State of the Climate 2022

National Centre for Hydrology and Meteorology

Royal Government of Bhutan

2023

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National Centre for Hydrology and Meteorology (NCHM)
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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 andmaking 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 anddecision 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 2022

As per the World Meteorological Organization (WMO) State of the Global Climate 2022, the global mean temperature comprising the near surface temperature over land and ocean for the year 2022 was 1.15 [1.02-1.28] °C above the 1850–1900 baseline, used as an approximation of pre-industrial levels. The WMO evaluation is based on six global temperature datasets, as shown in Figure 1 below, and despite the presence of La Nina, all of these datasets presently rank 2022 as either the fifth or sixth hottest year on record (1850–2022). The year 2022 is the third consecutive year of La Nina conditions, which has only occurred three times in the past 50 years.

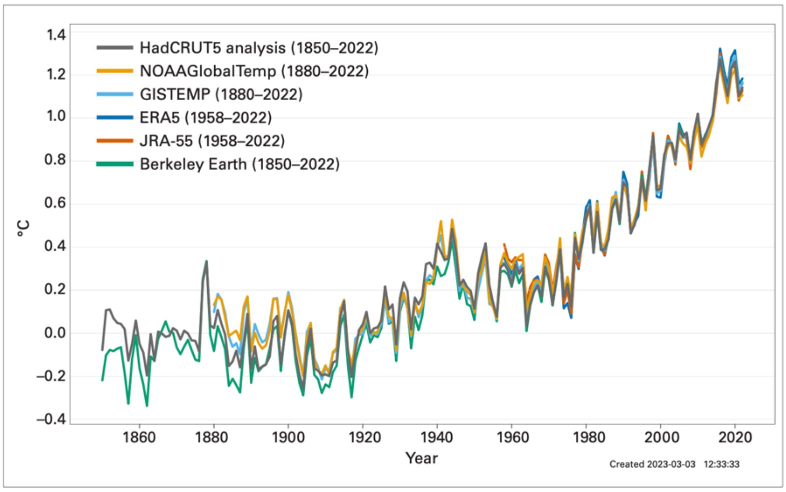


Figure 1: Global annual mean temperature difference from pre-industrial conditions 1850–1900 baseline for the six global temperature datasets 1850–2022.

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 1.14 [1.20 - 1.27] °C for the 10-year period from 2013 - 2022, showing continued warming. The overall warmth of variations in temperature anomalies across the globe is showed in Figure 2.

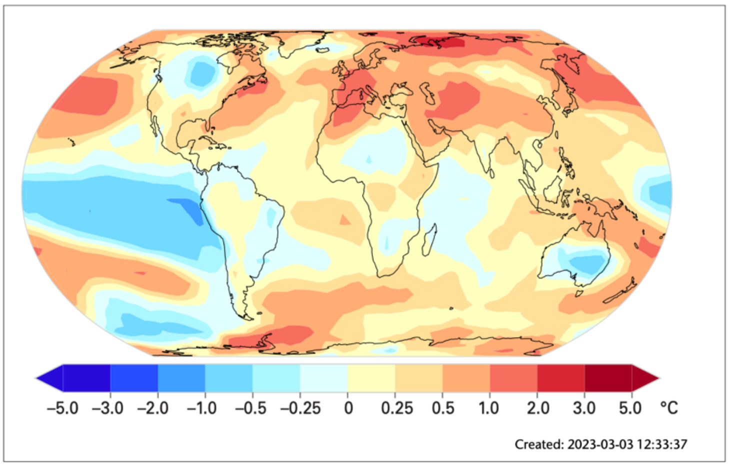


Figure 2: Near surface temperature differences between 2022 relative to the 1991-2020 long-term average.

2. CLIMATE HIGHLIGHTS - 2022

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.

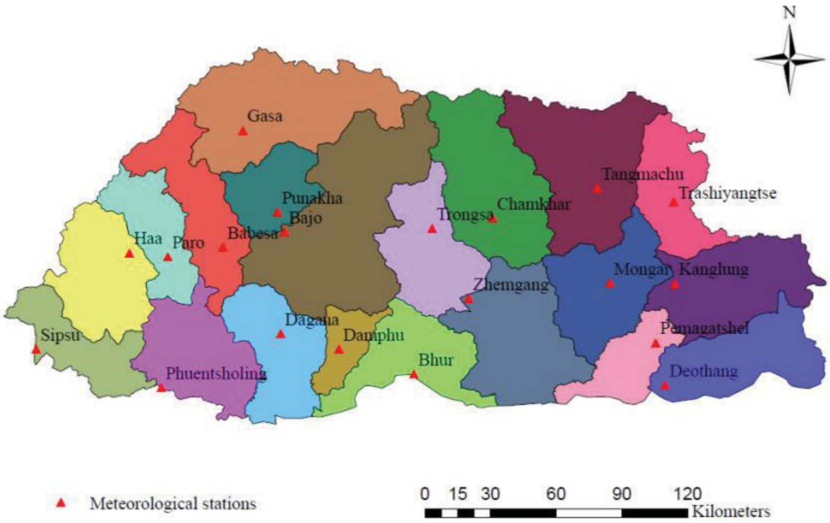


Figure 3: Location of Class A meteorological stations

2.2 Annual rainfall

The annual average rainfall (area average) was 2006.55 mm in 2022. 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 Bhur with 308.0 mm. Gasa experienced the highest number of rainy days with 211 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 accumulatedrain. However, the highest total annual rainfall was recorded at Phuentsholing with 8255.80 mm, Sipsu with 5604.10 mm followed by Bhur with 5326.30 mm.

2.3 Maximum and Minimum Temperature

The annual average maximum temperature was 22.61°C and minimum temperature was 12.22°C across the country. The highest daily maximum temperature was recorded at Punakhamet station with 38.5°C and the lowest daily minimum temperature was recorded at Haa met station with -12.5°C. Haa experienced a greater number of days with the minimum temperaturebelow or equal to zero with 138 days (minimum temperature <=0).

2.4 Monsoon Monitoring

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

2.4.1 Rainfall

During the summer of 2022, the country as a whole received near normal to slightly above normal rainfall against the long-term average 1996-2022.

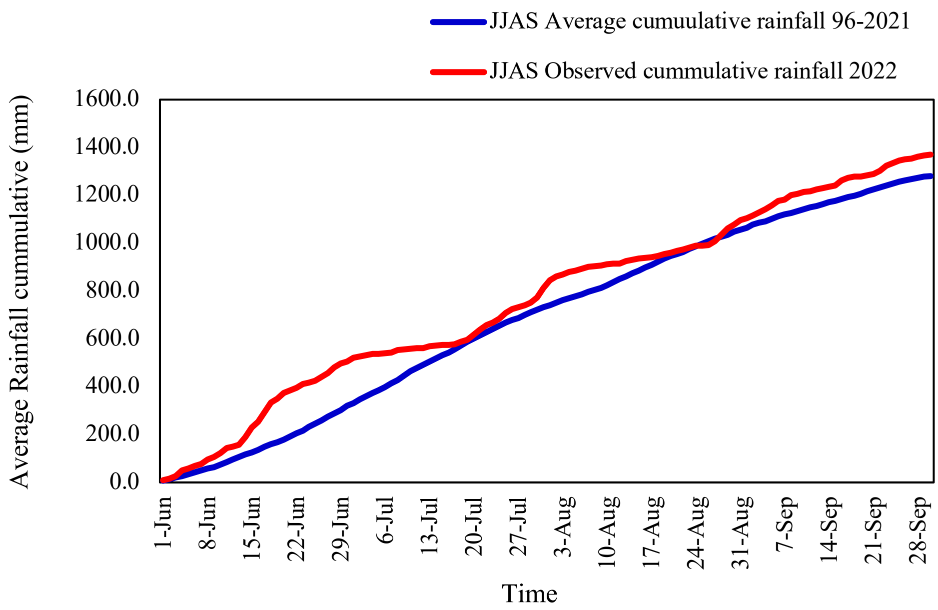


Figure 4: Observed rainfall of 2022 (JJAS) with long term average (1996-2022)

2.4.2 Temperature

During the summer of 2022, the country as a whole received near normal average temperatureagainst the long-term average 1996-2022.

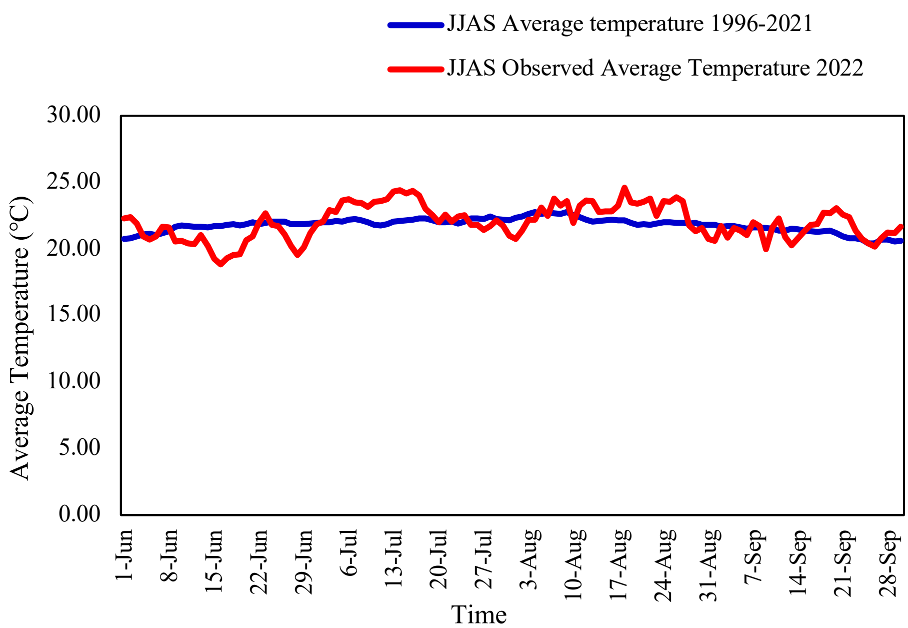


Figure 5: Observed average temperature of 2022 (JJAS) with long term average (1996-2022)

3. ANALYSIS OF TEMPERATURE - 2022

3.1 Maximum Temperature

A monthly climate monitoring report for the year 2022 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 2022. 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.

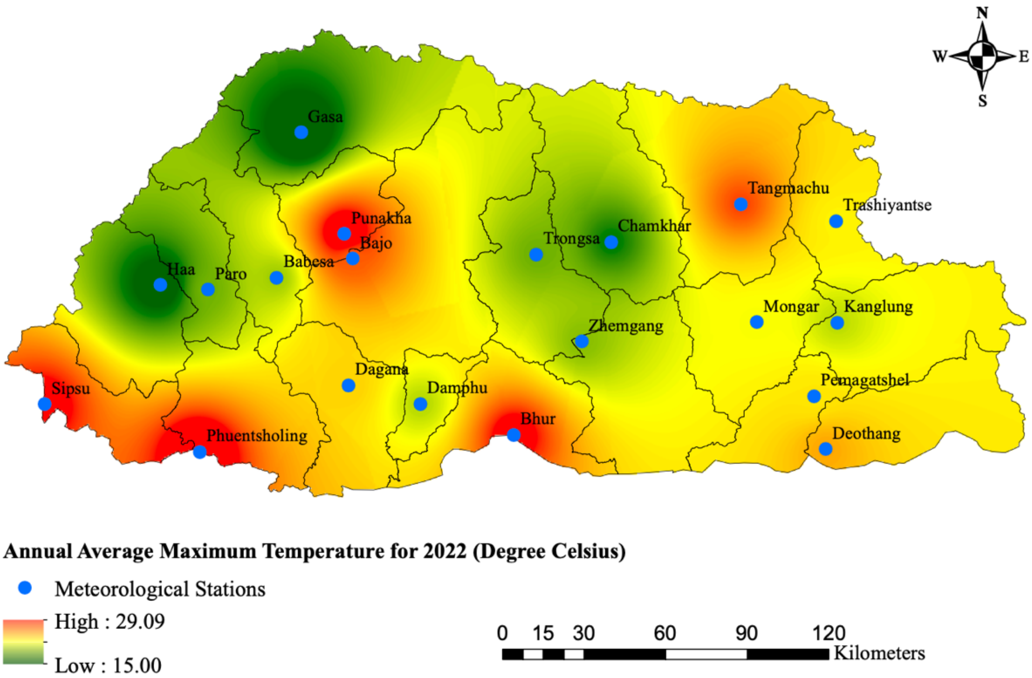


Figure 6: Spatial distribution of annual average maximum temperature for the year 2022

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 fourseasons.

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 maximumtemperature for the year 2022.

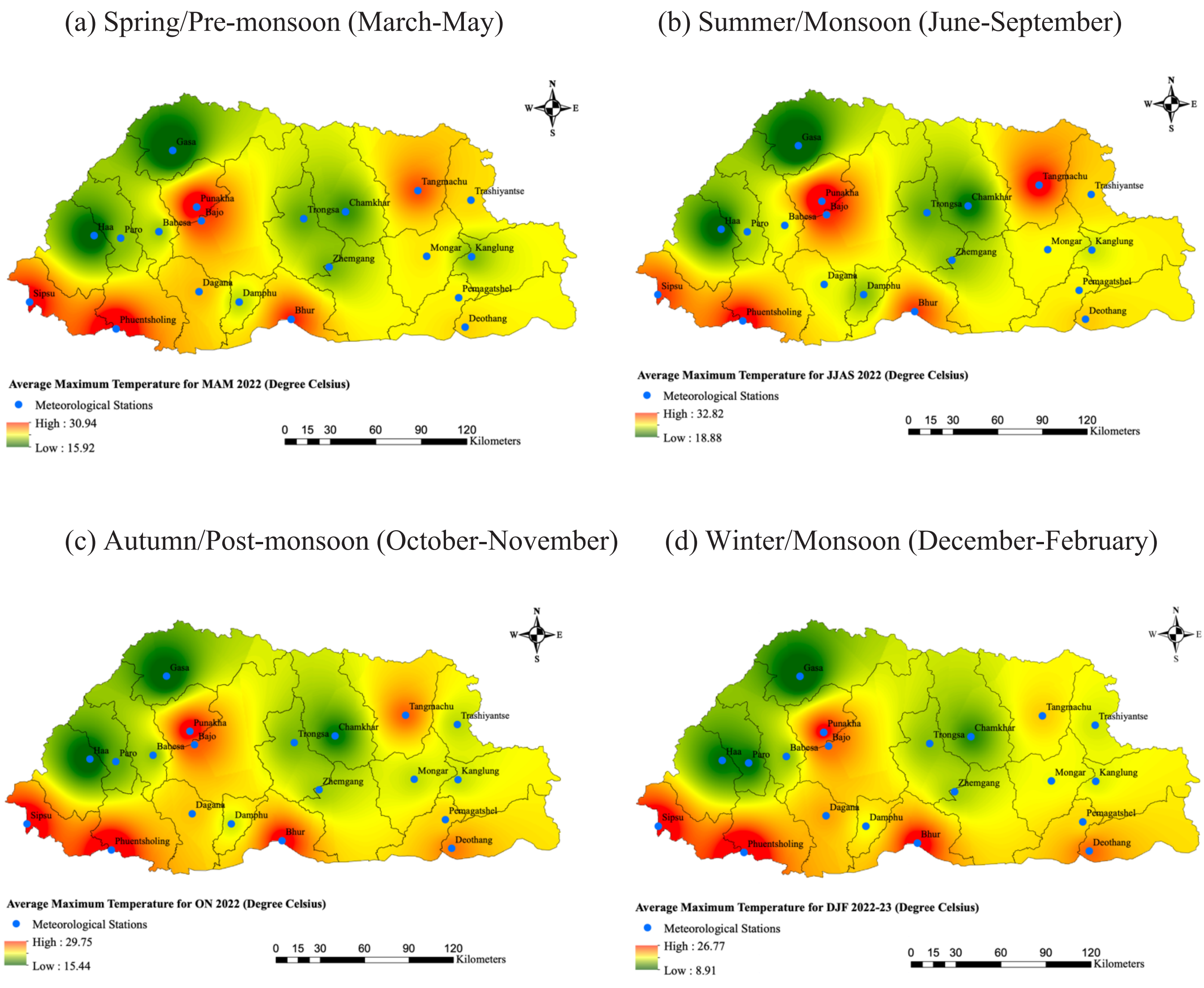


Figure 7: Spatial distribution of seasonal average maximum temperature for the year 2022

3.2 Minimum Temperature

A monthly climate monitoring report for the year 2022 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 2022. 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.

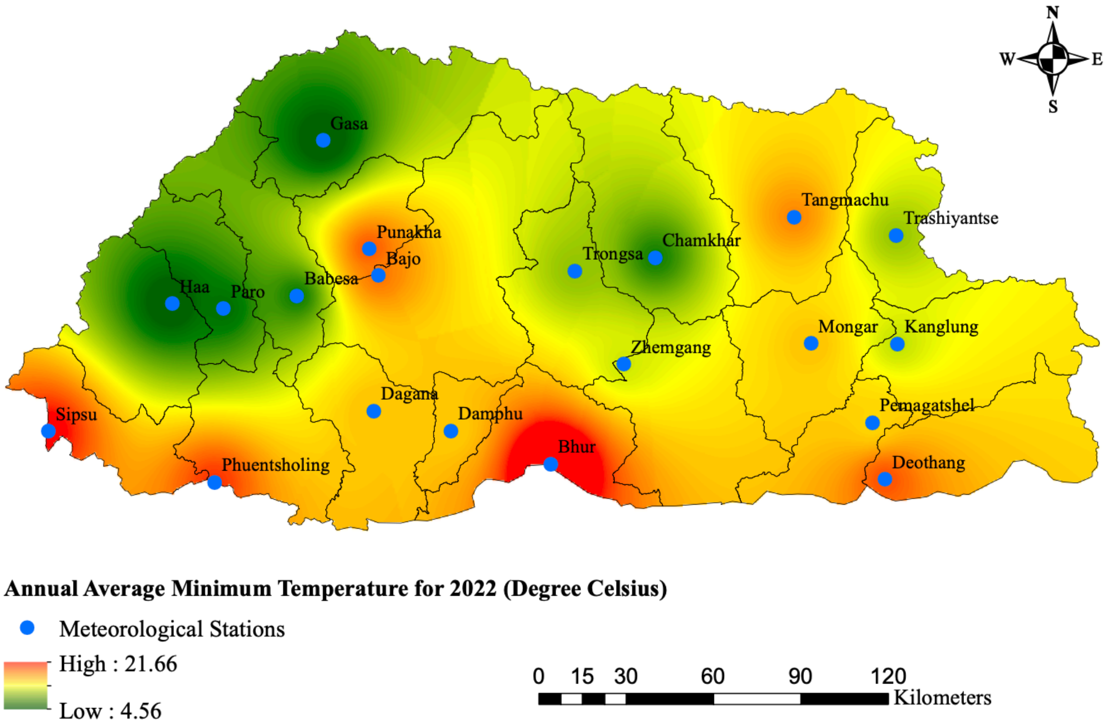
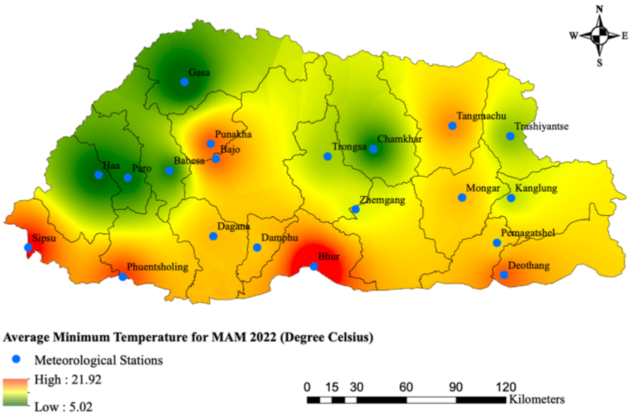


Figure 8: Spatial distribution of annual average minimum temperature for the year 2022

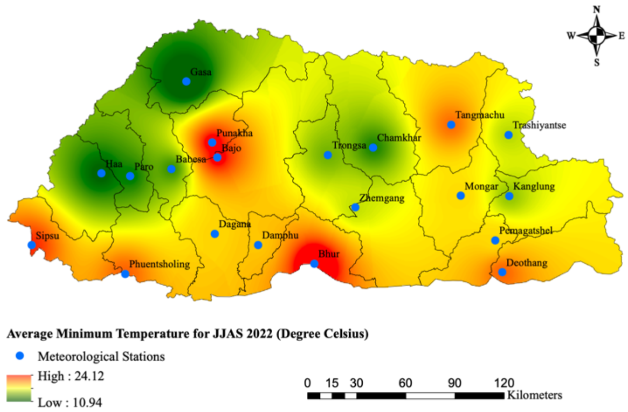
3.2.2 Seasonal spatial distribution of average minimum temperature

The following maps (Figure 9) show the spatial distribution of seasonal average minimumtemperature for the year 2022.

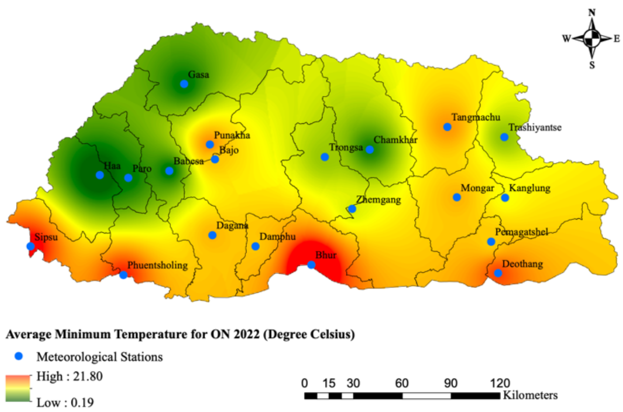
(a) Spring/Pre-monsoon (March-May)



(b) Summer/Monsoon (June-September)



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



(d) Winter/Monsoon (December-February)

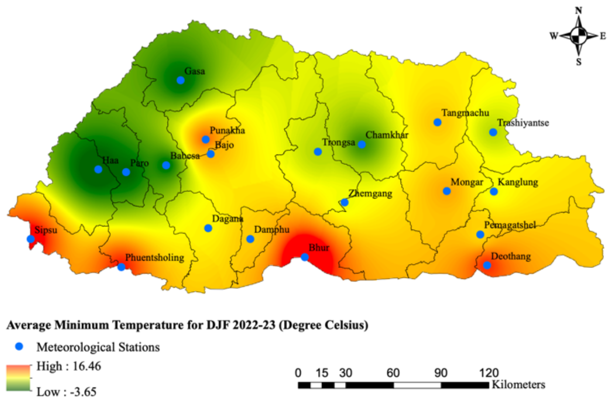


Figure 9: Spatial distribution of seasonal average minimum temperature for the year 2022

4. ANALYSIS OF RAINFALL - 2022

A monthly climate monitoring report for the year 2022 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 2022.

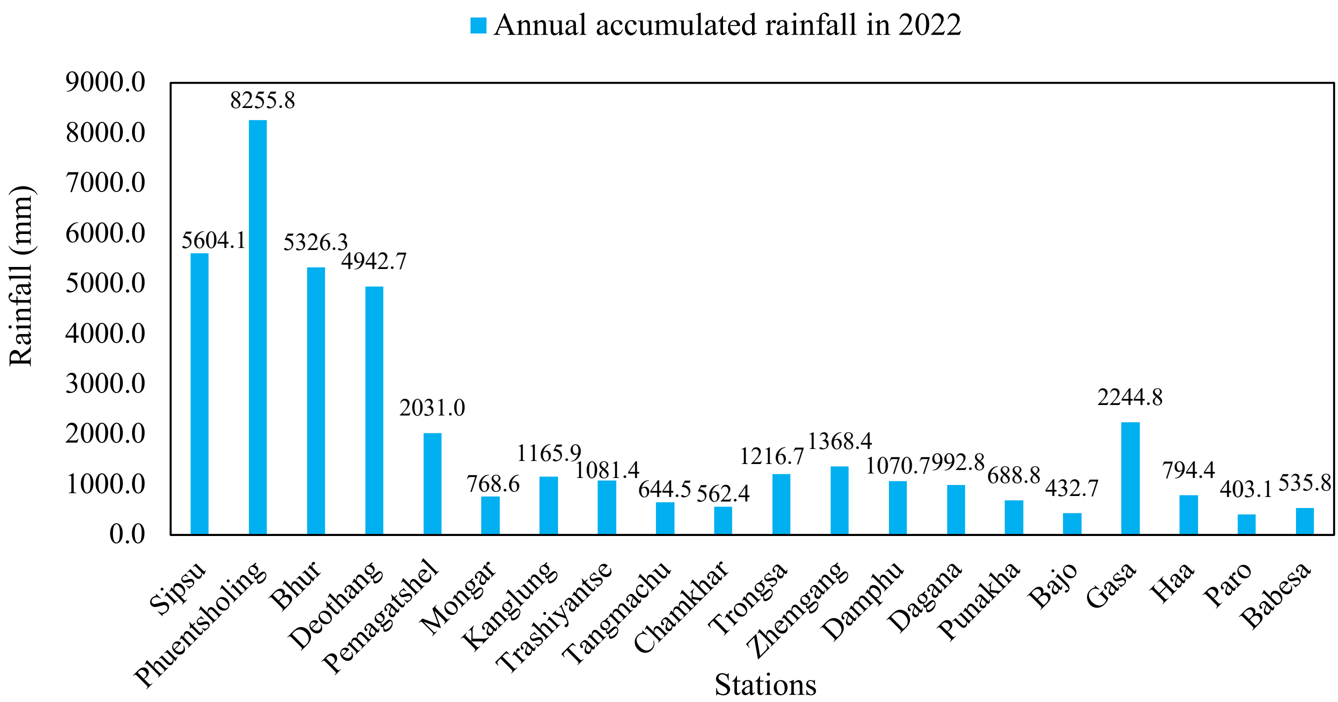
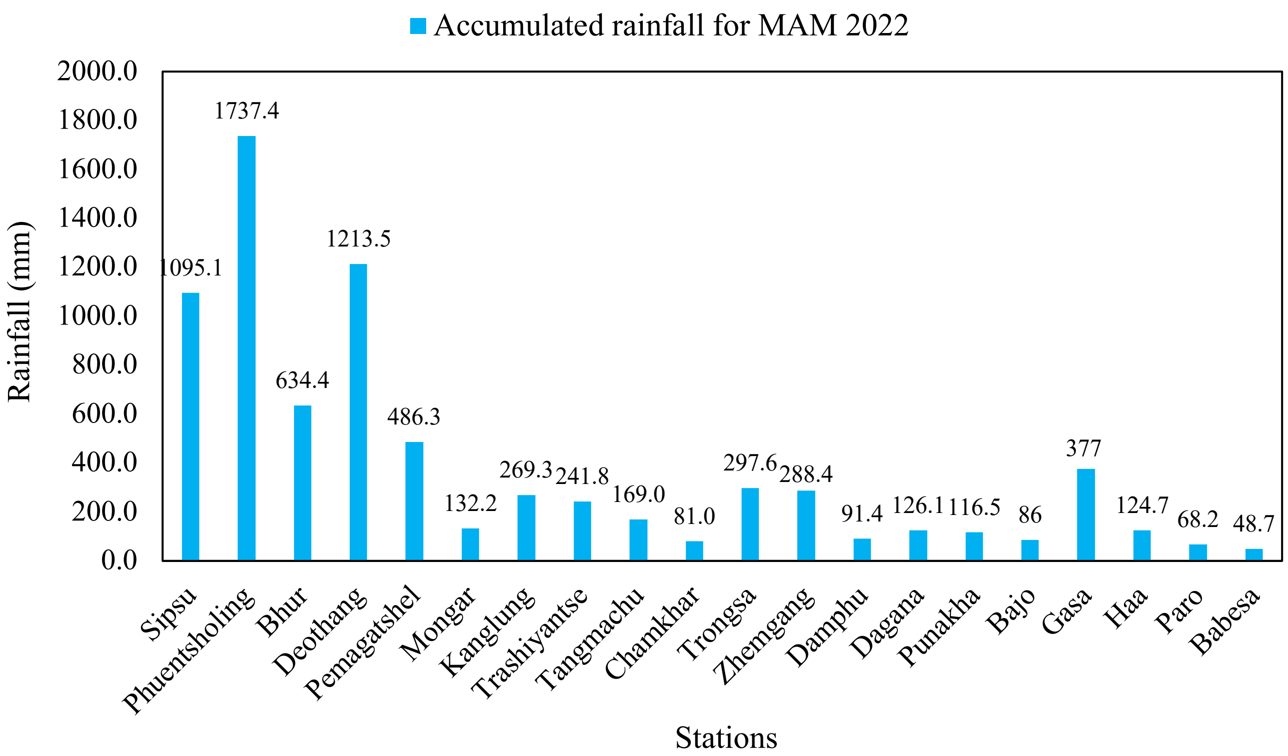


Figure 10: Annual accumulated rainfall for the year 2022

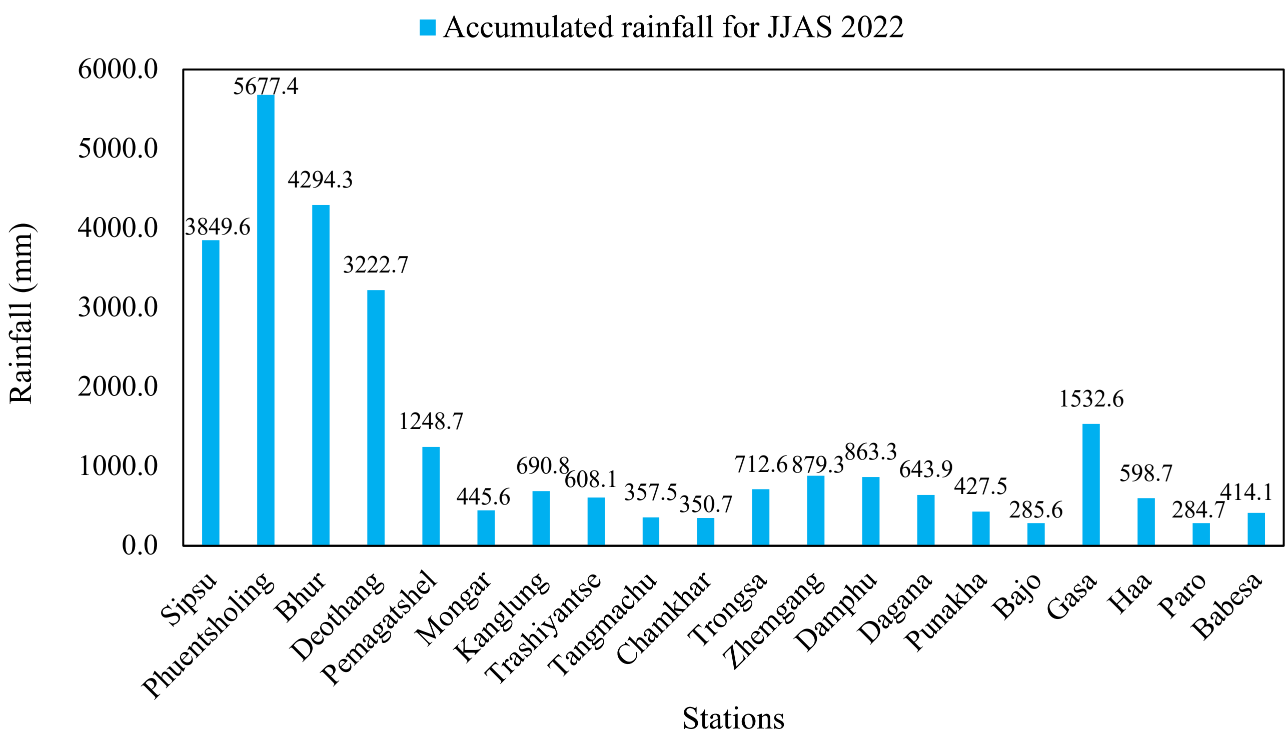
4.2 Seasonal spatial distribution of accumulated rainfall

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

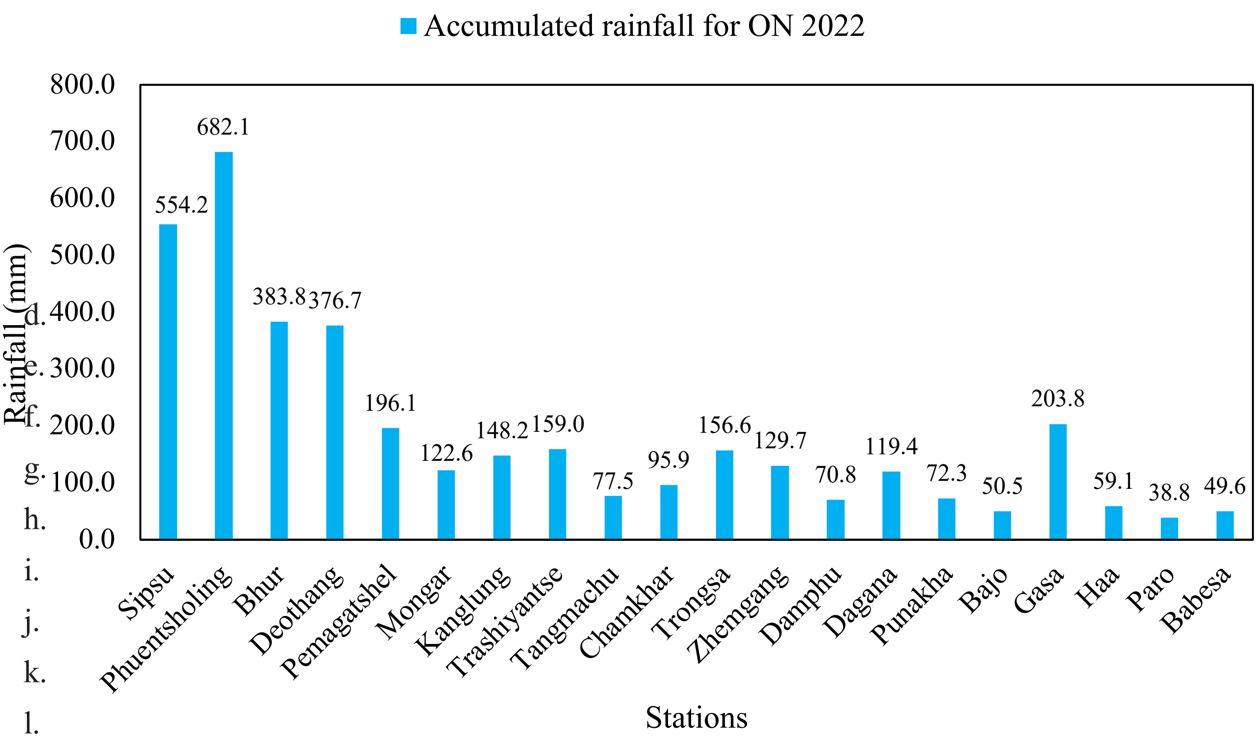
a. Spring/Pre-monsoon (March-May)



b. Summer/Monsoon (June-September)



c. Autumn/Post Monsoon (October-November)



d. Winter/Monsoon (December-February)

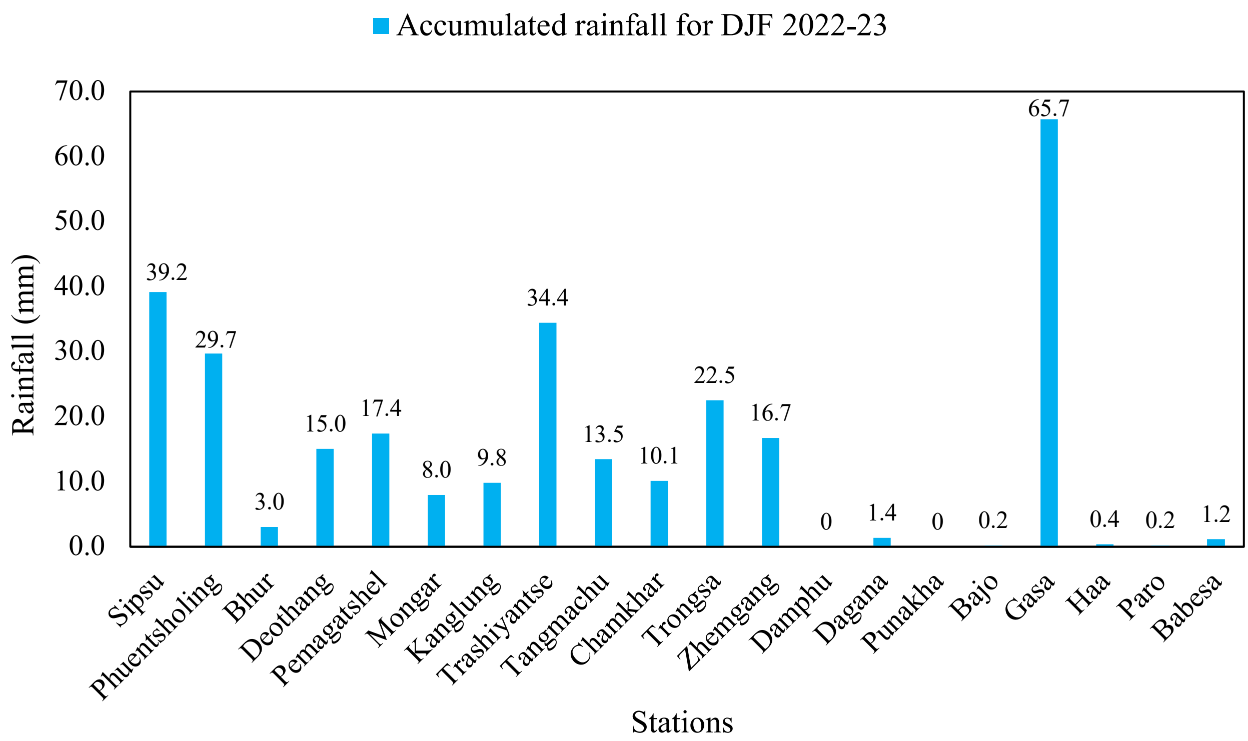
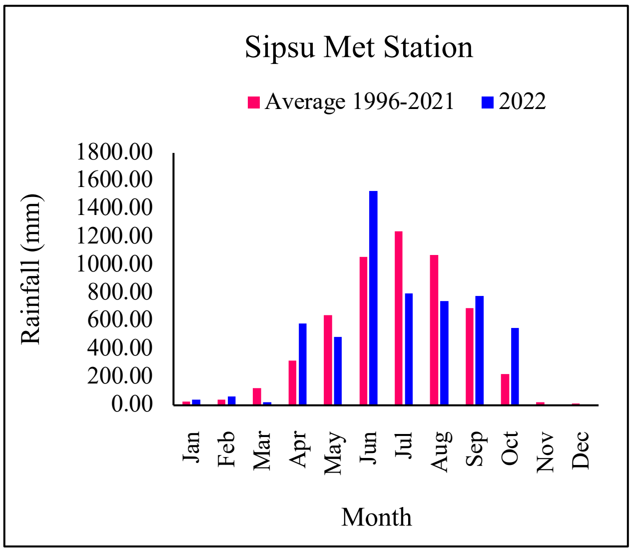
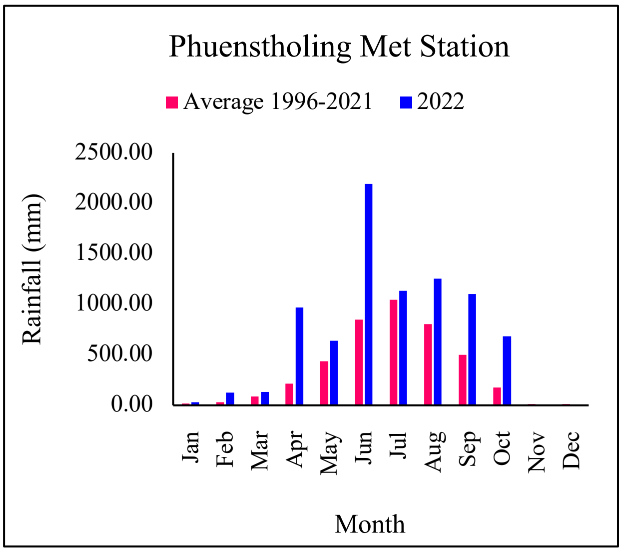


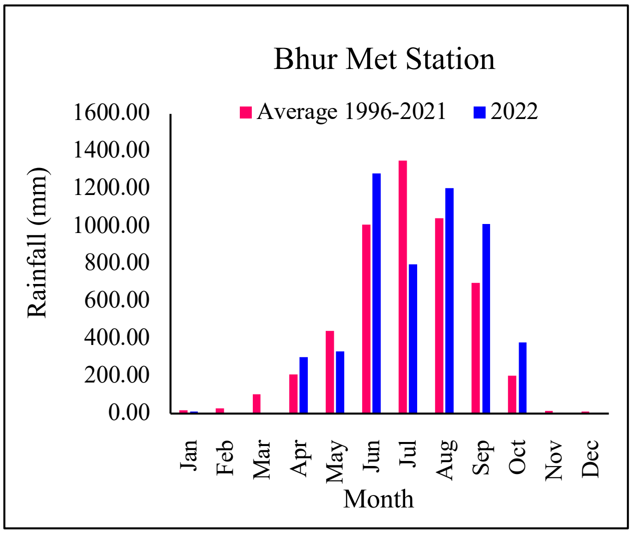
Figure 11: Spatial distribution of seasonal accumulated rainfall for the year 2022

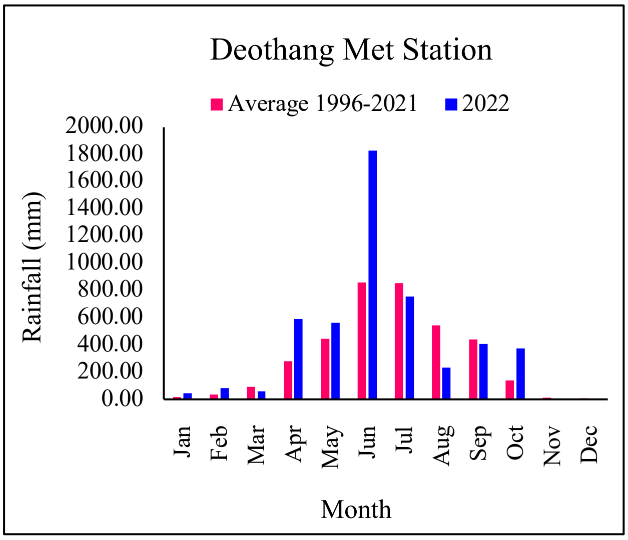
4.3 Comparison of monthly accumulated rainfall against long term average

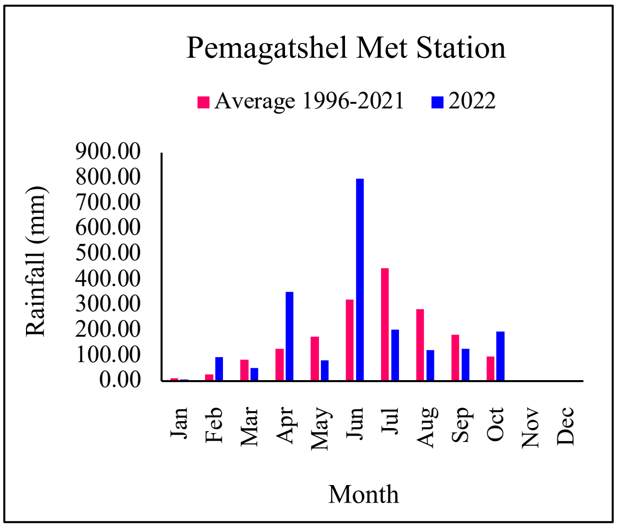
The following figures show the comparison of monthly accumulated rainfall of the year 2022 with their long-term average. Please note that the long-term averaging period in each station varies based on the data availability.

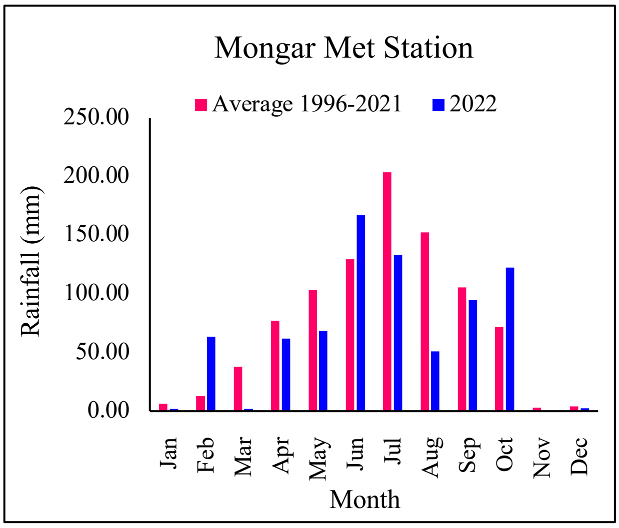


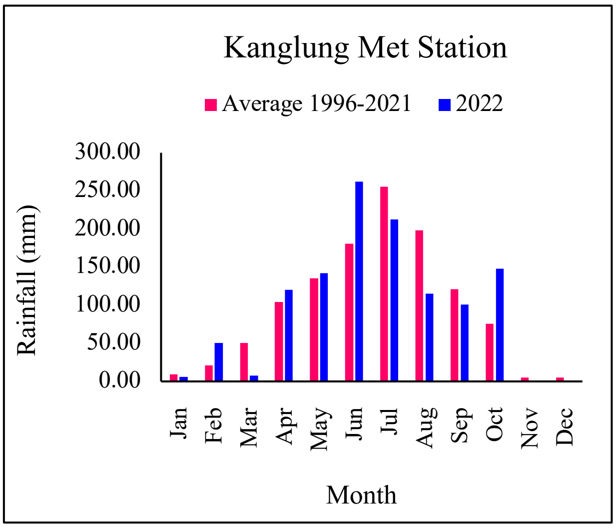


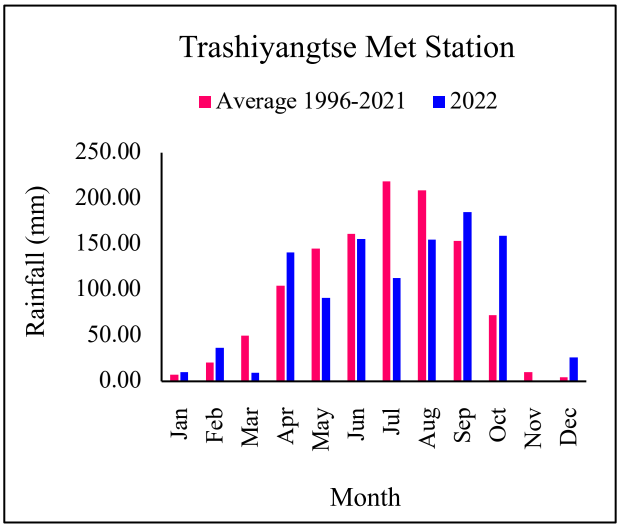


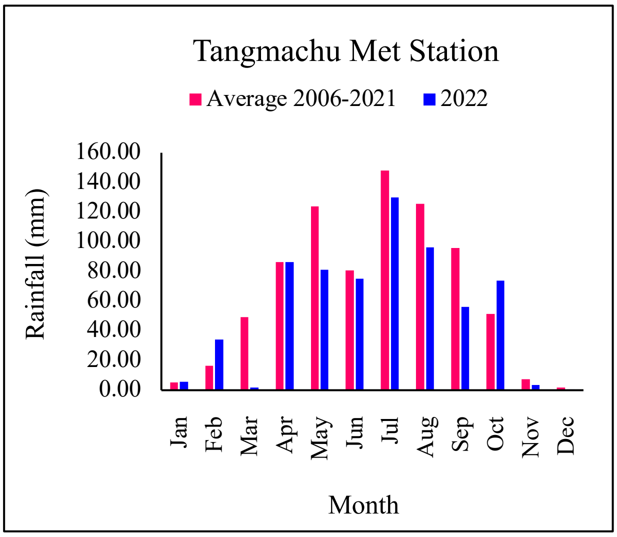


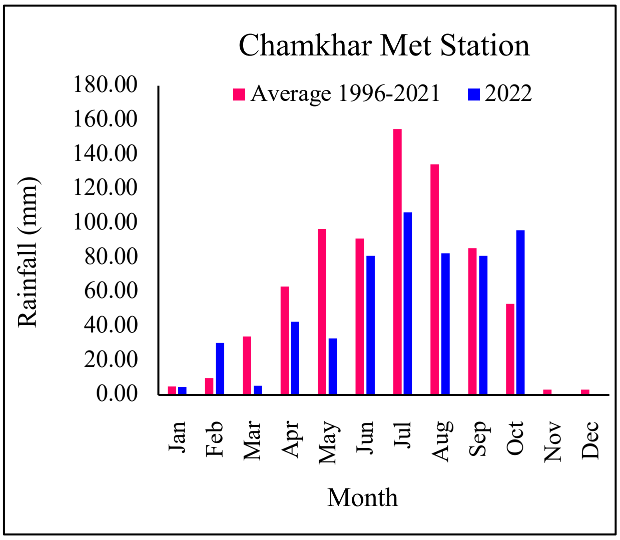

Pemagatshel Met Station
Average 1996-2021
2022
Rainfall (mm)
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

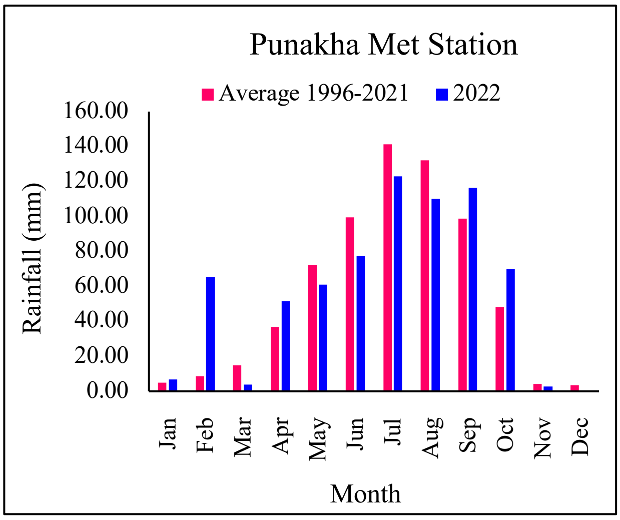

Mongar Met Station
Average 1996-2021
2022
Rainfall (mm)
250.00
200.00
150.00
100.00
50.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

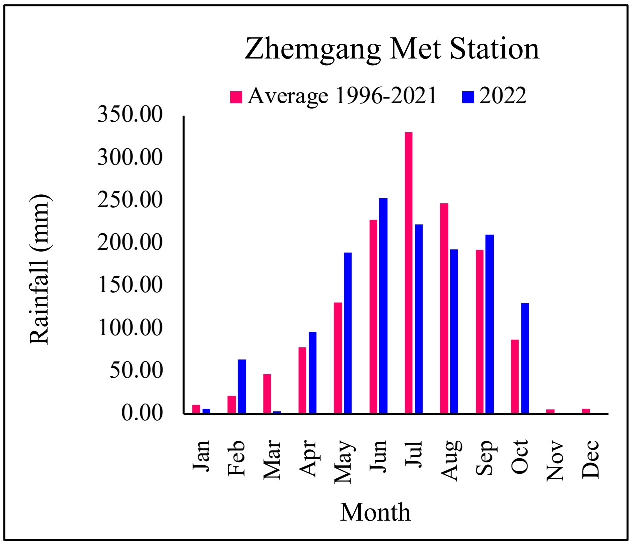

Kanglung Met Station
Average 1996-2021
2022
Rainfall (mm)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

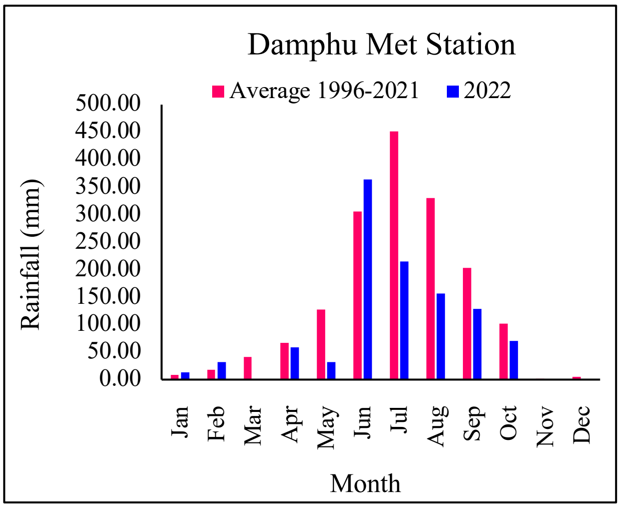

Trashiyangtse Met Station
Average 1996-2021
2022
Rainfall (mm)
250.00
200.00
150.00
100.00
50.00
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

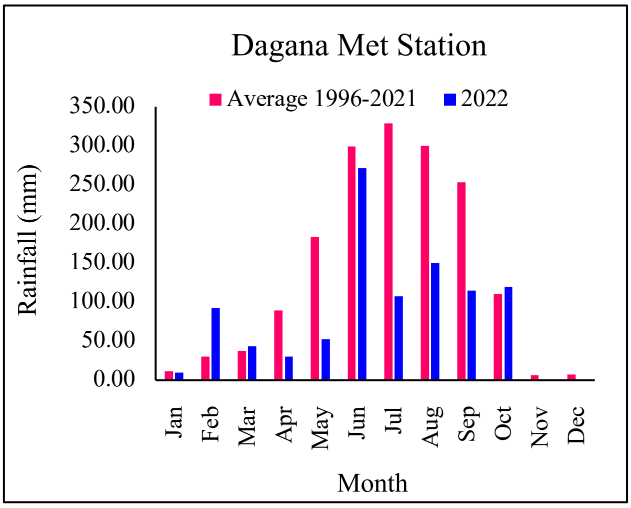

Tangmachu Met Station
Average 2006-2021
2022
Rainfall (mm)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

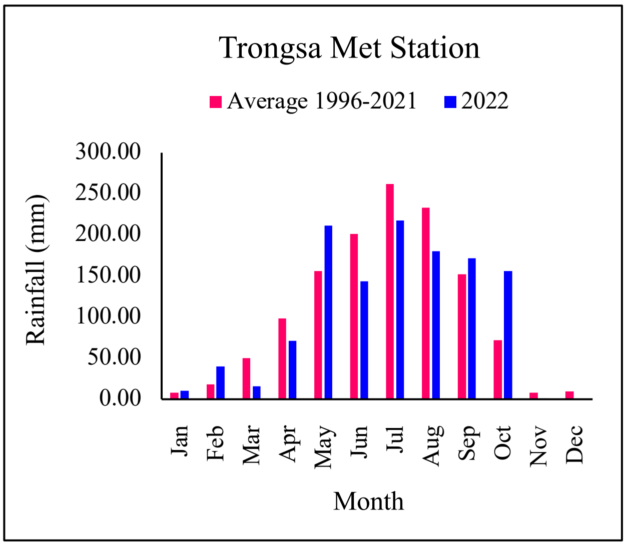

Chamkhar Met Station
Average 1996-2021
2022
Rainfall (mm)
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

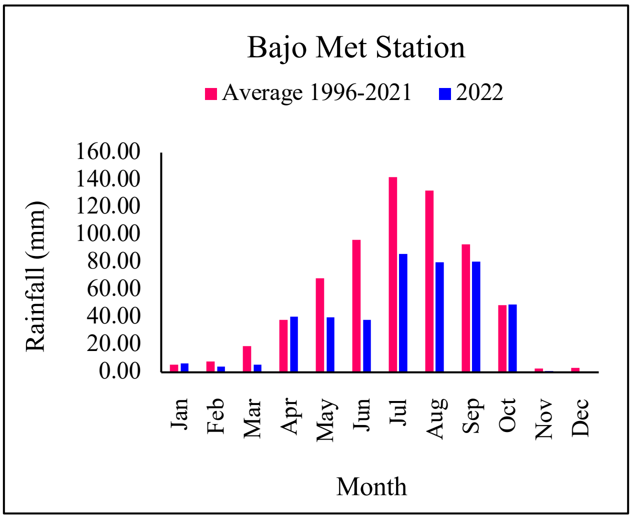

Punakha Met Station
Average 1996-2021
2022
Rainfall (mm)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

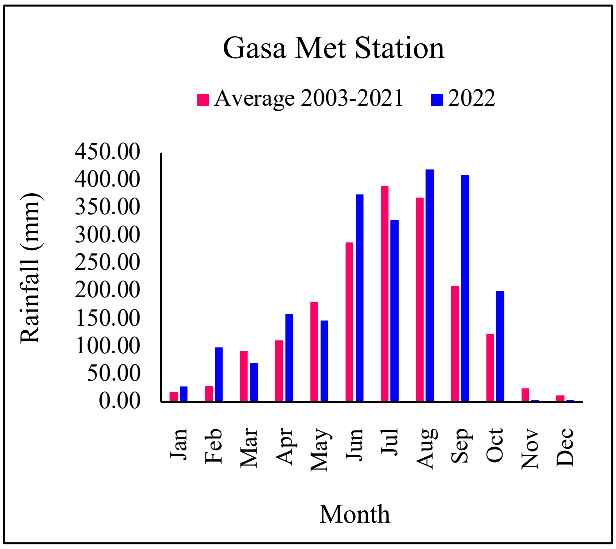

Zhemgang Met Station
Average 1996-2021
2022
Rainfall (mm)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

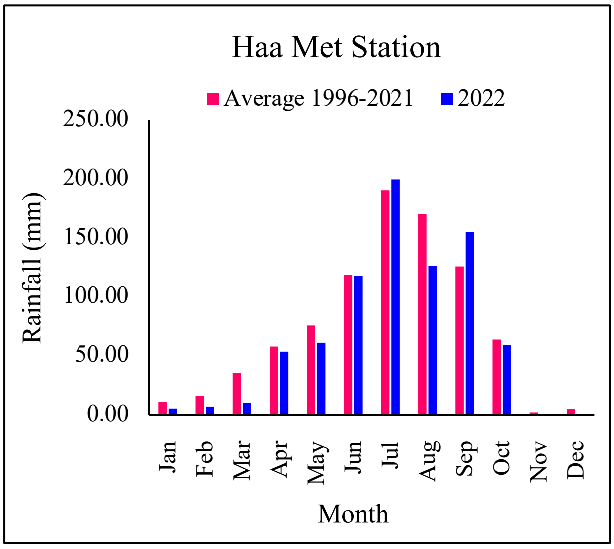

Damphu Met Station
Average 1996-2021
2022
Rainfall (mm)
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

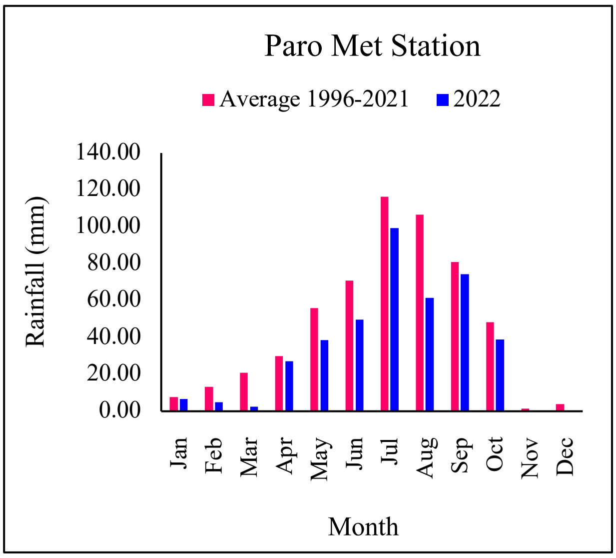

Dagana Met Station
Average 1996-2021
2022
Rainfall (mm)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Trongsa Met Station
Average 1996-2021
2022
Rainfall (mm)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Bajo Met Station
Average 1996-2021
2022
Rainfall (mm)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Gasa Met Station
Average 2003-2021
2022
Rainfall (mm)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Haa Met Station
Average 1996-2021
2022
Rainfall (mm)
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month



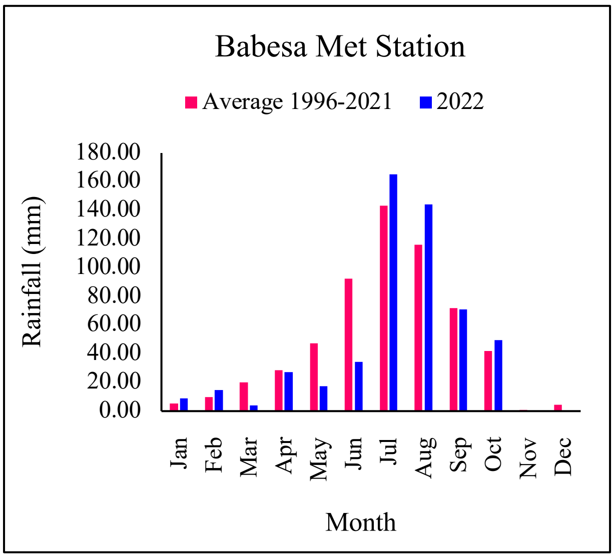


Figure 12: Comparison of total monthly rainfall of observed 2022 with long term average

5. ANNUAL STATISTICS

5.1 Annual statistics for 20 Agrometeorological stations – 2022

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	5604.10	27.73	18.05	176	131	0
Phuentsholing	8255.80	29.01	17.19	182	165	0
Bhur	5326.30	27.97	21.66	161	108	0
Deothang	4942.70	24.38	16.63	138	18	0
Pemagatshel	2031.00	22.83	12.99	105	14	1

Mongar	768.60	22.12	13.50	93	10	0
Kanglung	1165.90	21.09	10.71	113	2	5
Trashiyantse	1081.40	22.58	9.77	136	18	29
Tangmachu	644.50	26.42	15.16	86	115	0
Chamkhar	562.40	17.88	6.87	94	0	85
Trongsa	1216.70	19.70	9.57	139	0	23
Zhemgang	1368.40	20.13	10.94	122	1	4
Damphu	1070.70	20.98	13.37	85	0	0
Dagana	992.80	23.35	13.58	110	4	0
Punakha	688.80	29.09	16.47	108	199	0
Bajo	432.70	25.94	15.68	88	74	0
Gasa	2244.80	15.00	4.74	211	0	102
Haa	794.40	15.61	4.56	141	0	138
Paro	403.10	19.79	6.10	82	11	114
Babesa	535.80	20.59	6.78	79	8	92

5.2 Extreme records for 20 Agrometeorological stations - 2022

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	198.60	06th April	35.00	15th July	8.00	28th January, 29th January, 05th February

Phuentsholing	245.60	12th October	36.00	16th July	8.00	07th February
Bhur	308.00	01st August	35.50	16th July, 20th August	9.00	28th January, 29th January
Deothang	233.40	31st July	32.00	14th July, 15th July	5.00	06th February
Pemagatshel	161.40	17th June	32.00	14th July, 15th July	0.00	06th February
Mongar	60.60	24th October	31.00	14th July, 07th August	1.00	06th February
Kanglung	71.80	24th October	30.50	15th July	-1.00	06th February
Trashiyantse	52.00	24th October	31.5	16th July, 18th August, 26th August	-4.50	29th January
Tangmachu	43.60	24th October	37.00	14th July, 16th July	1.50	05th February, 06th February
Chamkhar	43.10	24th October	26.50	15th July	-12.50	06th February
Trongsa	98.00	22nd May	28.00	15th July, 16th July, 07th August, 24th August	-4.50	06th February
Zhemgang	74.60	15th May	30.00	15th July	-1.00	29th January
Damphu	49.00	17th June	27.00	08th August, 21st August, 02nd October	0.50	06th February
Dagana	74.40	04th February	30.50	14th July, 15th July	1.00	06th February
Punakha	39.80	08th September	38.50	15th July, 16th July	2.50	05th February, 06th February
Bajo	26.00	08th September	35.50	15th July	2.00	04th February, 05th February

Gasa	51.00	29th September	24.00	09th July, 18th July, 19th July	-9.00	28th January
Haa	29.90	14th July	25.00	13th August	-12.50	06th February, 07th February
Paro	23.90	09th September	31.00	12th August	-9.00	29th January
Babesa	48.80	03rd August	31.00	17th July	-7.50	29th January

SECTION B: HYDROLOGY

1. MAJOR FACTORS INCLUECNING 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. ANNUAL FLOW OF 2021 COMPARED WITH THE HISTORICAL FLOW

The annual average flow from recorded data as early as 1992-2020 is compared to the average flow of 2021 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 3. Comparative flow in each basin

Sl. No	Station Name	Basin/Sub Basin	Historical Average flow (till 2021) in m^3/s	Average flow 2022 in m^3/s
1	Tamchu	Wangchhu	59.7	50.6
2	Lungtenphu	Wangchhu	22.3	19.07
3	Kerabari	Punatsangchhu	454.2	406.1
4	Wangdirapids	Punatsangchhu	295.3	324.6
5	Yebesa on Mochhu	Punatsangchhu	114.2	104.0
6	Kurjey on Chamkhar	Manas	53.8	48.6
7	Muktirap on Kholongchhu	Manas	64.1	59.3
8	Sumpa on Kurichhu	Manas	176.6	164.8
9	Kurizampa on Kurichhu	Manas	294.9	267.3
10	Panbang on Drangmechhu	Manas	781.7	784.7

3. MAXIMUM AND MINIMUM FLOW RECORDED IN 2022

Table 4. Maximum and Minimum flow record and data 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	Tamchu	2529.17	308.7	23rd July	14.3	28th Feb
2	Lungtenphu	665.71	78.0	23rd July	3.7	5th March
3	Kerabari	9627.237	1388.6	2nd August	119.6	27th Feb
4	Wangdirapids	5647.62	1152.0	23rd July	67.9	2nd Feb
5	Yebesa	2223.30	429.4	1st August	19.7	25th Feb
6	Kurjey	1354.97	183.7	9th Sept	11.1	1st March
7	Muktirap	876.36	274.5	28th June	11.0	3rd Feb
8	Sumpa	7101.15	669.5	9th Sept	38.1	25th Feb
9	Kurizampa	8997.70	1185.1	9th Sept	65.5	4th Feb
10	Panbang	21006.1	5939.3	18th June	138.6	15th Feb

4. LOCATION MAP OF PRINCIPLE HYDROLOGICAL SATTIONS

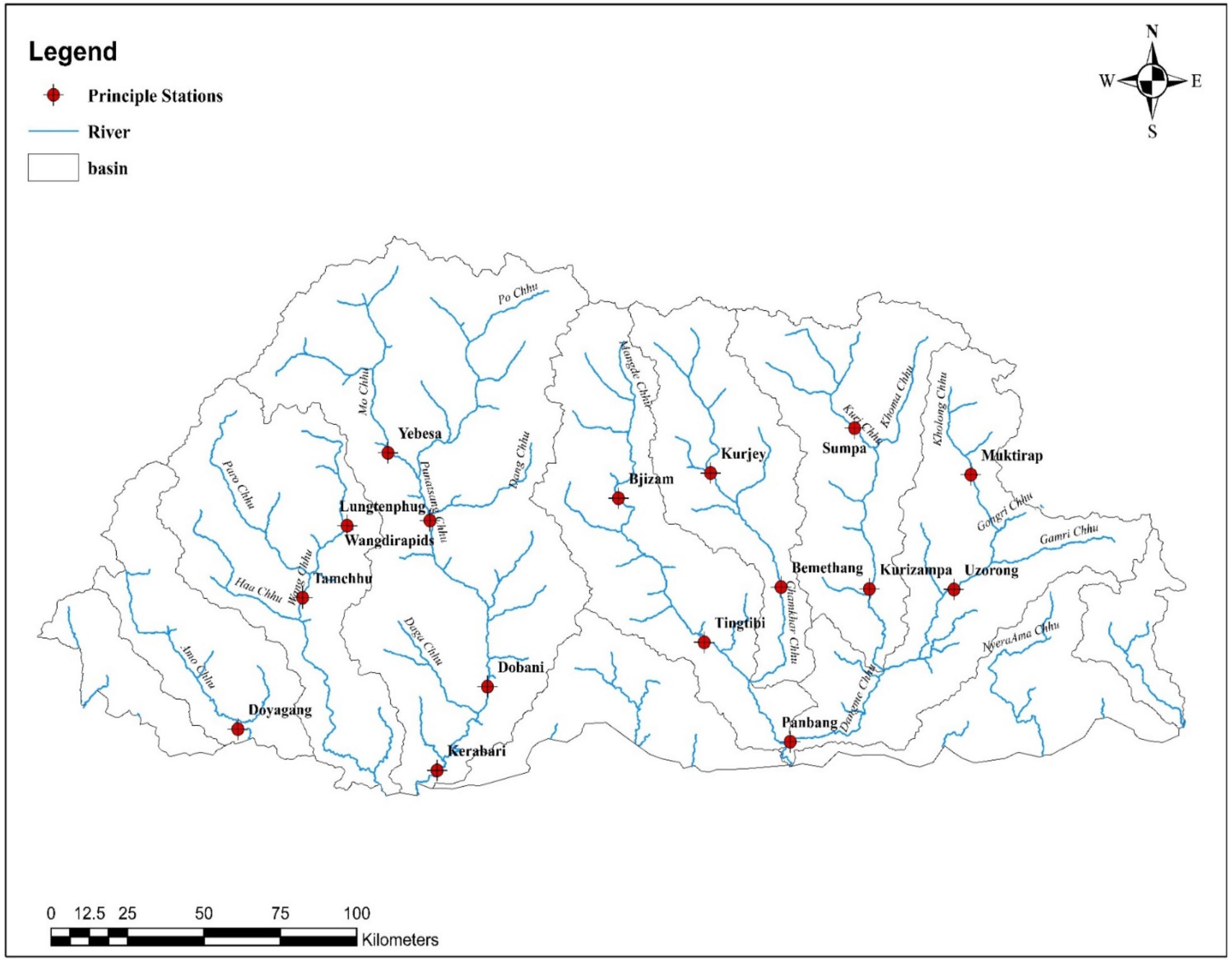
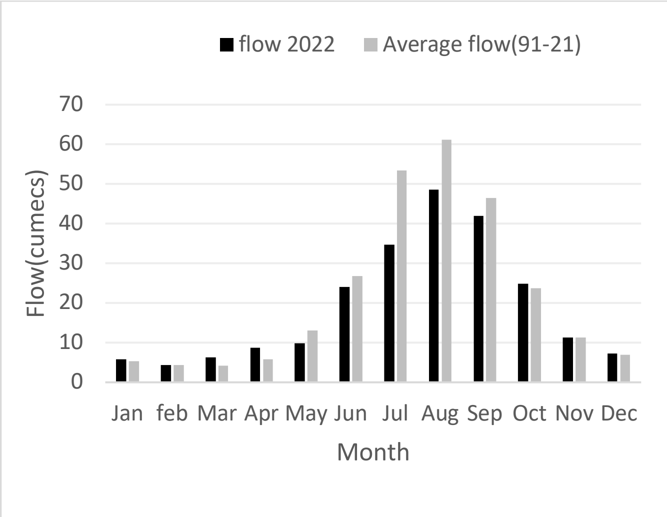


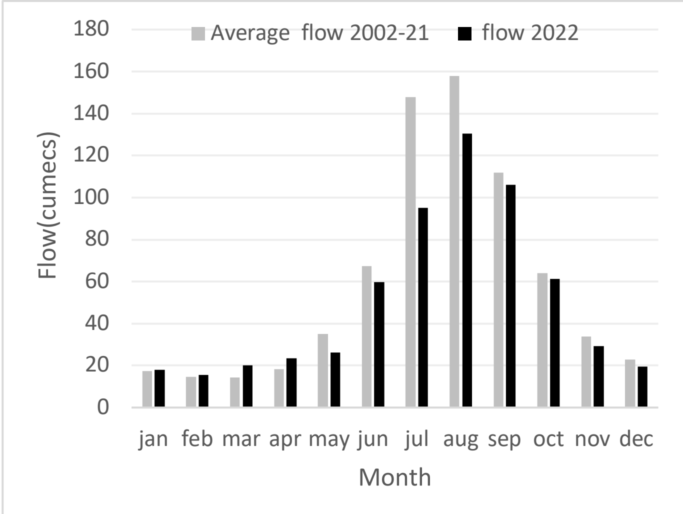
Figure 13: Location of Principle Stations

5. WANGCHU BASIN RIVER FLOW STATUS

5.1 STATIONWISE AVERAGE MONTHLY FLOW

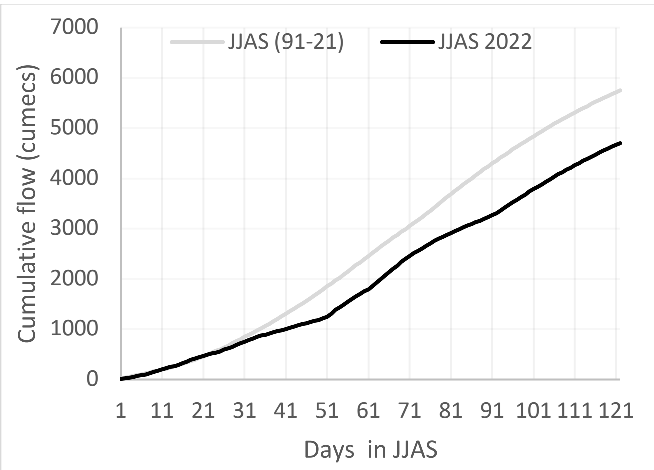


Station: Lungtenphu on Wangchhu

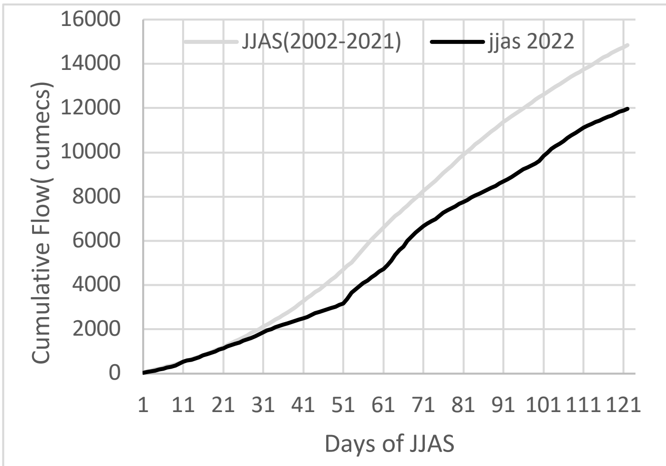


Station: Tamchu on Wangchhu

5.2 STATIONWISE JJAS CUMMULATIVE FLOW



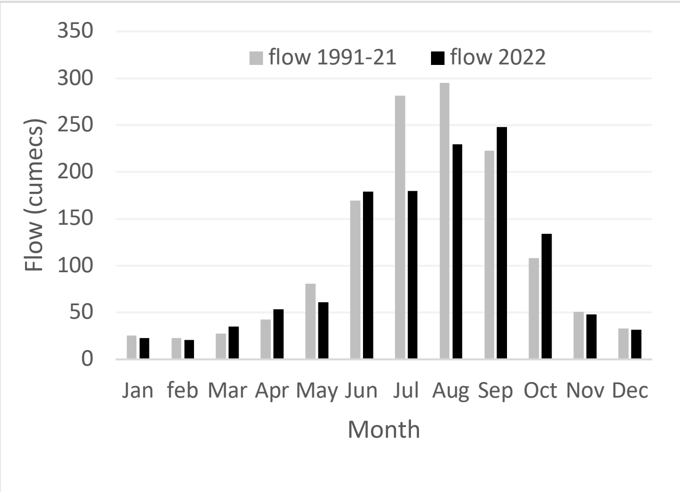
Station: Lungtenphu on Wangchhu



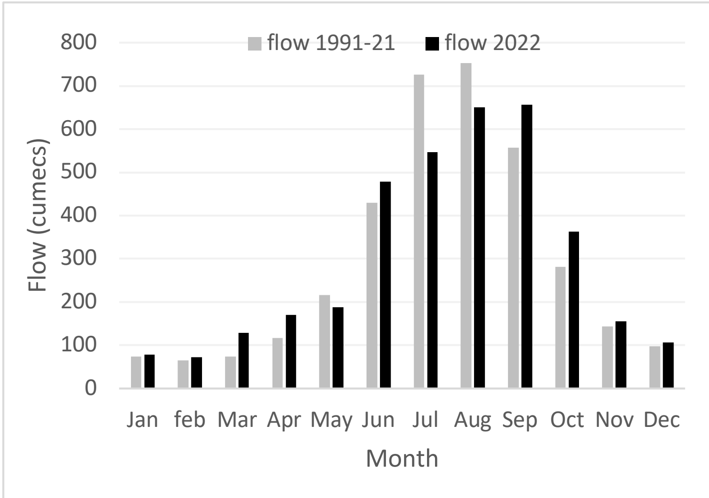
Station: Tamchu on Wangchhu

6. PUNATSANGCHHU RIVER FLOW STATUS

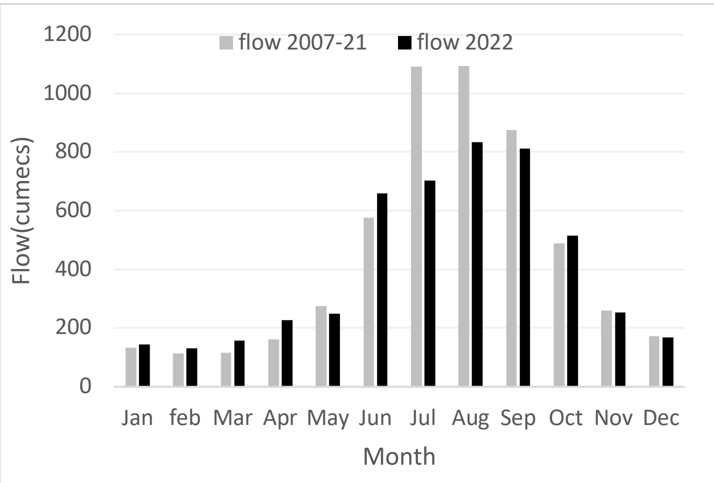
6.1 STATIONWISE AVERAGE MONTHLY FLOW



Station: Yebesa on Mochhu

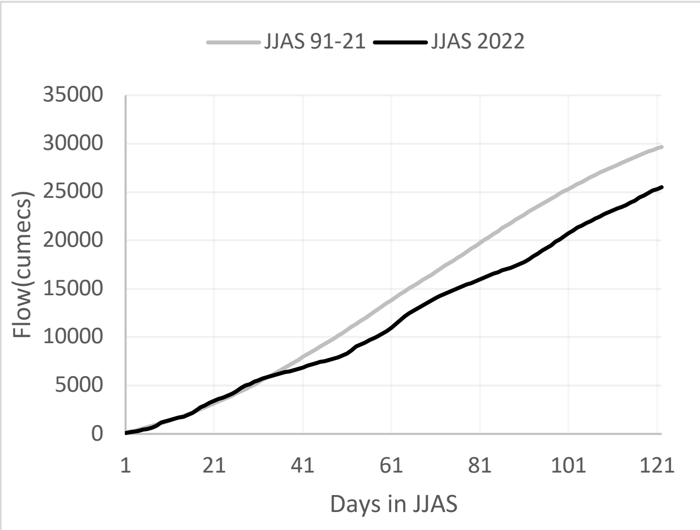


Station: Wangdirapids on Punatsangchhu

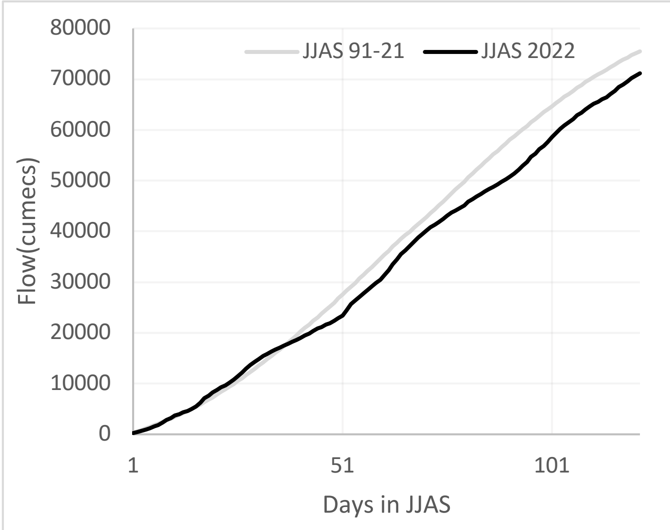


Station: Kerabari on Punatsangchhu

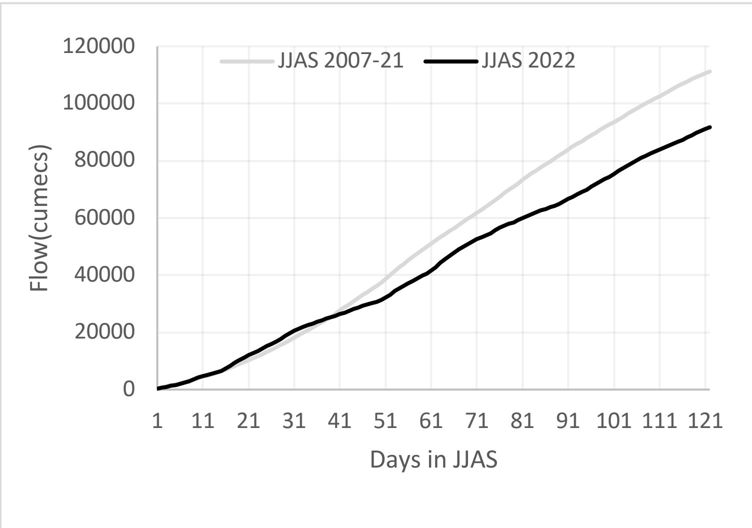
6.2 STATIONWISE JJAS CUMULATIVE FLOW



Station: Yebesa on Mochhu



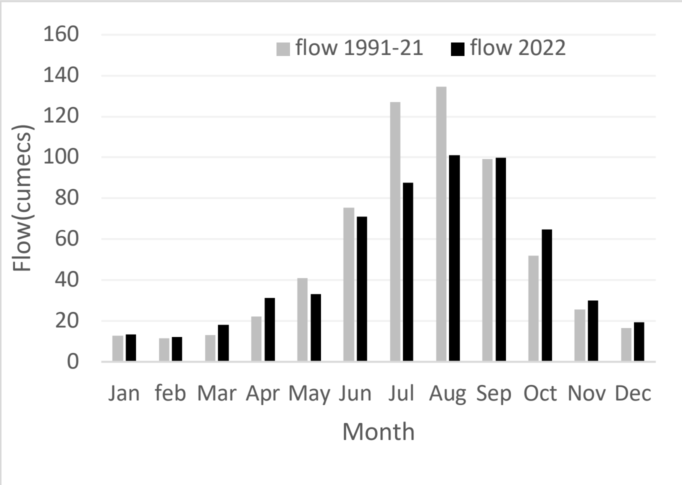
Station: Wangdirapids on Punatsangchhu



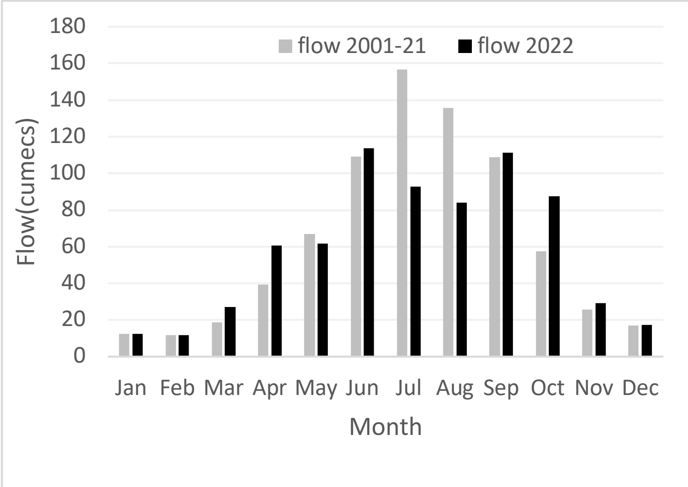
Station: Kerabari on Punatsangchhu

7. MANAS BASIN RIVER FLOW STATUS

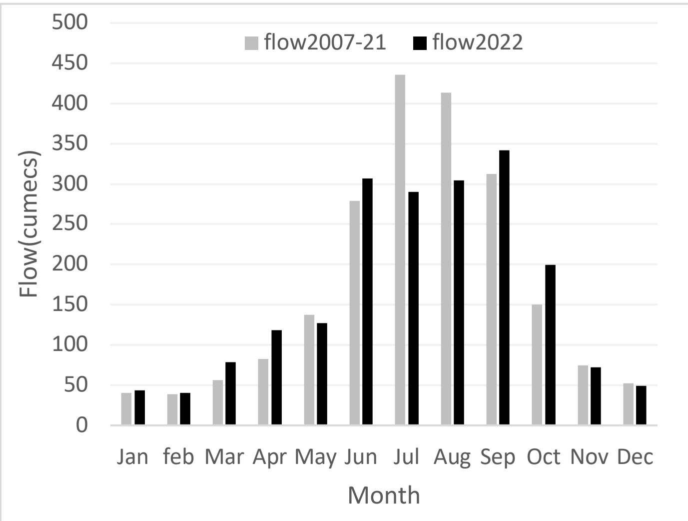
7.1 STATIONWISE AVERAGE MONTHLY FLOW



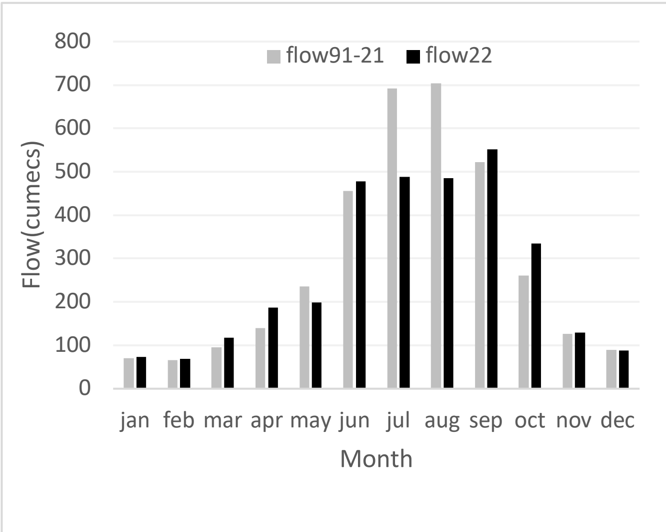
Station: Kurjey on Chamkharchhu



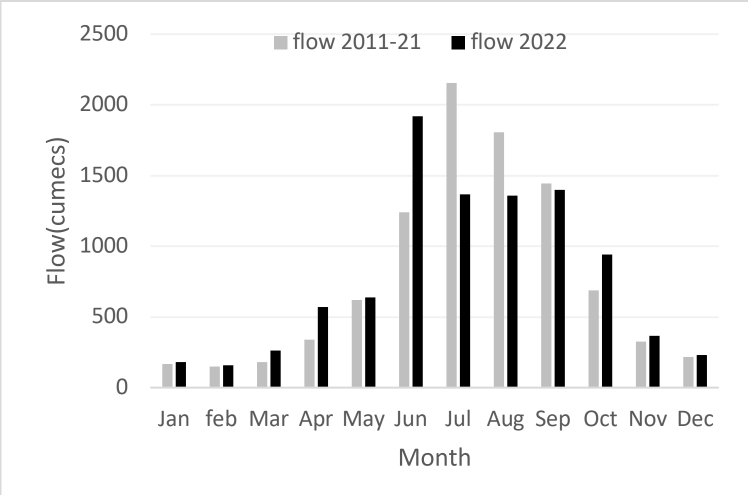
Station: Muktitrap on Kholongchhu



Station: Sumpa on Kurichhu

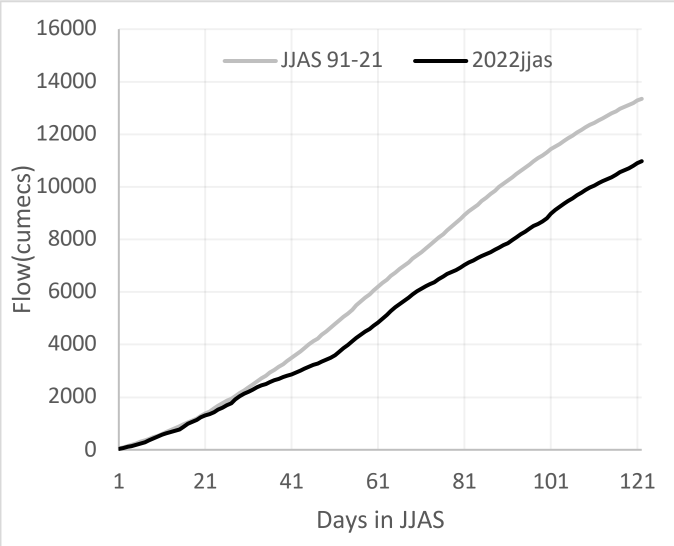


Station: Kurizampa on Kurichhu

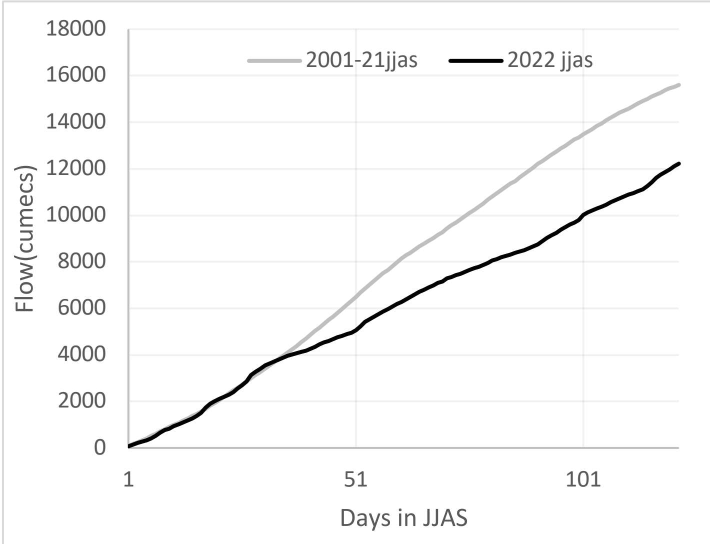


Station: Panbang on Drangmechhu

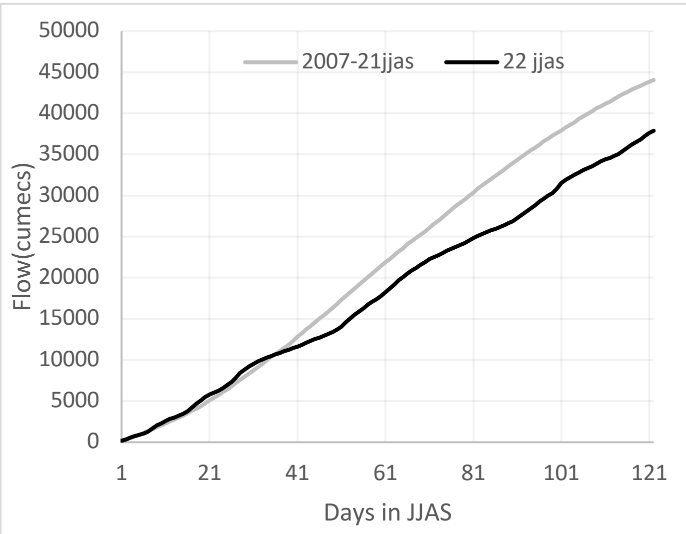
7.2 STATIONWISE JJAS CUMMULATIVE FLOW



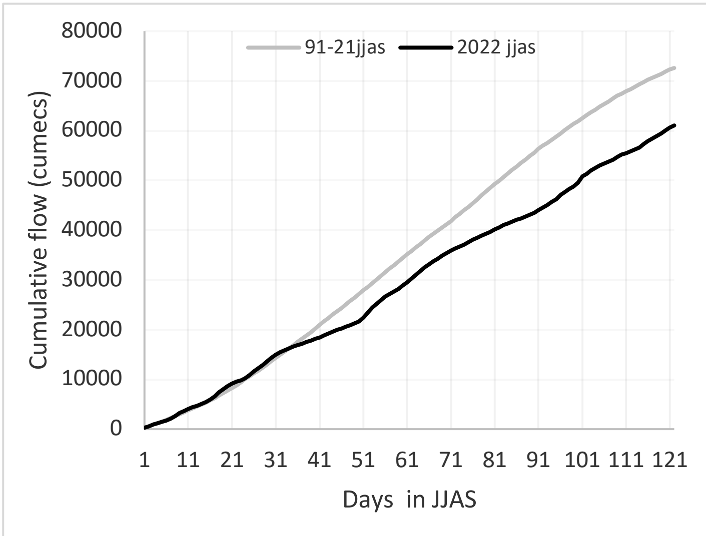
Station: Kurjey on Chamkharchhu



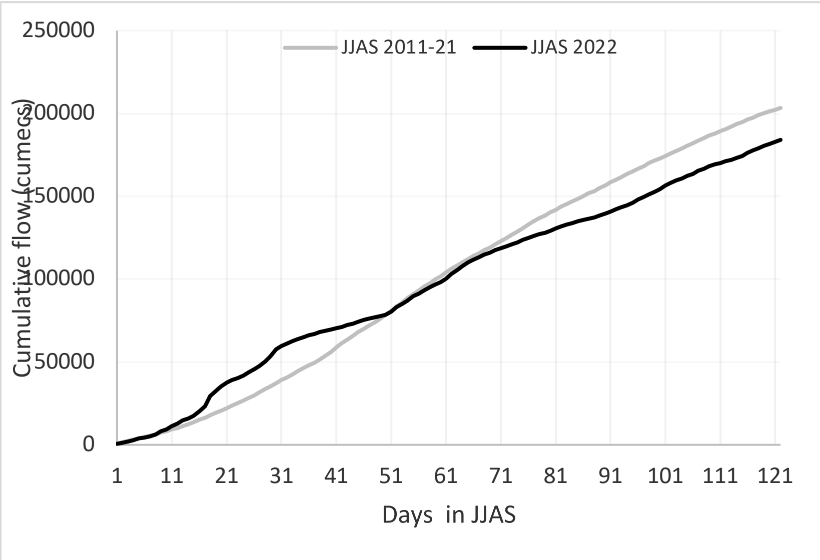
Station: Muktitrap on Kholongchhu



Station: Sumpa on Kurichhu



Station: Kurizampa on Kurichhu



Station: Panbang on Drangmechhu

SECTION C: CRYOSPHERE

1. GLACIERS

Bhutan, nestled in the Eastern part of the Himalayas is renowned for its majestic glaciers, distributed across the northern frontiers of the country. These glaciers are vital sources of freshwater for Bhutan's perennial rivers supporting agriculture, hydropower generation and ecosystem. As per the BGI 2018, Bhutan has 700 glaciers covering an area of approximately 630 km^2 accounting to 1.6 percent of the total area of the country. However, in the recent decades, these glaciers have been experiencing the impact of global climate change. Rising temperatures and changing precipitation patterns have led to glacier retreat, resulting in reduced glacier ice surface area and volume.

Out of 700 glaciers, the highest number of glaciers are situated in the 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 14 and table 5 shows the glacier map and basin to sub-basin wise distribution of glaciers in Bhutan respectively.

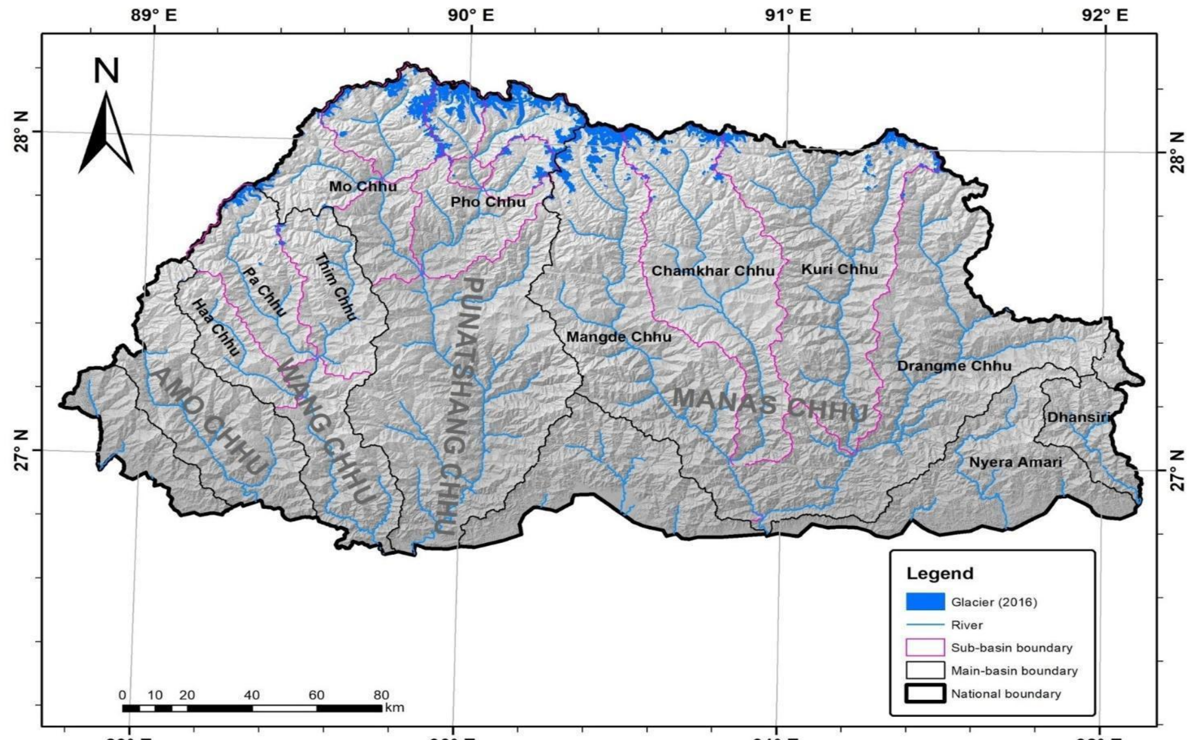


Figure 14: Sub-basin-wise distribution of glaciers of Bhutan. Pink polygons show the sub-basin boundary, dark blue polygons show the glaciers and light blue polygons are rivers of Bhutan

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
PunatsangChhu	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

Owing to numerous glaciers found in the northern frontiers of the country, Bhutan hosts hundreds of glacial lakes. As per the glacial lake inventory published (BGLI, 2021) in the past, Bhutan has 567 glacial lakes mapped through updated criteria. When Bhutan has numerous glacial lakes including some of the largest and most spectacular ones, they also pose a significant risk to the local communities due to the potential threat of glacial lake outburst flood (GLOFs). Altogether, these glacial lakes cover an area of 55.04 km^2. 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 15 and table 6 shows the distribution of glacier lakes in the northern frontiers and sub-basin wise distribution of the lakes respectively

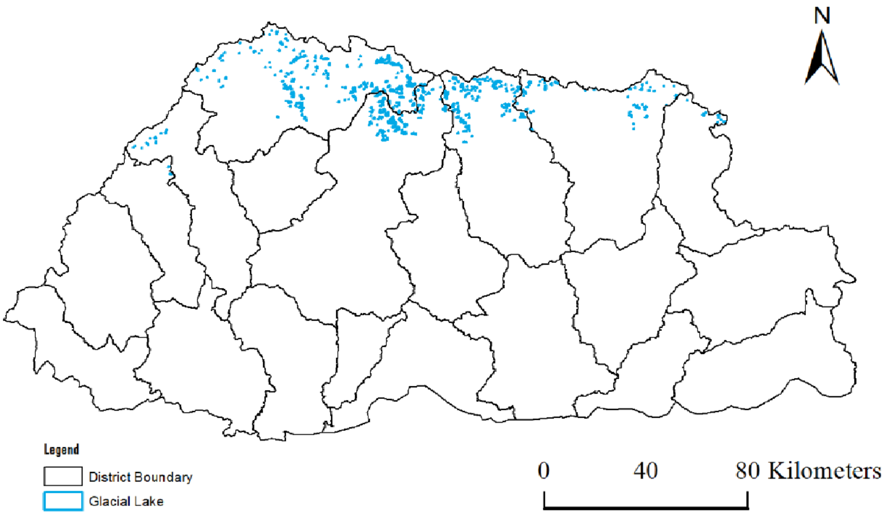


Figure 15: Distribution of glacial lakes in the northern frontiers of the country. Blue polygons are the distribution of glacial lakes and the black polygons are district boundaries.

Table 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)

According to the inventory on glaciers and glacial lakes of Bhutan (2001), Bhutan had 25 potentially dangerous glacial lakes. Later, through ground verification of those potentially dangerous glacial lakes, the number of potentially dangerous glacial lakes of the country has been updated. According to the updated inventory, Bhutan now has 17 potentially dangerous glacial lakes of which a maximum number of potentially dangerous glacial lakes are found in Pho Chhu sub-basin. Figure 16 and table 7 shows the locations and sub-basin wise distribution of 17 potentially dangerous glacial lakes of the country.

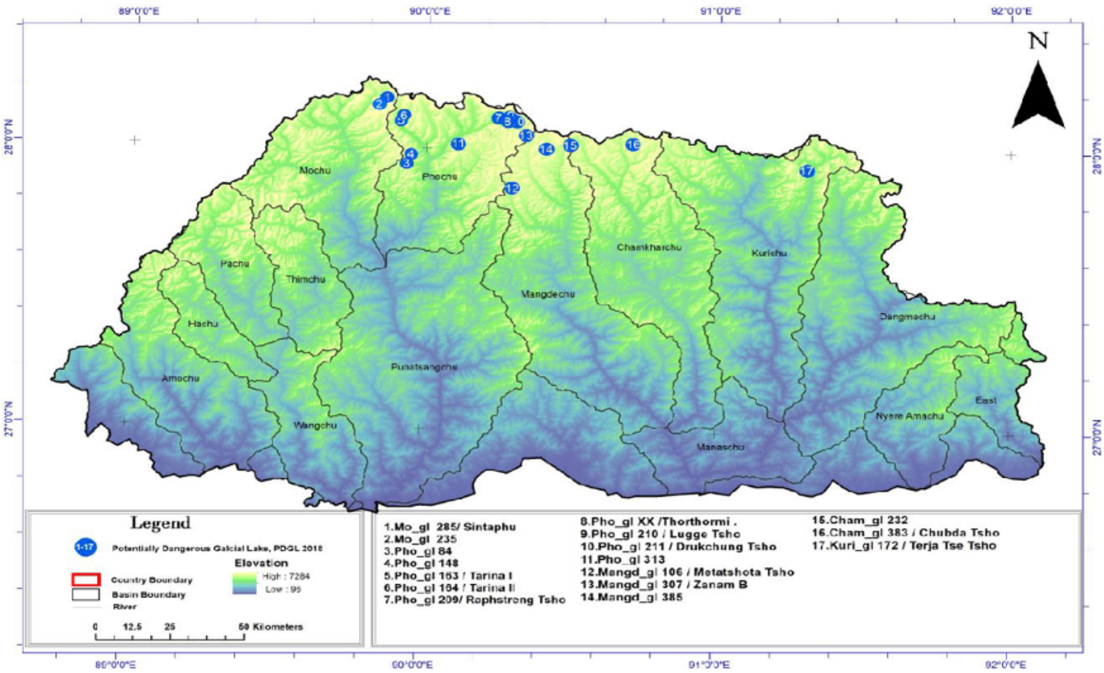


Figure 16: Sub-basin-wise distribution of potentially dangerous glacial lakes of Bhutan.

Table 7: 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

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 (headwater of Pho Chhu) and Thana (headwater of Chamkhar Chhu) glaciers respectively. Over the observation periods, both the glaciers have exhibited negative mass balance indicating glacier ice mass loss. In addition to the existing two benchmark glaciers, an additional benchmark glacier has been identified in the headwater of Thim Chhu, Shodug glacier representing uniform spatial distribution in the country. Figure 17 and Table 8 shows the location of three benchmark glaciers and glacier mass balance data of Gangju La and Thana glacier over the observation periods.

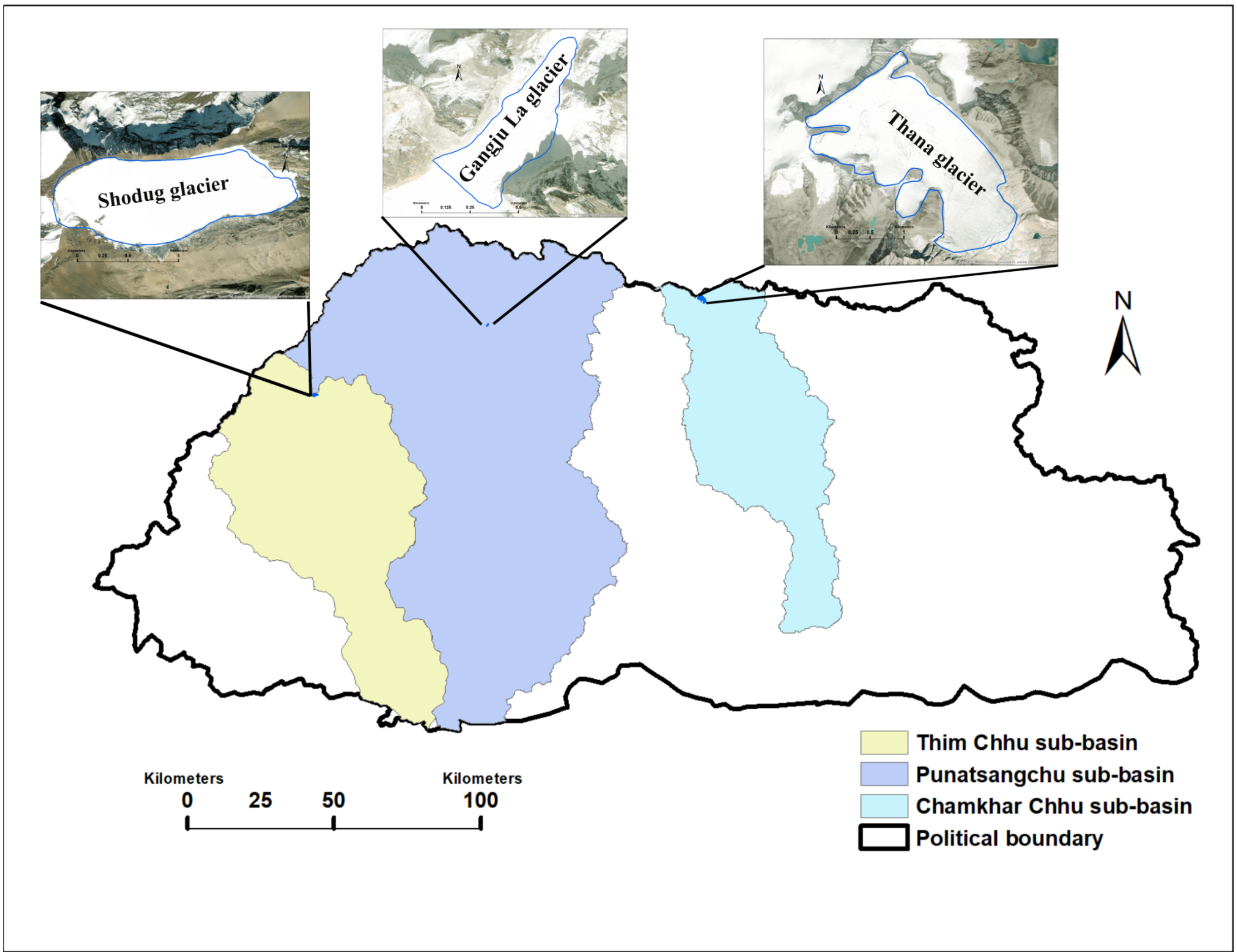


Table 17: Glacier mass balance of Thana and Gangju La

Table 8: Details on GangjuLa and Thana

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**
2020-21	-	**-1054**	**-1699**	**-2336**

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World Meteorological Organization (WMO). (2023) *State of the Global Climate 2022*