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# COMPARISON OF THE MEAN MAX ANNUAL, SEASONAL AND MONTHLY AIR TEMPERATURE VARIABILITY IN TBILISI AND SHOVI IN 1956-2022

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*Abstract: Some results of comparative analysis of the average maximum annual, seasonal and monthly air temperature variability in Tbilisi and Shovi during 1956-2022 against the background of global warming are presented.. The statistical characteristics of the mean max annual, seasonal and monthly air temperature in the period 1956-2022 (T), 1956-1985 ($T_1$) and 1993-2022 ($T_2$) for each point were studied.*

*It is shown that compared to Tbilisi, climate warming in Shovi is much more significant. For example, the increase in the mean annual max air temperature in Tbilisi in 1993-2022 compared to 1956-1885 was 0.8 ˚C, while in Shovi it was 1.9 ˚C. The situation is similar for the warm and cold half of the year. The maximum increase in the mean max monthly air temperature at both points was observed in August. At the same time, in Tbilisi - 1.9 ˚C, and in Shovi - 3.7 ˚C.*

*It is shown that the trend of the mean max annual and seasonal air temperature in 1956-2022 in Tbilisi is described by the second power polynomial, and in Shovi - by the third power polynomial. Using these equations, the average annual rate of increase in air temperature at both points was calculated. In particular, it was found that in 2011-2020 this speed in Shovi is three times higher than in Tbilisi.*

***Key words:*** *Mean max annual air temperature, climate change, thermal regime, statistical analysis.*

## Introduction

The problem of climate change is very relevant for almost all countries [1] including Georgia with the wide variety of climatic regions on its territory [2].

Our recent papers have studied the variability of average and average maximum air temperature in various regions of Georgia [3-7], assessed expected changes in air temperature using various methods, etc. [2, 8, 9]. In particular, it was found that long-term variability of air temperature in Tbilisi practically coincides with variations in the global average air temperature within the latitude range 24°N-64°N [3,4]. This makes possible to use air temperature data in Tbilisi as a reference to determine of the impact of global climate change impact on the thermal regime in various regions of Georgia. In addition, estimates were made of the average maximum annual, seasonal and monthly air temperature variability in 39 points of Georgia.

Studies have shown that, in general, as the altitude of the area increases, the influence of global climate change on air temperature increases [6,7]. This is confirmed by the intensification of glacier melting [10,11]. An example of the negative impact of this intensification on the environment is the disaster in Shovi on August 3, 2023, as a result of which more than 30 people died due to a mudflow commence by the melting of a glacier.

This fact once again confirmed the necessitate further develop research in the field of climate change, especially in mountainous areas (measurement of climate parameters, their analysis, short and long-term forecasts).

The new research results of a comparative analysis of the average maximum annual, seasonal and monthly air temperature variability in Tbilisi and Shovi against the background of global warming in 1956-2022 are provided in presented article.

**Study area, material and methods**

Study area – Tbilisi (41.72 *°N*, 44.8 *°E, 403 m a.s. l.*) and Shovi (42.7 *°N, 43.68 °E, 1507 m a. s. l.*). *For the analysis the mean max annual, seasonal and monthly air temperature data of the National Environment Agency data of Georgia are used. Period of observations covers 1956-2022 years.*

In the proposed work the data analysis is carried out with the use of the standard statistical analysis methods of random events and methods of mathematical statistics for the non-accidental time-series of observations [12].

The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; St Dev - standard deviation; $R^2$ – coefficient of determination; $K_{DW}$ – Durbin-Watson statistic; α - the level of significance; T, $T_1$ and $T_2$ - mean max annual, seasonal and monthly air temperature in 1956-2022, 1956-1985 and 1993-2020 accordingly. Difference between mean max *air temperature in 1993-2020 and 1956-1885* was produced with the use of Student's criterion with the level of significance α not worse than 0.15. The statistical program Data Fit 7 was used for calculations.

The regression equation on the trend curve represents the dependence the investigated parameter on time at the significant value of the determination coefficient and such values of $K_{DW}$, where the residual values are accidental. Using these equations, the average annual rate of changeability of air temperature at both points was calculated ($T_s$, ˚C/year).

**Results and discussion**

The research results are presented on Tables 1-4 and Fig. 1-4. Tables 1 and 2 show statistical characteristics of the mean max annual, seasonal and monthly air temperatire in Tbilisi and Shovi in 1956-2022, 1956-1985 and 1993-2022 periods.

Table 1. Statistical characteristics of mean max annual, seasonal and monthly air temperatire in Tbilisi.

| Location | Tbilisi | | | | | | |
|---|---|---|---|---|---|---|---|
| Period | 1956-2022 | | | | | 1956-1985 | 1993-2022 |
| Season/Month | Mean | Min | Max | St Dev | Cv (%) | Mean | Mean |
| Year | 19.0 | 17.1 | 20.6 | 0.9 | 4.8 | 18.7 | 19.5 |
| Cold | 11.5 | 9.2 | 14.5 | 1.1 | 10.0 | 11.3 | 11.9 |
| Warm | 26.6 | 24.4 | 29.0 | 1.1 | 4.1 | 26.1 | 27.1 |
| Jan | 6.8 | 0.4 | 11.0 | 2.3 | 33.1 | 6.6 | 7.3 |
| Feb | 8.3 | 1.9 | 13.2 | 2.8 | 33.2 | 7.8 | 9.1 |
| Mar | 12.7 | 8.3 | 18.9 | 2.2 | 17.6 | 12.1 | 13.3 |
| Apr | 18.9 | 14.6 | 24.5 | 2.3 | 12.3 | 18.7 | 18.8 |
| May | 23.8 | 20.5 | 27.9 | 1.8 | 7.4 | 23.9 | 24.0 |
| Jun | 28.2 | 25.4 | 32.4 | 1.7 | 6.2 | 27.5 | 28.9 |
| Jul | 31.2 | 28.1 | 35.2 | 1.6 | 5.2 | 30.6 | 31.7 |
| Aug | 31.1 | 27.5 | 36.7 | 2.1 | 6.7 | 30.2 | 32.1 |
| Sep | 26.3 | 22.5 | 30.3 | 1.8 | 6.9 | 25.7 | 26.8 |
| Oct | 19.7 | 15.2 | 23.7 | 1.8 | 9.1 | 19.5 | 20.1 |
| Nov | 13.1 | 6.9 | 16.9 | 1.8 | 13.6 | 13.2 | 13.1 |
| Dec | 8.3 | 3.3 | 12.4 | 1.9 | 22.8 | 8.4 | 8.3 |

Table 2. Statistical characteristics of mean max annual, seasonal and monthly air temperatire in Shovi.

| Location | Shovi | | | | | | |
|---|---|---|---|---|---|---|---|
| Period | 1956-2022 | | | | | 1956-1985 | 1993-2022 |
| Season/Month | Mean | Min | Max | St Dev | Cv (%) | Mean | Mean |
| Year | 12.9 | 10.0 | 17.6 | 1.6 | 12.7 | 12.1 | 14.0 |
| Cold | 5.9 | 2.6 | 10.2 | 1.5 | 26.1 | 5.5 | 6.7 |
| Warm | 19.8 | 16.9 | 25.0 | 2.0 | 10.2 | 18.6 | 21.3 |
| Jan | 1.1 | -5.5 | 5.3 | 2.2 | 200.5 | 1.2 | 1.4 |
| Feb | 3.1 | -4.7 | 8.4 | 2.6 | 82.2 | 2.7 | 3.9 |
| Mar | 6.2 | 1.3 | 13.0 | 2.5 | 40.6 | 5.6 | 6.8 |
| Apr | 12.4 | 7.1 | 19.7 | 2.8 | 22.8 | 11.5 | 13.4 |
| May | 17.6 | 12.2 | 23.5 | 2.4 | 13.7 | 16.7 | 19.0 |
| Jun | 21.1 | 17.5 | 27.8 | 2.5 | 11.9 | 19.9 | 22.7 |
| Jul | 24.0 | 20.1 | 29.1 | 2.3 | 9.6 | 22.7 | 25.5 |
| Aug | 24.1 | 19.0 | 30.9 | 2.9 | 11.8 | 22.5 | 26.2 |
| Sep | 19.7 | 13.8 | 26.9 | 2.7 | 13.8 | 18.5 | 21.2 |
| Oct | 14.5 | 9.0 | 22.3 | 2.7 | 18.7 | 13.5 | 15.9 |
| Nov | 8.0 | 2.4 | 16.9 | 2.9 | 36.1 | 7.7 | 8.9 |
| Dec | 2.5 | -1.6 | 10.5 | 2.2 | 87.9 | 2.3 | 3.1 |

The data of Tables 1 and 2 was used to analyze the mean max air temperature variability features in Tbilisi and Shovi (Fig. 1-4).

On Fig. 1 data on difference between mean max annual, seasonal and monthly air temperatire in Tbilisi and Shovi in 1993-2022 ($T_2$) and 1956-1985 ($T_1$) are presented.

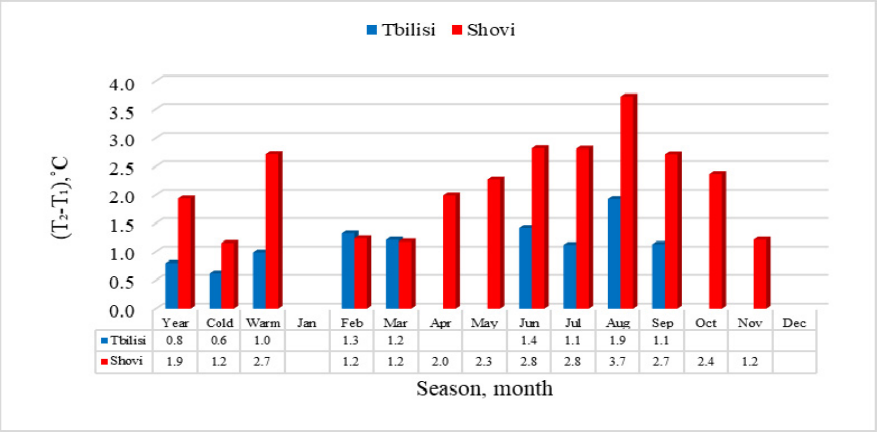


*Fig. 1. The difference between mean max seasonal and monthly air temperatire in Tbilisi and Shovi in 1993-2022 ($T_2$) and 1956-1985 ($T_1$).*

For comparison, we note that in Shovi in 1986-2015, compared with 1956-1985, the increase in mean max air temperature was [6,7]: Year – 1.1 ˚C, Warm – 1.7 ˚C, Apr – 1.3 ˚C, May – 1.2 ˚C, Jun – 1.6 ˚C, Jul – 1.9 ˚C, Aug – 2.4 ˚C, Sep – 1.9 ˚C, Oct – 1.5 ˚C.

As follows from Fig. 1 and data [6,7] in just seven years, a significant climate warming occurred in Shovi. Over the last thirty-year period, the mean max annual air temperature increased by 0.8 ˚C, in the warm half of the year - by 1.0 ˚C, in April - by 0.7 ˚C, in May - by 1.1 ˚C, in June - by 1.2 ˚C, in July – by 0.9 ˚C, in August – by 1.3 ˚C, in September – by 0.8 ˚C, in October – by 0.9 ˚C. In the cold half of the year, February, March and November, the increase in temperature became significant. Only in January and December there has not yet been a significant increase in the mean max air temperature.

This fact indicates the need to strengthen monitoring of climate parameters (especially air temperature and precipitation) and regular analysis of their variability. First of all, this concerns mountainous regions, where intensification of glacier melting occurs and natural disasters associated with this process (landslides, mudflows, etc.) is expected.

The mean max annual and seasonal air temperature trend in 1956-2022 in Tbilisi is described by the second power polynomial, and in Shovi - by the third power polynomial (Table 3, Fig. 2-4). The corresponding values of the $K_{DW}$ coefficients indicate that the residual components of these trends are accidental.

Table 3. Regression equation of mean max annual and seasonal air temperature trends in Tbilisi and Shovi trends in 1956-2022, $\alpha(R^2) < 0.005$, x - year.

| Location | Tbilisi | | | Shovi | | |
|---|---|---|---|---|---|---|
| Regression equation | $Y = a \cdot x^2 + b \cdot x + c$ | | | $Y = a \cdot x^3 + b \cdot x^2 + c \cdot x + d$ | | |
| Season | Year | Cold | Warm | Year | Cold | Warm |
| $R^2$ | 0.321 | 0.153 | 0.303 | 0.621 | 0.355 | 0.694 |
| $K_{DW}$ | 1.97 | 1.71 | 2.38 | 1.46 | 1.64 | 1.60 |
| $\alpha(K_{DW})$ | 0.05 | 0.05 | 0.05 | 0.01 | 0.05 | 0.025 |
| a | 0.001001 | 0.001056 | 0.000954 | 3.99E-05 | 5.06E-05 | 2.85E-05 |
| b | -3.96238 | -4.18763 | -3.76786 | -0.2362 | -0.30063 | -0.16818 |
| c | 3939.098 | 4161.749 | 3747.145 | 466.168 | 594.884 | 330.3432 |
| d | | | | -306673 | -392372 | -216277 |

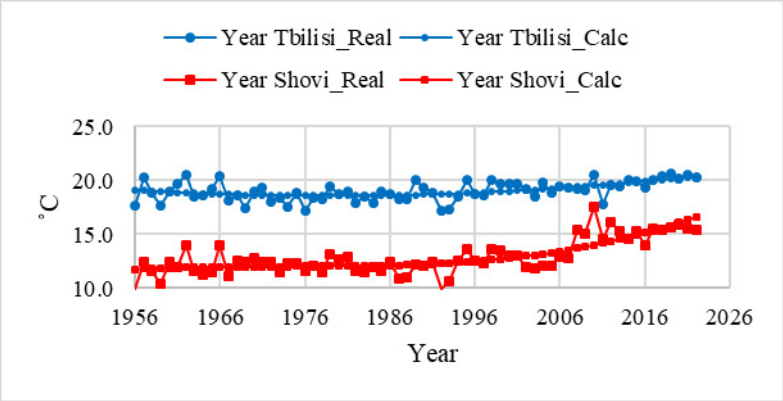


*Fig. 2. Trend of mean max annual air temperature in Tbilisi and Shovi in 1956-2022.*

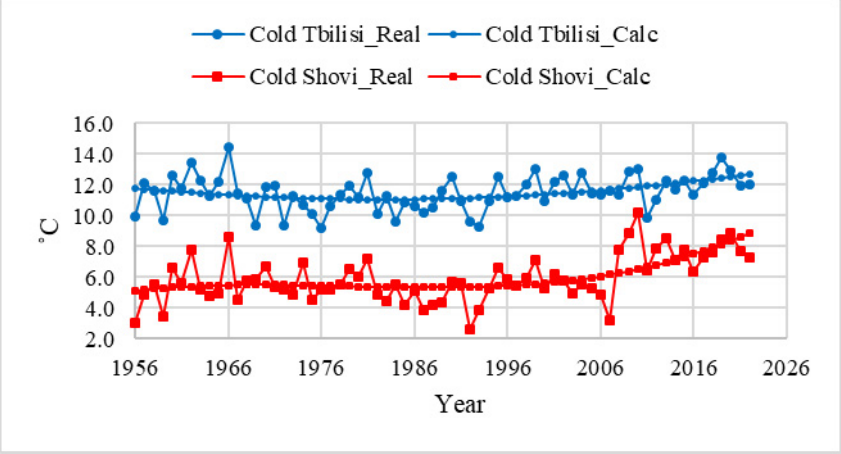


*Fig. 3. Trend of mean max air temperature in Tbilisi and Shovi in cold period in 1956-2022.*

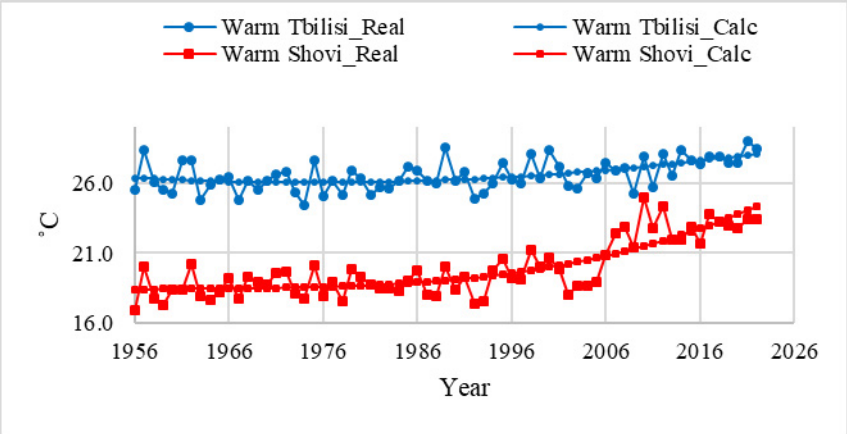


*Fig. 4. Trend of mean max air temperature in Tbilisi and Shovi in warm period in 1956-2022.*

As it follows from Fig. 2-4 the intensification of air temperature increase in both points, especially in Shovi, began in the nineties of the last century.

On Fig. 5 the mean max air temperature change rate in Tbilisi and Shovi in three periods of the year from 1956 to 2022 are presented.

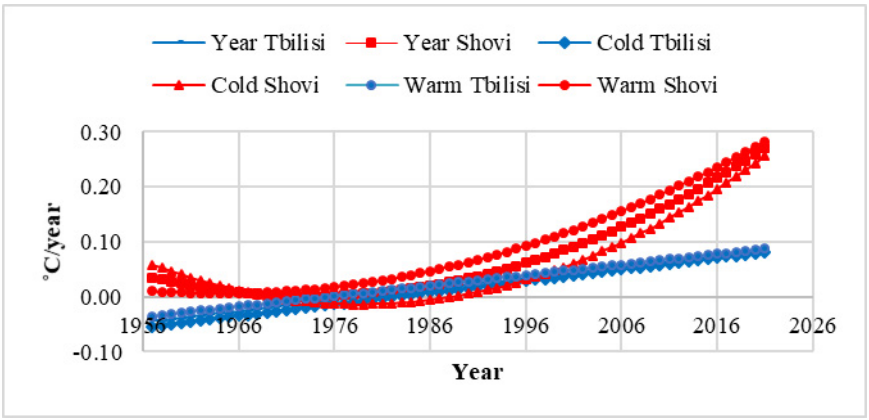


*Fig. 5. The mean max air temperature change rate in Tbilisi and Shovi in three periods of the year from 1956 to 2022.*

In Table 4 average decade of change rate in mean max air temperature in Tbilisi and Shovi in three periods of the year from 1991 to 2020 are presented.

Table 4. Average decade of change rate in mean max air temperature in Tbilisi and Shovi in three periods of the year from 1991 to 2020.

| Period | Location | Tbilisi | Shovi | Tbilisi | Shovi | Tbilisi | Shovi |
|---|---|---|---|---|---|---|---|
| | Season | Year | | Cold | | Warm | |
| 1991-2000 | $T_s$, °C/year | 0.03 | 0.06 | 0.03 | 0.03 | 0.04 | 0.09 |
| | $T_s$(Shovi)/$T_s$(Tbilisi) | | 1.8 | | 1.1 | | 2.3 |
| 2001-2010 | $T_s$, °C/year | 0.05 | 0.12 | 0.05 | 0.10 | 0.06 | 0.15 |
| | $T_s$(Shovi)/$T_s$(Tbilisi) | | 2.3 | | 2.0 | | 2.6 |
| 2011-2020 | $T_s$, °C/year | 0.07 | 0.21 | 0.07 | 0.19 | 0.08 | 0.23 |
| | $T_s$(Shovi)/$T_s$(Tbilisi) | | 2.9 | | 2.7 | | 3.0 |

In particular, as it is evident from Table 4, the highest increasing rate in the average maximum air temperature in Shovi in relation to Tbilisi is observed in 2011-2020 (according to annual data - 2.9 times, in the cold half of the year - 2.7 times, in the warm half of the year - 3 times).

## Conclusion

Taking into account the results obtained above, in the near future we envisage conducting the urgent analysis of air temperature variability in the mountainous regions of Georgia using new data (after 2015). In the future, we also plan to further expand our work on studying the climate change impact on its various elements in different regions of Georgia, as well as predicting these changes.

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