)
0
20
40
60
80
100
120
140
160
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

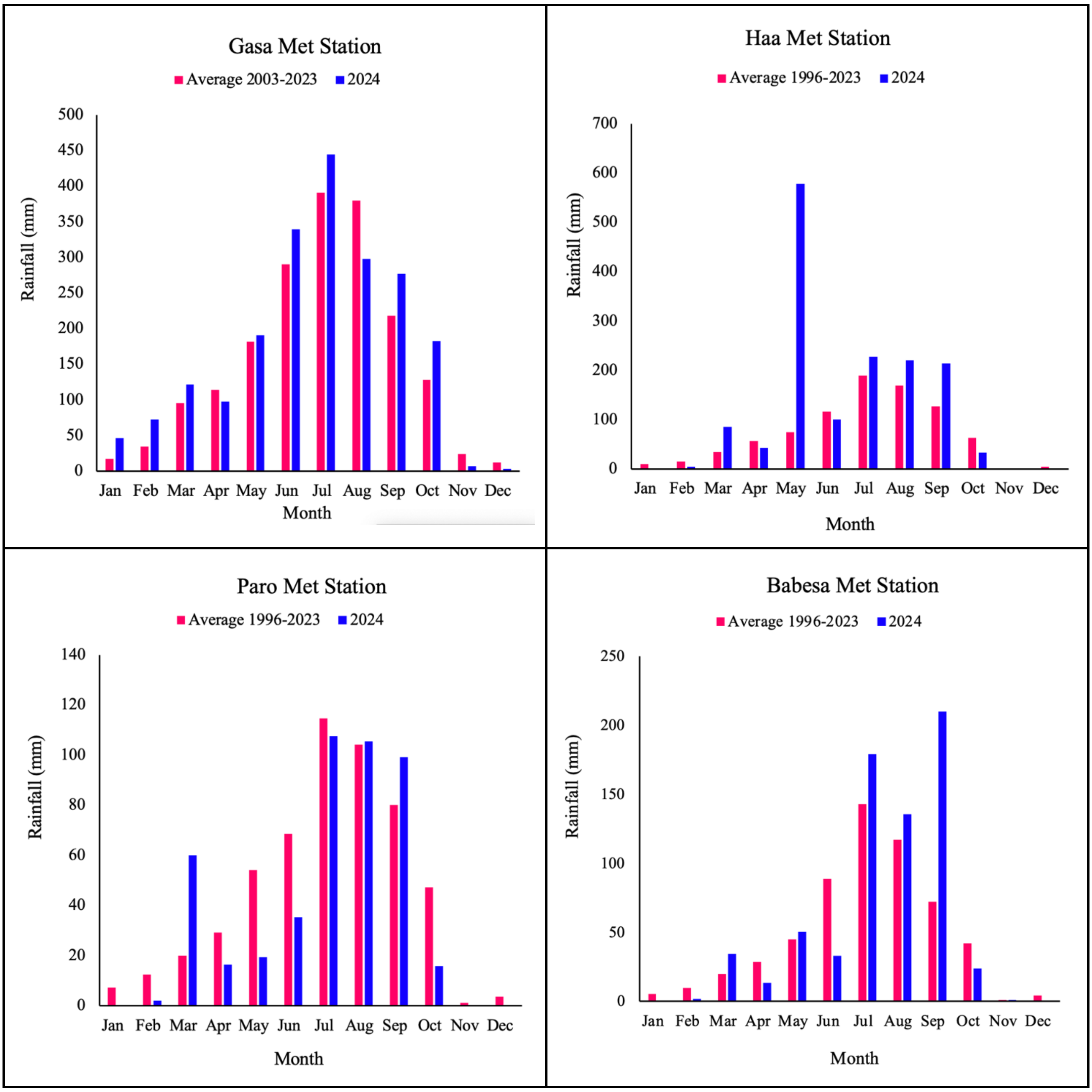


Figure 12: Comparison of total monthly rainfall of observed 2024 with long term average

5. ANNUAL STATISTICS

5.1 Annual statistics for 20 Agrometeorological stations – 2024

Table 1. Annual statistics for 20 Agrometeorological stations

Station	Annual total rainfall (mm)	Annual average maximum temp (°C)	Annual average minimum temp (°C)	Number of days with rainfall>=1mm	Number of days with Tmax>=30	No. of days with Tmin<=0
Sipsu	5040.90	28.24	18.23	153	144	0
Phuentsholing	6713.60	30.08	18.20	166	215	0
Bhur	4539.80	29.49	19.42	132	189	0
Deothang	2656.90	25.62	17.99	96	59	0
Pemagatshel	1560.30	23.77	13.54	97	30	0
Mongar	864.00	22.65	13.74	97	30	0
Kanglung	1018.80	23.11	10.98	97	17	0
Trashiyangtse	1085.20	22.50	10.16	139	17	28
Tangmachu	513.20	26.42	15.23	84	109	0
Chamkhar	673.50	18.54	8.03	105	0	60
Trongsa	1185.80	19.57	10.07	138	0	7
Zhemgang	1441.40	20.85	10.98	125	1	0
Damphu	1719.30	21.22	13.49	97	1	0
Dagana	1103.40	23.85	13.76	92	16	0
Punakha	622.40	29.75	16.93	83	212	0
Bajo	574.90	26.72	14.66	79	115	0
Gasa	2079.80	16.93	6.43	218	0	69
Haa	1510.70	16.22	4.68	137	0	131

Paro	461.30	20.07	6.43	74	6	104
Babesa	682.20	20.52	7.26	85	1	83

5.2 Extreme records for 20 Agrometeorological stations - 2024

Table 2. Annual extremes for 20 Agrometeorological stations

Station	24 hour Rainfall (mm)	Date of occurrence	Maximum temperature (°C)	Date of occurrence	Minimum temperature (°C)	Date of occurrence
Sipsu	178.2	29th June	37.0	21st and 23rd September	1.0	3rd February
Phuentsholing	210.6	7th May	39.5	26th May	7.0	7th February
Bhur	171.8	5th July, 5th August	40.0	25th May, 23rd September	8.0	22nd January
Deothang	165.0	29th June	35.0	23rd-24th September	8.5	7th February
Pemagatshel	194.4	28th June	36.0	22nd September	3.0	22nd and 26th and 28th January, 4th February
Mongar	53.8	22nd August	33.0	26th May	4.0	26th and 28th January
Kanglung	64.6	5th July	32.0	22nd September	1.0	6th February
Trashiyangtse	58.0	14th September	32.0	21st September	-1.5	1st- 2nd and 13th-15th January, 11th-12th February, 18th-19th December
Tangmachu	27.6	21st March	37.0	21st September	4.5	15th January
Chamkhar	40.1	5th August	28.0	7th September	-8.0	15th January

Trongsa	56.0	21st June	28.5	23rd September	-0.5	15th January, 24th February
Zhemgang	81.6	7th August	30.0	12th September	0.5	22nd, 25th-26th January
Damphu	198	29th June	30.0	22nd September	0.5	26th January
Dagana	56.6	27th September	33.5	25th May	3.0	26th January, 7th February
Punakha	29.5	22nd May	38.5	28th May	4.0	18-19th December
Bajo	49.5	17th July	35.5	26th May	2.0	18th December
Gasa	58.6	17th July	26.5	26th May, 15th July	-5.0	5th, 7th, 22nd - 23rd, and 27th January, 3rd February, 23rd and 25th December
Haa	70.8	27th September	26.0	15th, 19th-20th July	-9.0	24th December
Paro	39.0	20th March	30.0	26th May, 15th, 19th, 26th,27th, 30th July	-6.0	7th-8th and 10th February, 13-14th, 24-25th December
Babesa	50.6	27th September	30.0	29th July	-5.5	24th February

SECTION B: HYDROLOGY

1. MAJOR FACTORS INFLUENCING RIVER FLOW VARIABILITIES IN BHUTAN

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. A 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.

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.

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. EXTREME HYDROLOGICAL EVENTS RECORDED IN 2024

Sl. No	Flood Event Location	Date of Occurrence	Flood Classification	Causative Factors	Impact and Damages
1	Flash flood at Jakar Rongchhu, Lamai Goenpa, Bumthang	5/8/2024	Flash Flood	Heavy rainfall	Water source of Chamkhar town damaged, washed away, wooden footbridges, some agriculture fields were inundated
2	Flash flood at Dechencholing, Thimphu	10/8/2024	Flash Flood	Convective Thunderstorm	Inundated RBG campus, caused blockages in toilets and mud in houses, drinking water pipelines were destroyed, electricity disrupted in some parts of the area, submerged about 40 vehicles and washed away a hut affecting 23 huts.
3	Flash flood at Beta Rongchhu, Gangtey, Wangdue Phodrang	18/08/2024	Flash Flood	Heavy rainfall	Washed away water transmission pipe of Beta Primary school, damaged water source of seven households, damaged gabion wall of a farm road
4	Flash flood at Pugli, Phuntshopelri, Samtse	11/10/2024	Flash Flood	Torrential rainfall	Damaged crops and house belonging to two elderly residents

Table 3. Extreme events recorded in 2024

3. ANNUAL FLOW OF 2024 COMPARED WITH THE HISTORICAL FLOW

The annual average flow from recorded data as early as 1992-2023 is compared to the average flow of 2024 for stations located across Bhutan. Each station is located in different basins but does not serves as the representative flow of the whole basin. The following table shows the details.

Table 4. Comparative flow in each basin

Sl. No	Station Name	Basin/Sub Basin	Historical Average flow (till 2023) in m^3/s	Average flow 2024 in m^3/s
1	Tamchu	Wangchhu	58.9	52.2
2	Lungtenphu	Wangchhu	21.9	20
3	Kerabari	Punatsangchhu	449	423.4
4	Wangdirapids	Punatsangchhu	296	273.4
5	Yebesa on Mochhu	Punatsangchhu	113.2	92.4
6	Kurjey on Chamkhar	Manas	53.1	47.3
7	Muktirap on Kholongchhu	Manas	63.6	57.2
8	Sumpa on Kurichhu	Manas	173.6	189.8
9	Kurizampa on Kurichhu	Manas	291.2	260.5
10	Panbang on Drangmechhu	Manas	781.4	734.3

4. MAXIMUM AND MINIMUM FLOW RECORDED IN 2024

Table 5. Maximum and Minimum flow record

Sl. No	River basin	Station Name	Catchment area in sq.km	Max flow in m^3/s	Min flow in m^3/s
1	Wangchu Basin	Tamchu	2529.17	353.3	9.43
2		Lungtenphu	665.71	97.2	3.1
3	Punatsangchhu Basin	Kerabari	9627.237	2647.7	108.9
4	Manas Basin	Wangdirapids	5647.62	1217.8	51.7
5		Yebesa	2223.30	425	17
6		Kurjey	1354.97	138.8	10.6
7		Muktirap	876.36	285.6	10.4
8		Sumpa	7101.15	1022.5	31.1
9		Kurizampa	8997.70	1298.6	60.1
10		Panbang	21006.1	5251.2	123.5

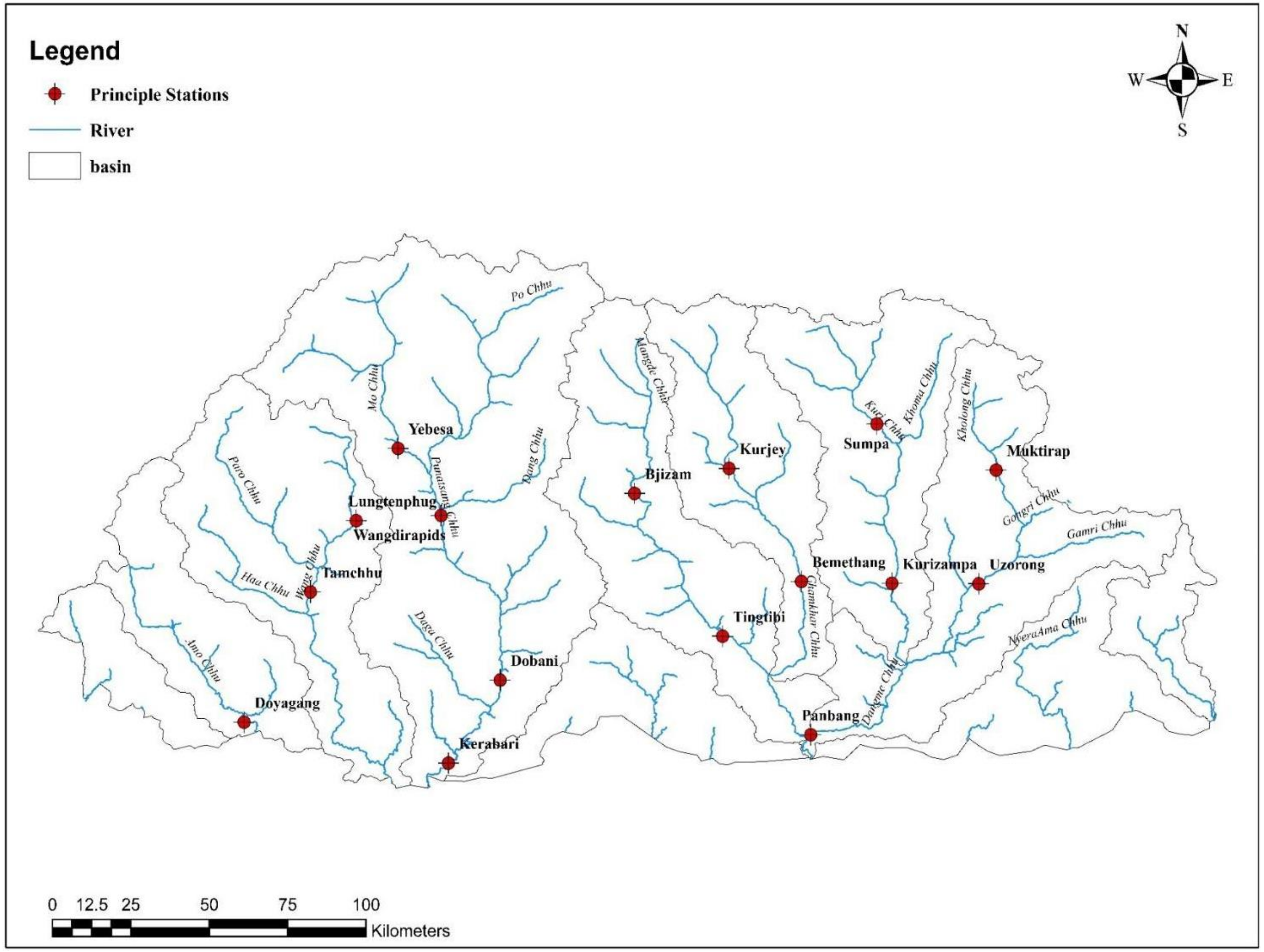
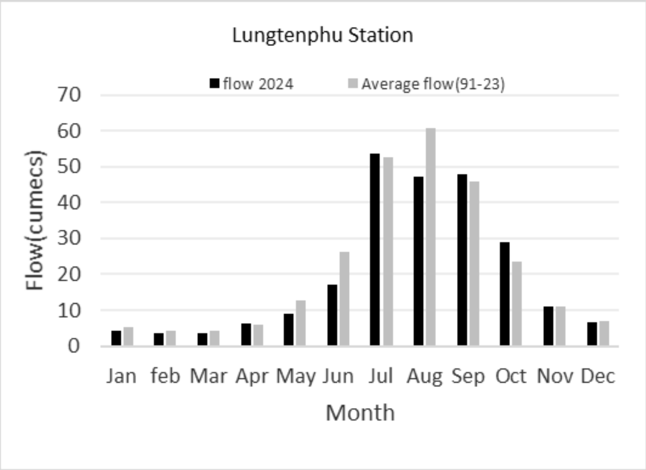


Figure 13: Location of Principle Stations

5. WANGCHU BASIN RIVER FLOW STATUS

5.1 STATION WISE AVERAGE MONTHLY FLOW



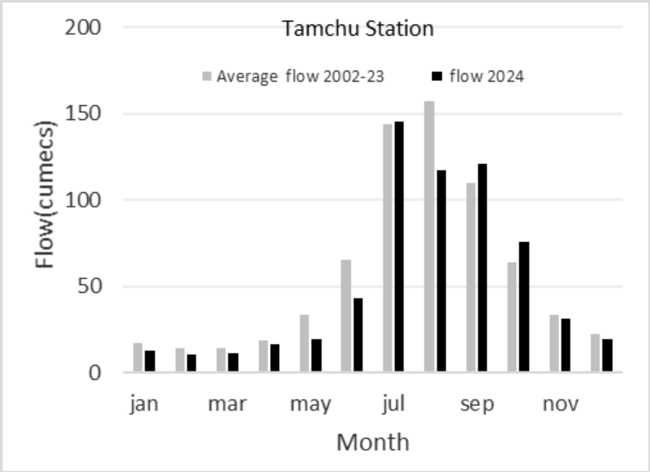
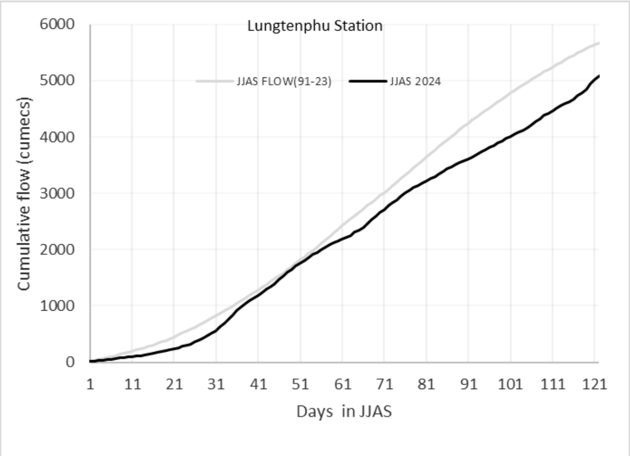


Figure 14: Station's average monthly flow in Wangchhu basin

5.2 STATIONWISE JJAS CUMULATIVE FLOW



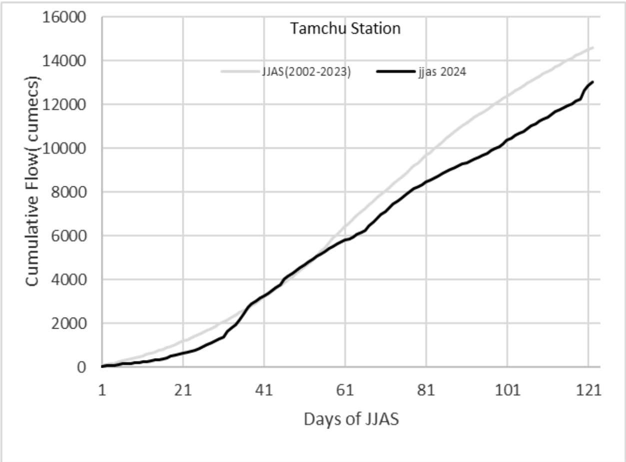


Figure 15: Station's JJAS cumulative flow in Wangchhu basin

6. PUNATSANGCHHU RIVER FLOW STATUS

6.1 STATIONWISE AVERAGE MONTHLY FLOW

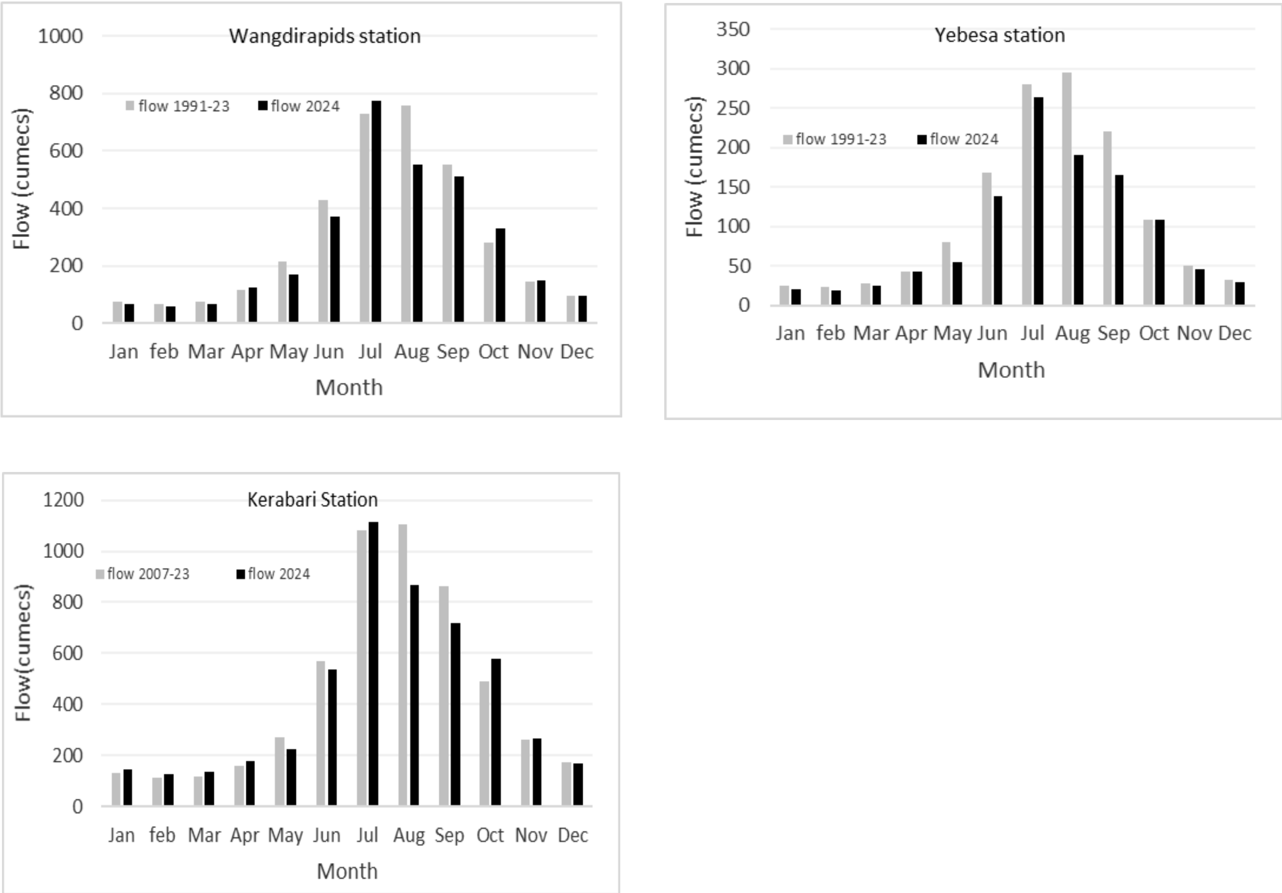


Figure 16: Station's average monthly flow in Punatsangchhu basin

6.2 STATIONWISE JJAS CUMULATIVE FLOW

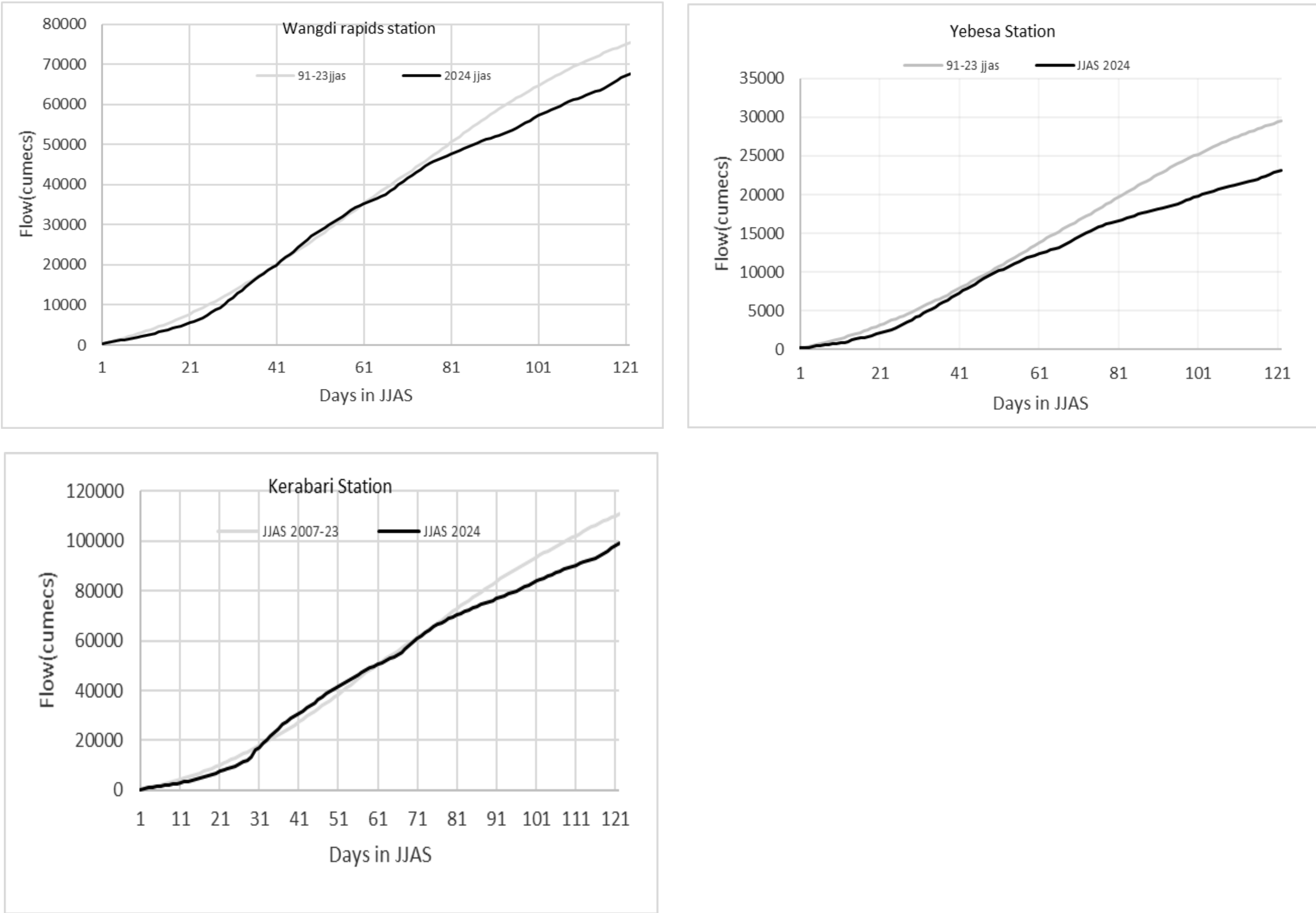


Figure 17: Station's JJAS cumulative flow in Punatsangchhu basin

7. MANAS BASIN RIVER FLOW STATUS

7.1 STATIONWISE AVERAGE MONTHLY FLOW

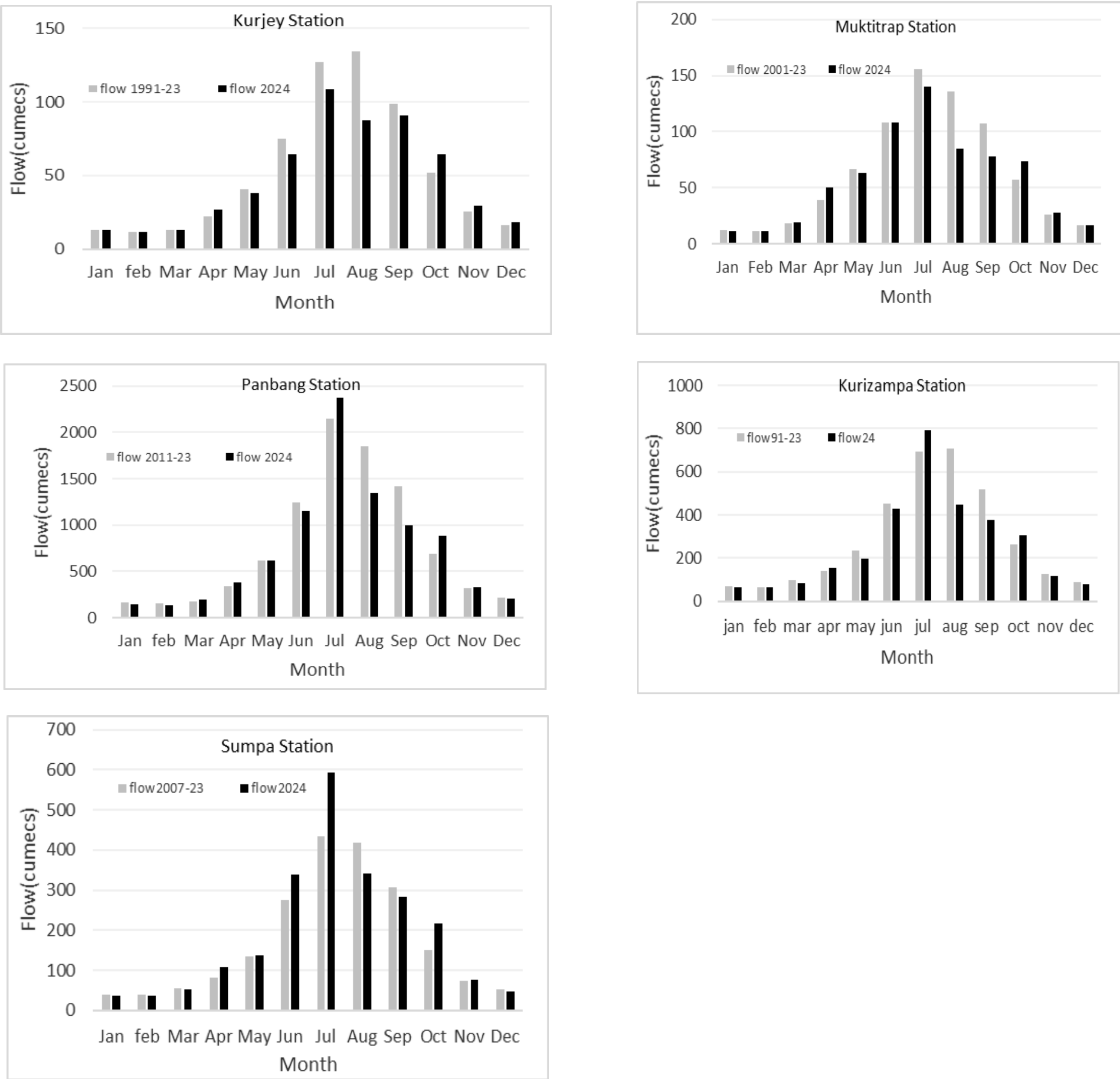


Figure 18: Station's average monthly flow in Manas Basin

7.2 STATIONWISE JJAS CUMMULATIVE FLOW

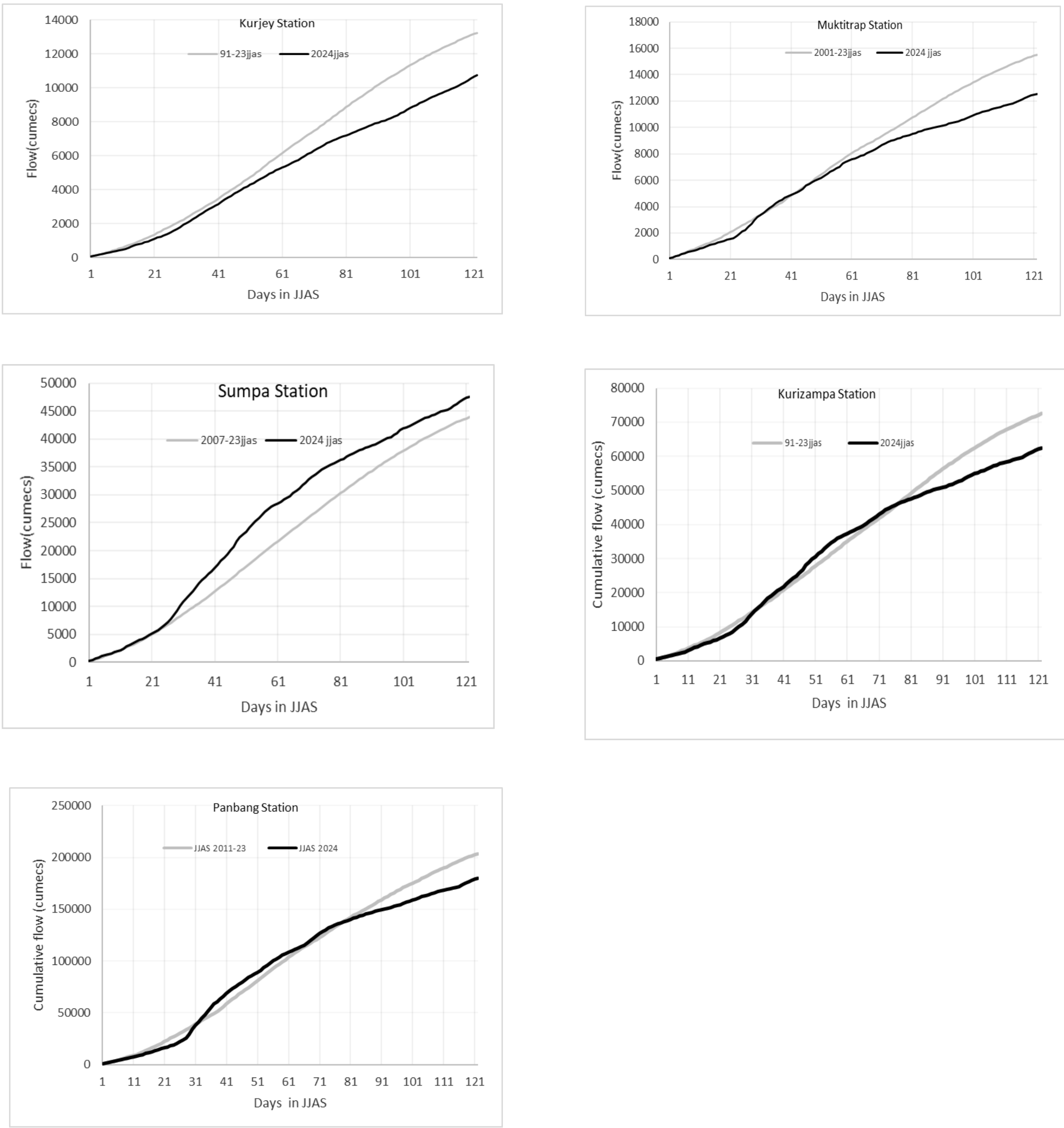


Figure 19: Station's JJAS cumulative flow in Manas basin

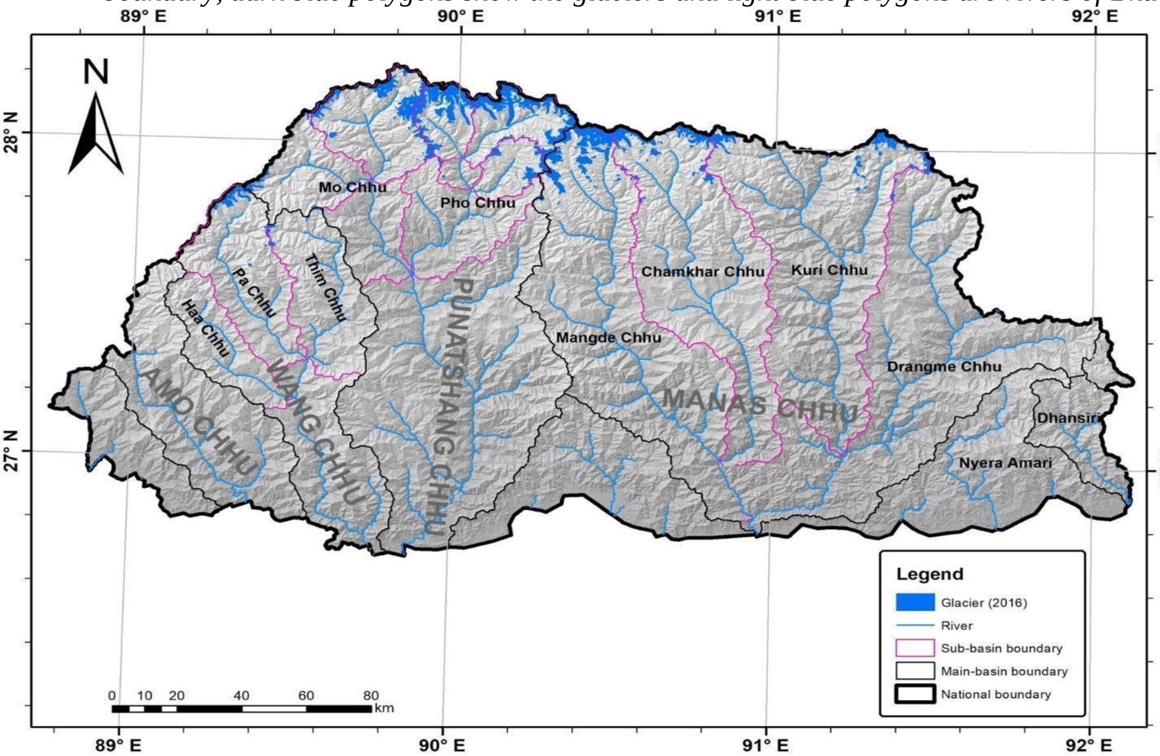
SECTION C: CRYOSPHERE

1. GLACIERS

There are 700 glaciers in Bhutan Himalaya which lies in the eastern part of the great Himalayan range.

The glaciated region occupies and area of 629.55 Km^2 accounting for 1.64% of the total land area of Bhutan. As a part of long term glacier monitoring program in Bhutan, three clean type 9(Type) have been bench marked (Gangju La, Thana and Shodug glaciers). Cryosphere Service Division under the National Centre for Hydrology and Meteorology is monitoring these three bench marked glaciers through mass balance estimation and morphological changes.

Figure 20: 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



Although the glacier area coverage is just little over 1% of the total land area, they play a vital role in sustaining the surface flow and act as an important part of water resource feeding the major river systems in the country. The past studies revealed the glacier melt water contributes in the range between 33% to 49% in the surface flow of the rivers, although the percentage contribution may vary in time and space. Apart from playing an important role in terms of water resource, studies in other parts of the world have found that they influence the climate system both at local and regional scale. Despite the importance of the glacier system in terms of water resource and role in the climate system, glaciers all over the world are receding and loosing mass continuously with and accelerated trend in the recent times. Glaciers in Bhutan have also not been spared from such phenomena. Some important scientific findings are provided in the following section on the morphological changes and mass loss observed on the three bench marked glaciers in Bhutan.

1.1 Morphological changes of three bench marked glaciers

The three bench marked glaciers namely Gangju La glacier located in the headwaters of Pho Chu, Thana glacier located in the headwaters of Chamkhar Chu and Shodug glacier located in the headwaters of Thim Chu were selected maintaining uniform coverage of the country.

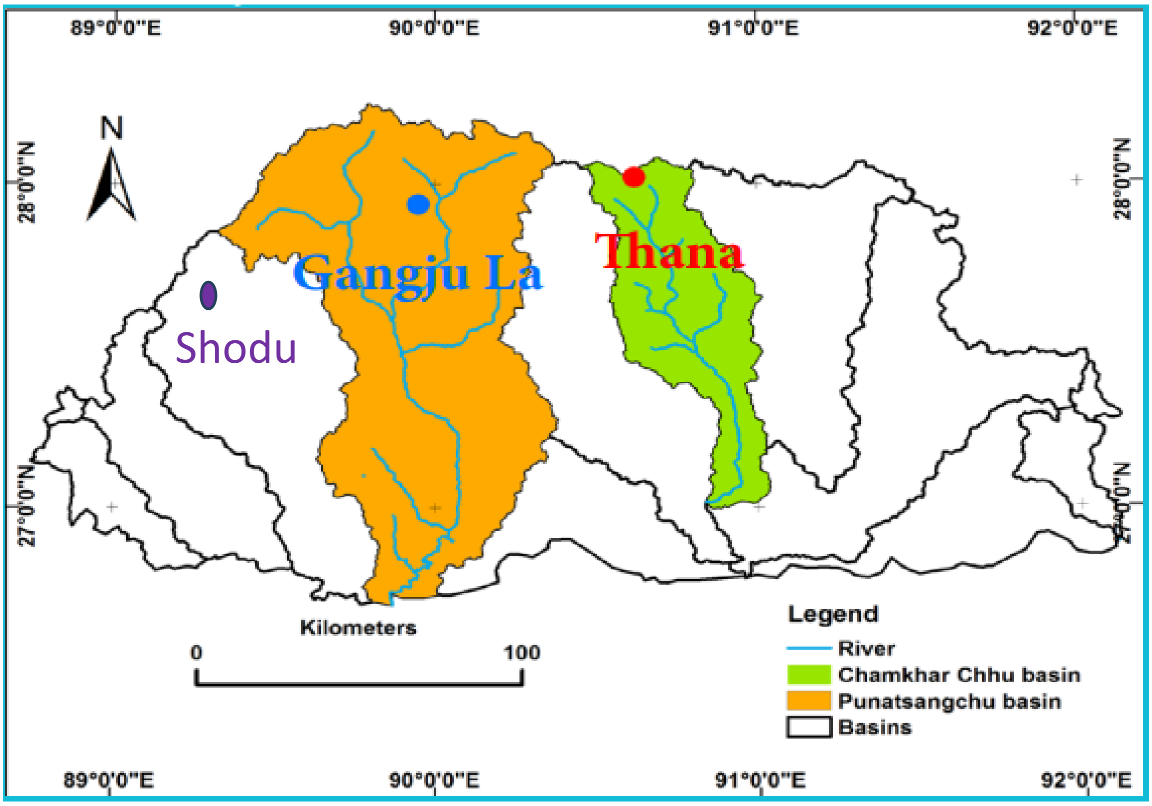


Figure 21: Location map of Three bench marked glaciers in Bhutan

Terminus retreat and aerial shrinkage were analysed for the three bench marked glaciers in Bhutan for different time scale; Gangju La glacier from 2004 to 2020, Thana glacier from 1990 to 2020 and Shodug glacier from 1990 to 2020 as shown in the table below.

Table 6. Terminus retreat rate and area change of Thana, Gangju La and Shodug glaciers

SL. No	Glacier Name	Time Period (Year)	Terminus Retreat rate (m/year)	Surface area change (%)
1	Thana	1990-2020	16.58	30.31
2	Gangju La	2004-2020	12.27	29.89
3	Shodug	1990-2020	7.01	15.24

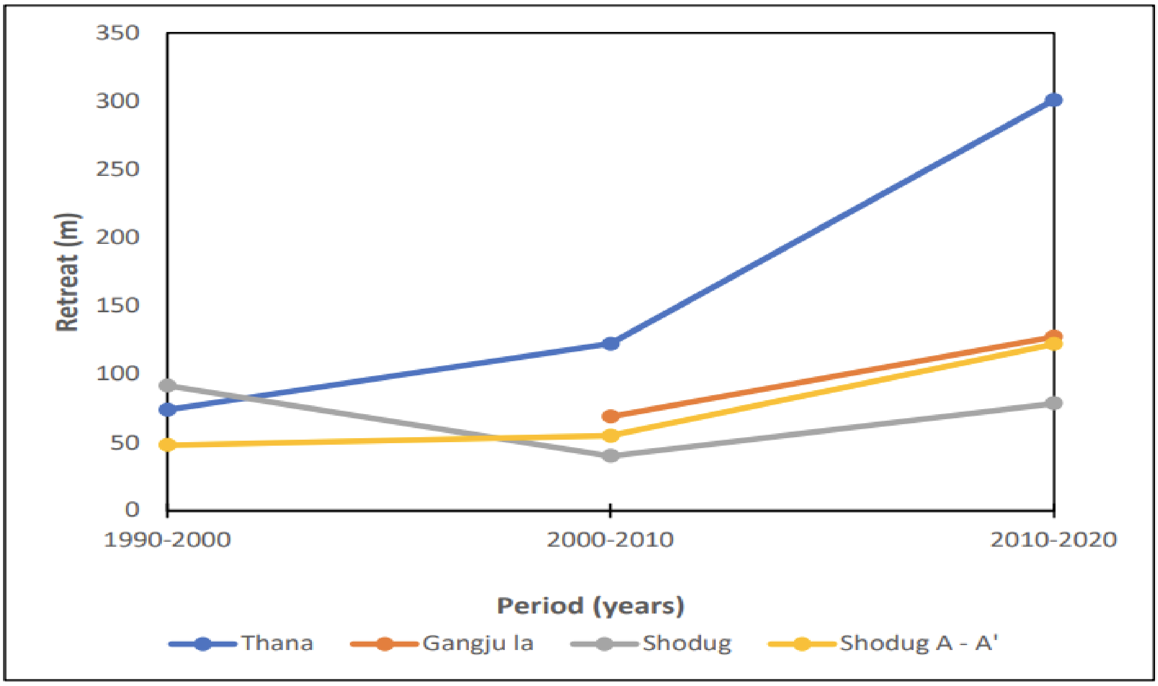


Figure 22: Terminus retreat of Thana, Gangju La and Shodug Glaciers in Bhutan

Figure 22 above shows the changes in terminus and area of the glaciers for the three bench marked glaciers on decadal time scale from 1990 to 2020. Some of the important findings and observation are as below:

a. All three glaciers are found to be receding in the analysis period which is for the last 30 years.
b. The retreat rates were observed to have accelerated in the recent time.
c. Retreat rate increases from west to east which means the glaciers located in the eastern part of the country are retreating more compared to the ones located in the western part.

As for the area change for the three bench marked glaciers, it was found that the glaciers are shrinking in the range of 15% to 30% in the last 30 years. The drastic changes in the area and accelerated retreat rate of the glacier terminus may be attributed to rising temperature in the region as well as local atmospheric conditions. However, such inference need to be scientifically studied.

1.2 Glacier Mass Balance for the three bench marked glaciers

Glacier mass balance is an important aspect of glacier monitoring process. The mass balance value determines the health of the glacier. The three bench marked glaciers in Bhutan Himalaya are also being monitored in terms of mass balance through both Direct (glaciological method) and Geodetic methods. The first mass balance observation started on Gangju La glacier, a small clean type glacier located in the headwaters of Pho Chu in 2003. Study on mass balance on Thana glacier started in 2015 but the real ground base data collection was initiated only from 2016. In an effort to have a uniform spread of bench mark glaciers in the country, the third bench mark glacier called Shodug glacier located in the headwaters of Thim Chu was identified in 2021.

Since the recognition and identification of the three bench mark glaciers in Bhutan, ground base data for mass balance estimation has been collecting on annual basis using different methods. The details of the record of mass balance values for different time period using different methods for the bench marked glaciers are provided in the table 7.

Table 7 Mass balance details on Gangju La and Thana Glaciers

	Gangju La (mm w.e. a-1)		Thana (mm w.e. a-1)	
Year	**Direct**	**Geodetic**	**Direct**	**Geodetic**
2003-2004	-1230			
2004-2011		-1790		
2011-2012		-2040		
2012-2013	-1810	-2020		
2013-2014	-1110	-1120		
2014-2016		-1350		
2016-2017			-660	-930
2017-2018		-2390	-1570	-1870
2018-2019		-1470	-1650	
2019-2020		-1660	-2645	-2910
2020-2021		-1054	-1699	-2336
2021-2022		-1572		-2014
2022-2023		-2288		-2287
2023-2024		-2522		-2513

Figure 23 shows annual mass balance of Gangju La and Thana glacier estimated using Direct and Geodetic methods for different years. Although no clear trend exists in the mass balance values for the glaciers, it is important to note that all the bench glaciers are losing mass drastically as depicted with negative values. Observation reveals that all the bench marked glaciers in Bhutan have been losing mass drastically. Such phenomena are depicted in figure 24 which shows cumulative mass balance over the years since the monitoring was initiated on the individual glaciers.

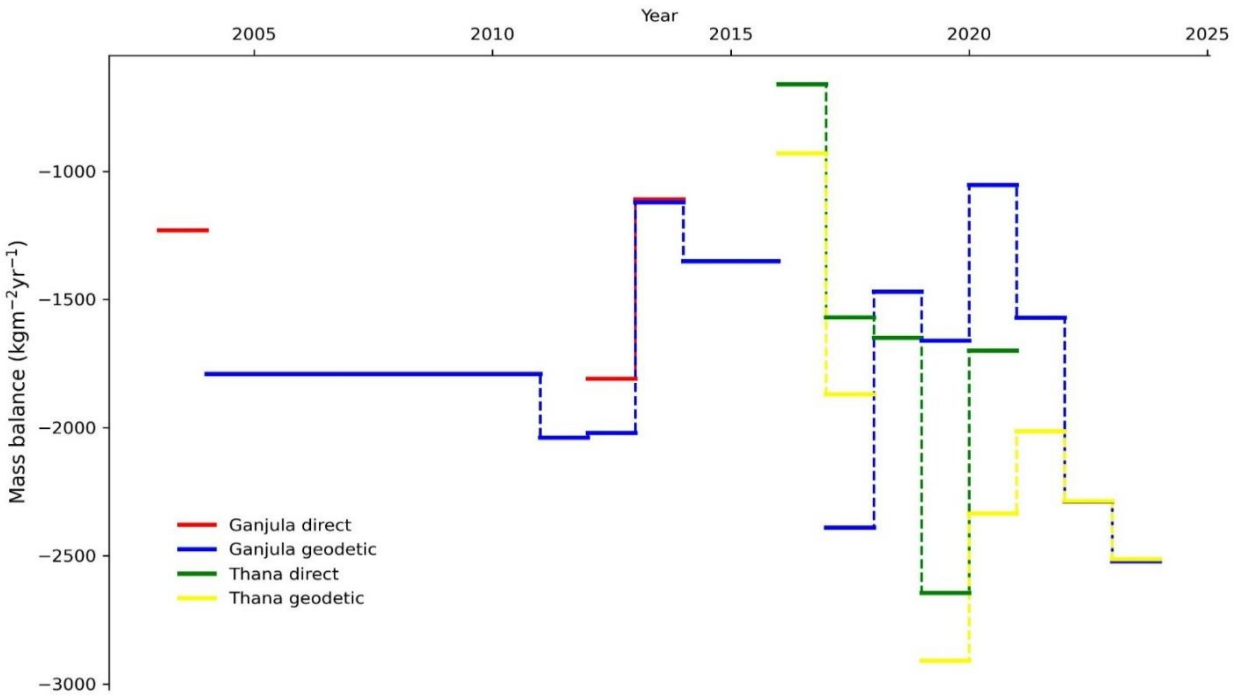


Figure 23: Mass balance of Gangu La and Thana glacier using different methods

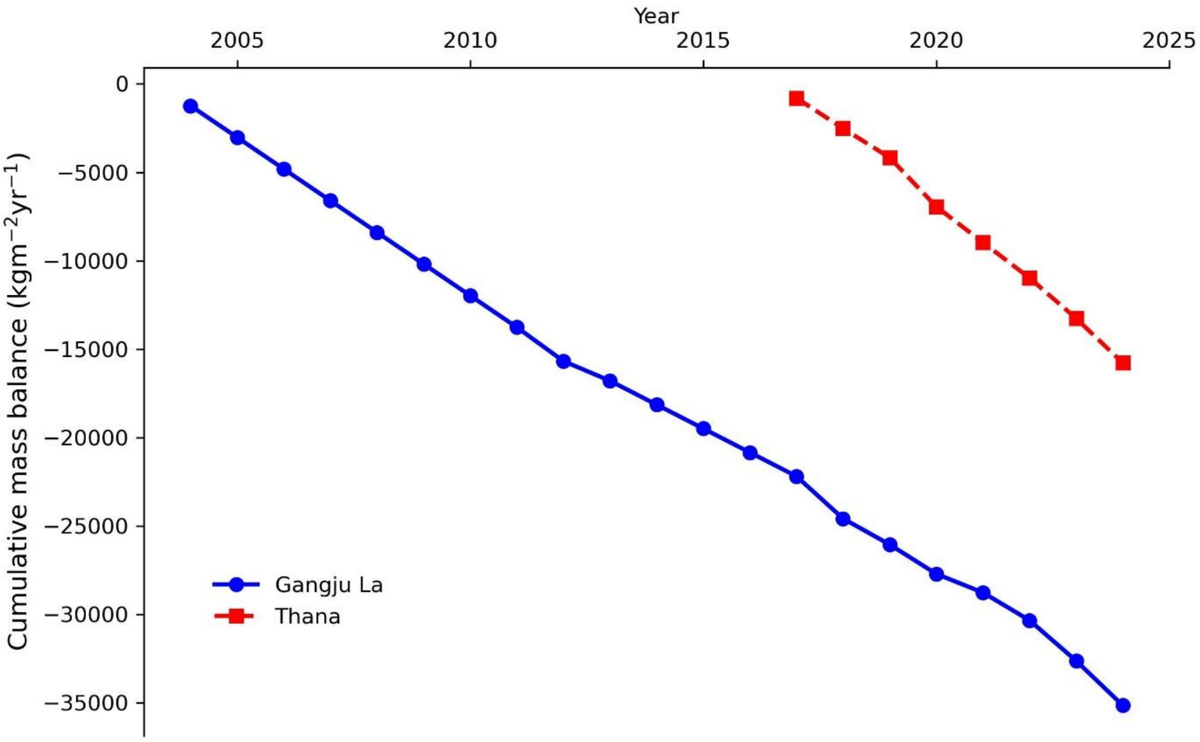


Figure 24 Cumulative Mass balance of Gangju La and Thana glacier

2. GLACIAL LAKES

As per the glacial lake inventory published (BGLI, 2021) There are 567 glacial lakes mapped through updated criteria. The number of glacial lakes drastically decreased comparing to the old inventory on glacial lakes published by ICIMOD in 2001. The huge difference in the number of glacial lakes was mainly due to updated criteria in the 2021 inventory. Total area covered by the glacial lakes is 55.04 km^2 which accounts for 0.14% of the total land area of Bhutan. The highest number of glacial lakes are found in Manas basin with 331 glacial lakes covering an area of 29.2 km^2 and the least in Wang Chhu basin (31 glacial lakes) covering an area of 0.6 km^2. Figure 25 and table 8 shows the distribution of glacier lakes in the Bhutan sub-basin wise distribution of the lakes respectively

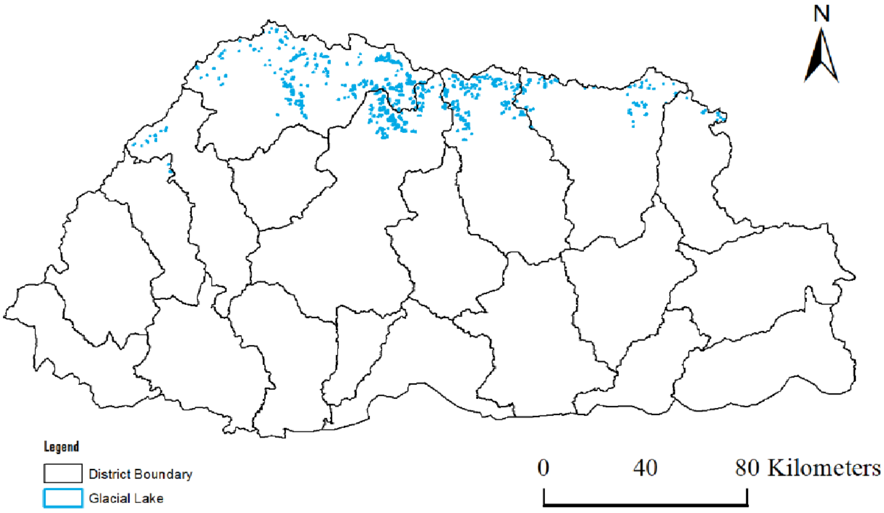


Figure 25: Distribution of glacial lakes in the northern frontiers of the country. Blue polygons are the distribution of glacial lakes and the black polygons are district boundaries.

Table 8. 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)

As per the re-assessment of Potentially Dangerous Glacial Lakes (PDGL) published in 2019 there are 17 PDGLs in Bhutan. Comparing to the earlier list of PDGL published as a part of inventory of glacial lakes in Bhutan by ICIMOD in 2001, there were 25 lakes categorized as PDGL. Since the first list of PDGLs were prepared entirely based on remote sensing materials, there was a requirement to ground check the lakes physically. Prior to the publication of the new list of PDGLs most of the earlier listed lakes were visited physically where some of the lakes were found to be not risky. Therefore, through ground truthing some of the earlier listed PDGL were delisted from the new updated list of PDGL. Among the sub basins, Pho Chu sub basin has the maximum of potentially dangerous glacial lakes. Figure 16 and table 7 shows the locations and sub-basin wise distribution of 17 potentially dangerous glacial lakes of the country.

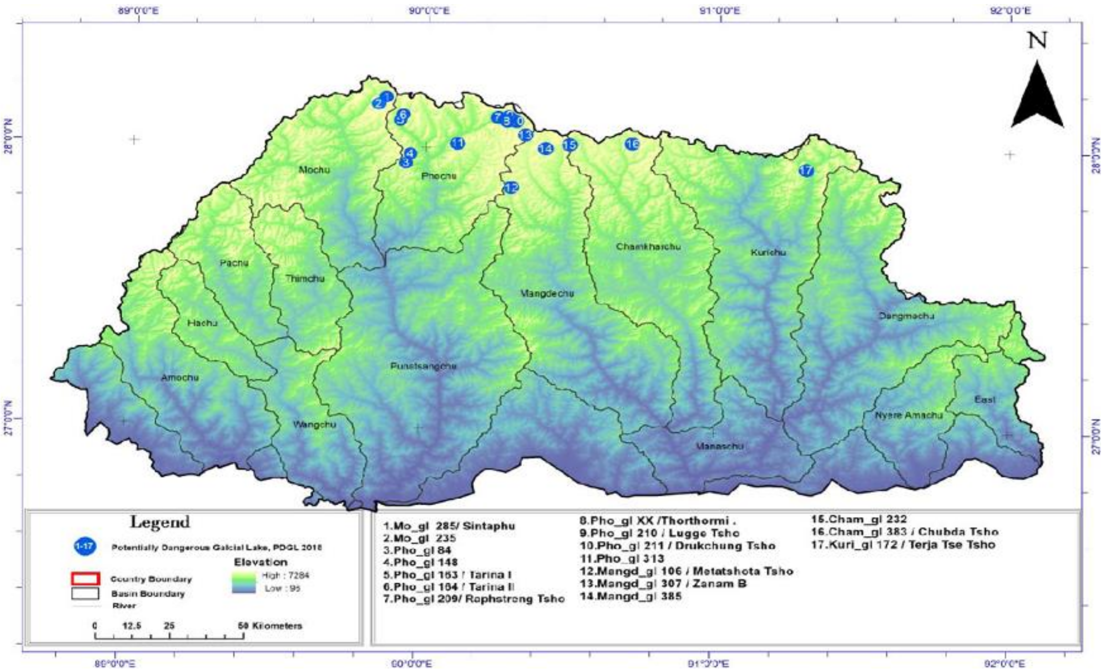


Figure 26 Sub-basin-wise distribution of potentially dangerous glacial lakes of Bhutan.

Table 9. Sub-basin-wise distribution of potentially dangerous glacial lakes of the 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

References:

Bhutan Hydromet Journal Vol. II (2023), NCHM

Bhutan Glacier Inventory 2018 (BGI 20218), NCHM

Bhutan Glacial Lake Inventory 2021 (BGLI 2021), NCHM

Re-assessment of Potentially Dangerous Glacial Lakes 2019, NCHM

Surface Hydrological Data Book 2024, NCHM

State of the Global Climate 2023, WMO