National Hydrometeorological Service - Skopje

IDENTIFICATION AND ANALYSIS OF EXTREME CLIMATE EVENTS IN THE REPUBLIC OF NORTH MACEDONIA

for the 4th National Communication on Climate Change

February, 2020

IDENTIFICATION AND ANALYSIS OF EXTREME CLIMATE EVENTS IN THE REPUBLIC OF NORTH MACEDONIA

INTRODUCTION

Changes in extreme weather and climate events have significant impact and are among the most serious challenges for our society, especially in addressing climate change (CCSP, 2008). As a result of the predictions that some extreme events will become more frequent, more widespread or more intense during the 21st century (IPCC, 2007), the demand for information services for weather and climate extremes is increasing. The sustainability of economic development and living conditions depends on our ability to deal with the risks associated with extreme events.

Many practical problems require knowledge of the behavior of extreme values. In particular, the infrastructure on which we depend for food, water, energy, shelter and transport is sensitive to high or low values of meteorological variables. The motivation for extreme events analysis is often to find the optimal balance between on one hand, adopting high safety standards that are very expensive, and on the other hand preventing major damage to equipment and facilities from extreme events that are likely to occur over the lifetime of such infrastructures (WMO, 1983).

EXTREME CLIMATE EVENTS

Extreme climate events are very unfavorable (fierce), rare and intense events that occur in a certain area in a certain period of time. These events deviate from the statistically determined schedule of climate events for a particular area. The analysis of extreme climate events is required because there are trends that have been observed in recent decades, which are expected to continue and intensify in the future. There is a general trend of decrease in the number of icing days, increase in the number of warm (tropical) nights, more frequent occurrence of warm spells, fewer days with precipitation and more intense rainfall.

Although extreme events do not occur frequently, they can have significant impacts: causing significant destruction of infrastructure, impacting our economy and health, and resulting in loss of life (IPCC 2013; WHO nd, 2012; Melillo et al. 2014). It is essential that meteorological communities improve their understanding and characterization of extreme weather and climate events in time and space with regionally and globally consistent methodologies. Because the climate varies regionally, the definition of an extreme weather or climate event and its threshold will vary from location to location. In other words, the extreme value of a particular climate element in one location may be within the normal range on another location. In addition to natural and geographical reasons, there are practical reasons for the different definitions: for example, on some regions the focus is on a particular societal sector that requires specific thresholds for taking action. This is the approach taken in defining warm spells in a heat warning system, for which a heat wave is defined specifically having in mind its potential impact on human health.

EXTREME EVENTS ANALYSIS

Extreme climate events can be assessed by researching climate change indices primarily data on daily maximum and minimum temperature and daily precipitation data.

METHODOLOGY

The analysis of extreme climate events for the Republic of North Macedonia, was based on the guidelines and recommendations of the World Meteorological Organization (WMO), such as the Guidelines on the Definition and Monitoring of Extreme Weather and Climate Events and the methodology recommended in the Guidelines on Analysis of Extremes in a Changing Climate in Support of Informed Decisions for Adaptation, WCDMP-No.72.

Climate Extreme Indices are defined by the Joint CCl/CLIVAR/JCOMM Climate Change Detection and Index Expert Team (http://www.clivar.org/organization/etccdi/etccdi.php, ETCCDI). The Guidance covers the extremes indices for the elements monitored on a daily basis such as air temperature and precipitation. These indices are widely used as a tool to assess and monitor changes in extreme events. They describe the special features of the extreme events, including the amplitude and frequency of occurrence. By using the same definitions and analyzing data in a standardized way, it is possible to compare results from different locations and obtain a coherent picture of change in the region and beyond.

DATA PREPARATION

When analyzing extremes, it is essential to meet the strict criteria for completeness of data series and to provide quality and long, continuous daily data series. This strict criterion needs to be met because in practice there are a number of days for which data are missing, and some analyzes of the extremes are critically dependent on the serial completeness of the data, which if not met could result in wrong conclusions.

To meet this criterion, the following activities were primarily undertaken:

- assessment of the available longer series of daily data on air temperature and precipitation,
- digitization of data in the meteorological database,
- data quality control**.**

DESCRIPTION OF EXTREMES INDICES

The basic package of descriptive extremes indices includes 27 extremes indices for temperature and precipitation. The indices describe special features of the extremes, including frequency, amplitude, and duration. Indices for extreme climate events are divided into five categories:

- Percentile indices - value of the given variable below which is a certain percentage of the entity, for example, 10th or 90th percentile from the minimum / maximum temperature,
- Absolute indices - represent the maximum or minimum value in the season / year, e.g. maximum 5-day precipitation,

- Threshold indices - number of days in which the temperature / precipitation deviates from the specified threshold, e.g. frost days (Tmin <0 C), wet days> 10mm,
- Duration indices - define the period of excessive or prolonged heat, cold, humidity or dryness,
- Other indices that have significant impact on society, daily inter-annual temperature range, intensity of daily precipitation.

One of the key approaches to the concept of indices involves calculating the number of days in a year that exceed specific thresholds. Many ETCCDI indices are based on percentiles with set thresholds for estimating moderate extremes that typically occur several times each year, instead of weather events that occur once in a decade. For precipitation, the threshold percentile is calculated from the sample of all wet days in the reference period. For temperature, the threshold percentile is calculated from five-day windows by centering each calendar day to calculate the average annual cycle. Such indices allow direct monitoring of trends in relation to frequency or intensity of events, which, although not particularly extreme, would still be stressful. The reason for choosing several percentile thresholds instead of fixed thresholds is that the number of days that the threshold percentile exceeds is more evenly distributed in space and has significance in each region.

Daily counting indices based on percentile thresholds express anomalies in the local climate. Thresholds are selected so that they exceed a fixed frequency, so the threshold values are location specific. Such indices allow for spatial comparisons because they sample the same part of the probability distribution of temperature and precipitation at each location.

Absolute threshold-based daily counting indices are less suitable for spatial comparisons of extremes than those based on percentile thresholds. The reason is that, over large areas, day-count indices based on absolute thresholds may sample very different parts of the temperature and precipitation distributions. For annual indices, this means that in another climate regime, the variability of such indices easily arises from a different season.

Absolute extremes values, such as the annual maximum consecutive 5-day precipitation (RX5day), can often be associated with extreme events affecting human society and the natural environment. Indices based on the number of days that cross certain fixed thresholds (for example, the 0°C threshold as used in the FD index) may also be related to the observed impacts, especially if the thresholds refer to values of physical, hydrological or biological significance.

Also trends in cold night indices TN10p (Percentage of days when TN < 10th percentile) and warm days TX90p (Percentage of days when TX > 90th percentile) are relevant for comparing changes with regard to heating and cooling needs.

ANALYSIS OF EXTREME EVENTS INDICES FOR THE REPUBLIC OF NORTH MACEDONIA

In the analysis of the extreme events indices for the Republic of North Macedonia data on daily values for the main meteorological elements were used, that is, air temperature and precipitation data from meteorological stations with a continuous series of historical data for the period from 1951-2019 such as: Bitola, Prilep, Shtip, Kriva Palanka, Berovo, Strumica, Demir Kapija, Gevgelija, Ohrid and Lazaropole.

A total of 27 indices were included, of which 16 refer to air temperature and 11 to precipitation.

Table 1. Temperature indices

Index	Definition
FD	Frost days: count of days where TN (daily minimum temperature) < 0°C.
SU	Summer days: count of days where TX (daily maximum temperature) > 25°C.
ID	Icing days: count of days where TX (daily maximum temperature) < 0 °C.
TR	Tropical nights: count of days where TN (daily minimum temperature) > 20 °C.
GSL	Growing season length: annual count between the first span of at least 6 days where TG (daily mean temperature) >5 °C and the first span in the second part of the year of at least 6 days where TG <5 °C.
TXx	Monthly maximum value of daily maximum temperature TX
TNx	Monthly maximum value of daily minimum temperature TN
TXn	Monthly minimum value of daily maximum temperature TX
TNn	Monthly minimum value of daily minimum temperature TN
TN10p	Cold nights: count of days where TN < 10th percentile
TX10p	Cold day-times: count of days where TX < 10th percentile
TN90p	Warm nights: count of days where TN > 90th percentile
TX90p	Warm day-times: count of days where TX > 90th percentile
WSDI	Warm spell duration index: count of days in a span of at least 6 days where TX > 90th percentile
CSDI	Cold spell duration index: count of days in a span of at least 6 days when TN < 10th percentile
DTR	Diurnal temperature range: mean difference between TX and TN

Table 2. Precipitation indices

Index	Definition
RX1day	Maximum one-day precipitation: highest precipitation amount in one-day period
RX5day	Maximum five-day precipitation: highest precipitation amount in five-day period
SDII	Simple daily intensity index: mean precipitation amount on a

	wet day
R10mm	Heavy precipitation days: count of days where RR (daily precipitation amount) ≥ 10mm
R20mm	Very heavy precipitation days: count of days where RR (daily precipitation amount) ≥ 20mm
Rnnmm	Count of days where RR ≥ user defined threshold in mm: RR> 30mm; 40mm; 50mm
CDD	Consecutive dry days: Maximum length of dry spell (RR < 1mm)
CWD	Consecutive wet days: Maximum length of wet spell (RR≥1mm)
R95pTOT	Precipitation due to very wet days (RR > 95th percentile)
R99pTOT	Precipitation due to extremely wet days (RR > 99th percentile)
PRCPTOT	Total precipitation in wet days (RR≥1mm)

The analysis of percentile indices was made in relation to the reference period 1961-1990. At the same time, an analysis was made in relation to the period 1986-2005, which period was used as a reference in the "Report on Climate Change Projections and Changes in Climate Extremes for the Republic of North Macedonia", for the following indices:

- **FD,** Frost days
- **SU,** Summer days
- **ID,** Icing days
- **TR,** Tropical nights
- **GSL,** Growing season length
- **WSDI,** Warm Spell Duration Index
- **CSDI,** Cold Spell Duration Index
- **RX1day,** Maximum one-day precipitation
- **RR40,** Days with precipitation when RR> 40mm
- **CDD,** Consecutive dry days

The analysis of each climate index individually is given below. Depending on the type of index, the maximum values within the analyzed period (1951-2019) are separated, and for the duration indices (warm and cold spells, dry and wet periods), tables with the frequency of occurrence are given, as well as tables with the length (first and last day) of the duration of the period.

The obtained results serve as a basis for establishing a database of extreme climate events that have occurred in the regions where the meteorological stations are located. These data are necessary for the analysis of climate change impacts as well as for implementing mitigation and adaptation measures.

TEMPERATURE INDICES

FROST DAYS

The temperature index called "*frost days*" belongs to the group of indices based on the number of days that exceed certain fixed thresholds. This index refers to the number of days with minimum daily air temperature Tn <0°C.

The highest annual number of frost days in the past 69 years, that is, 157 days were observed in Lazaropole, while the lowest number, 13 days were observed in Gevgelija. The highest annual number of frost days at almost all meteorological stations was recorded in 1953. A characteristic year with the lowest annual number of frost days was 2014 (Table 3).

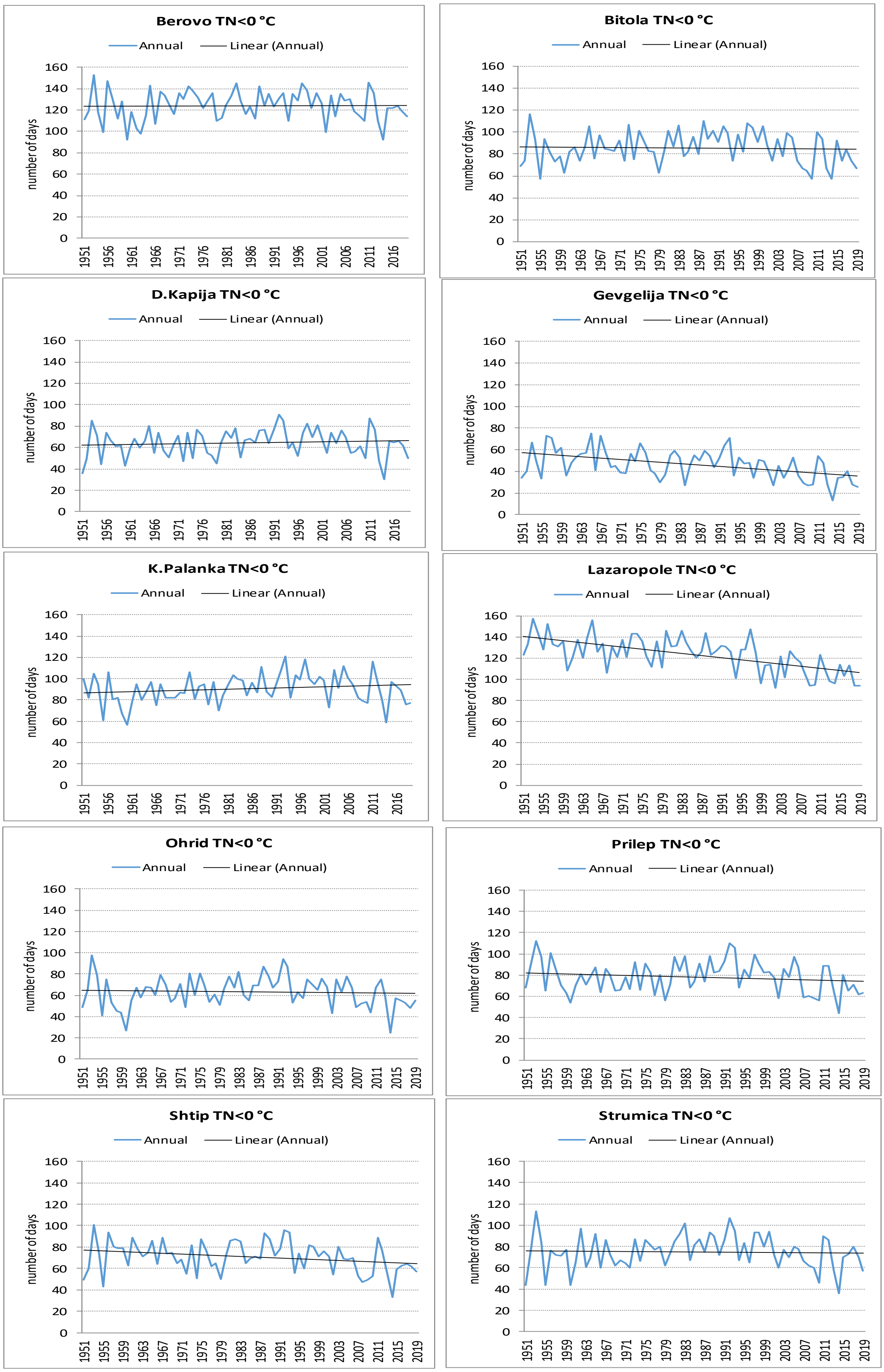
Table 3. Annual maximum and minimum number of frost days for the period 1951-2019

	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	75	91	101	153	116	121	157	98	112	113
year	1965	1992	1953	1953	1953	1993	1953	1953	1953	1953
min	13	30	33	92	57	57	92	25	44	36
year	2014	2014	2014	1960/2014	1955/2010/ 2014	1960	2002	2014	2014	2014

Most meteorological stations show a slight decrease in the annual number of frost days, with the exception of Lazaropole where the decrease is particularly pronounced (Graph 1), which coincides with the conclusion in the "Report on Climate Change Projections and Changes in Climate Extremes for the Republic of North Macedonia”. Namely, according to this report, in near future the expected decrease in the annual number of frost days compared to the average for 1986-2005, in all three scenarios RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high) is about 10-20 days. In the low scenario this change will remain constant until the end of the century, but in the other two scenarios the reduction in the number of frost days in the middle of the century will be greater, up to 20-30 days. Further decrease, more pronounced in the high scenario, is expected almost on the whole territory of the country in the last period of the century (2081-2100). In the high scenario, a total reduction of about 50 days is expected, compared to the period 1986-2005 (Table 4). The reductions are most significant at higher altitudes. According to the high scenario, one can expect almost no negative air temperatures to be registered in Gevgelija and the surrounding region by the end of the century.

Table 4. Average number of frost days for the periods 1951-2019 and 1986-2005

average	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
1951-2019	46	64	71	124	86	90	123	63	78	75
1986-2005	48	71	75	127	94	98	121	71	86	82



Graph 1. Annual number of frost days

ICING DAYS

The days when the maximum daily air temperature is negative, i.e. less than 0°C are called icing days.

The highest annual number of icing days (48) was observed in Lazaropole, while in Gevgelija, Demir Kapija, Shtip, Ohrid and Strumica in a certain number of years no icing days were observed (Table 5). The highest annual number of icing days at most meteorological stations was recorded in 1954 and 1963, respectively. Although this index is characterized by greater variability during the analyzed period, still the lower annual number of icing days in recent years shows a downward trend in the number of icing days (Graph 2).

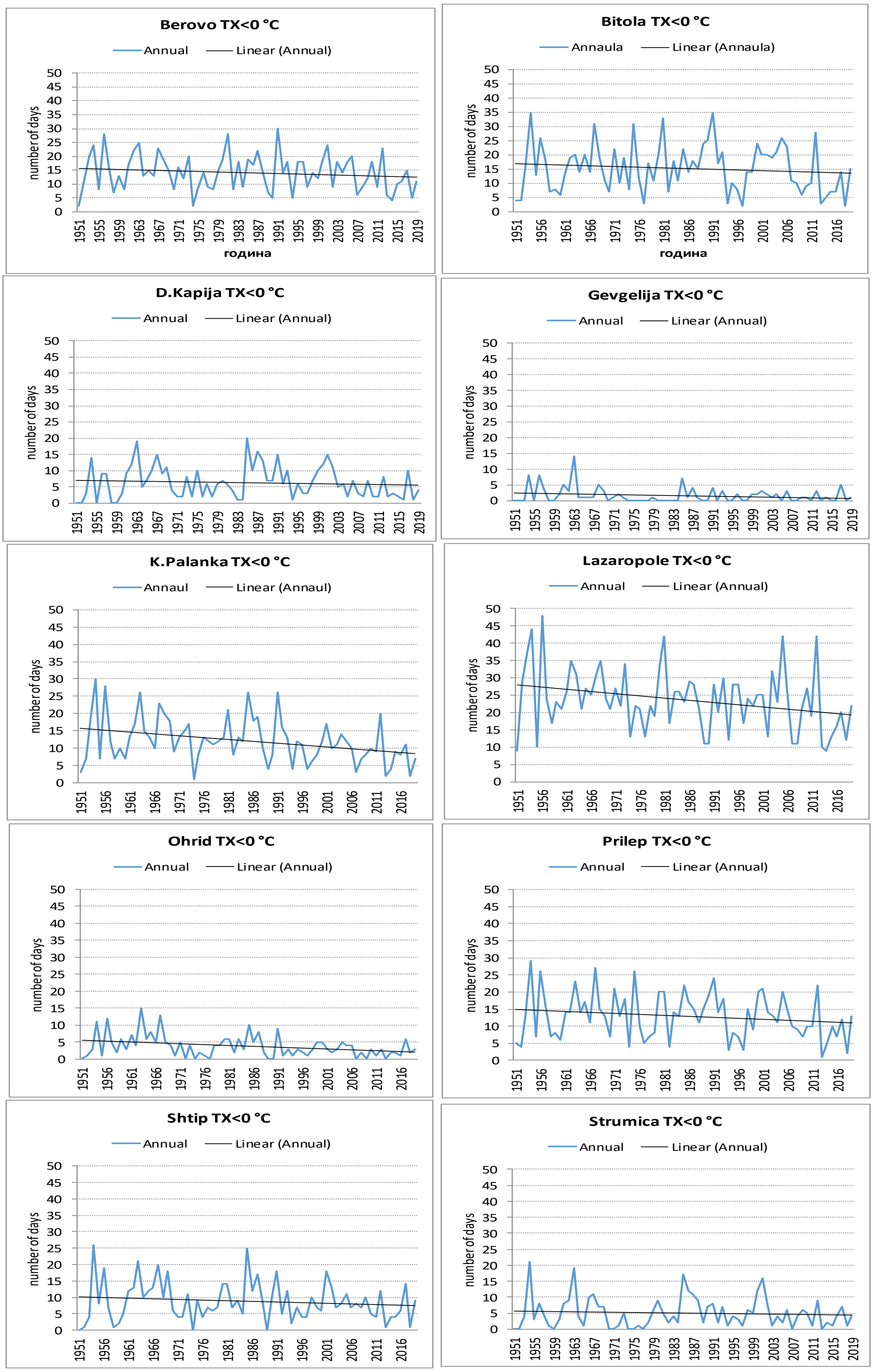
Table 5. Annual maximum and minimum number of icing days for the period 1951-2019

	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	14	20	26	30	35	30	48	15	29	21
year	1963	1985	1954	1991	1954	1954	1956	1963	1954	1954
min	0	0	0	2	2	1	9	0	1	0
year				1951/1974	1997/2018	1974	1951/2014		2013	

The number of icing days for the three future periods given in the scenarios RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high) is decreasing in all scenarios and in all future periods. The change is very similar to the decrease in frost days, but it is not as pronounced because the number of icing days is initially lower compared to the number of frost days. According to the high scenario, there will be no icing days at most stations by the end of the century (Table 6).

Table 6. Average number of icing days for the periods 1951-2019 and 1986-2005

average	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
1951-2019	2	6	9	14	15	12	24	4	13	5
1986-2005	1	8	9	15	18	12	23	3	14	6



Graph 2. Annual number of icing days

SUMMER DAYS

The temperature index "*summer days*" determines the number of days in which the maximum daily air temperature exceeds the fixed threshold Tx> 25°C.

In the period 1951-2019, the largest annual number of summer days, 178 were observed in Gevgelija, while in Lazaropole there were years in which the air temperature did not exceed 25 degrees Celsius at all (Table 7). Characteristic years with the lowest annual number of summer days are 1959 and 1976. The highest annual number of summer days at all meteorological stations was mainly observed in the last 20 years, especially in 2012, 2018 and 2019. As a result, at all stations there is a noticeable upward trend in the number of summer days (Graph 3).

Table 7. Annual maximum and minimum number of summer days for the period 1951-2019

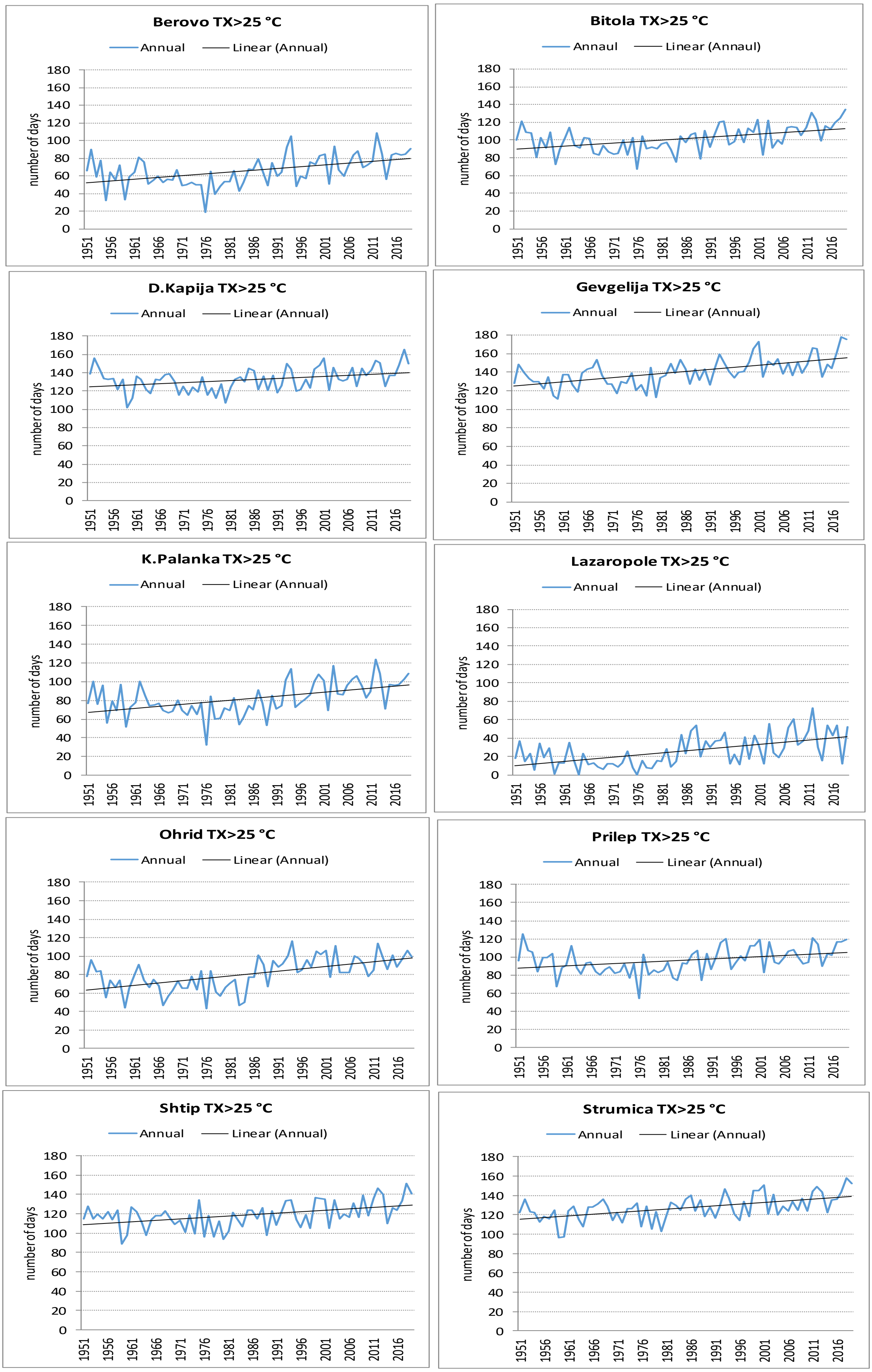
	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	178	165	151	109	134	124	73	116	125	158
year	2018	2018	2018	2012	2019	2012	2012	1994	1952	2018
min	111	102	89	19	67	32	0	43	54	96
year	1960	1959	1959	1976	1976	1976	1964/1976	1976	1976	1959

The annual number of summer days for the three future periods 2016-2035, 2046-2065 and 2081-2100 analyzed in the scenarios RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high) will keep the upward trend. It is expected that the number of summer days compared to the average for 1986-2005, will increase for up to 20 days in the low scenario in all three periods. In all three scenarios the change to take place in near future is the same. In the mid scenario, a further increase of up to 30 days is expected by mid- century, and up to 40 days at the end of the century.

Table 8. Average number of summer days for the periods 1951-2019 and 1986-2005

average	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
1951-2019	140	133	119	66	101	82	26	81	96	127
1986-2005	145	134	120	71	104	86	31	92	100	131

In the high scenario the change by the mid- century is very similar to the change in the mid scenario at the end of the century, but the expected change in the high scenario is even greater by the end of the century, and the expected increase is about 60 to 70 days for most of the territory, compared to 1986 -2005 (Table 8). According to this high scenario by the end of the century we could expect for example in Berovo to have approximately the same number of summer days per year as is we have currently in Strumica or as we had in Gevgelija for the period 1986-2006.



Graph 3. Annual number of summer days

TROPICAL NIGHTS

Tropical nights are days when the measured minimum daily air temperature is higher than 20°C (Tn> 20°C).

The highest annual number of tropical nights, 46 were recorded at the meteorological station Gevgelija, while at higher altitude stations, such as Berovo and Lazaropole there are no days when the minimum daily air temperature is higher than 20°C. Higher annual number of tropical nights, besides the ones registered in the last 20 years, were also observed at the beginning of the analyzed period. For example in Demir Kapija the maximum annual number of tropical nights was recorded in 1952, and in Strumica in 1959 (Table 9). In general, this index shows an upward trend, more or less in all the stations (Graph 4).

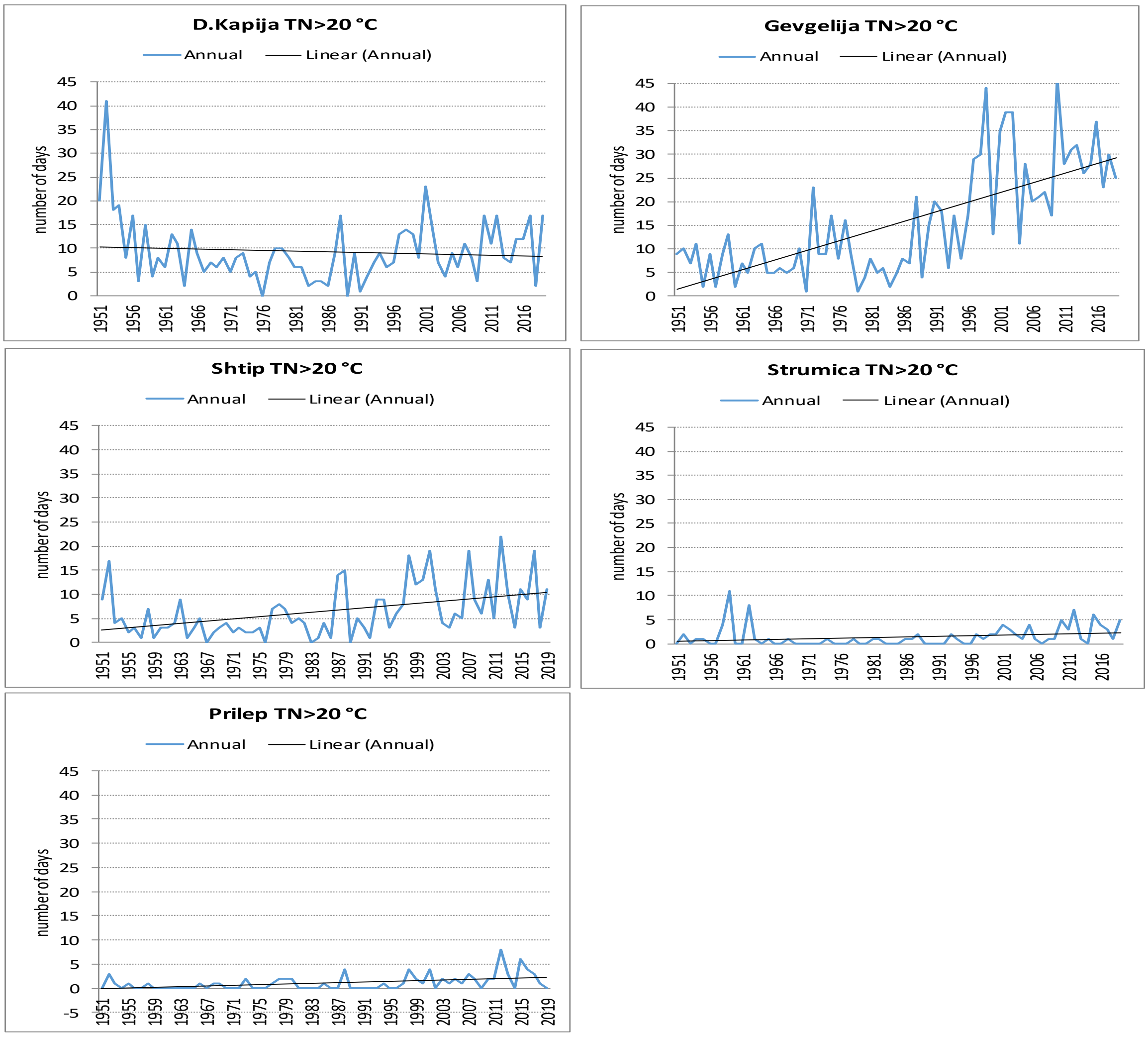
Table 9. Annual maximum and minimum number of tropical nights for the period 1951-2019

	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	46	41	22	0	2	1	0	4	8	11
year	2010	1952	2012		1952/1977/ 1997/2014	1952/1958/ 1977/1980		1962	2012	1959
min	1	0	0	0	0	0	0	0	0	0
year	1971/1979									

The annual change in tropical nights compared to the average for 1986-2005, for the three future periods given in the scenarios RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high) clearly shows that the increase in tropical nights is expected primarily in areas with lower altitudes. The change in the near future is the same for all scenarios and in average 5 more days with tropical nights are expected, with a maximum of 10 days. In the other two periods the change is the same as in the low scenario, but in the mid and high scenario the maximum change reaches 30 more days with tropical nights for the period 2046-2065. In the high scenario at the end of the century the maximum change in areas with low altitude is +60 days while in the mountains around +10 days are expected.

Table 10. Average number of tropical nights for the periods 1951-2019 and 1986-2005

average	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
1951-2019	15	9	6	0	0	0	0	0	1	1
1986-2005	20	9	8	0	1	0	0	0	1	1



Graph 4. Annual number of tropical nights

GROWING SEASON LENGTH

Growing season length is defined as count between the first span of at least 6 days with daily mean temperature TG >5°C and the first span in the second part of the year of 6 days with TG <5°C.

The shortest duration of the growing season was observed at the meteorological stations at higher altitudes, so in Lazaropole in 1965 the growing season lasted only 161 days (Table 11). At most stations, the shortest growing season was observed in 1997 (Table 11). The maximum length of the growing season of 365 days was observed in Gevgelija in 1974 and 2006, which means that in these years the growing season lasted a whole year.

Table 11. Maximum and minimum length of the growing season (1951-2019)

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropolr	Ohrid	Prilep	Shtip	Strumica
max	296	339	355	365	312	270	347	337	346	342
year	1977	2003	1987	1974/2006	1960	2019	2009	1963	2009	1971
min	173	194	247	255	190	161	239	225	245	250
year	1997	1997	2011	1982	1997	1965	1983	1982	1993	1997

Table 12. Average growing season length (days) for the periods 1951-2019 and 1986-2005

average	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropolr	Ohrid	Prilep	Shtip	Strumica
1951-2019	241	275	302	325	263	217	286	277	291	291
1986-2005	235	267	295	323	254	220	282	268	285	282

According to the annual change in the length of the growing season for the three future periods 2016-2035, 2046-2065 and 2081-2100 given in the scenarios RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high), the growing season length is expected to increase from 10-20 days in all three periods in the low scenario compared to the average for 1986-2005 . In all three scenarios there are similar changes to take place in the near future. In the mid scenario, a further increase of up to 30 days is expected by mid- century, and up to 40 days at the end of the century. In the high scenario the change to take place by the mid-century is very similar to the change expected at the end of the century in the mid scenario, but by the end of the century the change in the high scenario is even greater, and for most of the territory the expected increase is about 40 to 60 days, compared to 1986 -2005 (Table 12). In line with these predictions it might be expected by the end of the century in some places, such as Gevgelija, the growing season to last all year round.

Table 13. GSL, Growing season length

Berovo		Bitola		D.Kapija		Gevgelija		K.Palanka		Lazaropole		Ohrid		Prilep		Shtip		Strumica	
year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL
1977	296	2003	339	1987	355	1974	365	1960	312	2019	270	2009	347	1963	337	2009	346	1971	342
1979	289	1963	338	2008	347	2006	365	2009	310	2012	258	1987	343	2003	336	1963	340	2010	339
1960	287	2009	326	2009	347	1971	360	1979	307	1977	257	1963	341	2009	326	2010	339	2003	338
1966	282	2014	325	1971	342	1955	358	2014	307	2002	251	1970	329	1960	321	2003	335	2014	336
1971	280	1955	322	1979	342	2014	357	2007	303	2004	250	1956	327	2007	321	1987	333	2009	332
2014	278	2016	315	1963	340	2013	352	1974	296	2014	250	1972	327	1955	318	1994	331	2007	330
2016	276	1977	311	2010	339	1993	351	1959	293	1970	245	1960	323	1966	312	1970	328	1953	328
1957	273	1966	310	2014	339	1972	349	1966	293	2001	244	1979	323	1977	311	1972	327	1994	328
1969	273	1956	308	1970	337	2005	349	1956	292	2008	244	1955	322	1956	307	2008	327	2008	327
2019	271	2007	306	2003	336	2003/2015	348	1958/2004	292	1957/2000	243	2001/2007	322	1979/2004	307	2014	325	1972	326

* Ten years with the longest growing season

Table 14. GSL, Growing season length

Berovo		Bitola		D.Kapija		Gevgelija		K.Palanka		Lazaropole		Ohrid		Prilep		Shtip		Strumica	
year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL	year	GSL
1956/1973	209	1991	238	1954	262	1988	286	1953/1981	232	1973	179	1953	246	1993	244	1973	251	1981	252
2015	205	1983	237	1982	256	1995	273	1982	224	1956	177	1981	246	1973	243	1982	250	1973	251
1996	204	1982	225	1981	252	1954	263	1988	224	1958	171	2011	246	1953	240	1997	250	1982	251
1965	201	1973	212	1993	250	1978	259	1973	220	1997	168	1993	245	1991	238	1981	248	1993	250
1997	173	1997	194	2011	247	1982	255	1997	190	1965	161	1983	239	1982	225	1993	245	1997	250

* Five years with the shortest growing season

MAXIMUM AND MINIMUM VALUES OF THE DAILY MAXIMUM (TX) AND DAILY MINIMUM (TN) AIR TEMPERATURE

The maximum and minimum values of the daily maximum (TX) and daily minimum (TN) air temperature belong to the group of absolute indices. The maximum values of the daily maximum air temperature (TX) were recorded on July 24, 2007 for the meteorological stations in Berovo, Kriva Palanka, Demir Kapija, Gevgelija, Ohrid and Shtip and on July 7, 1988 for Bitola, Prilep, Strumica and Lazaropole. The highest maximum air temperature for the period 1951-2019 on the territory of the Republic of North Macedonia is 45,7°C measured on July 24, 2007 in Demir Kapija (Table 15).

Unlike the maximum values of the daily maximum temperature observed in only two years, the maximum values of the minimum air temperature (TN) for meteorological stations are observed in different years, and the highest minimum air temperature 26,8°C was measured on 13 August 1994 at the meteorological station Gevgelija (Table 16).

The minimum values of the daily maximum air temperature at most meteorological stations were recorded at the end of January 1963. The lowest maximum air temperature, -16,7°C was measured on January 9, 1979 in Bitola (Table 17). The minimum values of the minimum air temperature were observed in different years, and the lowest minimum air temperature -31,5°C was measured on January 27, 1954 at the meteorological station Berovo (Table 18).

Table 15. Monthly and annual maximum value of the daily maximum air temperature TX (°C)

	01		02		03		04		05		06		07		08		09		10		11		12		Annual		
	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	TXx	date	month
Berovo	17,7	21	21,7	23	27,2	30	27,6	21	30,6	30	35,2	26	39,0	24	39,2	2	33,5	18	31,5	15	26,6	2	20,2	4	**39,0**	**24**	**07**
	2007		2016		1952		1950		1969		2007		2007		1949		2015		1993		2004		1985				**2007**
Bitola	19,2	1	23,8	19	31,2	30	31,3	18	34,7	6	38,6	25	41,2	6	39,0	22	36,0	1	31,8	1	27,6	1	23,1	31	**41,2**	**6**	**07**
	1995		2014		1952		2016		2015		2007		1988		1958		1952		1994		1990		2009				**1988**
D.Kapija	21,0	19	23,6	18	31,0	31	35,3	10	37,0	28	43,1	26	45,7	24	44,5	22	39,7	5	34,6	1	27,1	2	23,6	18	**45,7**	**24**	**07**
	2007		1955		1952		1985		2008		2007		2007		1952		2015		2012		2018		1955				**2007**
Gevgelija	20,3	30	26,2	13	30,0	31	32,7	30	37,5	28	42,6	26	45,3	24	43,8	7	39,2	7	35,4	1	29,0	2	22,2	3	**45,3**	**24**	**07**
	2018		2002		1952		2013		2008		2007		2007		2012		2008		2012		2004		2010				**2007**
K.Palanka	19,2	21	22,0	17	29,6	30	29,2	10	33,2	28	36,0	27	40,2	24	38,2	7	35,2	18	31,3	1	27,0	1	19,7	19	**40,2**	**24**	**07**
	2007		2016		1952		1985		2008		1982		2007		2012		2015		2012		2008		1989				**2007**
Lazaropole	16,8	18	17,3	17	22,4	30	25,7	10	28,3	29	30,7	27	34,1	7	34,1	25	31,4	18	27,4	1	25,3	1	17,4	22	**34,1**	**7**	**07**
	1993		2016		1952		1985		2008		1982		1988		2007		2015		2012		2004		1989				**1988**
Ohrid	17,7	21	20,4	23	26,8	30	27,5	30	30,4	28	36,2	26	37,5	24	36,7	7	33,5	8	28,9	1	23,3	1	18,3	19	**37,5**	**24**	**07**
	2007		1977		1952		2013		2008		2007		2007		2012		2008		1994		1990		1989				**2007**
Prilep	19,9	21	21,8	18	31,9	30	29,9	10	33,7	29	38,8	25	41,5	7	39,4	11	36,6	1	32,3	2	26,4	2	21,0	31	**41,5**	**7**	**07**
	2007		2014		1952		1985		1969		2007		1988		1951		1952		1952		2004		2009				**1988**
Shtip	19,4	19	22,6	19	28,6	26	32,6	10	35,4	27	40,7	23	43,5	24	41,7	21	37,6	5	34,1	1	27,8	2	21,4	2	**43,5**	**24**	**07**
	2007		1960		2001		1985		1950		2007		2007		1999		2015		2012		2018		2010				**2007**
Strumica	19,0	28	22,5	18	28,7	27	33,0	26	35,6	28	41,2	26	43,4	6	40,5	22	37,8	6	32,2	3	27,3	2	23,0	2	**43,4**	**6**	**07**
	1952		2014		2001		2013		2008		2007		1988		1952		2008		1952		2018		2010				**1988**

Table 16. Monthly and annual maximum value of the daily minimum air temperature TN (°C)

	01		02		03		04		05		06		07		08		09		10		11		12		Annual		
	TNx	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**TNx**	**date**	**month**
Berovo	8,8	22	10,2	18	10,4	27	14,3	6	16,4	26	19,4	26	17,6	14	17,6	7	16,0	12	14,5	22	13,5	7	11,5	4	**19,4**	**26**	**06**
	2009		1955		1970		1989		1990		1996		1978		2016		1952		2003		2009		2008				**1996**
Bitola	10,5	1	12,8	18	16,2	26	17,1	9	18,2	13	23,1	26	21,6	31	21,3	23	21,1	12	17,3	6	14,4	25	13,5	26	**23,1**	**26**	**06**
	2010		1955		2001		1998		1968		2014		2013		1977		1952		1992		1969		1995				**2014**
D.Kapija	12,3	22	15,6	16	17,2	26	20,0	10	23,0	28	25,3	18	26,2	7	26,3	3	24,5	12	20,2	6	17,4	1	15,2	1	**26,3**	**3**	**08**
	2009		2016		2001		1998		1950		1979		1950		1950		1952		1992		2008		2010				**1950**
Gevgelija	11,2	22	13,0	13	14,0	23	16,8	21	21,7	25	25,3	18	26,2	7	26,8	13	24,5	1	19,0	4	16,4	7	13,0	4	**26,8**	**13**	**08**
	2009		1998		2001		2000		1973		2002		2000		1994		2003		1976		2009		2008				**1994**
K.Palanka	10,1	18	12,6	15	11,0	30	16,2	10	17,5	8	19,2	24	19,5	29	25,6	22	20,2	12	16,3	6	16,4	8	15,0	1	**25,6**	**22**	**08**
	1955		2016		1952		1998		1997		1958		1966		1977		1952		1992		2000		2010				**1977**
Lazaropole	6,0	11	9,7	16	12,5	30	14,2	9	14,5	30	18,3	30	18,6	21	17,5	11	15,2	8	17,0	6	12,7	1	10,6	1	**18,6**	**21**	**07**
	2016		2016		1952		1998		1969		2017		1956		1999		2008		1992		2008		2010				**1956**
Ohrid	9,5	1	13,7	16	13,8	30	15,2	10	16,8	12	22,4	30	22,3	27	22,7	22	20,8	6	19,2	6	15,6	14	14,2	1	**22,7**	**22**	**08**
	1995		2016		1952		1985		1968		2017		1955		1977		2015		1992		1961		2010				**1977**
Prilep	10,1	1	10,8	18	18,0	30	16,7	10	18,4	30	22,4	24	25,0	21	24,4	12	21,2	6	17,4	7	14,0	2	13,5	1	**25,0**	**21**	**07**
	1995		1955		1952		1985		1969		2016		2015		1994		2015		1992		1990		2010				**2015**
Shtip	12,6	9	15,3	16	16,0	31	18,5	2	20,5	20	24,4	20	26,0	31	25,0	22	24,0	7	21,4	6	19,0	2	15,3	2	**26,0**	**31**	**07**
	1995		2014		1952		2016		2015		2007		1988		1958		1952		1994		1990		2009				**1954**
Strumica	12,8	22	11,8	13	12,8	26	15,6	10	18,7	26	22,0	21	23,0	31	22,5	8	20,9	8	16,6	2	17,8	7	14,6	2	**23,0**	**31**	**07**
	2009		1979		1983		1998		1990		1952		1958		2012		1963		1962		2009		2010				**1958**

Table 17. Monthly and annual minimum value of the daily maximum air temperature TX (°C)

	01		02		03		04		05		06		07		08		09		10		11		12		Annual		
	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	TXn	date	month
Berovo	-13,0	23	-10,5	1	-7,1	6	0,4	8	5,7	25	7,8	7	11,4	1	10,4	27	7,9	23	-1,3	29	-3,0	24	-9,6	1	**-13,0**	**23**	**01**
	1963		1991		1987		1956		1991		1994		1971		1965		1964		1997		1975		1957				**1963**
Bitola	-16,7	9	-10,6	8	-6,5	1	-1,0	7	7,0	3	10,2	6	13,0	1	13,8	31	9,4	18	0,3	29	-4,8	30	-16,0	19	**-16,7**	**9**	**01**
	1979		2006		1963		2003		1970		1975		1971		1995		1971		1997		1955		1988				**1979**
D.Kapija	-11,6	6	-6,8	7	-4,0	1	5,2	7	9,2	25	13,4	6	15,0	1	14,3	31	10,6	18	3,1	29	-1,1	30	-11,0	20	**-11,6**	**6**	**01**
	1993		1956		1963		2003		1991		1975		1971		1995		1971		1997		1988		2001				**1993**
Gevgelija	-9,0	24	-6,5	4	-3,0	1	6,6	7	10,5	22	16,0	3	16,4	1	16,4	31	11,8	18	4,5	29	0,6	25	-3,0	18	**-9,0**	**24**	**01**
	1963		1956		1963		2003		1952		1966		1971		1995		1971		1997		1988		2001				**1963**
K.Palanka	-13,4	23	-10,3	6	-6,4	1	0,2	7	5,5	22	9,1	7	12,0	1	10,6	31	6,8	23	0,2	29	-4,9	25	-8,4	27	**-13,4**	**23**	**01**
	1963		1956		1963		2003		1952		1994		1971		1995		1964		1997		1988		1996				**1963**
Lazaropole	-15,5	7	-12,4	7	-10,2	10	-3,6	7	1,6	3	6,3	6	9,6	1	8,1	31	4,7	18	-2,8	29	-5,4	28	-13,2	1	**-15,5**	**7**	**01**
	2017		1956		1987		2003		1970		1975		1971		1995		1971		1997		1973		1957				**2017**
Ohrid	-10,8	23	-9,6	4	-4,8	10	1,7	7	7,6	3	11,7	3	13,5	1	14,0	27	8,5	18	-0,6	29	-1,2	23	-7,5	1	**-10,8**	**23**	**01**
	1963		1956		1987		2003		1970		1970		1971		1965		1971		1997		1975		1957				**1963**
Prilep	-12,6	27	-10,8	4	-6,9	4	-0,8	7	6,6	3	9,5	6	13,0	1	12,7	31	8,0	18	0,0	29	-1,8	25	-14,0	27	**-14,0**	**27**	**12**
	1954		1956		1987		2003		1970		1975		1971		1995		1971		1997		1988		1953				**1953**
Shtip	-12,3	24	-8,9	6	-6,3	1	3,6	7	7,7	1	12,4	17	15,5	1	14,8	31	9,0	18	1,9	29	-3,0	24	-11,3	21	**-12,3**	**24**	**01**
	1963		1956		1963		2003		1976		1983		1971		1995		1971		1997		1988		2001				**1963**
Strumica	-13,0	26	-7,2	6	-5,0	1	4,6	7	8,7	25	14,1	7	16,5	1	12,7	31	11,5	18	3,4	29	-0,6	25	-12,4	20	**-13,0**	**26**	**01**
	1963		1956		1963		2003		1991		1994		1971		1995		1971		1997		1988		2001				**1963**

Table 18. Monthly and annual minimum value of the daily minimum air temperature TN (°C)

	01		02		03		04		05		06		07		08		09		10		11		12		Annual		
	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	TNn	date	month
Berovo	-31,5	27	-26,2	4	-23,7	5	-18,0	8	-4,0	19	-1,8	8	1,7	23	0,2	21	-6,0	30	-12,2	28	-19,0	6	-24,6	19	**-31,5**	**27**	**01**
	1954		1950		1955		2003		1952		1962		1968		1949		1977		1988		1995		2001				**1954**
Bitola	-30,4	7	-28,1	8	-19,3	3	-19,4	8	-1,6	10	0,7	8	4,8	2	2,6	21	-2,4	30	-7,4	28	-15,6	6	-26,8	19	**-30,4**	**7**	**01**
	1993		2006		1996		2003		1957		1962		1964		1949		1970		1988		1995		1988				**1993**
D.Kapija	-23,2	7	-21,0	8	-19,0	8	-6,5	8	1,4	1	4,2	1	7,5	10	6,1	28	0,3	30	-5,7	29	-9,4	28	-21,7	21	**-23,2**	**7**	**01**
	1993		2006		1949		2003		1965		1997		1998		1965		1977		1988		1953		2001				**1993**
Gevgelija	-19,5	27	-15,0	1	-10,7	8	-4,4	9	0,5	10	7,4	2	8,4	20	6,8	26	0,0	30	-5,7	29	-9,5	29	-10,6	20	**-19,5**	**27**	**01**
	1963		1963		1952		2003		1957		1990		1970		1980		1977		1988		1953		2001				**1963**
K.Palanka	-23,3	8	-20,6	19	-14,6	1	-9,1	8	-1,0	6	1,3	8	4,8	15	4,2	29	-0,8	30	-5,3	28	-12,4	6	-19,0	19	**-23,3**	**8**	**01**
	2017		1985		2018		2003		2011		1962		1993		1981		1977		1988		1995		2001				**2017**
Lazaropole	-23,0	26	-23,4	1	-21,6	5	-14,7	8	-5,0	18	-3,4	8	0,4	23	0,0	28	-4,5	30	-10,6	23	-15,5	29	-20,1	30	**-23,4**	**1**	**02**
	1954		1991		1987		2003		1952		1962		1978		1965		1959		1972		1973		2014				**1991**
Ohrid	-17,2	26	-16,1	9	-16,0	13	-10,6	8	-0,2	18	2,3	8	4,7	2	5,0	28	1,0	30	-5,2	23	-9,6	21	-14,9	22	**-17,2**	**26**	**01**
	1954		1956		1971		2003		1952		1962		1971		1965		1977		1972		2005		1967				**1954**
Prilep	-23,6	9	-21,9	9	-15,8	5	-11,5	8	-0,2	13	1,9	1	6,1	2	3,8	21	0,1	30	-6,0	30	-13,0	6	-22,7	21	**-23,6**	**9**	**01**
	1979		1956		1955		2003		1978		1997		1964		1949		1977		1978		1995		2001				**1979**
Shtip	-22,7	26	-19,2	8	-15,4	5	-4,5	9	0,7	10	4,0	1	6,3	2	5,9	28	-0,4	30	-6,5	28	-11,5	6	-22,0	22	**-22,7**	**26**	**01**
	1954		2006		1955		2003		1957		1997		1964		1965		1977		1988		1995		2001				**1954**
Strumica	-27,3	7	-22,5	8	-9,6	5	-10,3	8	-2,0	10	4,0	8	6,1	3	5,0	23	-1,0	28	-8,5	29	-12,7	6	-25,5	20	**-27,3**	**7**	**01**
	1993		2006		1987		2003		1957		1962		1964		1962		2018		1988		1995		2001				**1993**

COLD NIGHTS AND COLD DAYS

Cold nights and cold days are indices based on percentiles where thresholds are set for estimating moderate extremes that usually occur several times each year. Cold nights are days with minimum daily temperature TN <10th percentile while cold days are days with maximum daily temperature TX <10th percentile.

The annual number of cold nights for the period 1951-2019 ranges from 3 days recorded in Gevgelija in 2014, to 76 which were recorded in Kriva Palanka in 1997 (Table 19), while the annual number of cold days ranges from 7 days observed in Gevgelija (2000) and Kriva Palanka (2019) up to 70 days in Strumica in 1956 (Table 20).

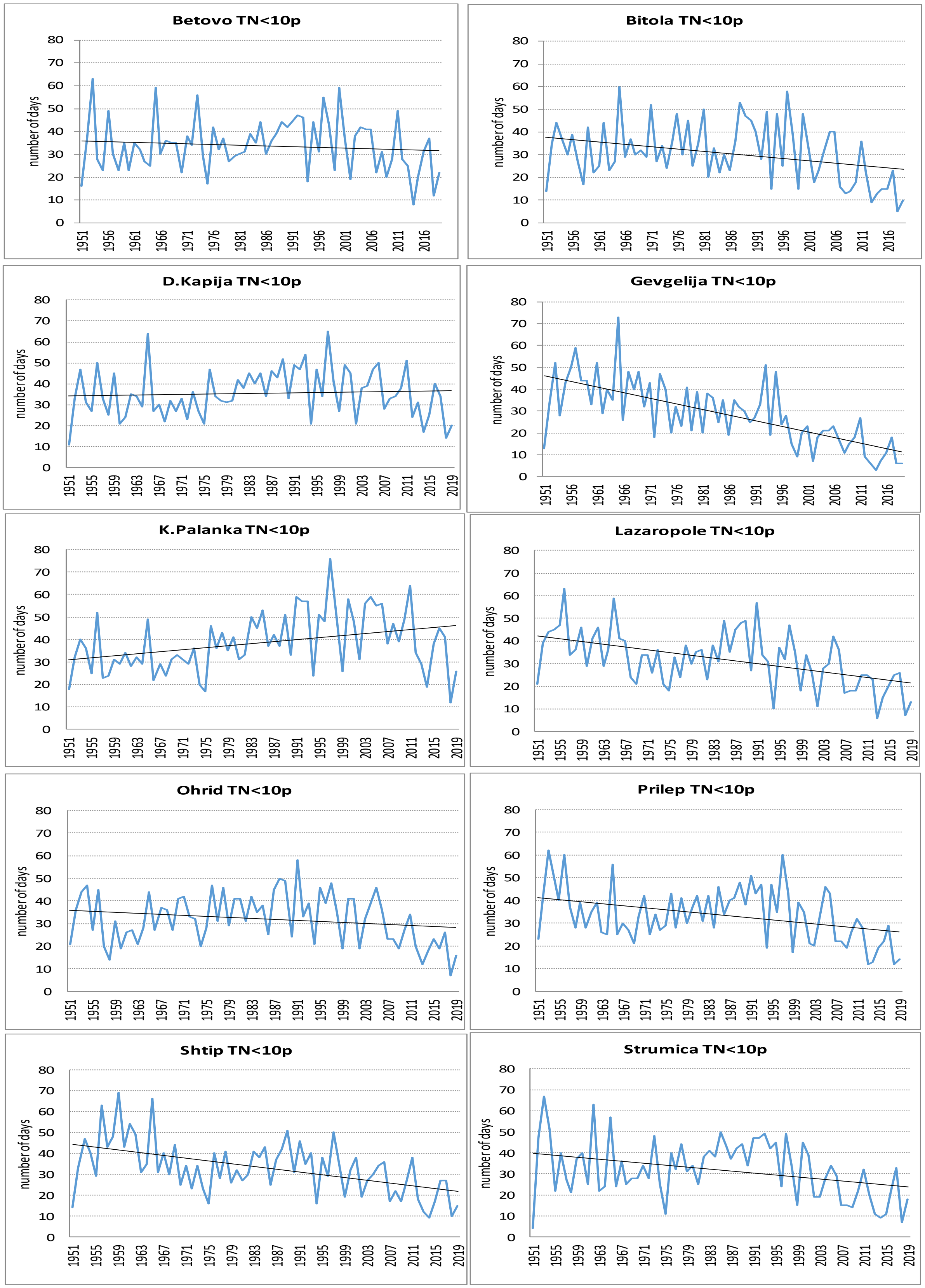
Table 19. Annual maximum and minimum number of cold nights for the period 1951-2019

	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	73	65	69	63	60	76	63	58	62	67
year	1965	1997	1959	1953	1965	1997	1956	1953	1953	1953
min	3	11	9	8	5	12	6	7	12	4
year	2014	1951	2014	2014	2018	2018	2013	2018	2013/2018	1951

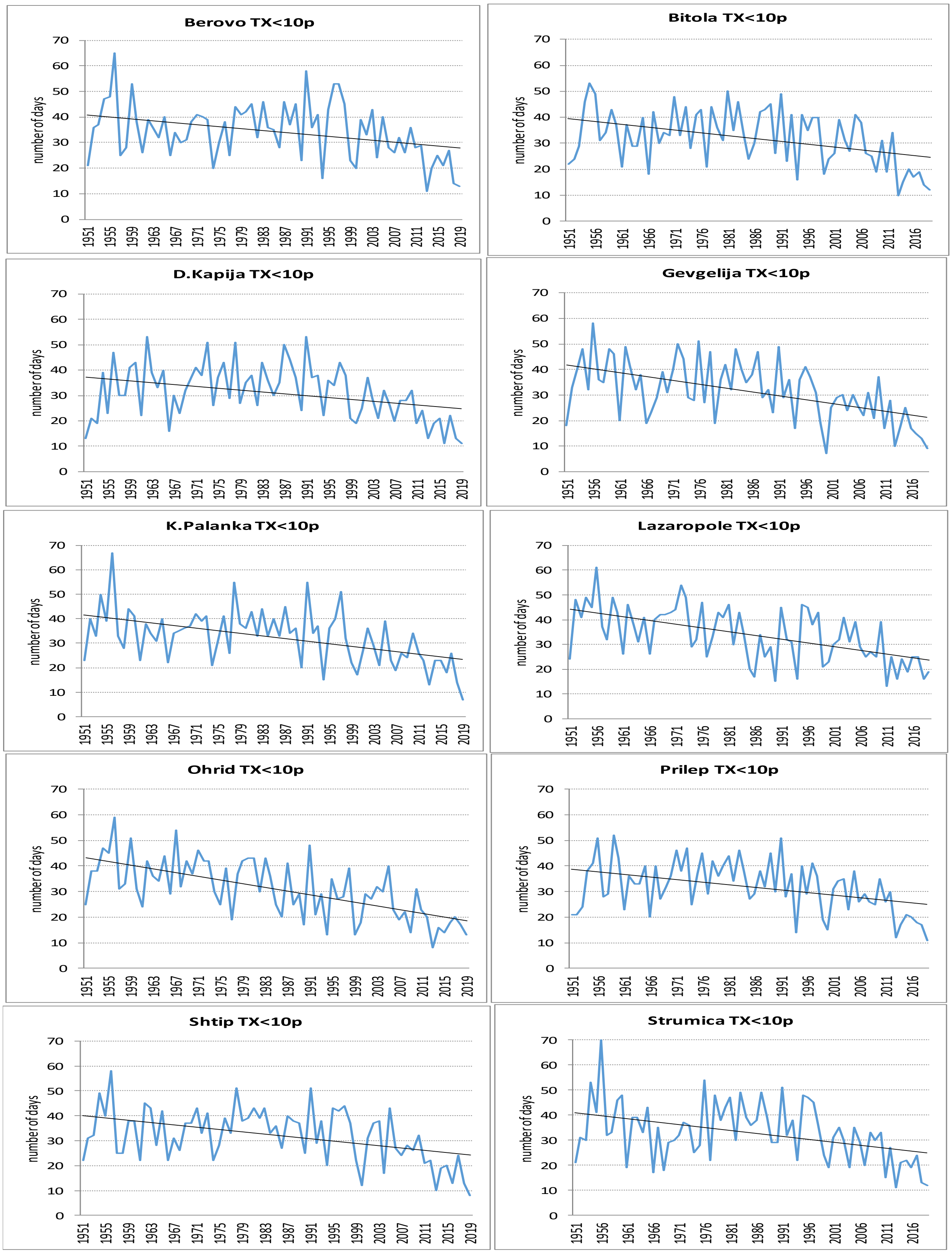
Table 20. Annual maximum and minimum number of cold days for the period 1951-2019

	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	58	53	58	65	53	67	61	59	52	70
year	1956	1962/1991	1956	1956	1955	1956	1956	1956	1959	1956
min	7	11	8	11	10	7	13	8	11	11
year	2000	2016/2019	2019	2013	2013	2019	2011	2013	2019	2013

In recent years, there is a decreasing number of cold nights (graph 5) and cold days (graph 6), thus both indices generally have a downward trend, with the exception of Demir Kapija and Kriva Palanka where the number of cold nights is increasing.



Graph 5. Annual number of cold nights



Graph 6. Annual number of cold days

WARM NIGHTS AND WARM DAYS

Warm nights are days with minimum daily temperature TN> 90th percentile, while warm days are days with maximum daily temperature TX> 90th percentile. The highest annual number of warm nights (115 days) and warm days (140 days) is observed in Gevgelija. The lowest annual number of warm nights (8 days) was recorded in Strumica, and the lowest number of warm days (12 days) in Berovo and Ohrid (Table 21 and Table 22).

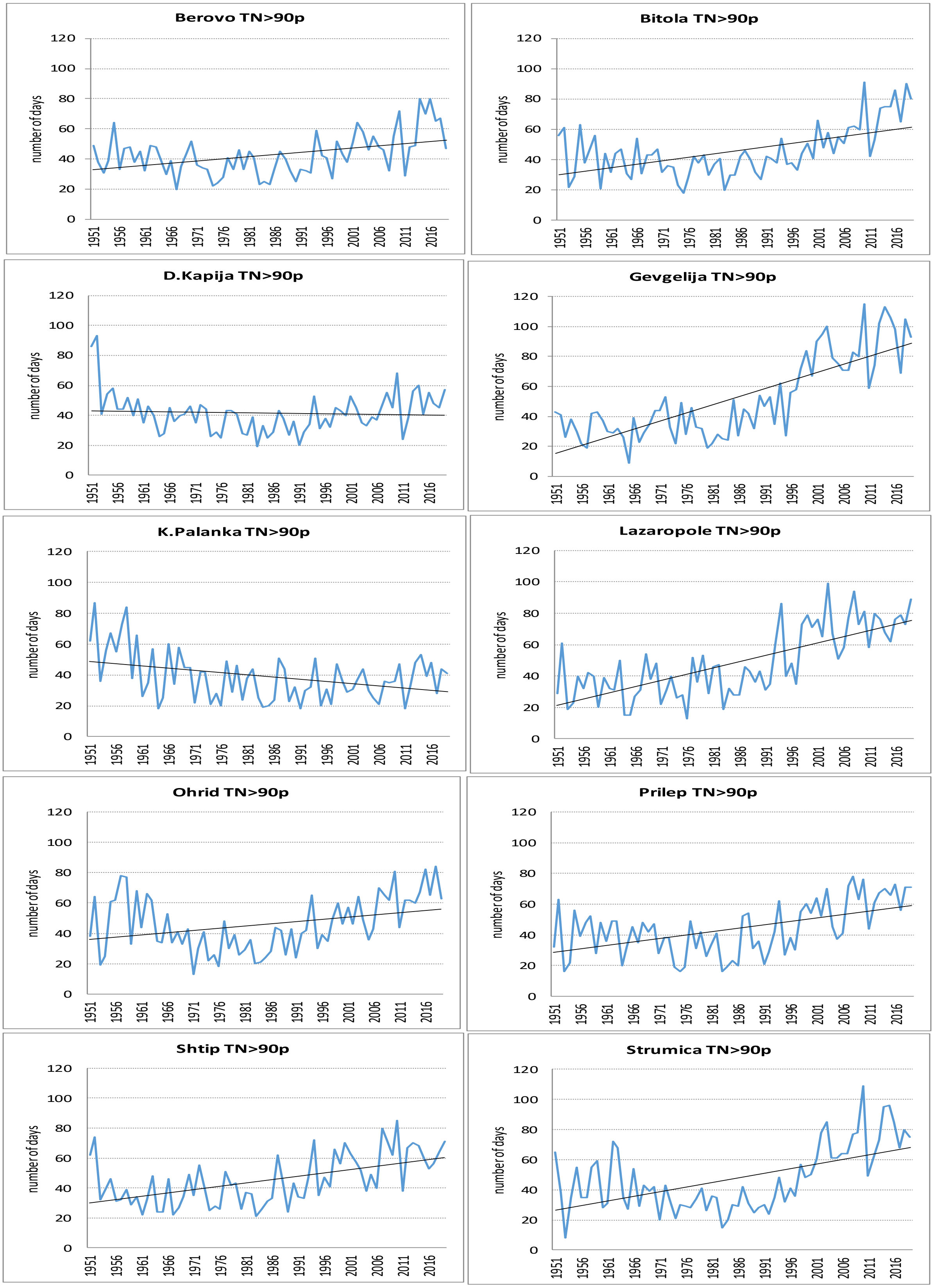
Table 21. Annual maximum and minimum number of warm nights for the period 1951-2019

	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	115	93	85	80	91	87	99	84	78	109
year	2010	1952	2010	2014/2016	2010	1952	2003	2018	2008	2010
min	9	19	21	20	18	18	13	13	16	8
year	1965	1983	1983	1967	1975	1964/1991/ 2011	1976	1971	1953/1975/ 1983	1953

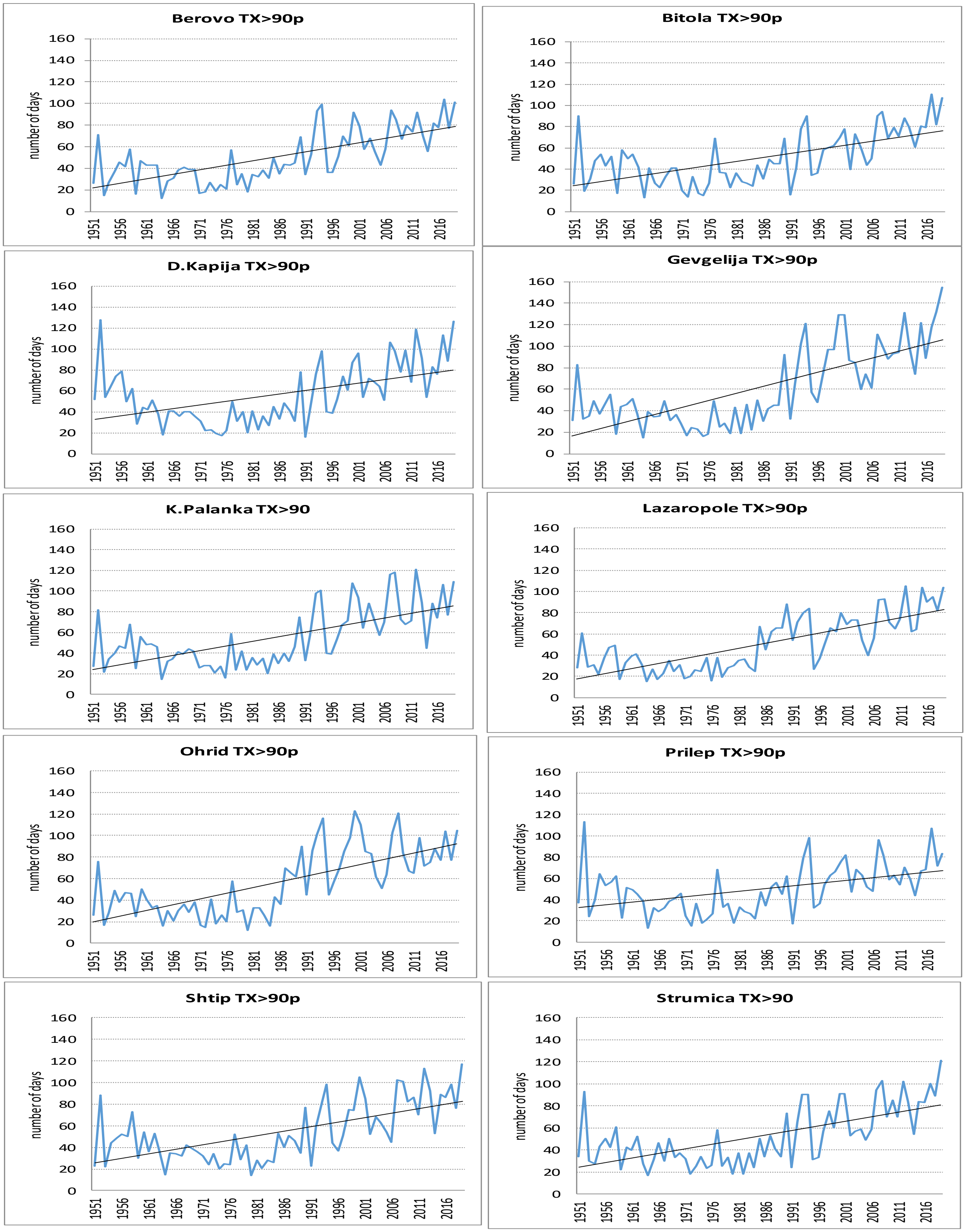
Table 22. Annual maximum and minimum number of warm days for the period 1951-2019

	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	140	128	117	104	111	121	105	123	113	121
year	2019	1952	2019	2017	2017	2012	23012	200	1952	2019
min	15	16	14	12	13	15	15	12	13	17
year	1964	1991	1980	1964	1964	1964	1964	1980	1964	1964

Both indices from the second half of the period 1951-2019 show an increase in the number of warm nights and warm days. The increasing trend is slightly more pronounced in the annual number of warm days, compared to the annual number of warm nights. Similar to the annual number of cold nights, for Demir Kapija and Kriva Palanka there is an opposite trend, a decrease compared to other stations (Graph 7 and Graph 8).



Graph 7. Annual number of warm nights



Graph 8. Annual number of warm days

WARM SPELL DURATION INDEX

The warm spell duration index defines the period of excessive or longer lasting heat during the year. The warm spell duration index is determined by the number of days with at least 6 consecutive days with maximum daily temperature TX greater than the 90th percentile for the calendar day calculated for a five-day window centered on each calendar day for the reference (base) period 1961-1990.

The warm spell as a climatic event differs from the warm spell duration index (period). There are various definitions of warm spells, but currently, there is no universally accepted one. Therefore, the team working on the "Guidelines on the Definition and Monitoring of Extreme Weather and Climate Events " recommends that a warm spell should be defined as a period of significantly unusual warm weather (maximum, minimum and mean daily temperature) for the specific region, which lasts at least three consecutive days during the warm period of the year based on local (station-based) climatic conditions, with observed thermal conditions above the respective thresholds.

According to the statistical processing of the maximum daily values of air temperature, it can be concluded that shorter warm spells are more common (6-day periods), and the longer warm spells occur less frequently. In the period from 1951-2019, the largest number of warm spells (165) were observed in Demir Kapija, and the lowest (121) in Prilep (Table 23).

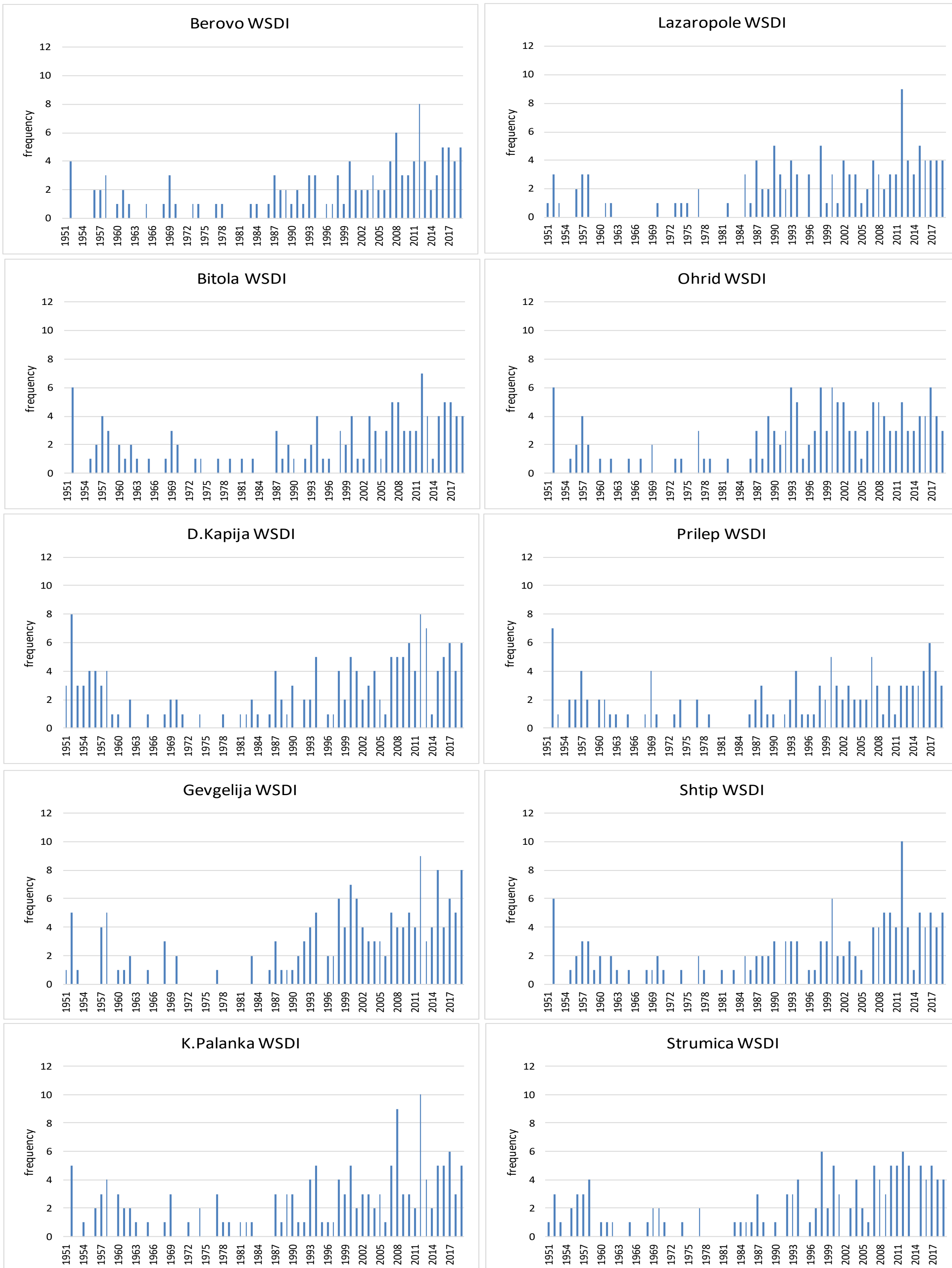
The analysis of the annual frequency of warm spells shows that the total number of spells is not evenly distributed over the years. The annual frequency of warm spells increases in the second half of the analyzed period, more precisely starting from 1987 their frequency increases and unlike the first half, in this period warm spells are recorded almost every year (Graph 9). It can also be noted that the highest frequency of warm spells has been observed in the last ten years and the maximum number of such periods was recorded at most of the stations in 2012. During 2012, 10 warm spells were observed in Shtip and Kriva Palanka, 9 in Gevgelija and Lazaropole, 8 in Berovo and Demir Kapija, 7 in Bitola and 6 in Strumica.

The highest total annual number of days in warm spells, generally coincides with the years with the highest frequency of warm spells (Graph10).

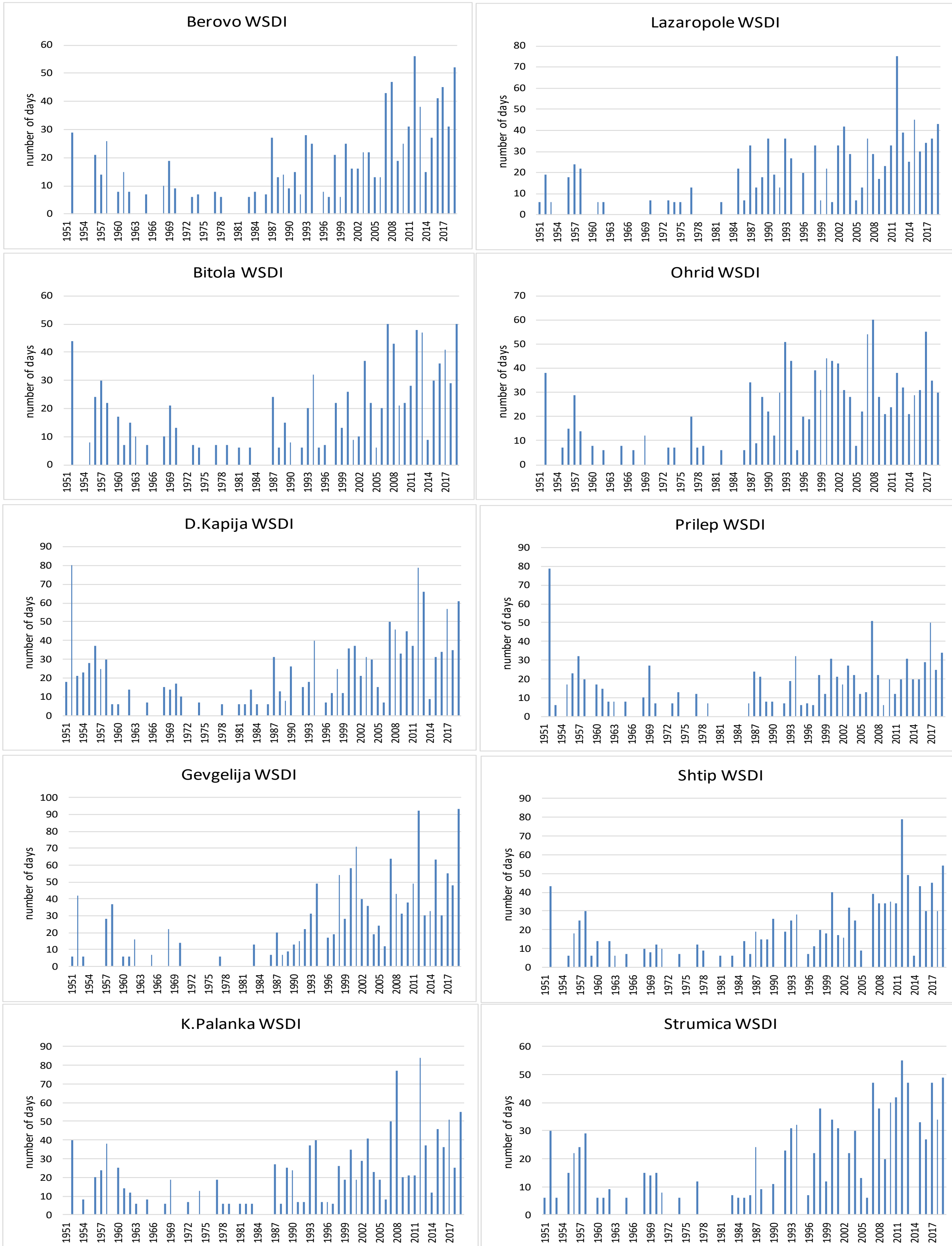
Table 23. WSDI, warm spells duration index: period of at least 6 consecutive days with TX> 90p (period 1951-2019)

number of days/ frequency	D.Kapija	Gevgelija	K.Palanka	Ohrid	Shtip	Strumica	Lazaropole	Bitola	Berovo	Prilep
6	50	39	52	49	48	42	37	38	34	46
7	33	34	34	29	27	27	32	31	27	22
8	29	24	20	28	18	25	21	24	25	20
9	14	16	11	14	15	9	11	11	18	11
10	12	10	10	10	11	5	5	12	9	6
11	4	10	4	5	5	8	10	1	2	4
12	10	8	7	4	4	5	5	2	4	3
13	4	8	2	3	2	6	2	1	1	
14	1	2	5		2		1		1	
15	4	2	1	2	2	1	1		2	2
16			1	2	1	2	3	1		3
17	3	2	2	3		2	1	3		2
18		2	1		2				1	1
19	1	2			1			1		1
20			1					1		
21										
22		1		1						
23		1								
frequency	**165**	**161**	**151**	**150**	**138**	**132**	**129**	**126**	**124**	**121**
number of days	**1369**	**1429**	**1236**	**1224**	**1124**	**1079**	**1053**	**1010**	**990**	**978**

The longest warm spell in the period 1951-2019 lasted for 23 days and was observed at the Gevgelija meteorological station in the period from 2-24 October 2001. It is interesting that at most stations the longest or some of the longest warm spells were observed in the period from 12 to 30 October 2019 (Table 24).



Graph 9. Annual frequency of warm spells



Graph 10. Total annual duration (days) of warm spells

Table 24. Longest warm periods (period 1951-2019)

Berovo

start	end	number of days
13.10.2019	30.10.2019	18
30.4.2003	14.5.2003	15
16.7.2007	30.7.2007	15
30.7.2017	12.8.2017	14
07.10.1993	19.10.1993	13

Bitola

start	end	number of days
22.10.2013	10.11.2013	20
12.10.2019	30.10.2019	19
26.8.1956	11.9.1956	17
29.4.2003	15.5.2003	17
08.1.2007	24.1.2007	17
19.8.2019	03.9.2019	16

K.Palanka

start	end	number of days
10.10.2019	29.10.2019	20
29.6.2012	16.7.2012	18
29.4.2003	15.5.2003	17
17.7.2015	02.8.2015	17
19.10.2004	03.11.2004	16

Lazaropole

start	end	number of days
13.10.2019	29.10.2019	17
29.4.2003	14.5.2003	16
19.10.2004	03.11.2004	16
30.6.2012	15.7.2012	16
04.6.2003	18.6.2003	15
30.7.2017	12.8.2017	14

Shtip

start	end	number of days
22.10.2013	09.11.2013	19
18.10.2004	04.11.2004	18
12.10.2019	29.10.2019	18
29.4.2003	14.5.2003	16
17.7.2015	31.7.2015	15
20.8.2019	03.9.2019	15

Strumica

start	end	number of days
28.8.1952	13.9.1952	17
13.10.2019	29.10.2019	17
30.4.2003	15.5.2003	16
20.8.2019	04.9.2019	16
30.4.1968	14.5.1968	15
08.10.1993	20.10.1993	13
15.3.2001	27.3.2001	13
13.1.2007	25.1.2007	13
21.2.2008	04.3.2008	13
26.4.2012	08.5.2012	13
24.4.2013	06.5.2013	13

Prilep

start	end	number of days
12.10.2019	30.10.2019	19
07.1.2007	24.1.2007	18
29.8.1952	14.9.1952	17
26.8.1956	11.9.1956	17
13.9.1987	28.9.1987	16
19.10.2004	03.11.2004	16
21.10.2013	05.11.2013	16

Gevgelija

start	end	number of days
02.10.2001	24.10.2001	23
06.1.2007	27.1.2007	22
20.7.1998	07.8.1998	19
19.8.2019	06.9.2019	19
20.8.2011	06.9.2011	18
13.10.2019	30.10.2019	18

D.Kapija

start	end	number of days
05.8.1952	23.8.1952	19
28.8.1952	13.9.1952	17
26.8.1956	11.9.1956	17
13.10.2019	29.10.2019	17
30.4.1968	14.5.1968	15
30.4.2003	14.5.2003	15
29.7.2017	12.8.2017	15
20.8.2019	03.9.2019	15
27.4.2012	10.5.2012	14

Ohrid

start	end	number of days
17.6.2008	08.7.2008	22
12.9.1987	28.9.1987	17
08.10.1993	24.10.1993	17
29.4.2003	15.5.2003	17
19.10.2004	03.11.2004	16
15.10.2019	30.10.2019	16
16.7.2007	30.7.2007	15
29.7.2017	12.8.2017	15

As per the "Report on Climate Change Projections and Changes in Climate Extremes for the Republic of North Macedonia" with regard to annual changes in extreme warm spells (WSDI index) for the three future periods given for the scenarios RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high), the duration of the warm spells is expected to remain the same in the RCP2.6 scenario, but on the other hand it is expected to increase in the other two scenarios. In the last period of the high scenario, in most of the territory, the expected increase is about 20 days, compared to the reference period 1986-2005 (Table 33). The number of warm spells is expected to increase by 1 additional event in the RCP2.6 scenario, but this change is more pronounced in the other two scenarios. In the mid scenario the change in the last period is equal to the change in the mid- century in the high scenario, which is about 6 additional events in a 20-year period. In the last period in the high scenario for most of the territory, there is a significant increase to 40 additional events in a 20-year period.

Table 25. WSDI, Frequency and duration of warm spells for the period 1986-2005

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropolr	Ohrid	Prilep	Shtip	Strumica
frequency	13	10	15	9	11	12	14	11	12	11
number of days	105	77	117	72	93	97	109	88	98	86

COLD SPELL DURATION INDEX

The cold spell duration index is determined by the number of days with at least 6 consecutive days when the minimum daily temperature TN is lower than the 10th percentile for the calendar day calculated for a five-day window centered on each calendar day for the reference (base) period 1961- 1990.

Similar to warm spells, there is a difference in the meaning of a cold spell as a climatic event and the cold spell duration index (period). As there is still no clear and consistent definition of a cold spell globally, the team working on the "Guidelines on the Defintion and Monitoring of Extreme Weather and Climate Events" recommends to define cold spell as a period of significantly unusually cold weather (maximum, minimum and mean daily temperature) over a large area, lasting for at least two consecutive days during the cold period of the year.

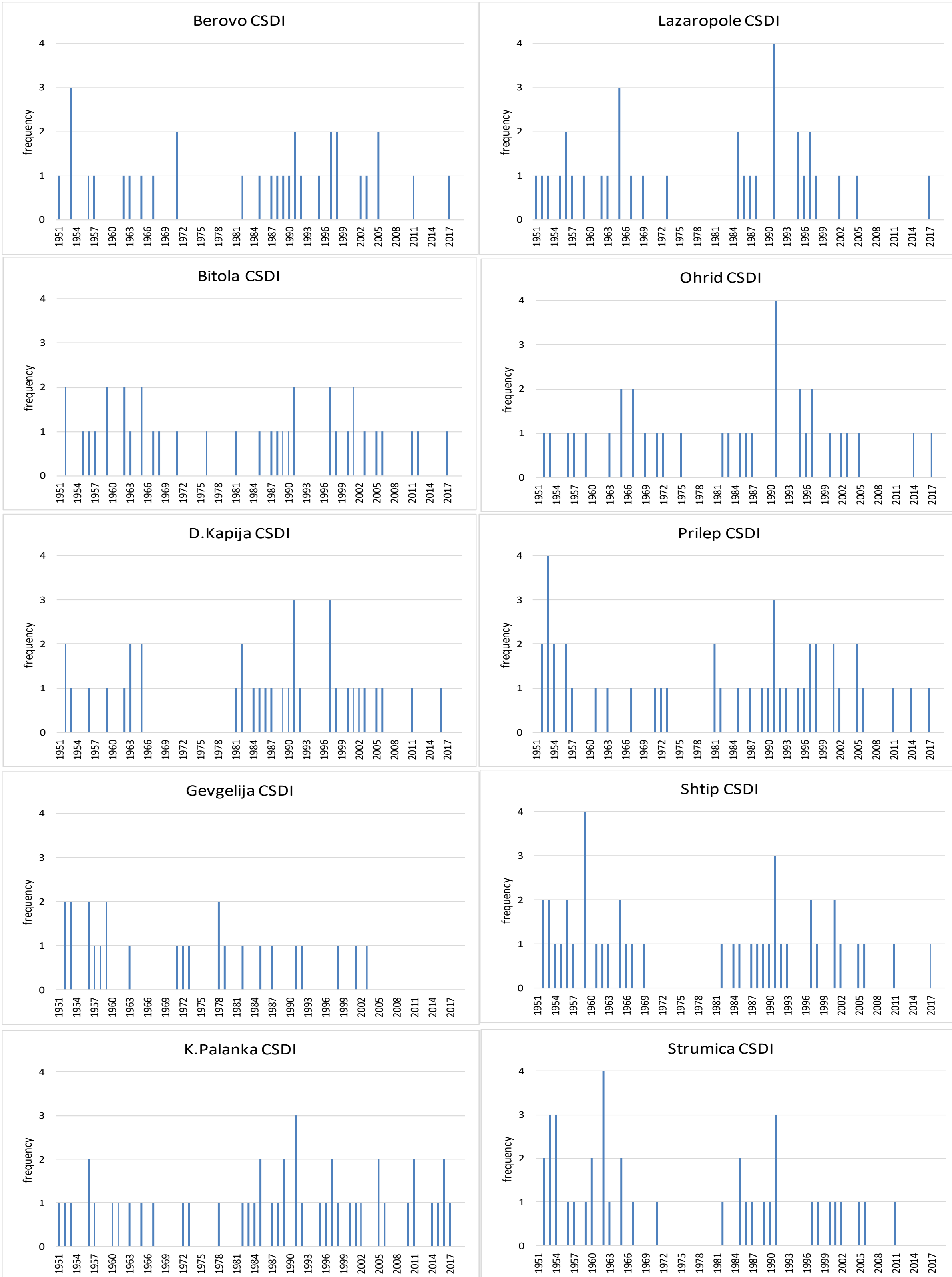
Shorter cold spells are more common in the period 1951-2019 (spells that last 6 days). Thus, for example, the highest number of 6-day cold spells (22) was observed in Kriva Palanka, and the lowest number (10) in Gevgelija and Berovo. Prolonged cold spells are less common and occur less frequently in the analyzed period. Unlike warm spells, cold spells have a much lower incidence. In the period from 1951-2019, the largest number of cold spells (46) was observed in Kriva Palanka, and the lowest (25) in Gevgelija (Table 26).

1991 stands out as a characteristic year with the largest annual number of cold spells (4 observed in Lazaropole and Ohrid). Cold spells are less common and in certain years / periods do not occur at all.

The longest cold spell in the period 1951-2019 lasted for 22 days and was observed at the meteorological station Kriva Palanka in the period from 30.03.-20.04.1997. At the other stations, the longest cold spells were observed in different years (Table 27).

Table 26. CSDI, cold spell duration index: period of at least 6 days with TN <10 p (period 1951-2019)

number of days/ frequency	K.Palanka	Prilep	Shtip	Strumica	Bitola	D.Kapija	Lazaropole	Ohrid	Berovo	Gevgelija
6	22	21	21	11	13	17	14	14	10	10
7	10	7	6	9	7	9	12	11	12	11
8	1	6	10	7	9	3	2	4	3	2
9	8	3	4	5	3	2	3	1	2	1
10		1		4		1			2	
11		1	1	3	1	2	2	2	1	
12	2	2	1		2	1			1	1
13	1			1				1		
14	1	1					1	1		
15		2							1	
16					1					
17										
18										
19										
20										
21										
22	1									
frequency	**46**	**44**	**43**	**40**	**36**	**35**	**34**	**34**	**32**	**25**
number of days	**355**	**339**	**307**	**316**	**277**	**251**	**247**	**251**	**244**	**174**



Graph 11. Annual frequency of cold spells

Graph 12. Total annual duration (days) of cold spells

Table 27. Longest cold periods (period 1951-2019)

Berovo		
start	end	number of days
12.3.1953	26.3.1953	15
05.1.1990	16.1.1990	12
04.3.1987	14.3.1987	11
Bitola		
start	end	number of days
22.12.1988	06.1.1989	16
05.1.1990	16.1.1990	12
25.1.2006	05.2.2006	12
04.3.1987	14.3.1987	11
D.Kapija		
start	end	number of days
03.3.1987	14.3.1987	12
22.1.1963	01.2.1963	11
23.5.1991	02.6.1991	11
Gevgelija		
start	end	number of days
22.1.1963	02.2.1963	12
02.2.1956	10.2.1956	9
18.5.1952	25.5.1952	8
04.3.1987	11.3.1987	8
K.Palanka		
start	end	number of days
30.3.1997	20.4.1997	22
12.2.1985	25.2.1985	14
04.3.1987	16.3.1987	13
Lazaropole		
start	end	number of days
16.5.1952	29.5.1952	14
21.1.1963	31.1.1963	11
04.3.1987	14.3.1987	11

Ohrid		
start	end	number of days
16.5.1952	29.5.1952	14
14.2.1985	26.2.1985	13
21.1.1963	31.1.1963	11
04.3.1987	14.3.1987	11
Prilep		
start	end	number of days
12.2.1985	26.2.1985	15
04.4.1997	18.4.1997	15
16.5.1952	29.5.1952	14
23.4.1982	04.5.1982	12
03.3.1987	14.3.1987	12
Shtip		
start	end	number of days
03.3.1987	14.3.1987	12
22.1.1963	01.2.1963	11
02.2.1956	10.2.1956	9
15.12.1961	23.12.1961	9
17.2.1985	25.2.1985	9
24.5.1991	01.6.1991	9
Strumica		
start	end	number of days
19.2.1954	03.3.1954	13
23.1.1963	02.2.1963	11
04.3.1987	14.3.1987	11
05.1.1990	15.1.1990	11
16.8.1960	25.8.1960	10
16.3.1962	25.3.1962	10
17.2.1985	26.2.1985	10
02.1.2000	11.1.2000	10

The change in cold spells compared to the average for 1986-2005, for the three future periods given in the scenarios RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high) is similar to the changes taking place with regard to frost and icing days. In near future, the expected reduction is the same in all scenarios and is about one day less in the cold spell (with a maximum change of -3 days). At the end of the century the biggest change is in the high scenario, in average up to 8 days shorter cold spells for 20 years, which in the RCP8.5 scenario means almost complete disappearance of cold spells (Table 28).

Table 28. CSDI, Frequency and duration of cold spells for the period 1986-2005

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropolr	Ohrid	Prilep	Shtip	Strumica
frequency	10	7	9	2	12	10	10	10	12	10
number of days	67	63	64	14	91	71	74	87	96	71

DAILY TEMPERATURE RANGE

Daily temperature range index is defined by the difference between the daily maximum TX and the daily minimum air temperature TN. The annual values of the temperature interval range between the lowest value of 8,9°C observed at the meteorological station Lazaropole and the largest difference of 15,2°C observed in Berovo. The difference between the maximum and minimum temperatures in the recent period is increasing, so as a result of this increase, there is an increasing trend of the annual temperature range at all meteorological stations (Graph 13).

Table 29. DTR-Daily temperature range (difference between TX and TN)

	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
max	14.2	13.5	13.0	15.2	13.3	13.8	11.7	12.2	12.5	14.4
year	1993	2012	1961.0	2000	2000/2017	2000	1990	2000	1952	2000
min	10.1	10.3	10.1	11.0	10.6	9.4	8.9	8.8	9.7	10.9
year	1972	1973	1972	1955	1991	1955	1972	1963	1972	1963

Table 30. Average annual temperature range for the periods 1951-2019 and 1986-2005

average	Gevgelija	D.Kapija	Shtip	Berovo	Bitola	K.Palanka	Lazaropole	Ohrid	Prilep	Strumica
1951-2019	12.1	11.8	11.4	13.0	12.0	11.3	10.0	10.4	11.0	12.7
1986-2005	12.3	12.1	11.4	13.3	12.2	11.9	10.3	11.1	11.3	13.0

Graph 13. Annual temperature range

PRECIPITATION INDICES

EXTREME PRECIPITATION

Extreme precipitation is a major threat that often leads to floods, landslides, infrastructure damage, major economic losses, especially in agriculture, and often to loss of life. Statistically significant increase in the number of extreme precipitation has been confirmed in many regions of the world, although this is not uniformed in all regions (IPCC 2013).

Similarly, climate change projections by the end of the 21st century indicate that it is likely that the events with annual maximum daily precipitation that occur once in 20 years (for 1981–2010) will become one in 5 to one in a 15-year events in many regions. This shows a trend of more frequent extreme precipitation events. It should also be noted that there is a high likelihood of having an increase in extreme precipitation even when the average precipitation will decrease (IPCC 2012).

Extreme precipitation varies seasonally and from region to region. Therefore, it is best to analyze the extreme precipitation for multiple periods, such as per hour, per day and per multi-day periods.

Because there are large variations in precipitation patterns around the world, it is not possible to use a single definition of extreme precipitation that is suitable for all regions.

Precipitation is generally considered extreme in one of the following cases:

(1) it exceeds a certain threshold, i.e. fixed threshold, which has a certain associated impact

(2) it is considered extreme because of its rarity, i.e. threshold based on percentage or based on the return period. For the percentage-based threshold, the incidence of precipitation is most often in the upper 90s, 95s, and 99s percentile. Such percentile thresholds are determined by aggregate density statistical functions generated by the observed data or by the probability distributions of extreme phenomena (such as Generalized Extreme Value, GEV). It should be noted that extremely rare events of extreme precipitation (with a return period of 100 years or more) are very important for planning and engineering.

The World Meteorological Organization defines extreme precipitation as: significant amount of precipitation that occurs for a period of one to several days (usually less than a week) with a total daily amount that exceeds a certain threshold defined for a particular location (according to the measurements of the meteorological station).

Extreme precipitation is not the same as heavy precipitation or heavy rain. In the International Meteorological Dictionary (WMO-No 182) heavy rain is defined as rain with an accumulation rate that exceeds a certain value, e.g. 7,6 mm/h. Therefore, heavy rain may not be extreme and extreme precipitation may not be a result of torrential rain.

While the characterization based on a fixed threshold of extreme precipitation is more closely related to the application objectives, the percentage-based thresholds are more evenly distributed in space and probably more significant and applicable if there are sufficient observational data.

MAXIMUM ONE-DAY PRECIPITATION

Subject of analysis were data on the daily quantities of precipitation measured at 10 main meteorological stations in the period 1951-2019. According to the WMO standards, the measurement of daily precipitation for a certain day is performed at 07.00 Central European Time and it refers to the total quantity of precipitation in the previous 24 hours. The highest value of these measurements during the year is the annual maximum of daily precipitation.

According to the multi-year data, the absolute maximum amount of daily precipitation in the country is registered in Gevgelija, on 05.06.2004, and it is 201,0 mm.

The maximum daily precipitation that was measured during the entire period of observations, at ten measuring points has higher values than the maximum daily precipitation measured during the period from 1986-2005 (except for Gevgelija and Strumica).

However, the simplest linear analysis of the values in the multi-year period shows that in all measuring points (except in Prilep) there is a greater or lesser trend of increase in the maximum daily precipitation.

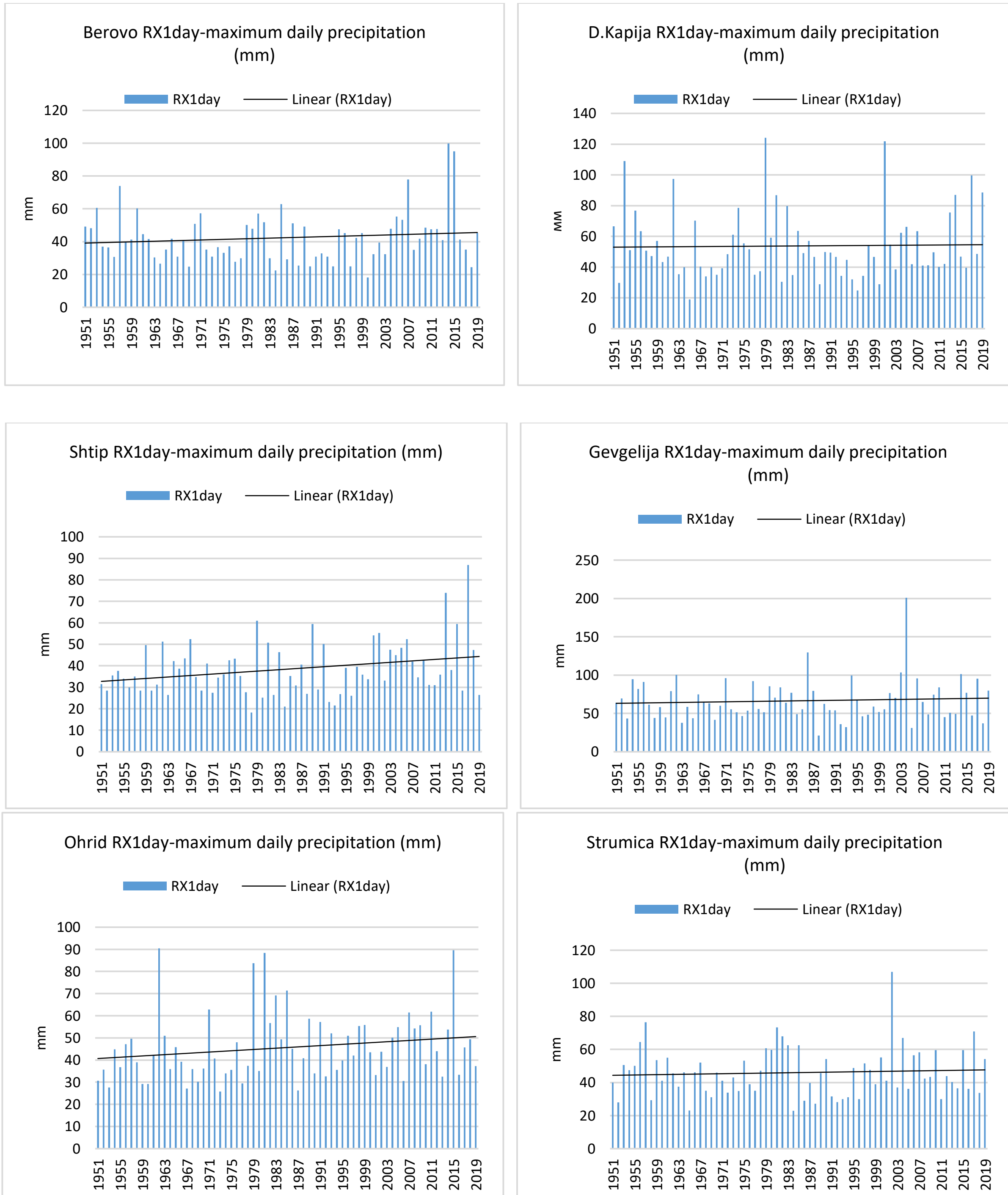
This is in line with the prepared climate scenarios, according to which in most parts of the country the daily extreme precipitation is expected to increase compared to the period 1986-2005. Also, in near future the increase is expected to be about 5%, and for the mid-century in the north and west even over 10%. By the end of the century, the change in the low and mid scenarios is expected to be the same. In the high scenario, at the end of the century the increase in some parts will be slightly higher and will be around 20%.

Table 31. Annual maximum of daily precipitation for the period 1951-2019

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
RX1day	99,8	116,0	124,2	201,0	97,0	154,4	90,4	120,2	86,9	107,0
date	24.7.2014	19.11.1979	19.11.1979	05.6.2004	05.7.1970	24.10.1981	16.11.1962	19.11.1979	24.5.2017	27.7.2002

Table 32. Annual maximum of daily precipitation for the period 1986-2005

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
RX1day	**55,2**	**50,0**	**121,9**	**201,0**	**63,0**	**89,8**	**58,7**	**77,9**	**59,5**	**107,0**
date	05.8.2005	16.8.1991	10.4.2001	05.6.2004	04.10.1998	02.12.2005	09.10.1989	31.7.1995	26.6.1989	27.7.2002



Graph 14. Annual maximum daily precipitation

Table 33. Ten highest annual values of maximum daily precipitation in the period 1951-2019

	Berovo		Bitola		D.Kapija		Gevgelija	
1	2014	99.8	1979	116.0	1979	124.2	2004	201.0
2	2015	95.0	1957	110.2	2001	121.9	1986	129.7
3	2007	77.9	1955	84.9	1953	109.0	2003	103.6
4	1957	74.0	1981	80.7	2017	99.6	2014	101.3
5	1985	62.9	1962	70.4	1962	97.4	1962	100.4
6	1953	60.6	2014	66.2	2019	88.6	1994	99.5
7	1960	60.3	1985	58.4	2014	87.0	1971	96.0
8	1971	57.2	2016	56.8	1981	86.8	2006	95.7
9	1981	57.1	1959	54.7	1983	79.7	2017	95.5
10	2005	55.2	2015	51.6	1974	78.5	1954	94.5
	max	**99.8**	**max**	**116.0**	**max**	**124.2**	**max**	**201.0**
	date	**24**	**date**	**19**	**date**	**19**	**date**	**5**
	month	**07**	**month**	**11**	**month**	**11**	**month**	**06**
	year	**2014**	**year**	**1979**	**year**	**1979**	**year**	**2004**

	K.Palanka		Lazaropole		Ohrid		Prilep	
1	1970	97.0	1981	154.4	1962	90.4	1979	120.2
2	2015	68.0	1979	112.2	2015	89.6	1981	88.8
3	2017	66.4	1955	97.4	1981	88.4	2015	78.4
4	1998	63.0	2018	92.5	1979	83.7	1995	77.9
5	1979	62.5	2005	89.8	1985	71.4	1955	77.2
6	2004	60.1	1976	87.2	1983	69.2	1962	76.7
7	1954	58.6	1969	85.0	1971	62.8	2011	72.8
8	1955	56.9	1962	82.8	2011	61.8	1975	56.4
9	2010	56.9	1985	79.7	2007	61.5	1993	55.8
10	1976	55.2	1970	77.8	1989	58.7	1985	55.0
	max	**97.0**	**max**	**154.4**	**max**	**90.4**	**max**	**120.2**
	date	**5**	**date**	**24**	**date**	**16**	**date**	**19**
	month	**07**	**month**	**10**	**month**	**11**	**month**	**11**
	year	**1954**	**year**	**1981**	**year**	**1962**	**year**	**1965**

	Shtip		Strumica	
1	2017	86.9	2002	107.0
2	2013	73.9	1957	76.4
3	1979	61.0	1981	73.3
4	1989	59.5	2017	70.9
5	2015	59.5	1982	68.0
6	2001	55.3	2004	66.9
7	2000	54.2	1956	64.5
8	1967	52.4	1983	62.5
9	2006	52.4	1985	62.5
10	1962	51.3	1979	60.7
	max	**86.9**	**max**	**107.0**
	date	**24**	**date**	**27**
	month	**05**	**month**	**07**
	year	**2017**	**year**	**1988**

MAXIMUM 5-DAY PRECIPITATION

The values of the annual maximum five-day precipitation are calculated as the largest sum of precipitation in five consecutive days. Thereby, the date under which the five-day precipitation is recorded indicates the sum from the previous five days.

The analysis of the multi-year data shows that the maximum five-day precipitation occurs most often in summer or autumn and that all values are above 100mm. Absolutely the highest five-day precipitation was recorded in Gevgelija and it amounted to 244,9mm on 06.06.2004. In this rainy episode, lasting from 01.06 to 06.06.2004, the maximum daily amount of precipitation ever recorded of 201,0mm was measured on 05.06.2004.

On the graph where the maximum annual five-day precipitation is presented, it is evident that unlike the daily maximum values, there is a less pronounced upward trend. For some measuring stations there is no significant trend visible, while in some there is a trend of decrease in the maximum annual five-day precipitation from the beginning to the end of the multi-year period.

Table 34. Annual maximum of five-day precipitation for the period 1951-2019

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	122,3	193,2	183,6	244,9	130,4	210,1	137,6	159,5	112,2	143,6
date	30	4	6	6	8	28	28	21	17	30
month	6	8	12	6	7	10	10	11	6	7
year	1957	1957	1983	2004	1970	1981	1981	1979	1983	2002

Table 35. Annual maximum of five-day precipitation for the period 1986-2005

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	88,5	93,9	132,0	244,9	91,7	193,5	110,7	83,0	109,9	143,6
date	6	20	13	6	1	20	20	3	30	30
month	8	10	4	6	10	11	11	8	6	7
year	2005	2003	2001	2004	1987	1999	1999	1995	1999	2002

Graph 15. Annual maximum of five-day precipitation

Table 36. Ten highest annual maximum five-day precipitation values in the period 1951-2019

	Berovo		Bitola		D.Kapija		Gevgelija	
1	1957	122.3	1957	193.2	1983	183.6	2004	244.9
2	2014	121.6	1979	162.6	1979	159.3	1983	205.8
3	1980	120.0	2016	128.3	1962	152.9	1994	190.6
4	2015	105.4	1981	127.7	2017	152.9	2017	186.0
5	1952	103.6	2014	123.4	1951	141.1	2010	173.9
6	2007	96.8	1964	108.7	2001	132.0	1976	165.2
7	1974	95.8	1983	104.9	1980	131.5	1986	159.1
8	1982	94.0	1962	97.6	1955	131.0	1952	158.3
9	1985	92.5	1959	96.8	1976	125.2	1962	155.9
10	2005	88.5	1952	95.6	1957	118.3	1985	150.7
	max	**122.3**	**max**	**193.2**	**max**	**183.6**	**max**	**244.9**
	date	**30**	**date**	**4**	**date**	**6**	**date**	**6**
	month	**06**	**month**	**08**	**month**	**12**	**month**	**06**
	year	**1957**	**year**	**1957**	**year**	**1983**	**year**	**2004**

	K.Palanka		Lazaropole		Ohrid		Prilep	
1	1970	130.4	1981	210.1	1981	137.6	1979	159.5
2	2010	122.1	1999	193.5	1962	134.3	1981	119.9
3	2015	107.1	1979	191.9	2015	126.5	2015	115.7
4	1961	97.2	2005	183.9	1985	119.3	1962	99.4
5	2009	94.2	1985	176.3	1963	113.6	2011	89.6
6	1954	92.8	1971	175.0	1999	110.7	1973	89.5
7	1957	92.2	2002	152.7	1991	107.8	1995	83.0
8	1987	91.7	1982	151.7	2003	104.4	1955	82.8
9	1976	91.1	1987	149.5	2002	100.2	2003	80.8
10	2017	88.9	1962	147.5	1979	99.0	1985	80.6
	max	**130.4**	**max**	**210.1**	**max**	**137.6**	**max**	**159.5**
	date	**8**	**date**	**28**	**date**	**28**	**date**	**21**
	month	**07**	**month**	**10**	**month**	**10**	**month**	**11**
	year	**1970**	**year**	**1981**	**year**	**1981**	**year**	**1979**

	Shtip		Strumica	
1	1983	112.2	2002	143.6
2	1989	109.9	1983	138.7
3	2017	107.6	1982	121.7
4	2006	90.8	1954	117.5
5	2005	90.7	1961	116.4
6	1979	90.5	1957	112.0
7	1955	90.0	1980	109.4
8	2013	84.4	1990	98.0
9	2004	79.1	2012	97.5
10	2003	78.8	1979	96.7
	max	**112.2**	**max**	**143.6**
	date	**17**	**date**	**30**
	month	**06**	**month**	**07**
	year	**1983**	**year**	**2002**

SIMPLE PRECIPITATION INTENSITY INDEX (SDII)

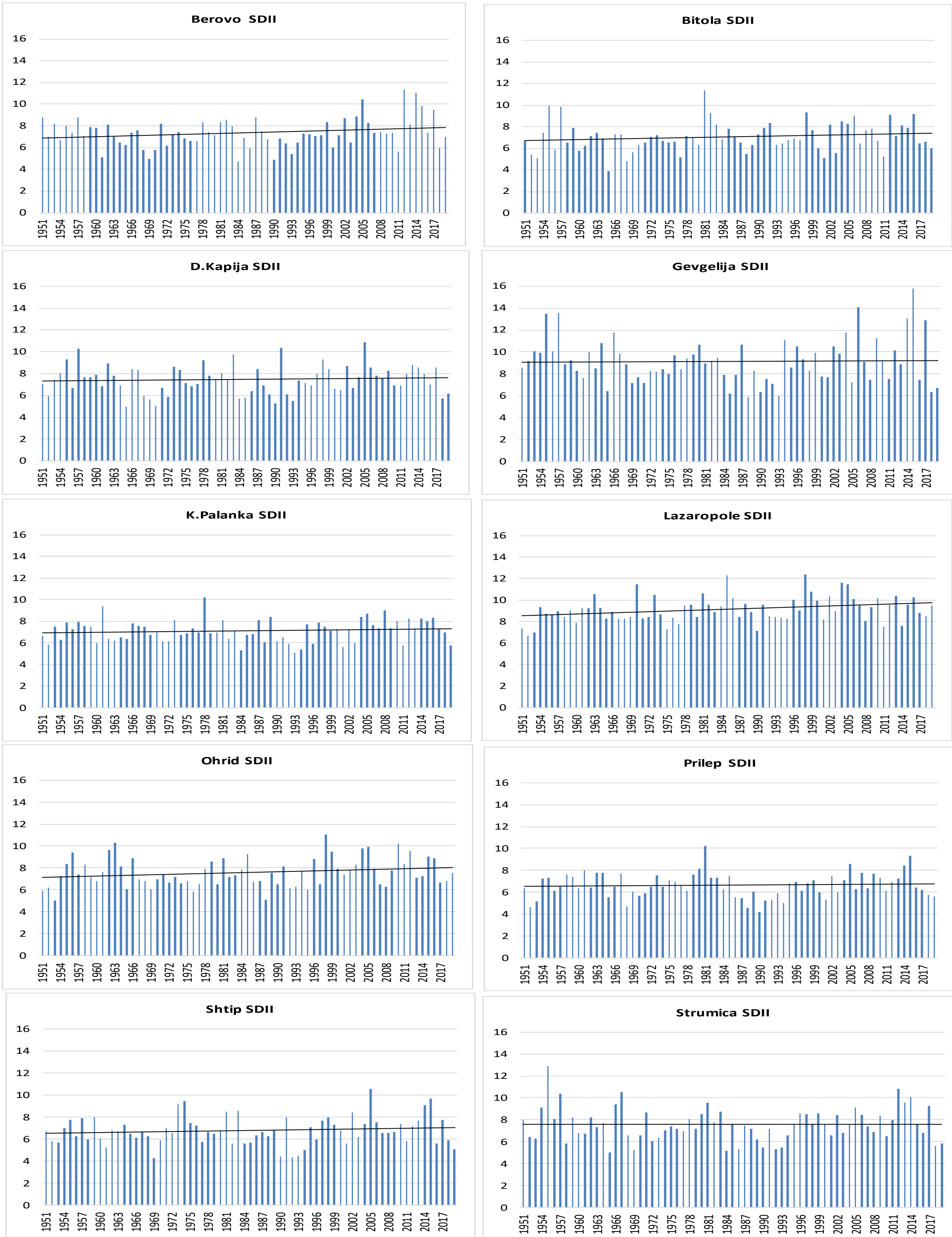
This index is calculated as the sum of the amount of precipitation on wet days (when precipitation is greater than or equal to 1 mm), divided by the total number of wet days (when RR≥1mm). For a period of one year, the average daily intensity means that the sum of precipitation from the days when precipitation is higher than or equal to 1mm is divided by the total number of days when there was precipitation ≥ 1mm.

The analysis of the data shows that the average mean daily intensity for the multi-year period 1951-2019 is the highest in Gevgelija and Lazaropole, and the lowest in Prilep and Shtip, and the results are similar for the period 1986-2005. The maximum average mean daily intensity of precipitation was recorded in Gevgelija, in 2015, when on rainy days there was an average of 15,8 mm of rain.

The analysis of the multi-year trend shows that there is no decrease in the values at any measuring station, but that the average daily intensity of precipitation either increases or it remains stable. The reason for the increase in the mean daily intensity may be the increase in the total amount of precipitation or decrease in the number of rainy days (or both at the same time).

Table 37. Average mean daily precipitation intensity for the periods 1951-2019, 1986-2005, and maximum annual mean daily precipitation intensity

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	11,3	11,4	10,9	15,8	10,2	12,4	11,1	10,2	10,6	12,9
year	2012	1981	2005	2015	1978	1998	1998	1981	2005	1955
SDII(1951-2019)	7,4	7,1	7,5	9,2	7,1	9,1	7,6	6,6	6,8	7,6
SDII(1986-2005)	7,2	7,0	7,5	8,6	6,9	9,5	7,7	6,1	6,7	7,2



Graph 16. Annual mean daily precipitation intensity

NUMBER OF DAYS WITH HEAVY PRECIPITATION (over 10mm), WITH VERY HEAVY PRECIPITATION (over 20mm) AND WITH PRECIPITATION OVER 40mm

According to the definitions of WMO, a day with heavy precipitation is a day on which the measured amount of precipitation is greater (or equal) than 10mm, and a day with very heavy precipitation is a day on which the rainfall is greater (or equal) than 20mm. Also, in this extremes index, users can define a specific precipitation threshold, which in this case is done by analyzing the number of days with precipitation over 40mm.

The data show that in the country the largest number of days with heavy rainfall is registered in Lazaropole (average 36 days per year), followed by Ohrid (23 days) and Gevgelija (22 days), and the lowest number is registered in Shtip (14 days). The average number of days with heavy precipitation is similar for the period 1986-2005.

The maximum number of days with heavy precipitation during a year was recorded in Lazaropole and Ohrid in 2010 (56 and 42 days). Also in 2014, a maximum number of heavy precipitation events was registered at several measuring points (in Berovo 34, in Kriva Palanka 31, in Strumica 32 and in Shtip 30). The lowest number of days with heavy precipitation was recorded in 1984, 1993, etc.

Table 38. Average annual number of days with heavy precipitation for the periods 1951-2019, 1986-2005; maximum and minimum annual number of days

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	34	32	27	34	31	56	42	27	30	32
year	2014	2002	1957;1983	1962	2014	2010	2010	2010	2014	2014
min	8	7	8	10	8	21	8	4	6	6
year	2000	1977	1984	2000	1993	2011	1993	1988	1988;1990; 1993;1994	1984
RR10 (1951-2019)	20	19	17	22	20	36	23	16	14	18
RR10 (1986-2005)	19	19	17	20	19	35	22	13	12	17

The average number of days in a year with very heavy precipitation, when the measured daily amount is 20mm or more, is lower than the number of days with heavy rainfall. Thus, in Lazaropole annually there are on average 13 days with very heavy rainfall, in Gevgelija 10 days, and the lowest number of such days in one year is registered in Prilep and Shtip (4 days in average).

The maximum number of days with very heavy precipitation was observed in certain years of the multi-year period 1951-2019, as was the case with Lazaropole in 2004 and 2012 and Gevgelija in 2014 when a total of 21 day with very heavy precipitation was recorded. In some years in Berovo, Bitola, Prilep, Shtip and Demir Kapija there were no such days at all.

Table 39. Average annual number of days with very heavy precipitation for the periods 1951-2019, 1986-2005; maximum and minimum annual number of days

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	11	12	14	21	11	21	14	9	12	14
year	1978;2017	2002	1983;2015	2014	1989;2008	2004;2010	1998; 2010;2012	1981	1974	1955;2013
min	0	0	0	2	2	7	1	0	0	1
year	2000	1953;1977	1965	1988;1993	1952;1971; 2011	1953;1968; 1994	1953	1988;1990	1978	1952;1984
RR20 (1951-2019)	6	5	6	10	6	13	7	4	4	6
RR20 (1986-2005)	5	5	5	8	5	14	7	4	4	6

The number of days when the precipitation is over 40mm is lower and this phenomenon is rarer, but not negligible. Thus, in several years at certain measuring stations there were 6 days with such extremely heavy precipitation (in Lazaropole in three years there were 6 days, and in Gevgelija in 2017 there were 6 such days).

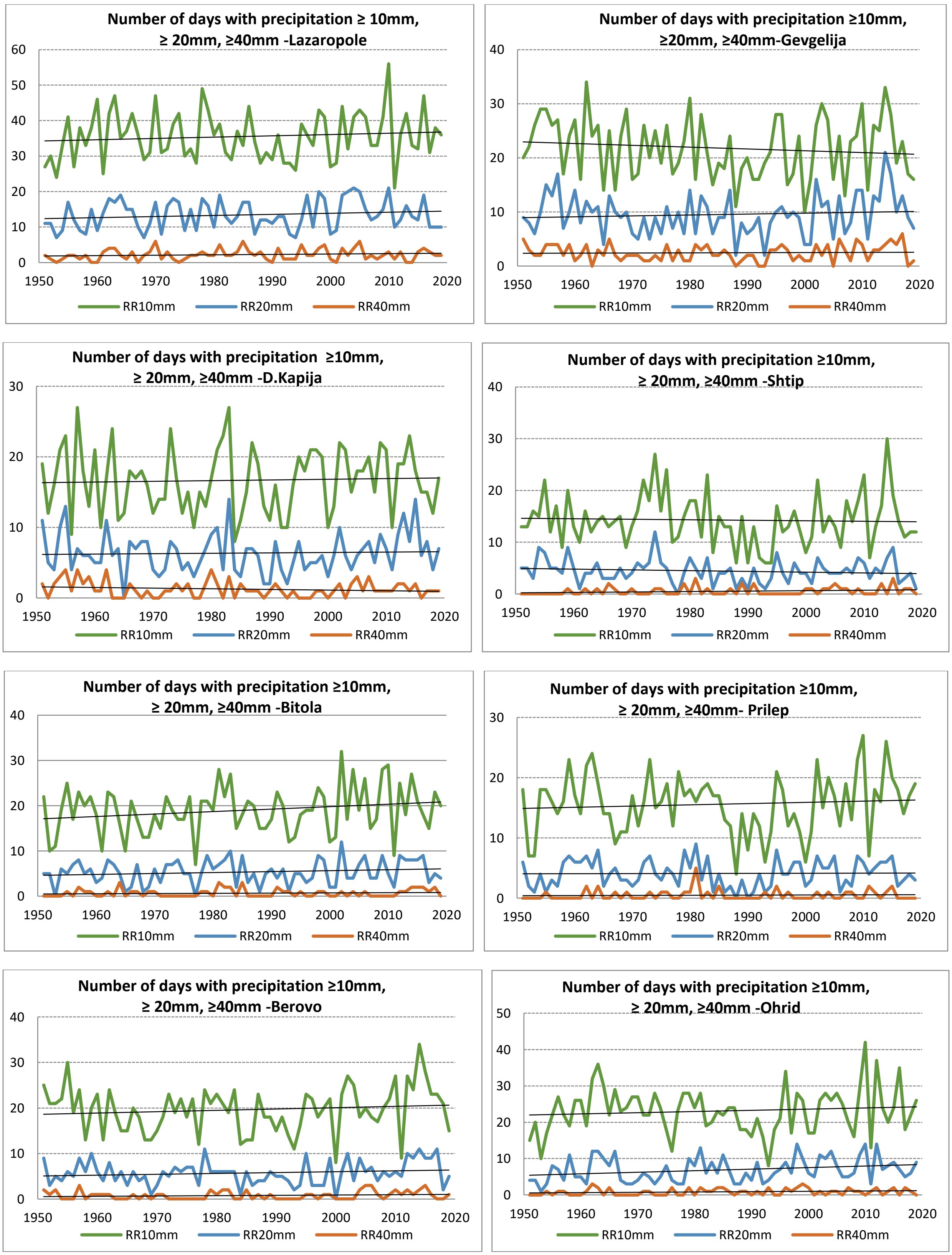
Table 40. Average annual number of days with precipitation over 40 mm for the periods 1951-2019 and maximum annual number of days

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	3	3	4	6	3	6	3	5	3	4
year	1957;2005; 2006;2015	1964;1981; 1985	1955;1957; 1962;1980	2017	1959;1976; 2018	1970;1985; 2005	1962;1999	1981	1981;2015	1980
RR40 (1951-2019)	1	1	1	2	1	2	1	0	1	1
RR40 (1986-2005)	1	0	1	2	1	3	1	0	1	1

According to the multi-year data, during the year on average there is one day with precipitation over 40mm at all measuring points, and in Lazaropole and Gevgelija there are on average two such days. It is interesting that in Prilep, although in one year (1982) there were five days with precipitation over 40 mm, on average such precipitation does not occur, which indicates the specificity of such extreme events.

Also, the average number of days with precipitation over 40mm for the multy-year period 1951-2019 in Lazaropole is 2, while in the period 1986-2005 it is 3, which can be a result of a greater number of such events in the recent years. This is also confirmed by the upward trend of days with precipitation over 40mm, as it is shown in the graphs.

Data on the annual number of days with precipitation over 10mm, over 20mm and over 40mm in the period 1951 to 2019 show that the number of days with heavy precipitation does not have a pronounced trend, but the number of days with very heavy precipitation and precipitation over 40mm increases at all measuring points (except Gevgelija).



Graph 17. Annual number of days with precipitation ≥10mm, ≥ 20mm and ≥40mm

Table 41. Ten years with the highest number of days with heavy precipitation, very heavy precipitation and precipitation over 40mm in the period 1951-2019

	Berovo						Bitola						Gevgelija					
		RR≥ 10		RR≥ 20		RR≥ 40		RR≥ 10		RR≥ 20		RR≥ 40		RR≥ 10		RR≥ 20		RR≥ 40
1	2014	34	1978	11	1957	3	2002	32	2002	12	1964	3	1962	34	2014	21	2017	6
2	1955	30	2014	11	2005	3	2010	29	1983	10	1981	3	2014	33	1957	17	1951	5
3	2015	28	2017	11	2006	3	1981	28	1979	9	1985	3	1980	31	2015	17	1966	5
4	2002	27	1959	10	2015	3	2004	28	1985	9	1957	2	2003	30	2002	16	2006	5
5	2010	27	1995	10	1951	2	2009	28	1998	9	1982	2	2010	30	1955	15	2009	5
6	2012	27	2002	10	1953	2	1983	27	2006	9	1983	2	1954	29	1960	14	2015	5
7	1951	25	2012	10	1979	2	2014	27	2009	9	1991	2	1955	29	1980	14	1955	4
8	2003	25	1951	9	1981	2	2006	26	2012	9	2014	2	1969	29	1987	14	1956	4
9	1957	24	1957	9	1982	2	1955	25	2016	9	2015	2	1982	28	2009	14	1957	4
10	1962	24	1999	9	1985	2	2012	25	1957	8	2016	2	1995	28	2010	14	1959	4

	D.Kapija						K.Palanka						Lazaropole					
		RR≥ 10		RR≥ 20		RR≥ 40		RR≥ 10		RR≥ 20		RR≥ 40		RR≥ 10		RR≥ 20		RR≥ 40
1	1957	27	1983	14	1955	4	2014	31	1989	11	1959	3	2010	56	2004	21	1970	6
2	1983	27	2015	14	1957	4	1989	29	2008	11	1976	3	1978	49	2010	21	1985	6
3	1963	24	1955	13	1962	4	1995	29	2010	10	2018	3	1963	47	1998	20	2005	6
4	1973	24	2013	12	1980	4	2015	28	1962	9	1961	2	1970	47	2003	20	1981	5
5	1955	23	1951	11	1954	3	1976	27	1973	9	1966	2	2016	47	2005	20	1995	5
6	1982	23	1962	11	1959	3	2002	27	2002	9	1979	2	1960	46	1964	19	1999	5
7	2014	23	1954	10	1983	3	1978	26	2012	9	1981	2	1986	44	1981	19	1962	4
8	1987	22	1981	10	2005	3	1961	25	1953	8	1987	2	2002	44	1996	19	1963	4
9	2002	22	2002	10	2007	3	2004	25	1959	8	2004	2	1979	43	2002	19	1991	4
10	2009	22	1980	9	1951	2	2007	25	1976	8	2005	2	1998	43	2016	19	1998	4

	Ohrid						Prilep						Shtip					
		RR≥ 10		RR≥ 20		RR≥ 40		RR≥ 10		RR≥ 20		RR≥ 40		RR≥ 10		RR≥ 20		RR≥ 40
1	2010	42	1998	14	1962	3	2010	27	1981	9	1981	5	2014	30	1974	12	1981	3
2	2012	37	2010	14	1999	3	2014	26	1964	8	1962	2	1974	27	1954	9	2015	3
3	1963	36	2012	14	1963	2	1963	24	1979	8	1964	2	1976	24	1959	9	1966	2
4	2016	35	1981	13	1965	2	1959	23	1995	8	1985	2	1983	23	2015	9	1979	2
5	1996	34	1962	12	1976	2	1973	23	1959	7	1995	2	2010	23	1955	8	1989	2
6	1962	32	1963	12	1979	2	2002	23	1962	7	2011	2	1955	22	1995	8	1991	2
7	1964	30	1966	12	1981	2	2009	23	1973	7	2015	2	1972	22	1980	7	2005	2
8	1966	29	2004	12	1984	2	1962	22	1983	7	1955	1	2002	22	1983	7	2013	2
9	2009	29	1958	11	1985	2	1978	21	2002	7	1967	1	1959	20	2002	7	1959	1
10	1973	28	1985	11	1993	2	1995	21	2005	7	1969	1	2015	19	2009	7	1962	1

	Strumica					
		RR≥ 10		RR≥ 20		RR≥ 40
1	2014	32	1955	14	1980	4
2	2002	28	2013	14	1955	3
3	1999	26	1954	11	1957	3
4	2013	26	1957	10	1959	3
5	1962	25	2002	10	1964	3
6	1963	25	2009	10	1985	3
7	1983	25	2012	10	2010	3
8	2017	25	1956	9	1951	2
9	1951	24	1960	9	1954	2
10	1954	24	1974	9	1956	2

MAXIMUM CONSECUTIVE WET DAYS (CWD)

This index shows the largest number of consecutive days with precipitation (days when the amount of precipitation is greater than or equal to 1 mm) during a certain period. Together with the index for consecutive dry days (CDD), they provide information on the possible continuity of wet or dry periods throughout the year.

Absolutely the longest period of consecutive wet (rainy) days was observed in Gevgelija, in 1969, when there were 15 consecutive wet days (from 21.02 to 07.03). In Lazaropole, on two occasions, the maximum rainy episode lasted 13 days, and in Ohrid two occasions lasted 12 days, etc. In Berovo and Bitola the maximum length of consecutive days with precipitation is 10 days, but in Berovo such a rainy period occurred only once, and in Bitola three times. As it can be seen in the table for some measuring stations there has never been a wet period that lasted more than ten days (Demir Kapija, Kriva Palanka, Prilep and Strumica).

Table 42. Maximum length of consecutive wet days and frequency of occurrence

number of days/ frequency	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
15				1						
14										
13						2				
12						2	2			
11				1		4	3		1	
10	1	3		2		9	3		0	
9	3	0	2	1	1	19	6		0	3
8	2	3	3	8	5	21	13	3	0	2
7	10	15	8	6	8	51	16	10	1	9
6	26	29	24	28	26	68	36	25	13	16
5	79	74	35	57	62	144	77	56	31	54

CONSECUTIVE DRY DAYS (CDD)

The CDD index called "consecutive dry days" belongs to the group of indices which are based on the maximum number of days that in continuity do not exceed a certain fixed threshold. This index refers to a period with a minimum amount of daily precipitation RR <1 mm.

The highest annual number of dry days in the past 69 years, is 103 days and these were observed in Demir Kapija, while the lowest number, 58 days were observed in Lazaropole (Table 43). The highest annual number of dry days at almost all meteorological stations is not observed in the same year. The years with the highest annual number of dry days are 1956, 1961, 1965, 1969, 1986, 1992, 2000, 2001, 2003, 2007, 2018 and 2019, which is a result of the general upward trend in the number of dry days.

The increase is particularly pronounced in some regions, which coincides with the conclusion in the "Report on Climate Change Projections and Changes in Climate Extremes for the Republic of

North Macedonia". Namely, the expected increase in the annual number of dry days according to all three scenarios RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high) is about 20-30 days. In the low scenario this change will be more pronounced at the end of the century, but in the other two scenarios the mid-century increase will be by more than 20 or 30 days. Further increase, more pronounced in the high scenario, is expected in the last period (2081-2100), in most of the country. In the high scenario an increase of about 40 days is expected, in comparison to the period 1986-2005. Greater increase is expected in areas of lower and higher altitudes. According to the high scenario, by the end of the century the whole territory will be exposed to extremely high risk of drought.

Table 43. Annual maximum number of consecutive dry days for the period 1951-2019

1951-2019	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	61	70	103	87	59	58	78	67	78	96
year	1961	1965	1969	1956	1969	2018	1986	1989	1992	1992

Table 44. Annual maximum number of consecutive dry days for the period 1986-2005

1986-2005	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	55	42	68	65	53	45	78	67	78	96
Year	1989	1986	2001	1992	2003	1986	1986	1989	1992	1992

Table 45. Maximum length of consecutive dry days and frequency of occurrence

number of days/ frequency	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
103			1							
102										
101										
100										
99										
98										
97										
96										1
95										
94										
93										
92										
91										
90										
89										
88										
87				1						1
86										
85										
84										
83										
82										
81										
80										
79										
78							1		1	
77										
76				1						
75										
74									1	
73										
72										
71										
70		1								2
69										
68			1							
67			1					1		
66							1			
65				1						
64		1								
63		2								
62										
61	1			1						
60	1		1					1	1	1
59					1			1		
58						1	3			
57										
56										
55	1			3			1		1	
54	1		1				1			1
53			2		1	1	2		1	1
52				1	3		1			1
51					1			1		1
50								2		1

Table 46. Longest dry periods

Berovo			Bitola			D.Kapija			Gevgelija			K.Palanka			Lazaropole			Ohrid			Prilep			Shtip			Strumica		
Start	End	Numbe rof days	Start	End	Numbe rof days	Start	End	Numbe rof days	Start	End	Numbe rof days	Start	End	Numbe rof days	Start	End	Numbe rof days	Start	End	Numbe rof days	Start	End	Numbe rof days	Start	End	Numbe rof days	Start	End	Numbe rof days
11.7.1961	09.9.1961	61	29.8.1965	06.11.1965	70	20.8.1969	30.11.1969	103	14.7.1956	08.10.1956	87	22.9.1969	19.11.1969	59	03.9.2018	30.10.2018	58	11.7.1986	26.9.1986	78	22.12.1988	26.2.1989	67	29.12.1991	15.3.1992	78	23.12.1991	27.3.1992	96
08.9.1965	06.11.1965	60	18.7.2019	19.9.2019	64	07.9.2001	13.11.2001	68	25.7.1961	08.10.1961	76	07.2.2003	31.3.2003	53	02.7.1974	23.8.1974	53	22.12.1988	25.2.1989	66	08.9.1965	06.11.1965	60	14.9.1969	26.11.1969	74	14.7.1956	08.10.1956	87
22.12.1988	14.2.1989	55	12.7.1953	12.9.1953	63	16.8.1986	21.10.1986	67	23.1.1992	27.3.1992	65	15.9.1965	05.11.1965	52	13.8.1986	26.9.1986	45	11.7.1960	06.9.1960	58	20.7.1952	16.9.1952	59	08.9.1965	06.11.1965	60	29.8.1965	06.11.1965	70
16.10.2011	08.12.2011	54	23.6.1974	24.8.1974	63	08.9.1965	06.11.1965	60	09.7.1974	07.9.1974	61	07.8.1986	27.9.1986	52	03.8.2008	13.9.2008	42	04.7.1962	30.8.1962	58	17.9.2001	06.11.2001	51	22.12.1988	14.2.1989	55	10.9.2018	18.11.2018	70
22.9.1969	07.11.1969	47	22.9.1969	09.11.1969	49	22.12.1988	13.2.1989	54	02.8.1962	25.9.1962	55	14.6.2007	04.8.2007	52	14.7.1956	23.8.1956	41	09.6.2007	05.8.2007	58	08.8.1986	26.9.1986	50	18.2.1953	11.4.1953	53	30.6.1953	28.8.1953	60
03.10.2005	16.11.2005	45	04.6.1978	22.7.1978	49	01.8.1988	22.9.1988	53	28.8.1965	21.10.1965	55	09.11.1953	29.12.1953	51	10.11.1953	19.12.1953	40	07.6.2012	31.7.2012	55	04.1.1993	22.2.1993	50	15.5.1973	30.6.1973	47	22.12.1988	13.2.1989	54
09.11.1953	21.12.1953	43	18.6.2007	05.8.2007	49	29.8.2018	20.10.2018	53	22.12.1988	14.2.1989	55	09.1.1989	25.2.1989	48	07.7.1965	15.8.1965	40	07.8.1992	29.9.1992	54	02.9.2018	20.10.2018	49	04.1.1982	19.2.1982	47	17.9.1969	08.11.1969	53
16.8.1986	27.9.1986	43	01.7.1965	15.8.1965	46	27.6.1968	13.8.1968	48	21.7.2019	10.9.2019	52	25.10.2011	06.12.2011	43	11.9.1985	20.10.1985	40	15.9.1965	06.11.1965	53	09.6.1997	26.7.1997	48	05.9.2018	20.10.2018	46	15.6.1978	05.8.1978	52
09.1.1982	19.2.1982	42	13.8.1962	24.9.1962	43	25.7.1961	09.9.1961	47	26.7.1992	12.9.1992	49	14.7.1956	23.8.1956	41				03.8.1991	24.9.1991	53	09.7.1974	24.8.1974	47	12.1.1988	25.2.1988	45	18.7.2019	06.9.2019	51
05.10.1977	14.11.1977	41	14.7.1956	24.8.1956	42	17.7.2000	01.9.2000	47	07.9.2001	24.10.2001	48	06.11.1986	16.12.1986	41				27.7.1952	16.9.1952	52	27.7.1992	11.9.1992	47	15.2.2003	31.3.2003	45	26.9.1977	14.11.1977	50
07.11.1986	17.12.1986	41	06.11.1986	17.12.1986	42	18.6.2007	31.7.2007	44	18.6.2007	04.8.2007	48	25.12.1963	02.2.1964	40				08.6.1997	25.7.1997	48	14.8.1987	28.9.1987	46	03.10.2005	16.11.2005	45	15.6.2007	31.7.2007	47
14.7.1956	22.8.1956	40	17.8.1986	26.9.1986	41	05.7.1965	15.8.1965	42	17.7.2000	01.9.2000	47	10.9.2018	19.10.2018	40				29.7.2008	13.9.2008	47	13.8.1962	25.9.1962	44	21.6.2007	04.8.2007	45	02.7.1966	16.8.1966	46
22.12.1987	30.1.1988	40	10.11.1953	19.12.1953	40	09.1.1982	19.2.1982	42	30.7.2008	14.9.2008	47							22.9.1969	06.11.1969	46	08.11.1953	20.12.1953	43	09.7.1974	21.8.1974	44	18.7.2000	01.9.2000	46
			28.9.2001	06.11.2001	40	30.12.1989	09.2.1990	42	22.9.1969	06.11.1969	46							28.6.1988	10.8.1988	44	09.1.1982	20.2.1982	43	06.11.1986	19.12.1986	44	08.11.1953	20.12.1953	43
						10.11.1953	20.12.1953	41	02.10.2018	16.11.2018	46							30.6.1978	11.8.1978	43	26.6.1985	07.8.1985	43	31.12.1989	12.2.1990	44	16.8.1986	27.9.1986	43
									11.3.1998	24.4.1998	45							27.8.2018	08.10.2018	43	11.9.1985	23.10.1985	43	12.7.2013	24.8.2013	44	12.9.1985	23.10.1985	42
									14.6.1984	27.7.1984	44							11.9.1985	22.10.1985	42	24.2.2019	07.4.2019	43	16.8.1986	27.9.1986	43	31.12.1989	10.2.1990	42
									16.8.1986	28.9.1986	44							05.6.2017	16.7.2017	42	27.7.1960	06.9.1960	42	09.11.1953	20.12.1953	42	05.1.1993	15.2.1993	42
									09.1.1982	19.2.1982	42							14.7.1956	23.8.1956	41	14.7.1956	23.8.1956	41	11.9.1985	22.10.1985	42	01.8.2013	11.9.2013	42
									12.9.1985	23.10.1985	42							09.11.1953	18.12.1953	40	17.10.1969	25.11.1969	40				07.11.1986	17.12.1986	41
									31.12.1989	10.2.1990	42																12.8.2011	20.9.2011	40
									08.8.1952	17.9.1952	41																		
									31.7.1960	09.9.1960	41																		
									01.3.1990	10.4.1990	41																		
									01.7.1993	10.8.1993	41																		
									04.10.1984	12.11.1984	40																		
									04.7.2001	12.8.2001	40																		

TOTAL DAILY PRECIPITATION EXCEEDING THE 95% PERCENTILE THRESHOLD (R95pTOT) AND TOTAL DAILY PRECIPITATION EXCEEDING THE 99% PERCENTILE THRESHOLD (R99pTOT)

In general, these indices show what is the annual sum of precipitation with larger daily quantities (above the 95th and above the 99th percentile), so-called very wet and extremely wet days. The threshold of 95 and 99 percentile is calculated from the daily precipitation data in the period 1961-1990, for each measuring station separately. They indicate that 95 or 99 percent of the daily precipitation values are above that threshold.

The maximum annual sum of precipitation from very wet days was measured in Lazaropole in 1981 and it is 506.3mm. It can be seen that in almost all places, the highest values are recorded after 2000.

It should be noted that in some years there is no daily precipitation over the 95 or over the 99 percentile, so the average annual value is calculated as the mean value of the total sum divided by the number of years in which they are registered. So, the average value of the annual sum of precipitation in very wet days ranges from 118,4 mm in Shtip to 238.6 mm in Lazaropole.

The maximum annual amount of precipitation from extremely wet days was measured in Gevgelija in 2009 and it is 283,3mm. Also, the highest average annual sum of extreme precipitation is in Gevgelija, 121,9mm.

Table 47. Maximum and average annual sum of precipitation with daily values above the 95th percentile

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	368,2	362,0	468,2	488,5	306,4	506,3	395,6	440,3	294,1	363,4
year	2014	2002	1962	2015	2010	1981	1962	1981	2015	2013
R95pTOT (1951-2019)	152,8	149,0	151,9	205,7	144,3	238,6	157,0	129,1	118,4	155,7
number of years	68	65	67	67	68	69	69	67	66	67

Table 48. Maximum and average annual sum of precipitation with daily values above the 99th percentile

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	207,3	236,8	221,8	283,3	169,4	277,2	221,1	342,5	141,6	175,4
year	1951	1981	1962	2009	1957	2005	1962	1981	1981	1957
R99pTOT (1951-	87,3	80,9	99,2	121,9	78,9	108,5	85,3	77,2	71,3	79,5
number of years	44	35	34	37	38	42	37	30	29	32

TOTAL SUM OF PRECIPITATION ON WET DAYS (with RR≥1mm) (PRCPTOT)

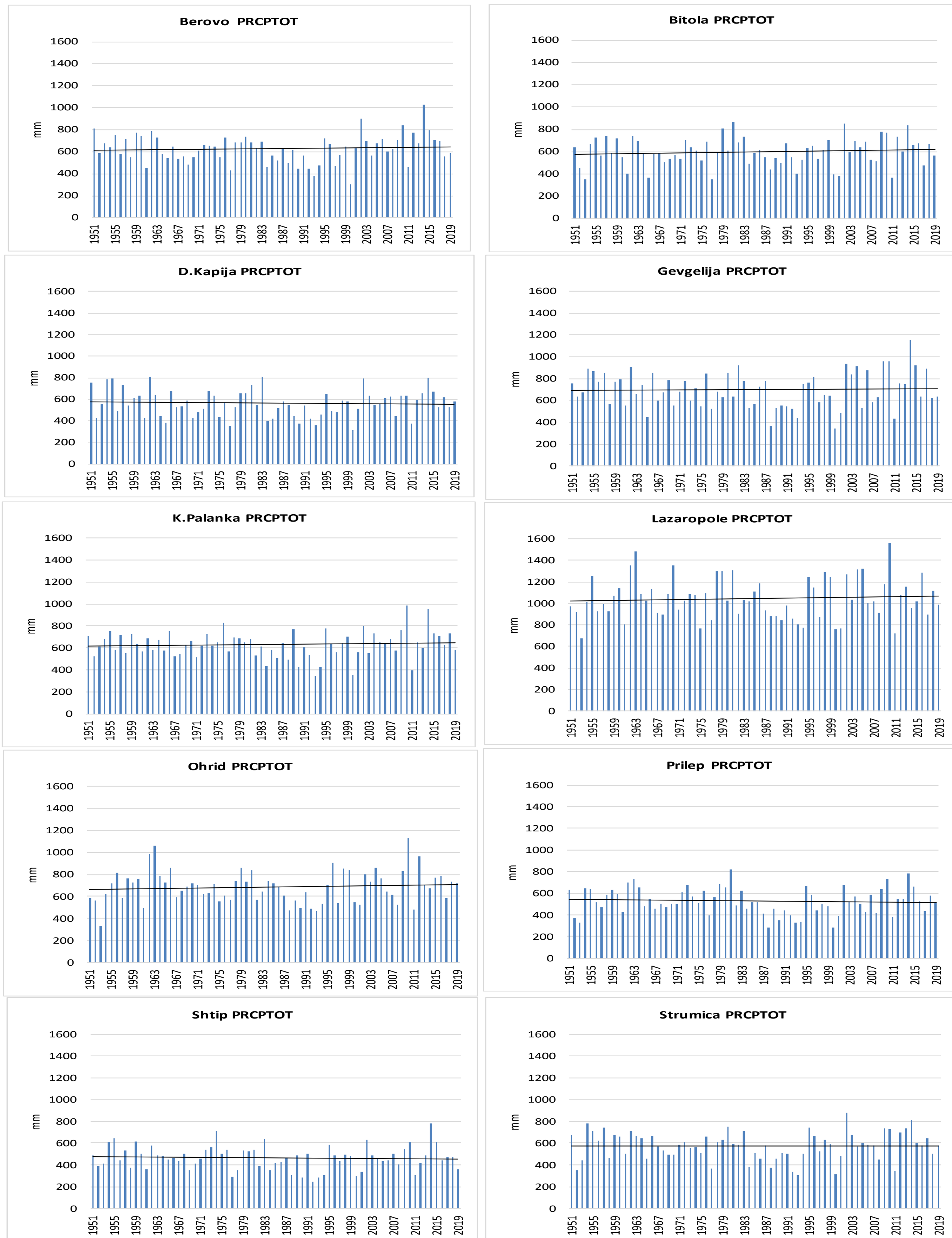
The total sum of precipitation on wet days (which are defined as days with precipitation greater than or equal to 1mm), for a specific period (month or year) is different from the total (monthly or annual) sum since precipitation with a daily amount of less than 1mm is not taken into consideration. So, this index has an approximate value with the total monthly or annual sum, but it is still different. Therefore, the difference between these two values is the amount of precipitation in the days when the daily value was between 0-1mm.

Absolutely the largest annual sum of precipitation was measured in 2010 in Lazaropole and it is 1555.8mm, while the lowest in Shtip in 1992 and it is 248.6mm. From the data for the multi-year period, the average annual sums range from 465.7mm in Shtip to 1046.1mm in Lazaropole.

Table 49. Maximum, minimum and average annual sum of precipitation with daily values higher than 1mm

	Berovo	Bitola	D.Kapija	Gevgelija	K.Palanka	Lazaropole	Ohrid	Prilep	Shtip	Strumica
max	1025,8	870	808,4	1151,6	982,6	1555,8	1130,5	818,6	783,5	875,7
year	2014	1981	1983	2014	2010	2010	2010	1981	2014	2002
min	301,7	348,3	314,3	342,5	348,6	679,2	328,7	283,6	248,6	306,7
year	2000	1953	2000	2000	1993	1953	1953	2000	1992	1993
PRCPTOT (1951-2019)	627,5	599,4	563,7	699,1	630,4	1046,1	688,3	529,6	465,7	575,5
PRCPTOT (1986-2005)	571,0	575,1	519,8	637,6	587,0	1020,9	651,0	457,7	421,7	534,1

The graphs for the annual sum of precipitation in the period from 1951, show no pronounced trends. Namely, at most measuring points the annual sum of precipitation varies equally above or below the average, while an insignificant decreasing trend is observed in Prilep and Shtip, and only in Lazaropole and Ohrid there is an insignificant trend of increase in the annual sum of precipitation.



Graph 18. Total annual sum of precipitation on wet days (RR≥1mm) for the period 1951-2019.

APPENDIX: ETCCDI indices

In this analysis, we have used the definitions of the basic set of 27 descriptive indices for climate extremes related to temperature and precipitation developed by the Expert Team on Climate Change Detection and Indices of CCl / CLIVAR / JCOMM (ETCCDI). http://www.clivar.org/organization/etccdi/etccdi.php

Temperature Indices:

1. **FD (frost days)**: count of days where TN (daily minimum temperature) < 0˚C

Let TNij be daily minimum temperature on day i in year j. Count the number of days where TNij < 0˚C.

2. **SU (summer days)**: Count of days where TX (daily maximum temperature) > 25˚C.

Let TXij be daily maximum temperature on day i in year j. Count the number of days where TXij > 25˚C.

3. **ID (icing days)**: count of days when TX < 0˚C.

Let TXij be daily maximum temperature on day i in year j. Count the number of days where TXij < 0˚C.

4. **TR (tropical nights)**: count of days when TN > 20˚C.

Let TNij be daily minimum temperature on day i in year j. Count the number of days where TNij > 20˚C.

5. **GSL, Growing season length**: Annual count of days between first span of at least 6 days where TG (daily mean temperature) >5˚C and the first occurrence after after July 1st (1 Jan in SH) of at least 6 days where TG<5˚C.

Let TGij be daily mean temperature on day i in year j. Count the annual (1 January to 31 December in the Northern Hemisphere, 1 July to 30 June in the Southern Hemisphere) number of days between the first occurrence of at least 6 consecutive days where TGij> 5°C and the first occurrence after 1 July (1 January in the Southern Hemisphere) of at least 6 consecutive days when TGij <5°C.

6. **TXx (monthly maximum value of daily maximum temperature)**

Let TXik be the daily maximum temperature on day i in month k. The maximum daily maximum temperature is then TXx = max (TXik).

7. **TNx (monthly maximum value of daily minimum temperature)**

Let TNik be the daily minimum temperature on day i in month k. The maximum daily minimum temperature is then TNx = max (TNik).

8. TXn (monthly minimum value of daily maximum temperature)

Let TXik be the daily maximum temperature on day i in month k. The minimum daily maximum temperature is then TXn = min (TXik).

9. TNn (monthly minimum value of daily minimum temperature)

Let TNik be the daily minimum temperature on day i in month k. The minimum daily minimum temperature is then TNn = min (TNik).

10. TN10p (cold nights): number of days where TN <10th percentile

Let Tnij be the daily minimum temperature on day i in period j and let TNin10 be the calendar day 10th percentile of daily minimum temperature calculated for a five-day window centered on each calendar day in the base period n (1961-1990). Count the number of days where TNij <TNin10.

11. TX10p (cold day-times): count of days when TX <10th percentile

Let Txij be the daily maximum temperature on day i in period j and let TXin10 be the calendar day 10th percentile of daily minimum temperature calculated for a five-day window centered on each calendar day in the base period n (1961-1990). Count the number of days where TXij <TXin10.

12. TN90p (warm nights): number of days where TN> 90th percentile

Let TNij be the daily minimum temperature on day i in period j and let TNin90 be the calendar day 90th percentile of daily minimum temperature calculated for a five-day window centered on each calendar day in the base period n (1961-1990). Count the number of days when TNij> TNin90.

13. TX90p (warm day-times): count of days where TX> 90th percentile

Let Txij be the daily maximum temperature on day i in period j and let TXin90 be the calendar day 90th percentile of daily maximum temperature calculated for a five-day window centered on each calendar day in the base period n (1961-1990). Count the number of days when TXij> TXin90.

14. **WSDI (warm spell duration index):** count of days in a span of at least six days where TX> 90th percentile

Let TXij be the daily maximum temperature of day i in period j and let TXin90 be the calendar day 90th percentile of daily maximum temperature calculated for a five-day window centered on each calendar day in the base period n (1961-1990). Count the number of days where, in intervals of at least six consecutive days TXij> TXin90.

15. **CSDI (cold spell duration index):** count of days in a span of at least 6 days where TN > 10th percentile

Let Tnij be the daily minimum temperature of day i in period j and let TNin10 be the calendar day 10th percentile of daily minimum temperature calculated for a five-day window centered on each calendar day in the base period n (1961-1990). Count the number of days where, in intervals of at least 6 consecutive days TNij <TNin10.

16. **DTR (diurnal temperature range):** mean difference between TX and TN (°C)

Let TXij and Tnij be the daily maximum and minimum temperatures on day i in period j. If I represents the total number of days in j then the mean diurnal temperature range in period j DTRj = sum (TXij - TNij) / I.

Precipitation indices

17. **RX1 day (maximum one-day precipitation):** highest precipitation amount in one-day period.

Let RRij be the daily precipitation on day i in period j. The maximum one-day value for period j is RX1dayj = max (RRij).

18. **RX5day (maximum five-day precipitation):** highest precipitation amount in a five-day period

Let RRkj be precipitation amount for the five-day interval k in period j, where k is defined by the last day. The maximum five-day values for period j are RX5dayj = max (RRkj).

19. **SDII (simple daily intensity index):** mean precipitation amount on a wet day

Let RRij be the daily precipitation amount on a wet day w (RR ≥ 1 mm) in period j. If W represents the number of wet days in j, then the simple precipitation intensity index is SDIIj = sum (RRwj) / W.

20. **R10mm (heavy precipitation days):** count of days in which RR (daily precipitation amount) is ≥ 10 mm

Let RRij be the daily precipitation amount on day i in period j. Count the number of days where RRij ≥ 10 mm.

21. **R20mm (very heavy precipitation days):** count of days where RR ≥20 mm

Let RRij be the daily precipitation amount on day i in period j. Count the number of days where RRij ≥ 20 mm.

22. **Rnnmm (count of days where RR ≥ user-defined threshold in mm)**

Let RRij be the daily precipitation amount on day i in period j. Count the largest number of consecutive days where RRij ≥ nn mm.

23. **CDD (consecutive dry days):** maximum length of dry spell (RR <1 mm)

Let RRij be the daily precipitation amount on day i in period j. Count the largest number of consecutive days when RRij <1 mm.

24. **CWD (consecutive wet days)**: maximum length of wet spell (RR ≥ 1 mm)

Let RRij be the daily precipitation amount on day i in period j. Count the largest number of consecutive days where RRi ≥ 1 mm.

25. **R95pTOT (precipitation due to very wet days) (> 95th percentile)**

Let RRwj be the daily precipitation amount on a wet day w (RR ≥ 1 mm) in period j and let RRwn95 be the 95th percentile of precipitation on wet days in the base period n (1961-1990). Then R95pTOTj = sum (RRwj), where RRwj> RRwn95.

26. **R99pTOT: precipitation due to extremely wet days (> 99th percentile)**

Let RRwj be the daily precipitation amount on a wet day w (RR ≥ 1 mm) in period j and let RRwn99 be the 99th percentile of precipitation on wet days in the base period n (1961-1990). Then R99pTOTj = sum (RRwj), where RRwj> RRwn99.

27. **PRCPTOT: total precipitation in wet days (>1mm)**

Let RRwj be the daily precipitation amount on a wet day w (RR ≥ 1 mm) in period j. Then PRCPTOTj = sum (RRwj).