The European Union for Georgia
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EMBRACETsalka

CENN
Shaping the Future by Changing Today

CLIMATE CHANGE

IN TSALKA MUNICIPALITY

TBILISI 2021

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CONTENT

1. PAST AND CURRENT TRENDS OF CLIMATE CHANGE (IN 1960-2019)

1.1. Multiannual climatic characteristics

Tsalka municipality is an administrative-territorial unit located in the eastern part of Georgia, in Kvemo Kartli region. The area of the municipality is 1,050.6 km^2, population – 21 000, administrative center – the town of Tsakla. The municipality consists of 1 town, 2 small towns and 48 villages. The municipality is bordered by Borjomi, Gori and Kaspi municipalities to the north, Akhalkalaki municipality to the west, Ninotsminda and Dmanisi municipalities to the south and Tetritskaro municipality to the east. The territory of the municipality has a complex geomorphological structure. Orographic units of the first order include: the Samsari range, the Kavakheti range and the Tsakla depression. The south facing slope of the Trialeti range is also within the boundaries of the municipality. The sloping alluvial Trialeti foothill plain is stretched longitudinally in the northern part of the Tsakla hill. The Chochiani lava plateau, with is separated from the south-eastern part of the Tsalka depression with the Dashbash hill and is located mostly on the right side of the Khrami river is within the administrative boundaries of Tsalka municipality.

The territory of the municipality belongs to the moderate humid climate zone of the moderate humid subtropical continental climate region[1] with cold winters and long summers, two annual maximum precipitation values, while the part of the municipality is characterized by a climate transitional from moderate humid subtropical to dry mountain sub-region. Several climate zones can be distinguished within the sub-region. The Tsalka depression has a high mountain steppe climate with cold and dry winters and long and warm summers. Highland areas are characterized by a mountain steppe climate with short summers and cold and dry winters, while the Samsari, Javakheti and Trialeti ranges (the highest locations) have moderate dry high mountain climate almost without summers. Average annual precipitation in Tsalka municipality varies within 600-740 mm. The spatial distribution of precipitation depends on the shape of the terrain, therefore the change in the amount of precipitation along with elevations is almost unnoticeable. Maximum precipitation occurs in spring and early summer, minimum - in winter.

The territory has been characterized on the basis of the data of the Tsalka meteorological station which is located at 1457 m above sea level. The climate in the town of Tsalka in moderate humid with cold winter and long summer and two annual maximum precipitation values. Based on observation data of 1931-1960, the mean annual temperature in the municipality is +5.9°C, average temperature in the coldest month (January) is -4.8°C, and in the hottest months (July) +16.1°C, absolute minimum is -34°C, and absolute maximum +33°C. Average annual relative humidity is 74%, annual precipitation 653 mm. Maximum monthly precipitation generally occurs in May (119 mm), and minimum in December (18 mm). Average annual wind speed is 2.0 m/sec. Prevailing winds blow from north-west and west.

[1] http://drm.cenn.org/paper_atlas/RA-part-2.pdf

1.2. Database created as a result of observations and the methodology for evaluation of current changes

The trends of changes in temperatures and precipitation, as well as in wind speeds and relative air humidity have been assessed. For this purpose data from 1960-2019 were used. The database (temperature, precipitation, wind speed, relative humidity) has been created on the basis of processed observation data from the hydrometeorological network[2]. In the process of creating the database, the data quality control and assurance procedure that had been introduced at the National Hydrometeorological Services following the recommendations of the World Meteorological Organization was used[3].

Seasonal and annual values of the following variables were estimated to detect changes in current climate parameters of the study area:

- Air temperature;
- Amount of precipitation;
- Wind speed;
- Relative air humidity;
- Extreme/sectoral climate indices of air and precipitation;
- Drought indices (SPI – Standardized Precipitation Index, SPEI - Standardized Precipitation Evapotranspiration Index).

To increase the reliability of the obtained results, the time series of the mentioned variables were checked for consistency[4], band the changes were evaluated by two methods: for each variable, trends were identified for which statistical reliability was assessed (Mann-Kendall method[5]), and the mean values of two 30-year periods (1960-1989 and 1990-2019) were compared.

As the extreme values of climate variables are more sensitive to climate change than their mean values, various climate characteristics (indices) are used to assess climate change, the calculation methodology of which is developed according to the recommendations of the Expert Group (ET-SCI) of the World Meteorological Organization (WMO)[6]. The values of these indices are given in Annex 1 and attached tables.

Extreme climate and draught indices were calculated for the study meteorological station[7]. On the basis of these indices the patterns of daily maximum and minimum air temperatures, values, frequency and intensity of extreme precipitation and change in rainfall shortage have been determined.

The meteorological station in Tsalka has been operational in a mode of a meteorological post since 2007, i.e. the station carries out observations twice a day and not within standard periods – every three hours. Therefore, the data on maximum and minimum air temperatures and precipitation for this period are available. As for wind speed and humidity, the data are available only up to 2006. Hence, the changes in parameters have been discussed between 1960-1989 and 1990-2006 periods, and trends have been built for 1960-2006.

[2] LEPL National Environmental Agency, Ministry of Environmental Protection and Agriculture of Georgia
[3] Guide to Climatological Practices WMO-No. 100
[4] Albert M.G. Klein Tank, Francis W. Zwiers* and Xuebin Zhang, 2009: Guidelines on Analysis of extremes in a changing climate in support of informed decisions for adaptation. Climate Data and Monitoring. WCDMP-No. 72, WMO-TD No. 1500
[5] http://www.stats.uwo.ca/faculty/mcleod/2003/DBeirness/MannKendall.pdf
[6] http://www.wmo.int/pages/prog/wcp/ccl/opace/opace4/ET-SCI-4-1.php
[7] http://ulysses.atmos.colostate.edu/SPI.html;
https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-evapotranspiration-index-spei

1.3. Analysis of obtained results

1.3.1. Main climatic characteristics

The diagrams below (Fig. 1.3.1.1-5) show mean values of different climate parameters for the two 30-year periods.

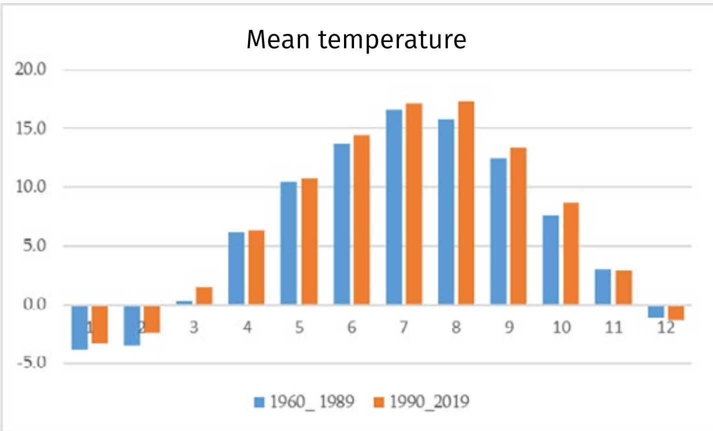
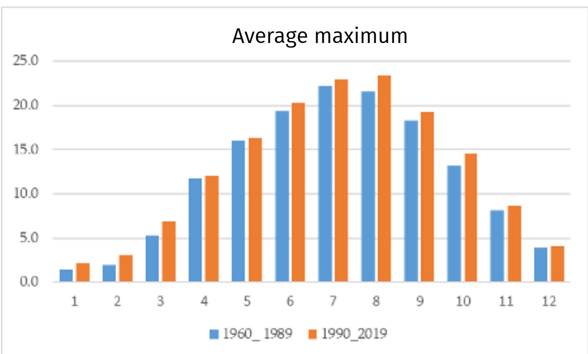


Fig. 1.3.1.1. Mean annual temperatures in the two 30-year periods (Tsalka, °C)

Mean temperature. The analysis of data shows that mean annual temperature in Tsalka between the two study periods has increased by +0.66°C and its current value is +7.1°C. Increase in temperature occurs in all seasons, however maximum increase in temperatures during the two 30-year period is recorded in summer. Fig. 1.3.1.1 shows that warming does not occur evenly during a year. The most intensive increase in temperature is recorded in February-March and August-October with the highest increment in August (+1.53°C), when mean monthly temperature reaches +17.3°C. Cooling occurs in November-December, however decrease in temperature is relatively insignificant and does not exceed 0.2°C. Currently temperature during the period in within -1.3°C, +2.9°C (see Annex 1, Table 1.1). In March and June-October warming is confirmed by linear trends. The warming is most noticeable in August when the trend slope is 0.47°C (i.e., the temperature rises by 0.47°C every 10 years) (see Table 1.3.1.1). Between the two periods the maximum of mean temperatures in an annual cycle has shifted from July to August.

Average maximum. Fig.1.3.1.2 shows that the growth rate of the annual value of this parameter between the two study periods was higher than that of other climate parameters. It has increased by +0.91°C and average annual maximum reached +12.8°C. Warming occurs mainly due to fall, and especially summer, when the difference between the two periods is +1.25°C. Currently average annual maximum temperature in summer is 22.3°C. Monthly change in temperature in positive and varies between +0.2 and +1.9°C (see Annex 1, Table 1.2). Largest deviations are recoded in March and August. Warming by this parameter is stable in all seasons which is confirmed by trends. The maximum rate of change is recorded in summer and makes +0.60°C in



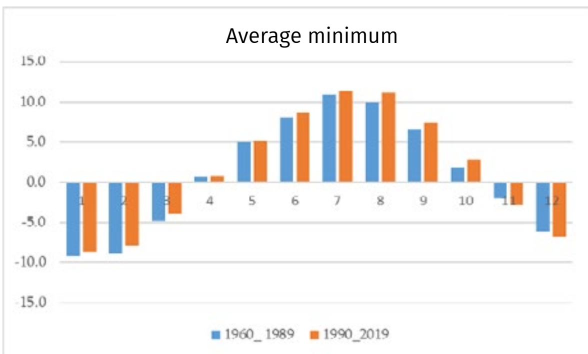


Fig. 1.3.1.2. Average maximum and minimum temperatures in the two 30-year periods by months (Tsalka, °C)

August. It seems, that increase in temperature in Tsalka is determined by increased temperatures during day time. Between the two periods the maximum of daily temperatures in an annual cycle has shifted from July to August (+22.2°C – July, 1960-1989, +23.5°C – August, 1990-2019).

Average minimum almost repeats the character of the average temperature change by months, although warming by this parameter is less intense. The difference in annual values between the two periods is up to 0.5°C (+1.4°C, 1990-2019), but exceeds 1°C in August. Currently the average minimum in August is +11.2°C (see Annex 1, Table 1.3). At the same time, the cooling trends are more pronounced in November-December, when the negative deviation between the two periods is almost one degree, and in 1990-2019 reaches -6.7°C, -2.9°C. The November cooling is also confirmed by trends (-0.270C/10y). It should be noted that this is the only stable decreasing trend in temperatures in the study area. As for the upward trends, as well as for the average temperature, they are certain for the summer months and early spring-fall, as well as for the average annual values (+0.190C/10y). The shift of maximum values in an annual cycle between the two periods is not observed. The warmest month by night temperatures is still July (+11.3°C), and the coldest - January (-8.7°C).

Absolute maximum. In certain months overlap of absolute maximums have been detected. The maximum positive deviation (+ 3.7°C) between the two periods was observed in March (see Annex 1, Table 1.4). Trends were revealed in the summer months, as well as in October. According to this parameter, the rate of warming is the highest in August (change rate 0.68°C/10y).

Absolute minimum. Despite the pronounced warming trends, the overlap of the absolute minimum by 2 degrees (i.e. cooling) compared to the previous period was observed in February and June. During the last 30-year period, the lowest minimum temperature (-33.4°C, February) was recorded, while in other months absolute minimums are increased by 1-3 degrees (see Annex 1, Table 1.5). The highest rates of warming are recorded in March. The linear trend steadily increases only in August (0.580C/10y, see Table 1.3.1.1). No other trends were detected during the year, indicating an unstable character of the change of this parameter.

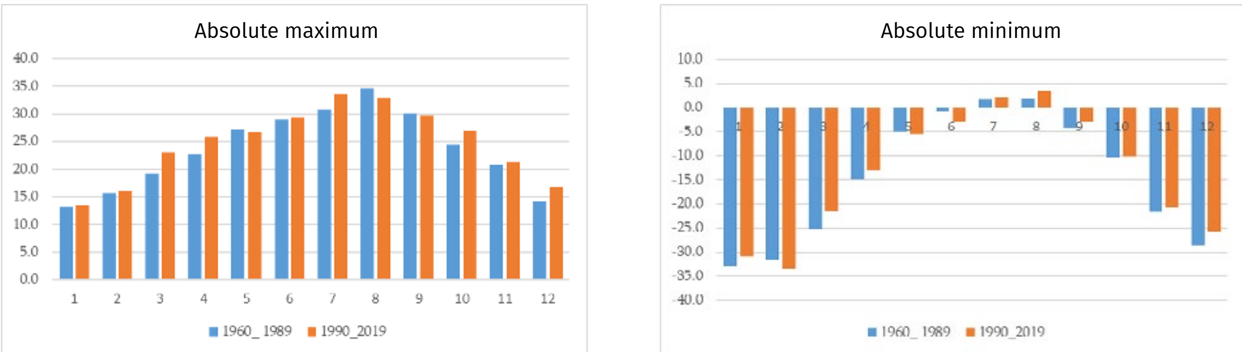


Fig. 1.3.1.3. Absolute maximum and minimum temperatures during the two 30-year periods by months (Tsalka, °C)

Average relative humidity. As indicated above, the measurements of ambient humidity had been carried out till 2006. Relative humidity between the two 1960-1989 and 1990-2006 periods by annual and seasonal values has decreased by 2-4% and currently is at 74-77% (see Annex 1, Table 1.25). The most significant decrease in humidity by months is observed in February-April. The largest negative deviation (-5.6%) is recorded in March (72.6%, 1990-2019). In addition to this period, this trend has been also detected in the early summer and fall. The changes are characteristic also to average annual values. The highest rate of decrease in humidity is observed in March (-1.8%/10 years), while the trend slopes are almost equal and amount to 1-1.5% in 10 years (see Table 1.3.1.1). The highest humidity in an annual cycle of the both periods is recorded in October (78.6%), while the driest month is shifted from January (75.1%, 1960-1989) to February (72.3%, 1990-2019).

Extreme values of humidity (wet and dry days). To evaluate the change in the extreme values of humidity, a so-called number of wet/humid (relative humidity in afternoon ≥80%, Rh80) and dry (minimum relative humidity ≤30%, Rh30) days was selected.

Against the background of the decrease in relative humidity, the number of wet days between the two periods has decreased by 1-3 days per month, which leads to a decrease of such days to 20 days per year and currently is 56 days. At the same time, the decreasing trends are certain and confirmed for annual values (5 days/10y), while they are most prominent in early spring-fall. No significant changes are observed in the annual cycle. In both the first and second 30-year periods, the maximum number of wet days per year (7-9 days) is recorded in late spring (May) and the minimum (3-4 days) - in July.

As for the extremely dry days, their number is increasing almost all year round, except January. The annual increase between the two periods is 9 days in average, while the annual increase corresponds to 19 days. The increase is most prominent in April and November (it has increased in the both periods, from 1 to 3 days in the second period). Positive trends are characteristic to transitional seasonal and annual values, when the rate of change is 3 days/10y. Maximums in an annual cycle have been shifted. If during the first period the highest recurrence rates of of such days (1.2 days, 1960-1989) was observed in October, in the second period the dry days are most often observed in November (3.2 days, 1990-2019).

The analysis of humidity extremes confirms the revealed patterns of change in average relative humidity.

Total annual precipitation during recent 60 years period has decreased. The difference between two periods indicates 8% (60 mm) decrease and currently total annual precipitation is 649 mm (see Annex 1, Table 1.14). A decreasing trend is shown in the change of precipitation all year round, except for April, while the largest negative deviations between the two periods are observed in July (-31%, 24mm), as confirmed by a linear trend (-6.67mm/10y). Changes in other months are not certain (see Table 1.3.1.1), and deviations range within ± 20% (-15 mm, + 5 mm). At the same time, in the period from July to November, the amount of precipitation decreases in each month. Consequently, the seasonal sums of precipitation are also reduced and precipitation decreases by 5-15% (10-35 mm) in all seasons, except winter. Both maximums and minimums are shifted in an annual cycle. In particular, in the first period the highest and lowest precipitation occurred in May (124 mm) and January (22 mm), while in the second period the wettest month is June (118 mm), and the driest - December (23 mm).

As for the **maximum 1-day precipitation and maximum 5-days precipitation,** in certain months of the second 30-year period months, the exceedance of both indices up to 15-20 mm are observed (see Annex 1, Tables 1.21-1.22). In June of the second period, an all-time high daily maximum (69 mm) was recorded, although the change trends for the both parameters are mostly negative. Increasing trends are recorded only in June and for 1-day maximums in November. Stable negative trends are detected in summer: in August for 5-days maximums, in July for both indices, when the trend slope is -1.7 and -3.4 mm in 10 years for 1-day and 5-days maximums respectively (see Table 1.3.1.1). 1-day maximums in an annual cycle are shifted (from August to June) and the maximum values of both indices (69mm, 100mm) are recorded in June.

Average wind speed between 1960-1989 and 1990-2006 two periods has been decreased for all seasons and months, by 0.3-1.1 m/sec in average and currently varies between 0.7-1.2 m/sec (see Annex 1, Table 1.26). Downward trends of wind speed in all months and seasons are stable. The linear trend slope, as well as the deviation between the two periods, is greatest in winter, especially in December, and is -0.33 m/sec/10y. The slope of the average annual trend is smaller (-0.20 m/sec/10y, See Table 1.3.1.1).

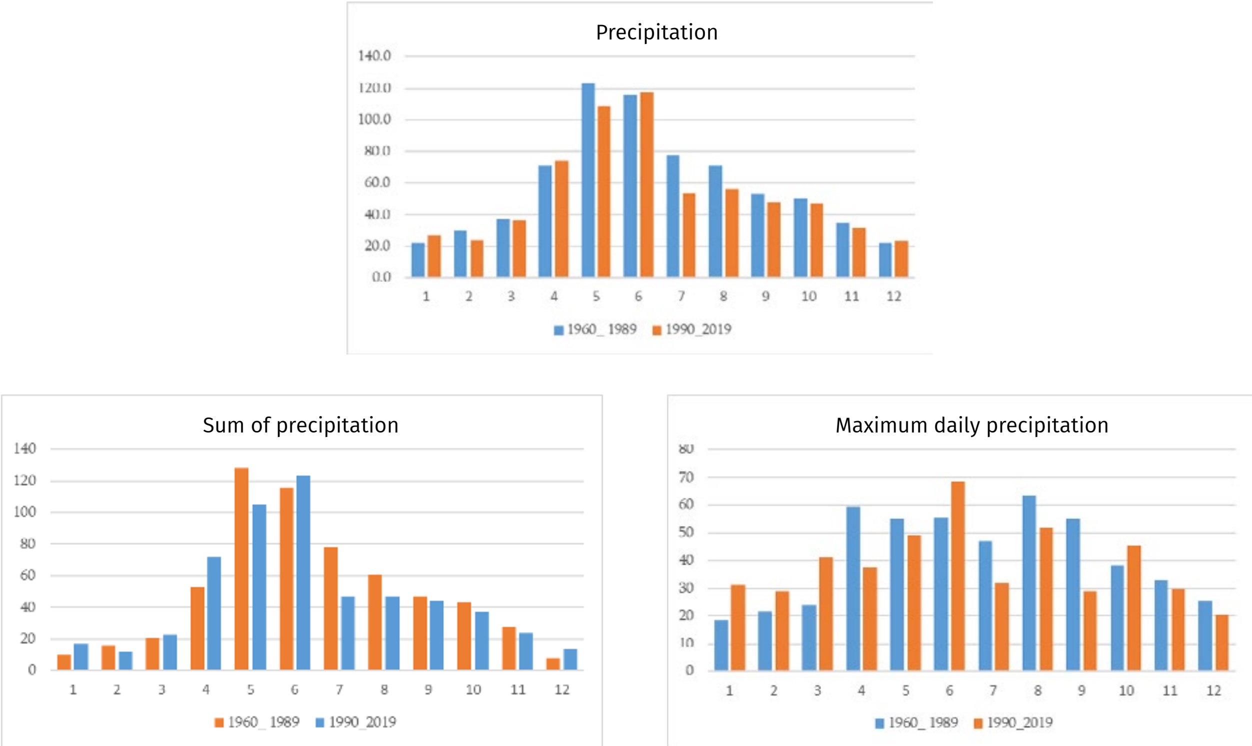


Fig. 1.3.1.4. Sum of precipitation and maximum daily precipitation in two 30-year periods by months (Tsalka, mm)

Number of strong[8] and extremely strong[9] windy days. As data on maximum wind speeds are available only from 1970, trends for the analysis of changes in the number of strong windy days have been built for 1970-2006, and the data from the 17-year period of 1990-2006 have been compared with those of the 20-year period of 1970-1989. It has been found that, despite the decrease in the average wind speeds, the linear trends corresponding to both characteristics of this parameter indicate increased frequency of such days in Tsalka municipality. The increase in number of strong windy days (Wg15) is observed almost all year round and currently the number of such days is 13 in average. The exceptions are January-February and July. The rate of growth is highest at the end of spring – in May (19 days in total). Extreme winds (Wg25) occur most frequently in March (3 days in total) and currently occur once every 2 years in average. Positive linear trends are identified only for strong winds - in May and November, while the seasonal number of such days steadily increases in spring (1.25 days/10y, see Table 1.3.1.1). The highest recurrence of such days in an annual cycle is observed in the second period, in March, in contrast to the first period, when the occurrence of strong- and extremely strong winds was highest in January. It shall be also be noted that annual distribution of such days is relatively even in the second period.

[8] Maximum wind speed ≥15 m/sec (Wg15)
[9] Maximum wind speed ≥25 m/sec (Wg25)

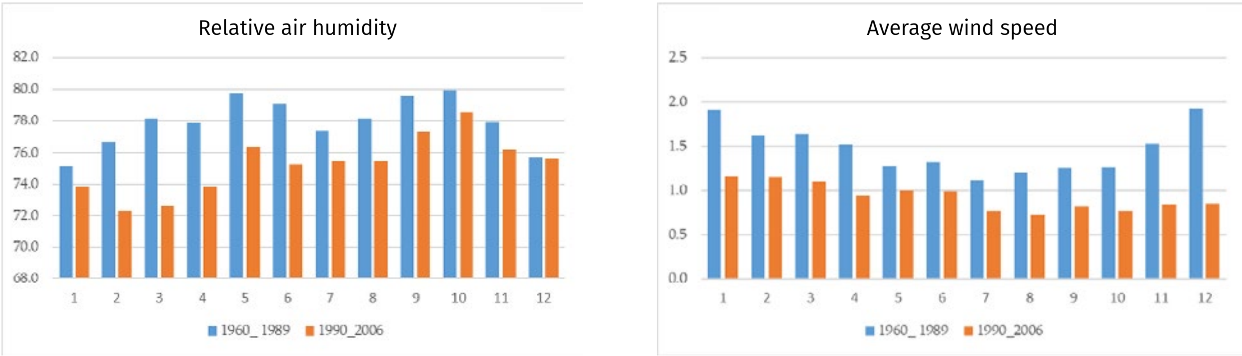


Fig. 1.3.1.5 Relative air humidity and average wind speed in the two periods by months (Tsalka, %, m/sec)

Table. 1.3.1.1. Rates of change in climatic parameters and extreme climate indices (value/10 years) in Tsalka (if trends are available)

#	Parameter	January	February	March	April	May	June	July	August	September	October	November	December	Winter	Spring	Summer	Fall	Year
1	Tmm	NA*	NA	0.405	NA	NA	0.294	0.258	0.470	0.305	0.292	NA	NA	NA	0.196	0.356	0.180	0.255
2	Txm	NA	NA	0.508	NA	NA	0.338	0.308	0.598	0.383	NA	NA	NA	0.273	0.261	0.446	0.242	0.299
3	Tnm	NA	NA	0.310	NA	NA	0.221	0.238	0.324	0.209	0.304	-0.270	NA	NA	NA	0.262	0.069	0.193
4	Txx	NA	NA	NA	NA	NA	0.313	0.295	0.682	NA	0.464	NA	NA	NA	NA	0.474		0.444
5	Tnn	NA	NA	NA	NA	NA	NA	NA	0.577	NA	NA	NA	NA	NA	NA	0.275	NA	NA
6	Tmge10	NA	NA	NA	NA	NA	NA	NA	NA	0.625	1.000	NA	NA	NA	NA	0.000	1.614	2.500
7	Tmlt10	NA	NA	NA	NA	NA	NA	NA	NA	-0.625	-1.000	NA	NA	NA	NA	0.000	-1.614	-2.500
8	Tx90p	NA	NA	2.389	NA	NA	1.688	NA	4.877	1.948	1.313	NA	NA	NA	1.512	2.970	1.087	1.950
9	Tx10p	NA	NA	NA	NA	NA	-1.812	NA	-1.051	-1.235		NA	NA	NA	NA	-1.354	NA	-0.785
10	Tn90p	NA	NA	NA	NA	1.643	2.753	3.072	2.276	2.954	NA	NA	NA	NA	1.326	2.756	1.460	1.583
11	Tn10p	NA	NA	NA	NA	NA	NA	NA	-1.744	NA	NA	1.313	NA	NA	NA	-1.152	NA	NA
12	FD	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.769	NA	NA	NA	NA	NA	NA
13	GSL	_**	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	NA
14	Gddgrow10	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	44.74
15	Hddheat18	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-85.00
16	Cddcold18	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	6.32
17	WSDI	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	1.90
18	CSDI	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	NA
19	HWN	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	0.45
20	HWD	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	1.11
21	CWN	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	NA
22	CWD	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	NA
23	PRCPTOT	NA	NA	NA	NA	NA	NA	-6.66	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

* No trend is observed

** Index cannot be calculated by months/seasons

24	R95ptot	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	NA
25	R99ptot	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	NA
26	R95p	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	NA
27	R99p	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	NA
28	R10mm	NA	NA	NA	NA	NA	NA	-0.25	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
29	R30mm	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
30	R50mm	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
31	Rx1day	NA	NA	NA	NA	NA	NA	-1.69	NA	NA	NA	NA	NA	NA	-1.45	NA	NA	NA
32	Rx5day	NA	NA	NA	NA	NA	NA	-3.41	-3.10	NA	NA	NA	NA	NA	NA	NA	NA	NA
33	CDD	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
34	CWD	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
35	RH	NA	-1.52	-1.76	-1.54	NA	-1.30	NA	NA	-1.03	NA	NA	NA	NA	-1.43	-0.95	NA	NA
36	RH30	NA	NA	NA	0.48	NA	NA	NA	NA	0.00	NA	NA	NA	NA	1.21	NA	0.78	3.00
37	RH80	NA	-0.63	-0.83	NA	NA	NA	NA	NA	-0.67	NA	NA	NA	NA	-1.74	NA	-1.59	-5.00
38	WS	-0.27	-0.21	-0.27	-0.21	-0.15	-0.11	-0.11	-0.20	-0.18	-0.20	-0.24	-0.33	-0.28	-0.22	-0.14	-0.20	-0.20
39	Wg15	NA	NA	NA	NA	0.00	NA	NA	NA	NA	NA	0.00	NA	NA	1.25	NA	NA	NA
40	Wg25	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Tmm - mean air temperature, °C
Txm - average maximum air temperature, °C
Tnm - average minimum air temperature, °C
Txx - absolute maximum air temperature, °C
Tnn - absolute minimum air temperature, °C
Tmge10 - number of days when mean air temperature is lot less than 10°C day
Tmlt10 - number of days when mean air temperature does not exceed 10°C day
Tx90p - percentage of hot days (TX>90), %
Tx10p - percentage of cold days (TX<10), %
Tn90p - percentage of warm nights (TN>90), %
Tn10p - percentage of cold nights (TN<10), %
FD - percentage of frosty nights (TN<0°C), day
GSL - growing season length (TM>5°C), day
Gddgrow10 - sum of active temperatures (TM>10°C), degree-day
R99p - sum of precipitation of extremely wet days (daily precipitation>99), mm
R10mm - number of wet days (daily precipitation≥10 mm), day
R30mm - number of wet days (daily precipitation ≥30 mm), day
R50mm - number of wet days (daily precipitation ≥50 mm), day
Rx1day - maximum 1-day precipitation, mm
Rx5day - maximum 5-days precipitation, mm
CDD - number of consecutive dry days, day
CWD - number of consecutive wet days, day
RH - relative ambient humidity, %
RH30 - number of days when relative humidity in the afternoon is less than 80%, day
RH80 - number of days when minimum relative humidity does not exceed 30%, day
WS - average wind speed, m/sec
Wg15 - number of strong windy days (maximum wind speed ≥15m/sec), day
Wg25 - number of extremely strong windy days (maximum wind speed ≥25 m/sec), day
Hddheat18 - heating degree day (TM<18°C), degree-day
Cddcold18 - cooling degree day (TM>18°C), degree-day
WSDI - warm spell duration index, day
CSDI - cold spell duration index, day
HWN - heat wave number, occurrence
HWD - heat wave duration, day
CWN - cold wave number, occurrence
CWD - cold wave duration, day
PRCPTOT - sum of precipitation, mm
R95ptot - percentage of wet days (100* R95p/sum of precipitation),%
R99ptot - percentage of extremely wet days (100* R99p/ sum of precipitation),%
R95p - sum of precipitation in extremely wet days (daily precipitation>95), mm

1.3.2. Seasonal changes

ხBased on data from the last 30 years, **winter** in the study area currently is milder than in the previous 30 years. However, the change in temperature regime compared to other seasons is not noticeable, as the warming trends observed in January-February are partially offset by the cooling in December (-0.20°C). The average increase in winter temperature is 0.5°C and currently the winter temperature is -2.3°C. Warming is more pronounced at the end of winter, in February (+1.04°C). The analysis of temperature parameters shows that winter warming occurs mainly due to increased daytime temperatures. The increase between the two periods for the average maximum temperatures is + 0.66°C (+3.1°C, 1990-2019), while the average minimums for this season have increased relatively slightly (+0.31°C) and for the second 30-year period equals -7.8°C. It seems that the decrease in night temperatures occurs due to the cooling trend in December, when the deviation between the two periods by this parameter reaches -0.66°C (-6.7°C, 1990-2019). Daily extreme temperatures have increased. In the second period, the exceedance of the absolute maximum by almost 3 degrees in December (+16.8°C) was observed. At the same time, in February, absolute minimum was overlapped (-1.7°C) when the lowest minimum temperature (-33.4°C, February) was recorded. Extreme temperature indices also confirm the winter warming. As the analysis of the indices show, winter warming occurs mainly due to the decrease in the percentage of cold days (Tx10p) and the increase in the number of warm days (Tx90p) (by 2-3% in average). The seasonal number of cold nights (Tn10p) has decreased, however the recurrence of warm nights (Tn90p) is decreasing too, which occurs mainly in early winter (December, -3%). The increased frequency (+5%) of frosty nights (FD) is observed in December. It shall be noted that the character of the change in temperature parameters described above during the winter season is statistically uncertain; the only stable trend was identified for average maximums (+0.27°C/10, see Table 1.3.1.1). Decrease in the number and duration of cold waves in the study area also indicated winter warming.

Seasonal sums of winter precipitation between the two 30-year periods have not changed and equal to 75 mm. The changes are not evenly distributed by months. The increase in precipitation in December (1 mm, + 4%) and especially in January (5 mm, + 21%) is offset by the trend of decreasing precipitation in late winter (February 19 mm, -6%). However, linear trends for both monthly and seasonal sums have a negative sign, indicating an unstable character of the changes. The analysis of indices show the cases of exceedance of 1-day and 5-day maximums (Rx1day, Rx5day) during winter of the second period. The seasonal number of days with more than 10 and 30 mm precipitation (R10, R30) is increased too. The changes in the precipitation of this season are not sustainable confirmed by the trend for any of the characteristics.

Against this background, there is an average 2% decrease in relative humidity (74%, 1990-2019) and a steady decrease in average wind speed (-0.28 m/sec/10y). The seasonal number of strong windy days also decreases, i.e., the winter in Tsalka became relatively warm, less humid and windy. Cold and frosty nights occur frequently at the beginning of the season.

Warming is more pronounced in **spring** than in winter. The average temperature increase exceeds 0.5°C (+6.2°C, 1990-2019) and, in contrast to winter, is confirmed by the linear trend (+0.20°C/10y, see Table 1.3.1.1). In this season warming occurs due to increase in maximums. The average maximum increase between the two periods is +0.75°C (+11.8°C, 1990-2019), while the increase of the average minimum is relatively insignificant (+ 0.36°C) and its average seasonal value in the second period equals to +0.6°C. The changes are certain only for the maximum temperatures the rate of change of which is +0.26°C/10y. Warming during the season is most pronounced in March, when the growth trends for all average temperatures are stable, and deviations between the two periods for the average night and day temperatures are +0.85°C and +1.59°C, respectively (see Annex 1, Tables 1.2-1.3).

As for temperature extremes, no overlaps of the absolute maximum were observed in March (+ 3.7°C) of the second period when the the highest monthly temperature + 23°C was recorded, although exceedance of the seasonal maximums did not occur during this season. The percentage of warm days and nights (Tx90p, Tn90p) increases seasonally (+5%) with approximately uniformly increasing trends. The increase in the number of days with temperatures above 10°C (Tmge10, +9%), the number of which has recently reached 25 days in average in noteworthy. The number of cold days (Tx10p) decreases at a relatively slow rate (-2%), while the recurrence of cold nights (Tx10p) increases in May and especially in April (+3). At the same time, the risk of spring frosts increases in April-May, as evidenced by the increase in frosty nights (FD, faily minimum Tmin <00C), especially in late spring, by almost 40% compared to the previous period (54 days in total, 1990-2019).

Decrease in precipitation during spring is indicated by all mean and extreme indices. The seasonal sum decreases by 5% and amounts to 219 mm. In the second period the seasonal number of days with low and heavy precipitation decreases (R10, R30), and the days with more than 50 mm of rainfall are no longer observed (see Annex 1, Tables 1.19-1.20). Dry periods are prolonged, daily maximum precipitation is decreased. A downward trend (-1.45 mm/10y) is revealed for 1-day maximums. No other stable trends for precipitation indices are observed during this season. As in winter, changes in precipitation during spring are not distributed evenly by the months. In particular, a slight increase in precipitation (+ 5%, 3 mm) is observed in April between the two periods, although the linear trend has a negative sign, indicating an uncertain character of the change.

Relative humidity (-1.4%/10y) decreases in spring with a stable trend against the background of decreased precipitation. The current seasonal average humidity is 74%. The deviation between the two periods is greatest in March (-5.6%). Trends were identified also for the number of dry and wet days. Dry days are more frequent throughout the spring, especially in April (2 days in average), while the recurrence of wet days decreases during the second 30-year period, especially in March (3 days in average).

As in other seasons, the average wind speed in spring shows a significant decrease (-0.22 m/sec/1y) and currently is 1 m/sec in average, while the maximum winds are characterized by upward trends. The number of days with both strong and extreme winds has almost doubled. The frequency of such days is highest in March and May. For example, during the first period, extreme wind was reported in Tsalka only once in spring, while during the second period (before 2006) – 6 times.

That is, spring became warmer and drier, with more frequent windy days. It should also be noted that the change in temperature regime is contradictory: increase in the recurrence of warm days and frosty nights occur at the same time.

The average **summer** temperature between the two periods has increased by almost 1°C and currently is +16.3°C. The slope of the relevant trend is + 0.36°C/10 sec. Both maximums (+1.25°C) and minimums (+0.71° C) are increased. The warming is most pronounced in August, when the increase in daily temperatures reaches almost 2°C and the average maximum is +23.5°C. All trends in average temperatures are stable both by seasons and months. The rate of change of average maximums is highest in August (+0.60°C/10y). The number of hot summer days and warm nights (Tx90p, Tn90p) has significantly increased (8-9% per season in average), while the percentage of cool days and cold nights (Tx10p, Tn10p) decreased by 3-5% in average. Relevant trends are stable for the seasonal values and August. Unlike other seasons, the upward trend for all indices of night temperatures in summer was revealed, i.e., in the summer season all indicators of warming are present in Tsalka. Changes in absolute maximums (+0.47°C /10y) and minimums (+0.27°C/10y) are evidenced by stable trends (see Table 1.3.1.1). During the second period, the overlap of temperature extremes in both directions are observed. In particular, in July there was a case of exceedance of the maximum of the previous period (+2.8°C), when the highest temperature for the last 30 years (+33.6°C) was recorded. At the same time, the overlap of the absolute minimum (-2.1°C) was observed when the temperature dropped to -3°C. However, frosty nights are also observed in June (FD, see Annex 1, Table 1.11). Likely, the number and duration of heat waves (HWN, HWD) will increase during the summer season.

The seasonal sum of precipitation decreases by 14% (228 mm, 1990-2019), which is the largest between the seasons, and the deviation between the two periods in July-August reaches 20-30%. Almost all extreme precipitation indices indicate decrease in precipitation. The exception is the increase in daily maximums (+5 mm), although the corresponding linear trend is steadily declining. Dry periods are prolonged. Thus, prolonged droughts pose risk in summer on the background of warming. Changes in precipitation regime during this season are uncertain and not confirmed by trends.

Relative humidity decreases steadily both in spring and summer (-0.95%/10y). In the second period (before 2006) the average humidity for this season is 75%. The number of wet days is decreased in every month, while an increase in the frequency of dry days is observed in August.

Average wind speed decreases with a noticeable trend in summer (-0.14 m/sec/10y), however the frequency of strong winds (Wg15) increases in June and August.

That is, summer became noticeably hot and relatively dry. The duration of heat waves steadily increased (HWN, +1.1 days/10yr, See Table 1.3.1.1), increasing the risk of droughts.

Warming in **fall** also occurs mainly due to increasing maximums (+0.98°C), while the difference in the average minimum and average seasonal temperatures between the two periods is relatively small making +0.28°C, +0.63°C (see Annex 1, Tables 1.1-1.3). Accordingly, the average temperature values for this season range from +2.5°C to +14.2°C. As in summer, the percentage of warm days and nights (Tx90p, Tn90p) has increased significantly (6-8% per season in average), including the number of days with temperatures above 10°C (Tmge10).

The increase of such days exceeds 50% in October and recently reached 38 in average per season. Relevant trends are stable by seasonal values and months except for November. The character of the temperature change during a season considerably varies by months. Significant warming in September-October (within about 1°C) is followed by November cooling, which is especially evident for minimum temperatures when the decrease in temperature between the two periods reaches -0.87°C (-2.9°C, 1990-2019). November cooling is stable and confirmed by the trend (-0.270C/10y). The analysis of temperature indices shows that the decrease in temperature is associated with a significant increase in number of cold and frosty nights (FD) in November.

In fall, as well as in summer, almost all characteristics of precipitation are decreased. Between the two periods the decrease in seasonal precipitation (11 mm, -8%) is observed. The seasonal sum of precipitation for the current period is 127 mm. The rate of decrease in precipitation almost similar in all months. The seasonal number of wet days is decreased by 11% in average, while the increase in frequency of days with hight precipitation is not observed. The average duration of consecutive wet days (CWDs) also decreases in every month, especially in September. All extreme precipitation indices indicate a decrease in precipitation in this season, although the changes are not significant and confirmed by trends.

In the fall, relative humidity between the two 30-year periods has decreased by almost 2% (77%, 1990-2019), which is predominantly determined by the decrease in the recurrence of extremely wet days (by 6 days in average) during this season. Trends confirm both an increase in dry days and a decrease in the seasonal number of wet days, although the rate of change for wet days is almost twice as high (-1.60 days/10y).

In fall, the average wind speed steadily decreases (-0.20 m/sec/10y), maximum wind speed increases too, which is reflected in the increase in the number of strong winds (Wg15), especially in November.

That is, fall became warmer and relatively dry, with more frequent windy days mainly due to its first half. The frequency of hot days and warm nights (Tx90p, Tn90p) is increased at the beginning of the season. As a result, the sum of active temperatures increased by 135 degree-days in average (GddGrow10, see Table 1.3.4.1). At the end of the season the increase in the number of cold (Tn90p) and frosty nights (FD) is recorded.

1.3.3. Extreme events

Mudflow and landslide processes. The analysis of precipitation indices shows the decrease in almost all extreme indices according to both deviations and linear trends between the two periods. In the second period, the exceedance of the maximum daily precipitation (Rx1day) was reported, however the corresponding trend has a negative sign. The percentage of days with heavy and extremely heavy precipitation (R95ptot, R99ptot) and the amount of precipitation on these days (R95p, R99p, 20-30%) are reduced (by 2-3%) in the annual sum of precipitation.

This region is not characterized by high precipitation. As for the number of days when mudflows may occur, the days with more than 90 mm of rainfall have not been recorded in Tsalka in the last 60 years, while the number of days with more than 50 mm of rainfall has decreased by 40% (by 0.1 days per year in average).

Table. 1.3.3.1. Changes in precipitation triggering mudflows and landslides, Tsalka

Mudflow and landslide processes	Sum of daily precipitation > 50 mm	Sum of daily precipitation > mm	The cases of exceedance of annual sum of precipitation by 200 mm and more
Change in number of events	-3	NA	+1

ეIt means that in this area, which belongs to the zone with limited and low susceptibility to mudflow and landslide processes, the risk of landslides is further reduced. At the same time, the cases of exceedance of the annual precipitation by 200 mm and more, which is a criterion for landslide processes, have been reported seven times during the entire study period, including four times during the second period. Therefore, the risk of landslides is low.

Heat waves. A heat wave in the context of health is treated as a period with sustained heat load or excessively hot weather, which leads to heat-related health damaging with one or several outcomes, including mortality, morbidity and severe health problems[10].

[10] According to the definition provided by the National Oceanic and Atmospheric Administration (NOAA), heat wave is “a period of abnormally and uncomfortably hot and unusually humid weather. Typically a heat wave lasts two or more days (http://w1.weather.gov/glossary/index.php?letter=h)“. Based on this definition, a general definition of heat waves can be harly introduced due to their variability in terms of geography and impacts that depends on local climate of specific region and the ability of the population to acclimatize.

Recently, the study of heat waves has gained increased attention due to their potentially devastating socio-economic effects. Major impacts are expected on public health, energy supply, water availability, agriculture, forestry and ecosystems, etc.

To date, there have been no quantitative indicators of heat waves that could have been used for different climatic zones. Recently the Expert Team on Climate Risk and Sector-Specific Climate Indices of the Commission for Climatology of WMO (WMO CCl ET-CRSCI, http://www.wmo.int/pages/prog/wcp/ccl/opace/opace4/ET-SCI-4-1.php) ðproposed new quantitative indices for heat waves (number of heat waves (HWN), duration (HWD), frequency (HWF), amplitude (HWA), average magnitude (HWM)) and software for their calculation (ClimPactv2, www.wmo.int/.../ETCRSCI_software_documentation_v2).

This methodology is based on several definitions of heat waves and their characteristics:

Heat wave - At least three day period when the combined effect of excess heat and heat stress is unusual for local climatic conditions.

Excess heat - unusually high heat that is insufficiently neutralized during the night due to unusually high temperatures. The three day average of maximum and minimum temperatures are compared with the basic (normative) climatic values.

Heat stress - a period with temperatures that exceed the temperatures of the previous period. A three day average of maximum and minimum temperatures correspond to the average values of the last 30 days.

Threshold temperatures for the occurrence of heat waves have been calculated for the study area (see Table 1.3.3.2). Also, the trends of change in the number of heat waves (HWN), duration (HWD), frequency (HWF), amplitude (HWA) and average magnitude (HWM) based on the data of the Tsalka meteorological station for 1960-1989 and 1990-2019 have been evaluated. For the period (see Table 1.3.3.3).

Table. 1.3.3.2. Threshold temperatures for the occurrence of heat waves, Tsalka

Month	Temperature, ^{0}C		
	1960-1989	**1990-2019**	**Change**
May	22.1	19.5	-2.6
June	24.7	25.7	1.0
July	27.1	28.0	0.9
August	26.1	28.2	2.1
September	24.8	26.6	1.8

Table. 1.3.3.3. Number and duration of heat waves in different periods, Tsalka

Period	Average number of heat waves (HWN)	Average duration of heat waves (HWD)	Maximum duration of heat waves (HWD)
1960-1989	1.9	4.4	14
1990-2019	3.3	8.8	38
Change	1.4	4.4	24

According to the obtained results, the threshold temperatures for the occurrence of heat waves in Tsalka in the warm period (May-September), especially at the end of the period, are shifted towards growth by 1.0-2.0 degree. Against the background of the detected warming, both the average and maximum duration of heat waves (HWD) and the average and number of heat waves have increased (HWN).

Excess heat factor (EHF) - an index providing a comparative measure of intensity, load, duration and spatial distribution of a heatwave event and describing a combined effect of excessive heat and heat stress

According to this methodology, the heat wave intensity categories are estimated based on the Excess Heat Factor (EHF) and a severe heat wave is defined as an event when the EHF exceeds a certain threshold depending on the climatic conditions of the area, and an extreme heat wave – as an event when the EHF is twice as much as a threshold value of the heat wave, causing more severe negative impacts.

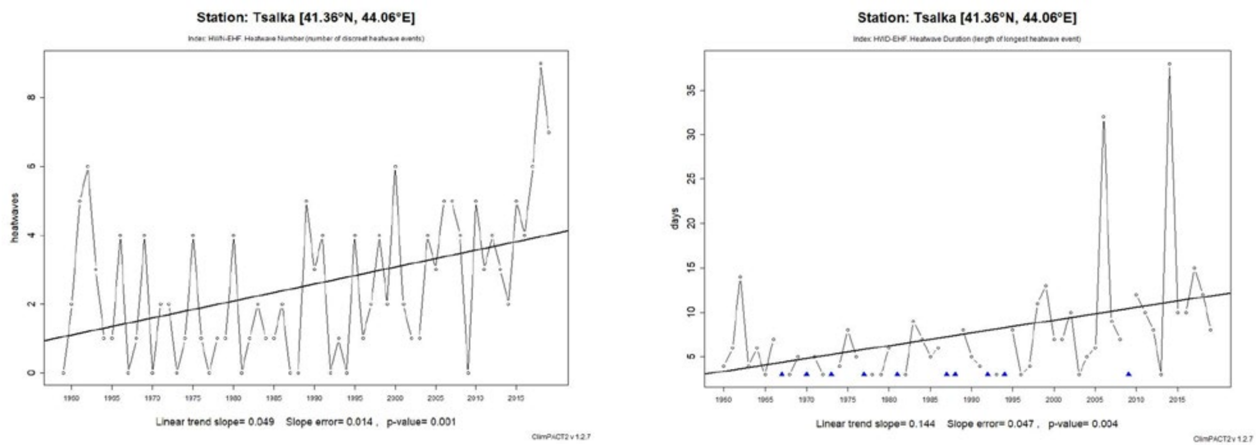


Fig. 1.3.3.1. Dynamics of the number and duration of heat waves in 1960-2019, Tsa

It shall be noted that the upward trend of change in all characteristics of heat waves (quantity, frequency, duration) is stable and confirmed by trends. For example, the frequency of heat waves (HWF) is characterized by a reliable upward trend with 4.0 day/10y rate of change. In addition, the analysis of data of 1960-2019 for Tsalka shows the decrease of magnitude (severity) of heat waves along with a significant increase in their duration and frequency, indicating the increased frequency of longer, but less severe heat waves. The Figure 1.3.3.1 shows the dynamics of the number and duration of heat waves in 1960-2019 in Tsalka.

1.3.4. Agro-climatic indices

3From the climatic parameters, the most important for the agricultural sector are air temperature, precipitation, number of frosty days and their seasonal distribution, the analysis of which is given in Chapter 3. In addition to these parameters, the growing season length[11] and the sum of active temperatures[12] are also important for agricultural crops.

Table. 1.3.4.1. Average length of growing season (>5°C; <5°C) and the sum of active temperatures (>10°C; <10°C). Ts

Period	Growing season length (GSL)	Sum of active temperatures, above 10°C (GddGrow)
1960-1989	213.2	637.0
1990-2019	214.4	771.8
Change	1.2	134.8

[11] **Growing season length (GSL)** is calculated as the number of days during the year between the dates of a steady transition of the average daily air temperature above and below the baseline threshold temperature
[12] **Sum of active temperatures (GddGrow)** is defined as the average daily air temperature above the baseline threshold limit temperature accumulated daily over a period of time.

Table 1.3.4.1 shows the mentioned climatic indices for Tsalka. The results show, that the sums of active temperatures (above 10°C) are significantly increased. The changes are stable and confirmed by an upward trend with 45°C day/10y rate of change. Between the two 30-year periods, the growing season length has increased by 1.2 days (> 5°C; <5°C) in average, however the changes are not stable (Fig. 1.3.4.1).

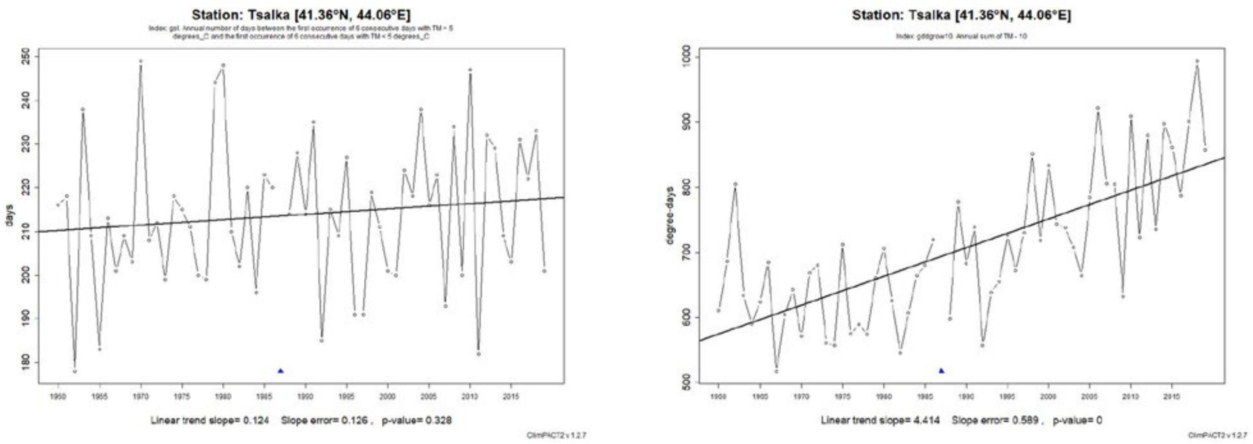


Fig. 1.3.4.1. Dynamics of growing season lengths and sums of active temperatures in 1960-2019, Tsalka

Thus, it can be concluded that the problem of heat required for agricultural crops will not arise in Tsalka municipality, however, the risk of frosting increases and the problem of the spread of pests and diseases may aggravate.

Drought has assessed using Standardized Precipitation and Standardized Precipitation Evapotranspiration Indices (SPI/SPEI).

The study presents the results calculated for 3-, 6-, 12-month time scales on the basis of SPI/SPEI index. Drought categories are defined according to the SPI/SPEI values given in the Table below.

Drought categories by SPI/SPEI

Factor	Category
+2.0 and higher	Extremely wet
from +1.5 to +1.99	Severely wet
from +1.0 to +1.49	Moderately wet
from -0.99 to +0.99	Near normal
from -1.0 to -1.49	Moderately dry
from -1.5 to -1.99	Severely dry
-2.0 and lower	Extremely dry

Also, using SPI/SPEI the information about the impact of drought according to the drought characteristics: severity, duration, time interval and intensity can be obtained[13].

The tables below show the changes in the incidence, duration, magnitude and intensity of droughts calculated on the basis of values of these indices for different time scales between the two periods. The Table 1.3.4.3 incudes the total number of months when drought of different severity have occurred by periods.

Table. 1.3.4.2. Drought characteristics of different time scales, Tsalka

Drought	Period	SPI			SPEI		
		3-month	6-month	12- month	3-month	6-month	12-month
Average number	1960-1989	33	17	10	34	21	12
	1990-2019	37	32	17	46	34	22
	Change	4	15	7	12	13	10
Average magnitude	1960-1989	1.73	3.18	5.10	1.82	2.67	5.00
	1990-2019	2.11	2.63	5.71	2.26	3.47	7.36
	Change	0.38	-0.55	0.61	0.44	0.80	2.36
Average magnitude	1960-1989	1.38	1.33	1.35	1.33	1.36	1.33
	1990-2019	1.51	1.46	1.44	1.43	1.52	1.43
	Change	0.13	0.13	0.09	0.10	0.16	0.10
Average intensity	1960-1989	0.99	0.67	0.76	0.92	0.79	0.56
	1990-2019	0.93	0.93	0.63	0.87	0.69	0.46
	Change	-0.06	0.26	-0.13	-0.05	-0.10	-0.10

[13] Negative and positive values of SPI/SPEI are considered to identify a drought event. For the i-th period of time (interval) a drought event occurs when the SPI/SPEI value is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI/SPEI becomes positive. To measure the duration and magnitude of a drought event, the value of the threshold drought index shall be determined.

Drought duration is a period when SPI/SPEI is continuously below the threshold.
Drought magnitude (severity) accumulated values of SPI/SPEI during a draught event.
Drought intensity the average value of a drought parameter below the threshold level, which is measured as the drought severity divided by the duration.

Table. 1.3.4.3. Number of months with severe and extreme droughts of various time scales, Tsalka

Drought	Period	SPI			SPEI		
		3-month	6-month	12- month	3-month	6-month	12-month
All (SPI/SPEI<-1.0)	1960-1989	57	54	50	62	57	57
	1990-2019	78	85	102	104	120	166
	Change	21	31	52	42	63	109
Severe (-2.0<SPI/SPEI<-1.5)	1960-1989	13	18	20	18	19	16
	1990-2019	23	23	41	28	41	53
	Change	10	5	21	10	22	37
Extreme (SPI/SPEI<-2.0)	1960-1989	6	3	3	3	4	6
	1990-2019	13	12	12	13	20	28
	Change	7	9	9	10	16	22

The tables show the increase in the number, duration and severity (magnitude) of droughts of all time scales against the background of the climate change described above (increase in temperature, decrease in precipitation). The duration of large time scales droughts has especially increased. In addition, the cases of severe and extreme lack of precipitation are increasing, which occur mainly due to the summer season, as in summer a trend of the most intense decrease in rainfall is observed. Increased likelihood of occurrence of all types of drought events occurring against the background of decreasing rainfall may affect not only agriculture but also water resources, in particular river discharge and groundwater.

It shall be also noted that the recurrence of droughts in most cases is higher when evaluating using SPEI than in case of using SPI, which confirms the importance of considering the factor of temperature when estimating drought, especially in conditions of identified warming.

Thus, the frequency of all types of droughts (both agricultural and hydrological) is increasing in Tsalka municipality, especially in summer, which eventually will be reflected not only on the development of various agricultural crops in relation to water scarcity, but also on water resources.

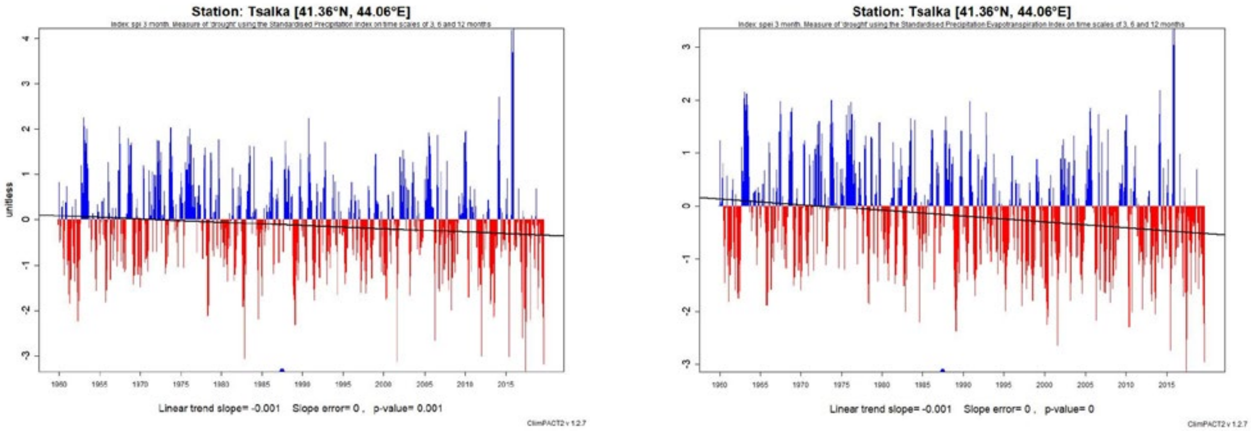


Fig. 1.3.4.2. Dynamic of indices of 3-month time scale droughts in 1960-2019, Tsalka

1.3.5. Building climate indices

Demand for heating and cooling in a building is determined by the outside air temperature. The relationship between the variability of the outside air temperature and, consequently, the energy demand of the building can be established by considering the heating and cooling degree days of the building. In fact, a degree day is a tool used to analyze the energy consumption in buildings. Depending on the climatic conditions, the key issue in determining degree days is the definition of a baseline temperature, which is directly related to the building's energy balance and energy consumption systems.

The concept of degree days is used to determine the energy required for heating and cooling, as well as to set standards for the thermal resistance of outer structures of a building.

The number of day-degrees of heating/cooling season[14] is determined by the difference between the average daily and baseline temperatures of the outside air. The baseline temperature is taken to be a temperature that is comfortable for comfortable temperature for people in the building and is set at tb=18°C.

The number of day-degrees of heating/cooling season has been calculated using the mentioned methodology (see Table 1.3.5.1) and the trends of changes of these indices had been evaluated based on the data of 1960-2019 (see Table 1.3.1.1).

Table. 1.3.5.1. Average number of degree days of heating/cooling, Tsalka

Period	Average number of heating degree days (HddHeat)	Average number of cooling degree days (CddCold)
1960-1989	4206.6	15.4
1990-2019	3987.5	34.2
Change	-219.1	18.7

[14] **Heating degree day** is a measure of how severe are climate conditions, or how low is temperature in winter in a given area.
Cooling degree day is a measure of how high is temperature in summer in a given areas

Based the obtained results, a stable upward trend for cooling degree days (CddCold) has been identified. The number of heating degree days (HddHeat) decreases too, which corresponds to the warming trend that has been identified in the study area. Both trends are almost equally pronounced (Fig. 1.3.5.1).

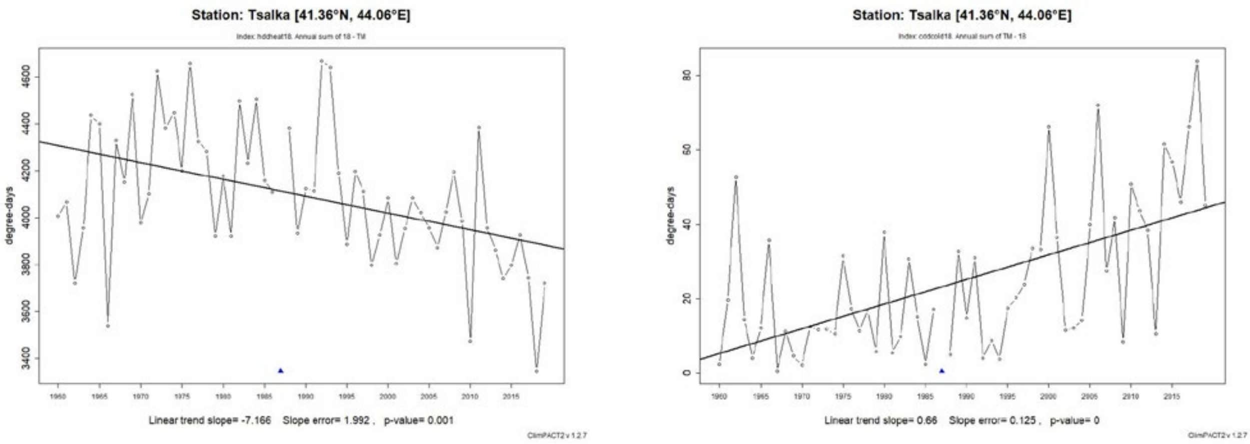


Fig. 1.3.5.1. Dynamic of degree days of heating and cooling in 960-2019, Tsalka

The results show that although the energy demand for heating in the building of Tsalka municipality has decreased, this reduction is surpassed by significantly increased energy demand for cooling during the summer, which ultimately means an increase in energy demand of buildings.

1.4. Conclusion

Based on the data of 60-year period - 1960-2019 obtained from the Tsalka meteorological station, the character of changes in the mean and extreme values, intensity, and recurrence of meteorological elements have been studied.

As a result of the study of mean **temperature** parameters in the study area the following have been identified:

- Recently the mean annual temperature in Tsalka has increased by + 0.66°C. The most intense temperature increase is observed in February-March and August-October, with the largest increase (+ 1.53°C) in August.
- Warming in spring-winter is uncertain. In certain months (November-December) cooling trends (up to -0.20°C) also dominate.
- Warming occurs mainly due to the increase in daytime temperatures. The growth rate of the mean average annual value between the two study periods is higher than that of other climate parameters and equals to +0.91°C reaching +1.88°C in August. Warming by this parameter is stable in all seasons and confirmed by trends. The rate of change reaches its maximum in summer.
- The rate of increase of night temperatures is lower. The difference in annual values between the two periods is up to 0.5°C, but exceeds 1°C in August. The cooling trends are more pronounced in November-December, when the negative deviation between the two periods is almost one degree. The November cooling is also confirmed by trends (-0.270C/10y).

Changes in extreme temperature indices indicate the following:

- Significant increase in number of hot days (TX90p) and warm nights (TN90p) along with significant decrease in number of cold days (TX10p), significant decrease in number of cold nights (TN10p) in summer, and significant increase in frequency of cold days and frosty nights (FD) in November.
- Trends in within-year variability of frequency of cold nights and frosty days in winter have not been identified, while the number of hot days and warm nights in summer and fall has increased significantly, which confirms the summer-fall warming trend that has been established on the basis of mean climatic parameters.
- The results indicate that the increase in mean temperature during the warm period (May-September) occurs due to the increase in heat waves (HW) and the significant increase in their duration. The decrease in the number and duration of cold waves (CW) is however not significant which is reflected on an unstable characters of warming of the cold period.
- Stable positive changes are also observed in the recurrence of warm spell days (Wsdi) throughout the year, while changes in the frequency of cold spell days (Csdi) are not confirmed by trends.
- For the majority of parameters, the trends confirm the increase in so-called accumulated sums of temperatures in the warm period, i.e., degree days indices (GddGrow, HddHeat, CddCold).

The analysis of characteristics of **precipitation** shows that:

- Changes in precipitation regime are not stable. Annual precipitation is reduced by of 8% in average. In the time series of monthly precipitation sums the only trend with a negative sign was identified in July (-31%, -6.7 mm/10y) was revealed. However, from July to November, the amount of precipitation decreases in the range of 10-30% every month. The increase in precipitation between the two 30-year periods is greatest in January (+21%).
- Both maximums and minimums are shifted in an annual cycle. In particular, in the first period

the highest and lowest precipitation occurred in May and January, while in the second period the wettest month is June and the driest - December.

Changes in extreme precipitation indices confirm the instability of the changes. Only a few sustainable trends have been detected.

- Most of them are observed in July and indicate a decrease in precipitation, that occurs due to a significant decrease in the number of wet days (R10) and maximum daily precipitation (Rx1D, Rx5D). Also, the share days with heavy precipitation in the total amount of precipitation is reduced (R95ptot, R99ptot, R95p, R99p). Precipitation indices also indicate a decrease in precipitation due to an increase in the duration of wet periods (CDD) in winter and spring.
- Therefore, there is an increase in frequency of droughts and a reduction in risks of floods and hazardous geological processes.
- The analysis of drought indices shows the increase in the number, duration and severity (magnitude) of droughts of all time scales. The duration of large time scales droughts has especially increased. In addition, the cases of severe and extreme lack of precipitation are increasing, which occur mainly due to the summer season, as in summer a trend of the most intense decrease in rainfall is observed.

Relative **humidity** has decreased within 2-4% by seasons. The most significant decrease in humidity is observed in February-March (4-6%). Increase in humidity is not recorded in any of the months. The trends are stable in February-April and June (-1.8%/10y - March). Therefore,

- The number of wet days (relative humidity ≥80%) is reduced throughout a year, by 20 days a year in average. The decline occurs in all seasons, mostly in the transitional seasons. The rate of the decline is highest in March (3 days). The changes are pronounced in February-March and September.
- The increase in number of dry days (relative humidity ≤30%) increases throughout a year, except for January. The average annual increase between the two periods is 9 days. The rate of growth is highest in April and November. Positive trends are more pronounced in the transitional seasons and for annual values when the rate of change is 3 day/10y.

The average **wind** speed decreases by 0.4-0.8 m/sec in all months and in all seasons of the year. The rate of change is highest in winter, especially in December. Although:

- The increase in number of strong windy days (≥15 m/sec) is observed almost all year round. The exceptions are January-February and July. The rate of growth is highest at the end of spring – in May (19 days in total). Extreme winds (≥25 m/sec) occur most frequently in March (3 days in total).
- Positive linear trends are identified only for strong winds - in May and November, while the seasonal number of such days steadily increases in spring (1.25 days/10y).

Due to the character of the trends in the above climatic parameters, the following changes are identified in the study areas by **seasons:**

- Winters in Tsalka have become relatively warm, less humid and windy. Cold and frosty nights are more frequent at the beginning of the season.
- Springs have become warmer, drier and less rainy, with more frequent windy days. The change in temperature regime is contradictory: increase in the recurrence of warm days and frosty nights occur at the same time.
- Summers have become noticeably hot and relatively dry. The duration of the heat waves steadily

increases, the risk of droughts increases too.

- Fall, mainly due to its first half, became warmer and relatively dry, with frequent windy days. The frequency of hot days and warm nights is increased at the beginning of the season. As a result, the sum of active temperatures increased by 45 degrees in average. At the end of the season the increase in the number of cold and frosty nights is recorded.

Finally, it can be concluded that the study of current climate change trends confirms warming in the study area. The **following indicators of climate** change are present:

- Increase in ground air temperature.
- Increase in frequency of hot days, decrease in recurrence of cold days.
- Increase in frequency and duration of warm spells/heat waves.
- Changes in precipitation regime.
- Increase severity and duration of droughts.

In terms of impacts on different sectors, the changes in climatic parameters will further exacerbate the exiting risks due to their character. It shall be also noted that almost all trends in reduction of these risks are statistically uncertain, and the recurrence of conditions that contribute to the aggravation of risks (such as increased magnitude of drought events, increase in number of heat waves and dry days, increase in energy demand for cooling, increase in the number of days with strong winds) increases in a relatively stable manner.

2. FUTURE CLIMATE CHANGE SCENARIO (FOR 2021-2050)

2.1. Methodology to estimate future changes

Information provided by global models is a primary source used to predict the future climate and to estimate the impact of climate at any scale - from global to local. Available global models typically operate at a very coarse scale (several hundred kilometers) and are not able to provide the useful information and small-scale details that are required to study climate impacts and ways of adaptation. To obtain such climatic information, a horizontal scale of 10–15 km is required, especially in areas with complex orography and coastlines such as the Black Sea basin region of the South Caucasus. Information obtained from global models achieves the required scales and accuracy after being processes using regional climate models and statistical methods.

Climate simulation requires appropriate resources for data calculation and storage in addition to the scientific and technological potential, which are quite limited in Georgia and thus, we have to limit ourselves to a global/regional model-based simulation, although we establish its relevance to available studies and results. Georgia's Third National Communication to UNFCCC contains a forecast calculated according to A1B scenario of global model MPI-ESM-MR, which was downscaled using regional model RegCM_v.4.0 for South Caucasus domain with 20 km resolution on the basis of which climate change scenarios for 33 meteorological stations have been constructed.

Global model MPI-ESM-MR was developed at the Max Planck Institute for Meteorology (MPIM) on the basis of a weather model of the European Centre for Medium-Range Weather Forecasts (ECMWF). The applicability of the results of the ECMWF weather model for the territory of Georgia have been systematically tested for several decades and is recognized as the best product for weather forecasting. As for its climate version (ECHAM), it is being still refined/improved. It was included in all phases of the CMIP (Coupled Models Intercomparision Project) project and is one of the best options, especially for Europe.

The goal of the CMIP is to coordinate different climate model outputs by regions and reflect the results in IPCC Assessment Reports . In Georgia's Second and Third National Communications to UNFCCC the assessments were based on previous versions of MPI-ESM-MR, while the Fourth National Communication the result obtained from the 5th version of the model are included. In this version of the mode the description of near-surface processes and relevant data, as well as advection schemes, cloud parameterization, long-wave radiation code are improves, which leads to significant improvements in simulating the existing climate.

Climate projections in the Third National Communication are based on SRES scenario. These scenarios have been developed on the recommendation of the IPCC, which provide an estimate of the number of future emissions based on existing knowledge of greenhouse gases and their driving forces. There are grouped around 4 so-called storylines and the 40 SRES scenarios are presented by the four families (A1, A2, B1, and B2). Index A corresponds to a path of world development where economic development is given priority while environmental issues are neglected. Index B indicates opposite trends; and the numbers 1 and 2, respectively, indicate two opposite development trends - globalization and regionalization. Since 2014, by the recommendation of IPCC new scenarios RCP (Representative Concentration Pathway scenarios) which are not based on socio-economic storylines are being developed. They make projections of the global thermal regime based on the stabilization of the radiation budget (this is the difference between total

[15] http://cmip-pcmdi.llnl.gov/cmip5/availability.html
[16] http://www.ipcc.ch/report/ar5/wg1/

incoming and outgoing radiation measured in W/m2). Within new scenarios also exist three main categories of high (RCP 8.5W/m² 2100 year), medium (RCP 4.5W/m²) and low (RCP 2.6 W/m²) scenarios, corresponding to SRES A2, A1B and B1 ones. In the Fourth National Communication RCP 4.5W/m² scenario is used which is not as strict as A1B scenario presented in the previous Communication.

A regional model RegCM-4.6.0 version has been released to improve the global scale. The Regional Climate Model (RegCM) was originally developed by NCAR and is mostly used for regional climate studies and seasonal projections. The model is currently being upgraded and developed at the Abdus Salam International Center for Theoretical Physics (Trieste, Italy). It is a representative of a family of local (LAMs) models in which large-scale meteorological data from GCM provide initial and time-dependent meteorological boundary conditions (LBCs) for high resolution RCM simulations. In this version the mechanisms for describing and parameterizing a number of physical and chemical processes are improved, and in our case this model takes into account dust and aerosol effects. This was preceded by a study on the effect of dust on the simulation of the South Caucasus regional climate. In addition, the one way nesting technique of RegCM-4.6.0 allows to improve horizontal scale. All simulations of the regional climate model were performed first on a rougher scale (30 km) and relatively large area, and then calculated on a 10-km grid.

The calculation was carried out in three stages: 1. The observation data archive (ERAinerim) for 1986-2015 was used as the initial and boundary conditions of the model. The results of the calculation are used to diagnose and calibrate the regional model. 2. The regional model was run with initial and boundary conditions of MPI-ESM-MR global model for 1960-2005. The results of the calculation are used to estimate the distribution of future climatic parameters and changes in mean values. 3. Simulation with the initial and boundary conditions of the same MPI-ESM-MR global model for 2006-2100. This simulation of the global model is based on the RCP 4.5 scenario. All simulations of the regional climate model were performed first on a rougher scale (30 km) and relatively large area, and then calculated on a 10-km grid.

The simulation performed under the ERAinerim boundary conditions was performed in two versions: with and without the aerosol effect. The simulations were compared with the observation data, with the time series of the observation of the climate stations, as well as with the data interpolated on the observation grid. Based on the results, the simulation, where aerosol effect is taken into account, are closer with the observations. Therefore, simulations on the global model with the initial and boundary conditions were performed taking into account the aerosol effect. Simulation for 1960-2005 was compared with the simulation performed with ERAinerim boundary conditions for the period when they match - 1985-2005. Model bias correction procedure of the model was performed.

Based on the above simulation, future trends in climate change were assessed for the Tsalka station of the Georgian meteorological network for the next 30-year period - 2021-2050. Scenarios were built for both key climatic parameters such, as mean monthly and annual values of air temperature, wind and relative humidity, as well as for maximum and minimum sums of precipitation and temperature. Specific climatic parameters, so-called indices were also calculated, the assessment of which is important for individual sectors.

2.2. Analysis of obtained results

2.2.1. Main climatic indices

The scenario of future climate change is developed for Tsalka municipality. The change of climatic parameters is estimated for 2021-2050. The results of the model (on a scale of 10 km) were calibrated according to the data of actual observations of the Tsalka meteorological station for 1991-2010. The Figure 2.2.1.1 shows the average values of mean temperatures and sums of precipitation for each month obtained as a result of 30-year observations and simulation, and Figure 2.2.1.2 shows their dynamics by years.

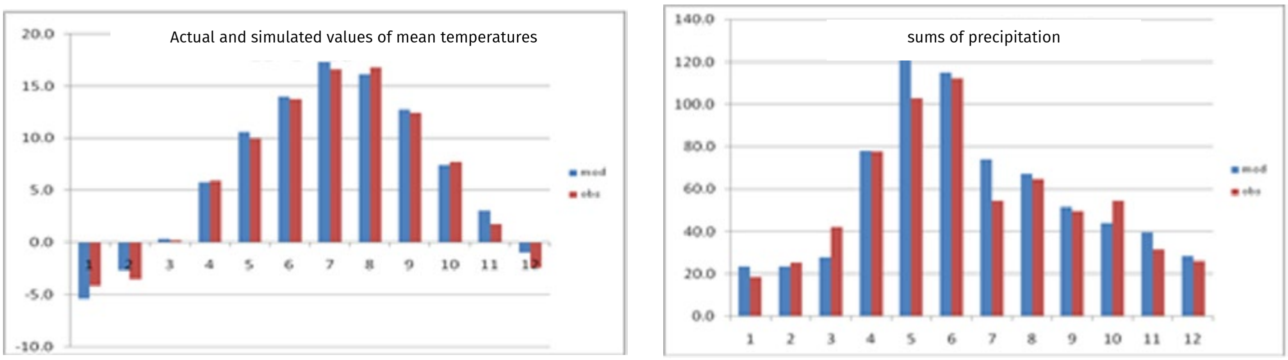


Fig. 2.2.1.1. Actual and simulated values of mean temperatures and sums of precipitation in 1991-2010 (Tsalka, ^{0}C, mm)

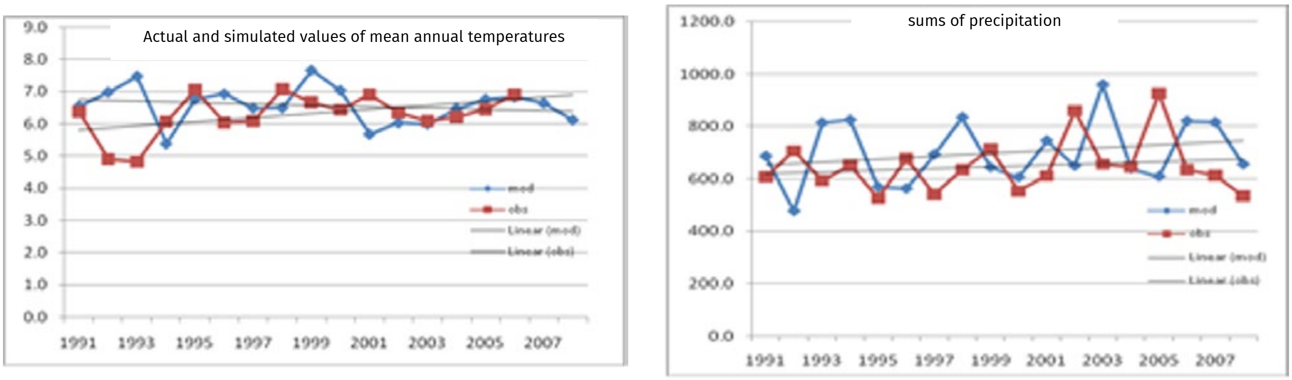


Fig. 2.2.1.2. Actual and simulated values of mean annual temperatures and sums of precipitation in 1991-2010 (Tsalka, ^{0}C, mm)

The figures show certain deviations between the mean multiannual simulated and actual data for the 30-year observation period. However, the annual frequency distribution can be considered satisfactory. As for the annual curves, the model fails to accurately describe the natural annual variation for both parameters (the cold year of 1992 is noteworthy). However, both simulated variables repeat the trend of the change. Therefore, special factors were calculated to approximate simulated data to observation time series and to calibrate the results of the model.

A scenario of change of simulated climatic parameters for Tsalka municipality is discussed below.

Mean temperatures, both actual and simulated, continue to increase. The increase between the values of the scenario and the second observation period (1990-2019) is positive in all months, increasing annually by 0.4ºC to 7.6ºC. During the observation period, maximum warming occurs in summer, while according to the scenario, the highest rate of increase is recorded for winter mean temperature (0.6ºC) reaching -1.7ºC, and the rate of warming is the lowest in summer (0.3ºC; 16.6ºC). The maximum increase in temperature is expected in May (0.8ºC; 11.6ºC), and the minimum - in March (0ºC), that's why the average increase in temperature during spring is not so high. (See Annex 1, Table 1.1)

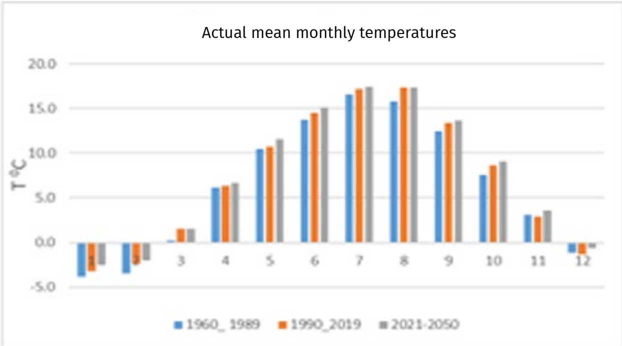


Fig. 2.2.1.3. Actual mean monthly temperatures for 1960-1989 and 1990-2019 observation and 2021-2050 simulated periods (Tsalka, ºC)

Future changes in mean maximum temperatures have an increasing character. Annually they will grow by 0.7 degrees and reach 13.5ºC, although the trends identified by months and seasons during the observation period will not continue. The change of the upward trend into downward in March is the only negative increase between the months. Maximum warming is expected in December (1.3ºC, 5.4ºC), although this parameter in winter increases at the lower rate compared to other seasons. The rate of increase of mean maximum temperature is highest in fall (0.8ºC, 15ºC) (see Annex 1, Table 1.2).

Mean minimum temperatures increase in all seasons and throughout the year at a higher rate than the maximum. Its annual increase will be 4.4 (5.8ºC), which will occur mainly due to the increase of summer and partly fall minimum temperatures. This parameter also increases in winter and spring but at a lower rate. From June to September this increase is in the range of 5.5-6.5 degrees and the corresponding temperatures are in the range of 12.8ºC to 17.8ºC, in other months the increase is in the range of 2-4 degrees, and the temperatures are in the range of -4.9ºC, -6.6ºC (See Annex 1, Table 1.3).

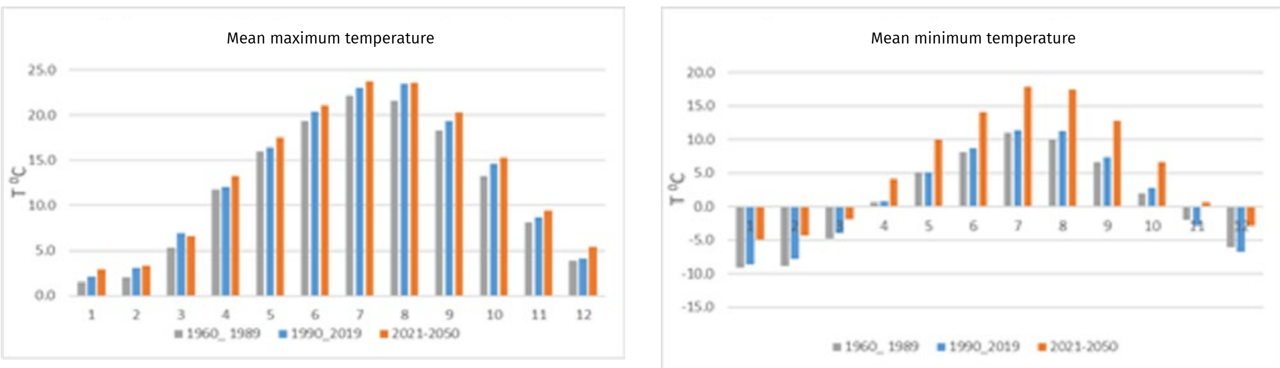


Fig. 2.2.1.4. Mean maximum and minimum temperatures by months for 1960-1989 and 1990-2019 observation and 2021-2050 simulated periods (Tsalka ºC)

Absolute annual maximum temperature will increase by 3 degrees and reach 36.6ºC in August of the forecast period. This is also the maximum change of this parameter by months. In February, April and October of the forecast period maximum temperatures will drop to 0.3ºC-1.0ºC. Maximum temperatures grow only in spring and summer, but remain unchanged in other seasons. (See Annex 1, Table 1.4).

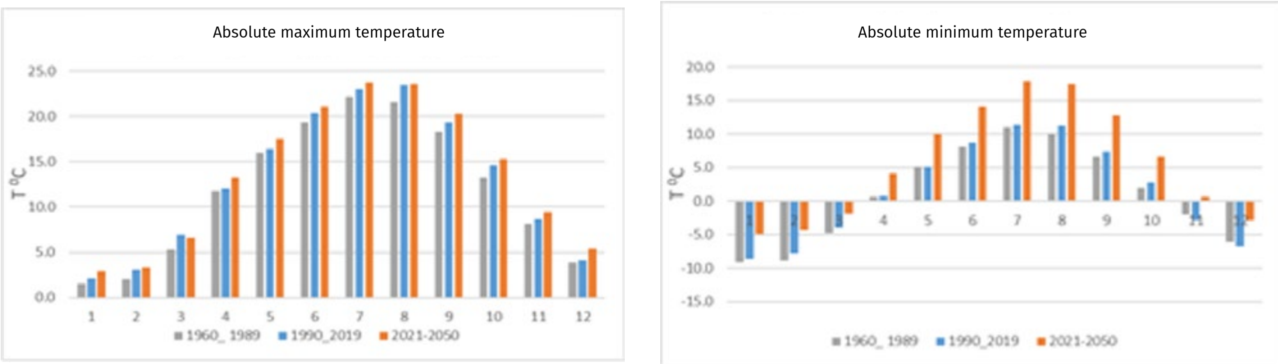


Fig. 2.2.1.5. Absolute maximum and minimum temperatures by months for 1960-1989 and 1990-2019 observation and 2021-2050 simulated periods (Tsalka, ºC)

Absolute minimum temperature will change as follows: annually it will increase by 1.8 degrees and its lowest value will be -31.6ºC. Seasonal and annual rates of increase will be equal in winter, while in spring and summer the upward and downward trends will offset each other. It shall also be noted that in summer only positive values of the minimum temperature are expected, due to the increase of the minimum temperature by 3.3ºC (0.3ºC) in June. In the majority of months cooling occurs within 0.4-3.2ºC (see Annex 1, Table 1.5).

The annual value of relative humidity remains almost unchanged during the forecast period (increases by 0.3% up to 75.6%) and seasonally these parameters change slightly (by less than 1%), although the graph in Fig.2.2.1.6 shows that it varies over the months. These changes have positive and negative trends, the maximum increase is recorded in August (4%, 78.3%) and the negative - in January and July (3%) (see Annex 1, Table 1.25).

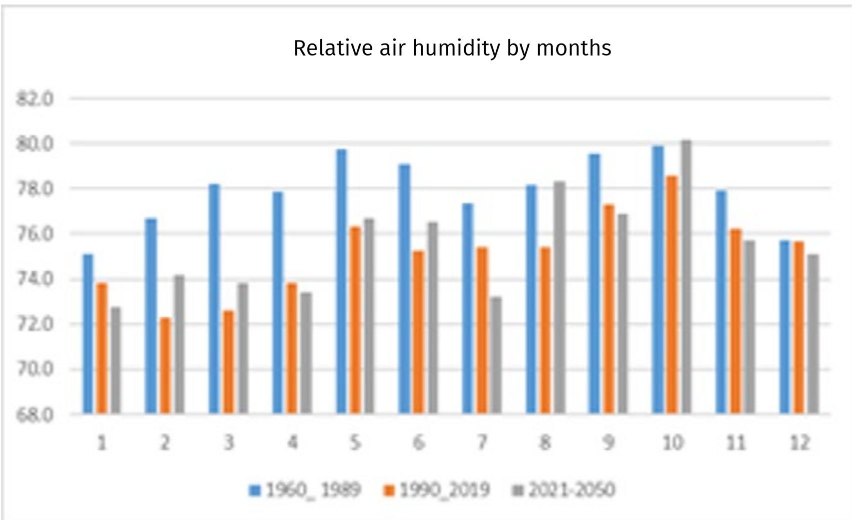


Fig. 2.2.1.6. Relative air humidity by months for 1960-1989 and 1990-2019 observation and 2021-2050 simulated periods (Tsalka, %)

Annual precipitation decreased by 7% between the two observation periods, the annual sum of forecasted precipitation in 2050 will be 5% (664 mm) higher than in the second observation period due to inceased precipitation in all seasons with the exception of spring, which will decrease by about 1% (213 mm) by this period. The rate of increase in precipitation in highest in July (23 mm, 45%), while the highest rate of decrease in precipitation occurs in April (11 mm, 16%) (see Annex 1, Table 1.14).

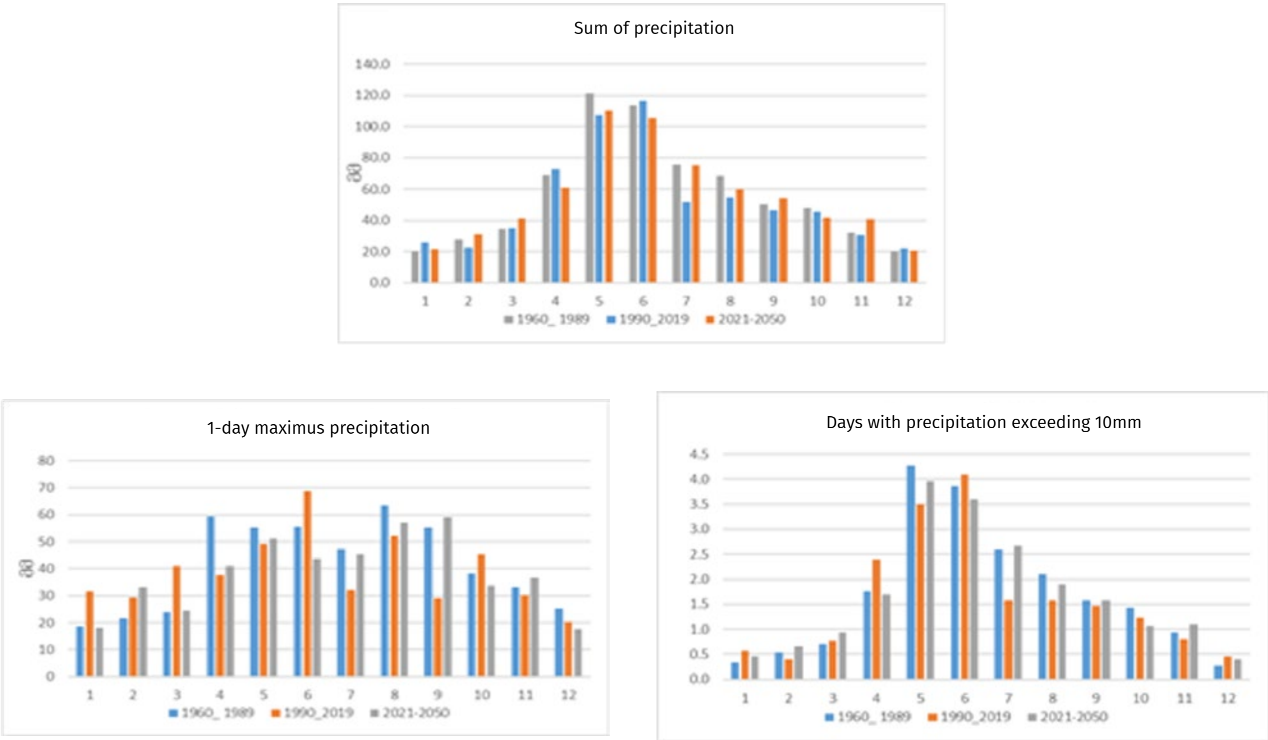


Fig. 2.2.1.9. Sum of precipitation, 1-day maximus and the number of days with precipitation exceeding 10mm by months for 1960-1989 and 1990-2019 observation and 2021-2050 simulated periods (Tsalka, mm, day)

Annual maximum daily precipitation during the both period occurs during the summer season (August - 63 mm, June - 69 mm), and while in 2021-2050 the maximum will shift to September and decrease by 14% (59 mm). The seasonal maximum will decrease by 17% (57 mm) only in summer, while in other seasons this parameter will increase, especially in fall (59 mm, 31%). This value varies by months, the biggest change compared to the previous period is recorded in September, where, according to the scenario the daily maximum will be doubled (100%, 59 mm), in other months the deviation varies from -43% to + 43%. (See Annex 1, Table 1.21).

The number of days with precipitation exceeding 10mm have been decreased between the observation periods, while the scenario predicts its increase almost reaching its past values (20). As a result, the total number of such days in a 30-year period will increase by 36 and reach 600, mainly due to the summer season. In winter and fall such days will increase by 10 to 33 in total, while in spring they decrease slightly. The largest increase by months occurs in July (33 in total) and the largest decrease in April (21 in total) (see Annex 1, Table 1.19).

The average wind speed, after a significant decrease between the two observation periods, according to the 2021-2050 forecast, will slightly fluctuate with respect to the values observed in the second observation period. The average annual wind speed will increase by 0.3 m/sec and reach 1.3 m/sec, and will be closer to the data recorded in the first observation period, which is due to its increase in fall and winter. The average wind speed increases in all months, however in fall and winter months this change is in the range of 0.5-0.7 m/sec. The average wind speed during the summer months actually does not change (see Annex 1, Table 1.26).

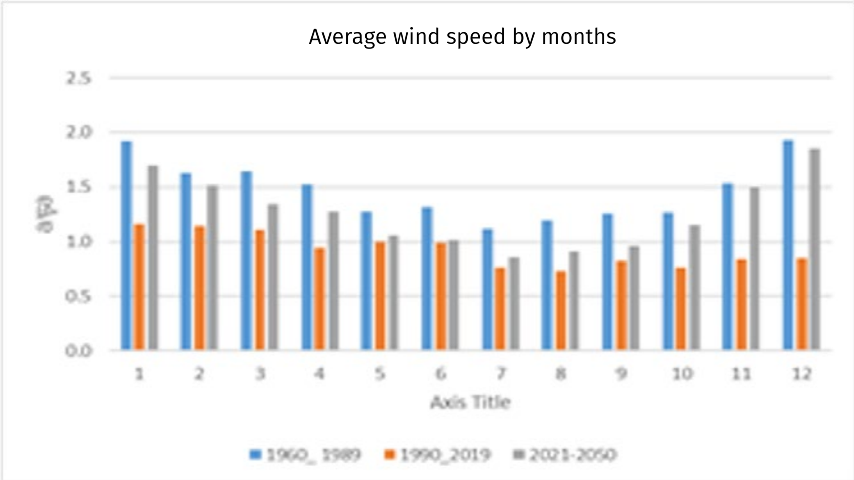


Fig. 2.2.1.12. Average wind speed by months for 1960-1989 and 1990-2019 observation and 2021-2050 simulated periods (Tsalka, m/sec)

2.2.2. Seasonal changes

According to the climate change scenario, all three parameters of the average winter temperature in Tsalka show a **sharp increase.** The mean minimum temperature increases at a higher rate than the maximum. In particular, the mean temperature increases by 0.6^{0}C, as compared to 1990-2019, mean maximum will increase by 0.4^{0}C and the minimum - by 2.3^{0}C. As for the absolute maximum and minimum of winter, the first remains unchanged during the forecast period, while the second decreases. It means that during the mentioned period the temperatures higher than those recorded during the observation period will not be observed and more severe frosts that those recorded in the second forecast period can be expected. However, as the mean maximum and minimum increase, the number of such events will be smaller and the number of days when the maximum and minimum are among the highest 10 percent group of temperatures that are typical for this period will increase. On the other hand, the number of lowest (10%) maximums decreases, but the minimums increase slightly, which means that the winter season in Tsalka during this period still will be quite frosty. The sum of precipitation continues to increase during the observation period (8%). The increase in seasonal precipitation occurs due to increased number of days when the daily precipitation exceeds 10 mm. The daily maximum precipitation increases slightly, but the amount of maximum precipitation in 5 days decreases. The duration of dry period increases. According to the scenario, average relative humidity remains unchanged and the average wind speed increases by 0.3m/sec. Thus, in 2021-2050, winters in Tsalka will be warmer with increased precipitation, however the number of severe frost events will not change.

In **spring,** the temperature continues to increase. Mean minimum temperature (3.5^{0}C) still increases at a higher rate than the maximum (0.7^{0}C), but it should be noted that the absolute minimum will be lower in spring by -3.2^{0}C. The absolute maximum increases by 1.4^{0}C. The average number of frosty days (ID) in 2021-2050 decreases (0.6), as does the number of cold days with frosty nights (FD). The percentage of colder maximums and minimums decreases by 2.1 and 8.8, respectively, while the percentage of warmer days for maximums increases by 2 and for the minimums - by 15. The seasonal sum of precipitation changes insignificantly, decreasing by 2 mm, which is less than 1%. The number of days with precipitation above 10 mm (2) and 30 mm decrease by 6. The number of days with precipitation above 50 mm (2) increases too. The daily maximum precipitation increases by 2 mm, while the amount of precipitation occurring in 5 days increases significantly (35 mm, 43%). Thus, the intensity of precipitation in summer will increase. The average seasonal values of relative humidity and wind speed increase very slightly by 1% and 0.2 m/sec, respectively. The combination of these parameters suggests warmer spring in Tsalka, but with larger variability of maximum and minimum temperatures, increased risks of spring frosts, the number of days with heavy precipitation.

During the observation period the highest rate of warming - 0.9 degrees was in **summer,** however, according to the scenario the rate of warming is summer was the lowest compared to other seasons - 0.30C. The mean maximum temperature will increase by 0.5 degrees, while the mean minimum will raise by 6^{0}C. The absolute maximum and minimum will increase almost at the same rate (by 3.0^{0}C and 3.3^{0}C). The percentage of days when both the maximum and the minimum temperatures are among the highest 10 percent group of temperatures that are typical for this period will increase will increase by 4 and 11, while the percentage of days when maximum and the minimum temperatures are among the lowest 10 percent group will decrease by 1.8 and 5, respectively. According to the scenario, negative temperatures will no longer be observed in summer. a 13% decrease in the second observation period the seasonal sum of precipitation will increase again (8%). During the observation period, the seasonal maximum of the sum of precipitation was recorded in summer. This index decreases by 17%, and the maximum precipitation in 5 days - by 8%. The number of days with daily precipitation exceeding 10 mm will increase (13%, 28), while the number of days with daily precipitation exceeding 30 and 50 mm remains unchanged.

Thus, the intensity of precipitation in summer will decrease, however the days with abundant precipitation will be most expected during that season. The average seasonal values of relative humidity and wind speed increase very slightly by 1% and 0.1 m/sec, respectively. During the forecast period, the number of warm nights in summer will increase, daily precipitation will be distributed more evenly creating more favorable conditions for agriculture.

The intensity of warming in **fall** was lower than in summer. According to the forecast, it will warm up by another 0.4 degrees and reach 8.7^{0}C. The rate of warming of mean minimums in this season is higher (4^{0}C) than that of mean maximums (0.8^{0}C). In the fall, the absolute maximums will not change, while the minimums will increase by 0.50C, although remain low (-20^{0}C). The percentage of cold days and nights when maximum and the minimum temperatures are among the lowest 10 percent group will decrease by 3% and 7%, respectively. While the number of hot days and nights will increase by 0.2% and 13%.

During this season the seasonal sum of precipitation will change contrary to the trend that was observed during the observation period. In particular, after a slight decrease (6%) in the last period, it will increase by 12% according to the scenario. In the forecast period the annual maximum daily precipitation shifts to September and increases by 31%, as well as the maximum precipitation in 5 days (29%). The number of days with precipitation of more than 10, 30 and 50 mm will increase in fall. Accordingly, in 2021-2050 the intensity of precipitation will remain unchanged, as the seasonal sum and the number of wet days increase at a similar rate. The high probability of frosts in fall still remains.

2.2.3. Extreme events

Future values of extreme climatic indices for 2021-2050 were calculated on the basis of daily data on sum of precipitation and maximum and minimum temperatures. The description of the indices and the methodology of their calculation are similar to that used for the calculation of extreme indices based on the observation data. Only few cases of heavy and extreme precipitation (number of days with a daily precipitation exceeding 30 and 50 mm) were recorded in Tsalka municipality during the observation period and the probability of their significant increase in the future is low.

The annual number of wet days with precipitation exceeding 30 mm has decreased between observation periods and, according to the scenario, it will increase again to its pervious value. Although such amount of precipitation does not create a risk of mudflows, but it poses some risks to agricultural activities. According to the scenario, wet days with precipitation exceeding 50 mm are not expected. The maximum amount of precipitation occurred in 5 consecutive days (Rx5day), according to the scenario, increases especially during the transitional seasons, as well as the number of days when the daily precipitation exceeds 10 and 30 mm. The analysis of the reviewed indices shows that the annual distribution of precipitation during the forecast period will occur due to the days with daily precipitation of 30 mm or lower, and the intensity of daily precipitation will decrease. It shall be noted that the cases of precipitation exceeding annual sum of precipitation by 200 mm and more, which is a trigger of landslides, will decrease during the forecast period, although the probability of singular events will remain.

Table. 2.2.3.1. Changes in precipitation triggering mudflows and landslides, Tsalka

Mudflow and landslide processes	Sum of daily precipitation > 50 mm	Sum of daily precipitation > mm	The cases of exceedance of annual sum of precipita-tion by 200 mm and more
1960-1989	53	7	1
1990-2010	37	4	9
2021-2050	52	0	1

From the temperature indices, the following indices that are important for agriculture gave been considered: number and average and maximum duration of heat waves. This index also affects human health, livestock breeding and crop farming. The values of these indices are given in Table 2.2.3.2 for both observation and forecast periods.

Table. 2.2.3.2. Number and duration of heat waves in different periods, Tsalka

Period	Period	Average number of heat waves (HWN)	Average duration of heat waves (HWD)
1960-1989	1.9	5.6	14
1990-2019	3.3	8.1	38
2021-2050	5.7	13.3	33

The table shows a considerable increase in the average number and duration of heat waves both during the observation period and according to the forecast. The maximum duration, which increased almost three times in the second forecast period, is reduced by 5 days in 2021-2050. However this will not mitigate the negative impact caused by this phenomenon considerably.

2.2.4. Agro-climatic indices

Growing season length (GSL) and sum if active temperatures (GddGrow) have been assessed from parameters that are important for agriculture. Table 2.2.4.1 contains actual and predicted values of these parameters.

Table. 2.2.4.1. Average length of growing season (>5°C; <5°C) and the sum of active temperatures (>10°C; <10°C). Tsalka

Period	Growing season length (GSL)	Sum of active temperatures, above 10°C (GddGrow)
1960-1989	213.2	637.0
1990-2019	214.4	771.8
2021-2050	223.5	893.5

The data shows a slight increase in growth season during the observation period, and in the future it will be prolonged by 9 days, becoming 223 days. The sum of active temperatures will also increase by 120 degrees in the future, which will allow to farm other crops and may even lead to changes in agricultural practices.

Drought has assessed using Standardized Precipitation and Standardized Precipitation Evapotranspiration Indices (SPI/SPEI). The Table contains the number of recurrence, duration, magnitude and intensity for the three periods.

Table. 2.2.4.2. Drought characteristics of different time scales, Tsalka

Drought	Period	SPI			SPEI		
		3-month	6-month	12- month	3-month	6-month	12- month
Average number	1960-1989	33	17	10	34	21	12
	1990-2019	37	32	17	46	34	22
	2021-2050	29	15	9	33	17	9
Average magnitude	1960-1989	2	3	5	2	3	5
	1990-2019	2	3	6	2	3	7
	2021-2050	3	2	4	4	7	12
Average magnitude	1960-1989	1.38	1.33	1.35	1.33	1.36	1.33
	1990-2019	1.51	1.46	1.44	1.43	1.52	1.43
	2021-2050	1.90	2.45	1.04	2.13	3.30	2.17
Average intensity	1960-1989	0.99	0.67	0.76	0.92	0.79	0.56
	1990-2019	0.93	0.93	0.63	0.87	0.69	0.46
		1.30	1.17	1.14	1.34	1.28	1.17

The number of droughts, which has increased for all types of droughts during the observation period, will decrease in 2021-2050 which is directly correlated with the decrease and increase in precipitation. Duration of droughts, except for 6- and 12-month SPIs, are increasing. The intensity and magnitude of all types of drought increase too. As a result, the occurrence of droughts during this period will decrease, however their severity and duration will increase.

2.2.5. Building climatic indices

Table 2.2.5.1 contains average values of heating and cooling degree days, which are especially important for agriculture, livestock breeding, greenhouse and cool-storage sectors.

Table. 2.2.5.1. Average number of degree days of heating/cooling, Tsalka

Period	Average number of heating degree days (HddHeat)	Average number of cooling degree days (CddCold)
1960-1989	4206.6	15.4
1990-2019	3987.5	34.2
2021-2050	3628.1	56.0

The Table shows that the average number of heating degree days (HddHeat) is gradually decreasing. As this is a measure of how low is temperature in winter in a given area, this parameter predicts less severe condition in winter. In the second observation period the average number of degree days when the building needs heating is significantly decreases. According to the forecast this index will be further decreased by 120 degree days, but during this period the winters are still severe. In contrast, the number of cooling degree days increases. This parameter shows how high the temperature is during the summer. Based on these data, the number of cooling degree days in the forecast period will increase almost 4 times compared to the first period.

2.3. Conclusion

According to the future scenario, by the middle of the century the temperatures - both average and maximum - will increase in all seasons.

- The mean minimum temperature will increase at a higher rate than the maximum, although the negative minimums will be recorded throughout the year, except summer, and in certain months will even be lower than during the observation period.
- The number of hot days and warm nights will increase and the number of frosty nights and cold days will decrease.
- The length of growing season and the sum of active temperatures will increase. But the maximum duration of the warm period will be reduced and conversely, the maximum duration of the cold period will be prolonged.
- Based on these temperature data, warmer weather is forecasted, however the risk of occurrence of severe frosty days and spells still exists.

Seasonal and especially annual changes in the amount of **precipitation** are insignificant, however

- annual distribution by months is more important.
- including decreased precipitation in April and June.
- but this decrease will be somehow balanced by the increase in July.
- on the whole, the intensity of precipitation will decrease due to increased number of wet days with precipitation exceeding 10 mm.

The number of droughts will decrease in 2021-2050. Duration of droughts, except for 6- and 12-month SPIs, are increasing. The intensity and magnitude of all types of drought increase too. As a result, the occurrence of droughts during this period will decrease, however their severity and duration will increase.

ANNEX 1

Values of climatic parameters[1]

Table 1.1 Mean air temperature (Tmm), ⁰C

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-3.9	-3.4	0.3	6.2	10.5	13.7	16.6	15.8	12.4	7.6	3.1	-1.1	6.5
1990-2019	-3.3	-2.4	1.5	6.4	10.7	14.5	17.2	17.3	13.3	8.7	2.9	-1.3	7.1
2021-2050	-2.5	-2.1	1.5	6.6	11.6	15.1	17.4	17.4	13.6	9.0	3.5	-0.6	7.6
Difference 1[2]	0.60	1.04	1.22	0.19	0.26	0.79	0.61	1.53	0.91	1.12	-0.15	-0.20	0.66
Difference 2[3]	0.7	0.3	0.0	0.3	0.8	0.6	0.3	0.1	0.3	0.4	0.6	0.7	0.4

Table 1.2. Mean maximum air temperature (Txm), ⁰C

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	1.5	2.0	5.3	11.8	16.0	19.3	22.2	21.6	18.3	13.2	8.1	3.9	11.9
1990-2019	2.2	3.1	6.9	12.0	16.4	20.4	23.0	23.5	19.3	14.6	8.7	4.1	12.8
2021-2050	2.9	3.3	6.6	13.2	17.5	21.1	23.7	23.5	20.3	15.3	9.4	5.4	13.5
Difference 1	0.67	1.08	1.59	0.26	0.40	1.05	0.81	1.88	1.02	1.35	0.56	0.22	0.91
Difference 2	0.73	0.24	-0.34	1.21	1.14	0.73	0.71	0.06	1.01	0.73	0.75	1.26	0.69

Table 1.3. Mean minimum air temperature (Tnm), ⁰C

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-9.2	-8.9	-4.8	0.6	5.0	8.1	10.9	10.0	6.6	1.9	-2.0	-6.1	1.0
1990-2019	-8.7	-7.9	-4.0	0.7	5.1	8.6	11.3	11.2	7.4	2.8	-2.9	-6.7	1.4
2021-2050	-4.9	-4.3	-1.9	4.1	10.0	14.1	17.8	17.4	12.8	6.6	0.6	-2.9	5.8
Difference 1	0.53	1.01	0.85	0.12	0.11	0.54	0.41	1.18	0.81	0.90	-0.87	-0.62	0.41
Difference 2	3.79	3.56	2.06	3.37	4.83	5.46	6.46	6.26	5.39	3.79	3.46	3.84	4.36

[1] Source: https://www.ecad.eu/download/millennium/millennium.php#temp
[2] The difference between the second (1990-2019) and first (1960-1989) periods of observation
[3] The difference between the third forecast period (2021-2050) and the second observation period (1990-2019)

Table 1.4. Absolute maximum air temperature (Txx), ⁰C

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	13.2	15.7	19.3	22.8	27.1	29.0	30.8	34.6	30.1	24.5	20.8	14.2	34.6
1990-2019	13.5	16.1	23.0	25.9	26.7	29.4	33.6	33.0	29.7	27.0	21.4	16.8	33.6
2021-2050	14.7	15.1	23.0	25.1	28.1	30.0	33.6	36.6	29.7	26.7	22.2	16.8	36.6
Difference 1	0.3	0.4	3.7	3.1	-0.4	0.4	2.8	-1.6	-0.4	2.5	0.6	2.6	-1.0
Difference 2	1.2	-1.0	0.0	-0.8	1.4	0.6	0.0	3.6	0.0	-0.3	0.8	0.0	3.0

Table 1.5. Absolute minimum air temperature (Tnn), ⁰C

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-32.9	-31.7	-25.2	-15.0	-5.1	-0.9	1.7	1.9	-4.4	-10.4	-21.8	-28.5	-32.9
1990-2019	-31.0	-33.4	-21.6	-12.8	-5.6	-3.0	2.0	3.3	-3.0	-10.3	-20.6	-25.6	-33.4
2021-2050	-31.6	-30.2	-24.8	-13.6	-4.8	0.3	1.3	2.9	-3.9	-8.9	-20.1	-27.5	-31.6
Difference 1	1.9	-1.7	3.6	2.2	-0.5	-2.1	0.3	1.4	1.4	0.1	1.2	2.9	-0.5
Difference 2	-0.6	3.2	-3.2	-0.8	0.8	3.3	-0.7	-0.4	-0.9	1.4	0.5	-1.9	1.8

Table 1.6. Number of days when the mean temperature Tmm≥10 ° C (Tmge10), day

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	0	0	0.1	3.9	18.6	28.2	31.0	30.7	24.3	7.3	0.7	0	144.8
1990-2019	0	0	0.3	4.6	19.7	28.9	31.0	31.0	26.1	11.2	0.5	0	153.4
2021-2050	0	0	0.3	7.6	23.8	29.3	31.0	31.0	27.8	14.1	1.8	0.2	167.0
Difference 1	0	0	0.2	0.7	1.1	0.7	0.0	0.3	1.8	3.8	-0.13	0	8.6
Difference 2	0	0	0.1	3.2	5.7	0.9	0.0	0.0	2.3	3.5	1.2	0.2	17.0

Table 1.7. Percentage of hot days (TX> 90 percentile) (Tx90p),%

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	10.5	10.9	10.7	10.4	10.7	10.3	11.0	9.9	10.5	10.6	10.3	9.9	10.5
1990-2019	11.8	14.7	19.9	13.0	14.6	16.4	12.8	28.5	17.6	18.7	15.6	14.7	16.5
2021-2050	18.1	17.8	17.2	14.7	21.3	24.6	19.8	21.3	19.1	17.6	17.9	23.0	19.4
Difference 1	1.3	3.8	9.2	2.6	3.9	6.1	1.8	18.6	7.1	8.1	5.3	4.8	6.0
Difference 2	6.3	3.1	-2.7	1.7	6.7	8.2	7.0	-7.2	1.5	-1.1	2.3	8.3	2.9

Table 1.8. Percentage of cold days (TX <10th percentile) (Tx10p),%

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	11.0	10.6	10.4	10.9	10.6	10.3	10.4	10.9	10.6	10.4	10.9	10.3	10.6
1990-2019	8.2	6.1	5.5	9.2	9.9	4.7	6.7	5.9	7.0	7.1	9.7	11.2	7.6
2021-2050	4.9	4.7	5.5	8.3	3.9	3.3	6.0	3.5	4.0	4.9	4.7	4.8	4.9
Difference 1	-2.8	-4.5	-4.9	-1.7	-0.7	-5.6	-3.7	-5.0	-3.6	-3.3	-1.3	0.9	-3.0
Difference 2	-3.3	-1.4	0.0	-0.9	-6.0	-1.4	-0.7	-2.4	-3.0	-2.2	-5.0	-6.4	-2.7

Table 1.9. Percentage of warm nights (TN> 90 percentile) (Tn90p),%

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	10.9	10.8	10.2	10.5	9.9	10.4	10.0	9.8	9.7	10.5	10.3	10.3	10.3
1990-2019	8.9	11.3	15.4	14.0	16.5	18.0	17.4	19.5	20.6	17.1	10.0	7.4	14.7
2021-2050	19.7	19.9	22.0	16.6	29.4	34.6	25.9	24.8	24.8	26.6	23.2	17.1	23.7
Difference 1	-2.0	0.5	5.2	3.5	6.6	7.6	7.4	9.7	10.9	6.6	-0.3	-2.9	4.4
Difference 2	10.8	8.6	6.6	2.6	12.9	16.6	8.5	5.3	4.2	9.5	13.2	9.7	9.0

Table 1.10. Percentage of cold nights (TN <10th percentile) (Tn10p),%

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	10.4	10.5	10.8	10.3	10.8	10.0	10.6	10.7	9.8	10.2	10.4	10.8	10.4
1990-2019	8.4	6.5	7.6	12.9	11.5	7.3	10.4	4.2	7.4	6.3	15.6	10.0	9.0
2021-2050	6.6	8.3	5.9	4.4	2.7	3.0	5.2	4.3	4.8	4.1	4.2	8.7	5.2
Difference 1	-2.0	-4.0	-3.2	2.6	0.7	-2.7	-0.2	-6.5	-2.4	-3.9	5.2	-0.8	-1.4
Difference 2	-1.8	1.8	-1.7	-8.5	-8.8	-4.3	-5.2	0.1	-2.6	-2.2	-11.4	-1.3	-3.8

Table 1.11. Number of frosty nights (TN <0 °C) (FD), day

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	29.7	26.6	26.9	12.4	1.3	0.1	0	0	0.9	9.2	19.5	27.2	153.7
1990-2019	30.2	27.1	25.6	12.8	1.8	0.1	0	0	0.8	7.8	21.5	28.4	156.1
2021-2050	29.1	25.9	24.1	8.9	0.5	0	0	0	0.4	5.8	16.4	26.1	137.2
Difference 1	0.5	0.5	-1.3	0.4	0.5	0	0	0	-0.1	-1.4	2.0	1.2	2.4
Difference 2	-1.1	-1.2	-1.5	-3.9	-1.3	-0.1	0	0	-0.4	-2.0	-5.1	-2.3	-18.9

Table 1.12. Warm Spell Duration Index (WSDI), day

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-[4]	-	-	-	-	-	-	-	-	-	-	-	3.0
1990-2019	-	-	-	-	-	-	-	-	-	-	-	-	15.6
2021-2050													8.8
Difference 1	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Difference 2													-6.8

Table 1.13. Cold Spell Duration Index (CSDI), day

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-	-	-	-	-	-	-	-	-	-	-	-	1.7
1990-2019	-	-	-	-	-	-	-	-	-	-	-	-	2.3
2021-2050													3.9
Difference 1	-	-	-	-	-	-	-	-	-	-	-	-	0.7
Difference 2													1.6

Table 1.14. Sum of Precipitation (PRCPTOT), mm

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	22.5	29.8	37.2	71.1	123.9	115.6	77.3	70.6	52.9	50.3	34.7	22.5	708.4
1990-2019	27.3	24.1	36.2	74.4	109.0	117.6	53.5	56.6	47.7	47.3	32.0	23.4	648.9
2021-2050	21.6	31.0	41.5	61.2	110.1	105.5	75.2	60.2	54.2	41.9	41.0	20.4	663.8
Difference 1	4.8	-5.7	-1.0	3.3	-14.9	2.0	-23.8	-14.0	-5.2	-3.0	-2.7	0.9	-59.5
Difference 2	-5.7	6.9	5.3	-13.2	1.1	-12.1	21.7	3.6	6.5	-5.4	9.0	-3.0	14.9

Table 1.15. Share of days with heavy precipitation (100 * R95p / Sum of Precipitation) (R95ptot),%

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-	-	-	-	-	-	-	-	-	-	-	-	21.3
1990-2019	-	-	-	-	-	-	-	-	-	-	-	-	18.3
2021-2050													17.1
Difference 1	-	-	-	-	-	-	-	-	-	-	-	-	-3.0
Difference 2													-1.2

[4] index is not calculated by months

Table 1.16. Share of days with extreme precipitation (100 * R99p / Sum of Precipitation) (R99ptot),%

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-	-	-	-	-	-	-	-	-	-	-	-	5.9
1990-2019	-	-	-	-	-	-	-	-	-	-	-	-	4.4
2021-2050													2.9
Difference 1	-	-	-	-	-	-	-	-	-	-	-	-	-1.5
Difference 2													-1.6

Table 1.17. Precipitation from days with heavy precipitation (daily precipitation> 95 percentile) (R95p), mm

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-	-	-	-	-	-	-	-	-	-	-	-	149.4
1990-2019	-	-	-	-	-	-	-	-	-	-	-	-	119.8
2021-2050													120.7
Difference 1	-	-	-	-	-	-	-	-	-	-	-	-	-29.6
Difference 2													0.9

Table 1.18. Precipitation from days with extreme precipitation (Daily Precipitation> 99 Percentile) (R99p), mm

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	-	-	-	-	-	-	-	-	-	-	-	-	43.7
1990-2019	-	-	-	-	-	-	-	-	-	-	-	-	31.3
2021-2050													23.3
Difference 1	-	-	-	-	-	-	-	-	-	-	-	-	-12.4
Difference 2													-8.0

Table 1.19. Number of wet days (daily rainfall ≥10 mm) (R10mm), mm

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	0.3	0.5	0.7	1.8	4.3	3.9	2.6	2.1	1.6	1.4	0.9	0.3	20.4
1990-2019	0.6	0.4	0.8	2.4	3.5	4.1	1.6	1.6	1.5	1.2	0.8	0.5	18.8
2021-2050	0.5	0.7	0.9	1.7	4.0	3.6	2.7	1.9	1.6	1.1	1.1	0.4	20.0
Difference 1	0.3	-0.1	0.1	0.6	-0.8	0.2	-1.0	-0.5	-0.1	-0.2	-0.1	0.2	-1.6
Difference 2	-0.1	0.3	0.1	-0.7	0.5	-0.5	1.1	0.3	0.1	-0.1	0.3	-0.1	1.2

Table 1.20. Number of wet days (daily rainfall ≥30 mm) (R30mm), mm

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	0	0	0	0.20	0.4	0.6	0.20	0.3	0.1	0.03	0.03	0	1.8
1990-2019	0.03	0	0.1	0.03	0.2	0.5	0.03	0.2	0	0.03	0.03	0	1.2
2021-2050	0	0	0	0.2	0.3	0.4	0.2	0.3	0.2	0.1	0.1	0	1.7
Difference 1	0.03	0	0.1	-0.17	-0.2	-0.1	-0.17	-0.1	-0.1	0	0	0	-0.6
Difference 2	-0.03	0	-0.1	0.17	0.1	-0.1	0.14	0.1	0.2	0.04	0.04	0	0.5

Table 1.21. Maxumum 1-day precipitation (Rx1day), mm

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	18.5	21.6	23.9	59.4	55.2	55.4	47.2	63.4	55.3	38.1	33.1	25.2	63.4
1990-2019	31.5	29.3	41.0	37.6	49.2	68.7	32.0	52.1	29.2	45.2	30.1	20.4	68.7
2021-2050	18.1	33.1	24.5	41	51.1	43.8	45.3	57.1	59.1	33.8	36.8	17.5	59.1
Difference 1	13	7.7	17.1	-21.8	-6	13.3	-15.2	-11.3	-26.1	7.1	-3	-4.8	5.3
Difference 2	-13.4	3.8	-16.5	3.4	1.9	-24.9	13.3	5	29.9	-11.4	6.7	-2.9	-9.6

Table 1.22. Maxumum 5-days precipitation (Rx5day), mm

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	42.6	53.4	42.8	71.1	86.7	105.8	62.2	81.0	78.4	63.9	71.5	41.9	105.8
1990-2019	66.1	41.0	57.0	67.0	81.5	99.6	59.3	62.5	56.3	68.0	78.8	39.5	99.6
2021-2050	38.5	60.3	48.7	66	116.9	91.8	74.2	83.4	101.8	54.9	87.5	38.3	116.9
Difference 1	23.5	-12.4	14.2	-4.1	-5.2	-6.2	-2.9	-18.5	-22.1	4.1	7.3	-2.4	-6.2
Difference 2	-27.6	19.3	-8.3	-1.0	35.4	-7.8	14.9	20.9	45.5	-13.1	8.7	-1.2	17.3

Table 1.23. Maximum number of consecutive dry days (CDD), day

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	51	58	17	31	16	14	22	20	20	42	38	39	58
1990-2019	31	38	25	28	15	20	20	23	39	33	23	36	39
2021-2050	37	58	26	25	16	14	20	20	19	42	38	39	58
Difference 1	-20	-20	8	-3	-1	6	-2	3	19	-9	-15	-3	-19
Difference 2	6	20	1	-3	1	-6	0	-3	-20	9	15	3	19

Table 1.24. Maximum number of consecutive wet days (CWD), day

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	8	7	5	10	11	13	9	8	9	9	7	7	13
1990-2019	8	6	7	7	12	10	7	5	6	13	6	6	13
2021-2050	8	7	7	10	11	12	9	8	9	9	7	7	12
Difference 1	0	-1	2	-3	1	-3	-2	-3	-3	4	-1	-1	0
Difference 2	0	1	0	3	-1	2	2	3	3	-4	1	1	-1

Table 1.25. Average relative humidity (RH),%

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	75.1	76.7	78.2	77.8	79.7	79.1	77.4	78.2	79.6	79.9	77.9	75.7	77.9
1990-2019	73.8	72.3	72.6	73.8	76.4	75.2	75.4	75.4	77.3	78.6	76.2	75.6	75.2
2021-2050	72.8	74.2	73.8	73.4	76.7	76.6	73.2	78.3	76.9	80.2	75.7	75.1	75.6
Difference 1	-1.3	-4.4	-5.6	-4.0	-3.3	-3.9	-2.0	-2.8	-2.3	-1.3	-1.7	-0.1	-2.7
Difference 2	-2.3	-2.5	-4.4	-4.4	-3.0	-2.5	-4.2	0.1	-2.7	0.3	-2.2	-0.6	-2.3

Table 1.26. Average wind speed (WS), m/sec

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
1960-1989	1.9	1.6	1.6	1.5	1.3	1.3	1.1	1.2	1.3	1.3	1.5	1.9	1.5
1990-2019	1.2	1.1	1.1	0.9	1.0	1.0	0.8	0.7	0.8	0.8	0.8	0.8	0.9
2021-2050	1.7	1.5	1.3	1.3	1.1	1.0	0.9	0.9	1.0	1.2	1.5	1.9	1.3
Difference 1	-0.8	-0.5	-0.5	-0.6	-0.3	-0.3	-0.4	-0.5	-0.4	-0.5	-0.7	-1.1	-0.5
Difference 2	0.5	0.4	0.2	0.3	0.1	0.0	0.1	0.2	0.1	0.4	0.7	1.0	0.3

Proud to be diverse!

27 Betlemi Street,
0105, Tbilisi, Georgia
info@cenn.org
cenn.org
tsalkalag.ge