

## **Changeability of the Meteorological Parameters Associated with Holiday Climate Index in Different Mountainous Regions of Georgia in 1956-2015**

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### **ABSTRACT**

*Statistical data on meteorological parameters associated with the Holiday Climate Index (monthly mean maximum air temperature, monthly mean relative air humidity, cloud cover, monthly precipitation, wind speed) in thirteen mountainous regions of Georgia (Bakmaro, Bakuriani, Borjomi, Goderdzi, Gudauri, Khaishi, Khulo, Lentekhi, Mestia, Pasaunauri, Shovi, Stepantsminda, Tianeti) from 1956 to 2015 are presented. In particular, the changeability of the indicated meteorological parameters during 1986÷2015 in comparison with 1956÷1985 for above enumerated points is studied.*

**Key Words:** *Meteorological parameters, Holiday Climate Index.*

### **Introduction**

In recent decades, the problem of global climate change has acquired special significance [1,2]. At the same time, the air temperature and other climatic elements changing has considerable spatial and temporal inhomogeneities both in the global (Global Land, Global Land of the Northern and Southern Hemisphere, Zonal territories, etc.) [1-6], and regional scales (even the territory of small countries with complex terrain) scales [7-9].

This problem is also of great importance in Georgia due to the diversity of climatic regions on its territory [10-17].

Sustainable development of various spheres of the national economy, including resort and tourism industry is largely determined by climate change, which is of vital importance.

The resort and tourist potential of the area is especially preconditioned by its bioclimatic conditions. Therefore, it is important to identify existing and future changes of these conditions under the impact of climate change.

In particular, information on the changeability of the different simple thermal indices as well as the Tourism Climate Index (TCI) [18] and the Holiday Climate Index (HCI) [19] in the recent decades in different countries (including some locations of Georgia) is represented in [8,20-30].

Simple thermal indices include more than one meteorological parameter and consider the combined action of the air temperature, humidity, wind speed and etc. on the human organism [31-34]. For example, to determine the monthly mean values of TCI following data are necessary: mean and maximum mean air temperature, mean and mean minimum relative humidity, precipitation, sunshine duration and wind speed [18].

Primarily, in the work [35] the investigating results of changeability of the mean monthly values of meteorological parameters, used to determine TCI values and different simple thermal indices on the two

regions of Georgia (Adjarian Autonomous Republic and Kakheti) during the period from 1961 through 2010 are presented.

This work is the continuation of the previous research. Results of statistical analysis of meteorological parameters data associated with the Holiday Climate Index in thirteen mountainous regions of Georgia (Bakhmaro, Bakuriani, Borjomi, Goderdzi, Gudauri, Khaishi, Khulo, Lentekhi, Mestia, Pasanauri, Shovi, Stepantsminda, Tianeti) from 1956 to 2015 are presented below.

### Study Area, material and methods

The research for thirteen mountainous regions of Georgia (Bakhmaro, Bakuriani, Borjomi, Goderdzi, Gudauri, Khaishi, Khulo, Lentekhi, Mestia, Pasanauri, Shovi, Stepantsminda, Tianeti) is carried out. Table 1 presents the information on the coordinates and heights of the location of those 13 meteorological stations whose data were used in the work.

Table 1. Coordinates and heights of the 13 mountainous meteorological stations in Georgia.

Location (Abbreviation)	Latitude, N°	Longitude, E°	Height, m, a.s.l.
<b>Bakhmaro (Bakh)</b>	42.32	41.85	1926
<b>Bakuriani (Bak)</b>	43.52	41.73	1665
<b>Borjomi (Borj)</b>	43.40	41.83	789
<b>Goderdzi (God)</b>	42.52	41.63	2025
<b>Gudauri (Gud)</b>	44.48	42.47	2194
<b>Khaishi (Kha)</b>	42.18	42.95	730
<b>Khulo (Khu)</b>	42.32	41.65	914
<b>Lentekhi (Lent)</b>	42.73	42.78	760
<b>Mestia (Mest)</b>	42.75	43.05	1441
<b>Pasanauri (Pas)</b>	44.70	42.35	1070
<b>Shovi (Sho)</b>	43.68	42.70	1507
<b>Stepantsminda (Step)</b>	44.65	42.67	1744
<b>Tianeti (Tian)</b>	44.97	42.12	1099

In the work Georgian National Environmental Agency on monthly mean meteorological parameters data associated with the Holiday Climate Index [19, 36-38] (max air temperature, air relative humidity, total cloud cover, precipitation sum and wind speed) in the period from 1956 through 2015 are used.

For the data analysis the standard statistical methods of the studies were used [39]. The difference between the mean values of the meteorological parameters into 1986-2015 and 1956-1985 with the use of Student's criterion was determined (level of significance not worse than 0.15).

The following designations are used below:  $T_{max}$  - mean maximum air temperature (°C), RH- mean relative humidity (%), CC – mean total cloud cover (amount); P - sum precipitation - (mm), V - mean wind speed (m/sec).  $\Delta T_{max}$ .  $\Delta V$  - the difference between the mean values of the meteorological parameters during 1986-2015 and 1956-1985 periods.

### Results and discussion

The obtained Results are available on the Tables 2-6 and Fig. 1-10.

#### *Mean max air temperature*

The mean annual, half year and monthly min and max air temperature ( $T_{max}$ ) data are presented in Table 2 and Fig. 1. The range of variability of the mean values of  $T_{max}$  for the indicated stations is as follows:

Mean Year - from 6.6 °C (Goderdzi) to 16.4 °C (Borjomi); Mean Cold - from 0.0 °C (Goderdzi) to 9.7 °C (Khulo); Mean Warm - from 13.3 °C (Goderdzi) to 23.9 °C (Khaishi); Min - from -11.8 °C (Goderdzi) to -0.5 °C (Borjomi); Max - from 23.4 °C (Goderdzi) to 35.0 °C (Borjomi).

Table 2. The mean min, monthly mean, max and mean seasonal values of  $T_{max}$  (°C) in thirteen locations of Georgia in 1956-2015.

Location	Mean Year	Mean Cold	Mean Warm	Min	Max
Bakhmaro	8.6	3.0	14.2	-8.2	24.2
Bakuriani	11.3	5.1	17.5	-5.7	27.7
Borjomi	16.4	9.4	23.5	-0.5	35.0
Goderdzi	6.6	0.0	13.3	-11.8	23.4
Gudauri	7.8	2.0	13.7	-8.8	25.4
Khaishi	16.3	8.7	23.9	-1.3	33.7
Khulo	15.8	9.7	22.0	-1.6	31.4
Lentekhi	15.8	7.9	23.7	-1.9	34.5
Mestia	13.4	5.9	20.9	-6.4	30.2
Pasanauri	14.5	7.4	21.6	-2.9	33.0
Shovi	12.6	5.7	19.5	-5.5	30.8
Stepantsminda	10.6	4.5	16.7	-5.7	27.4
Tianeti	14.4	7.6	21.2	-1.7	31.6

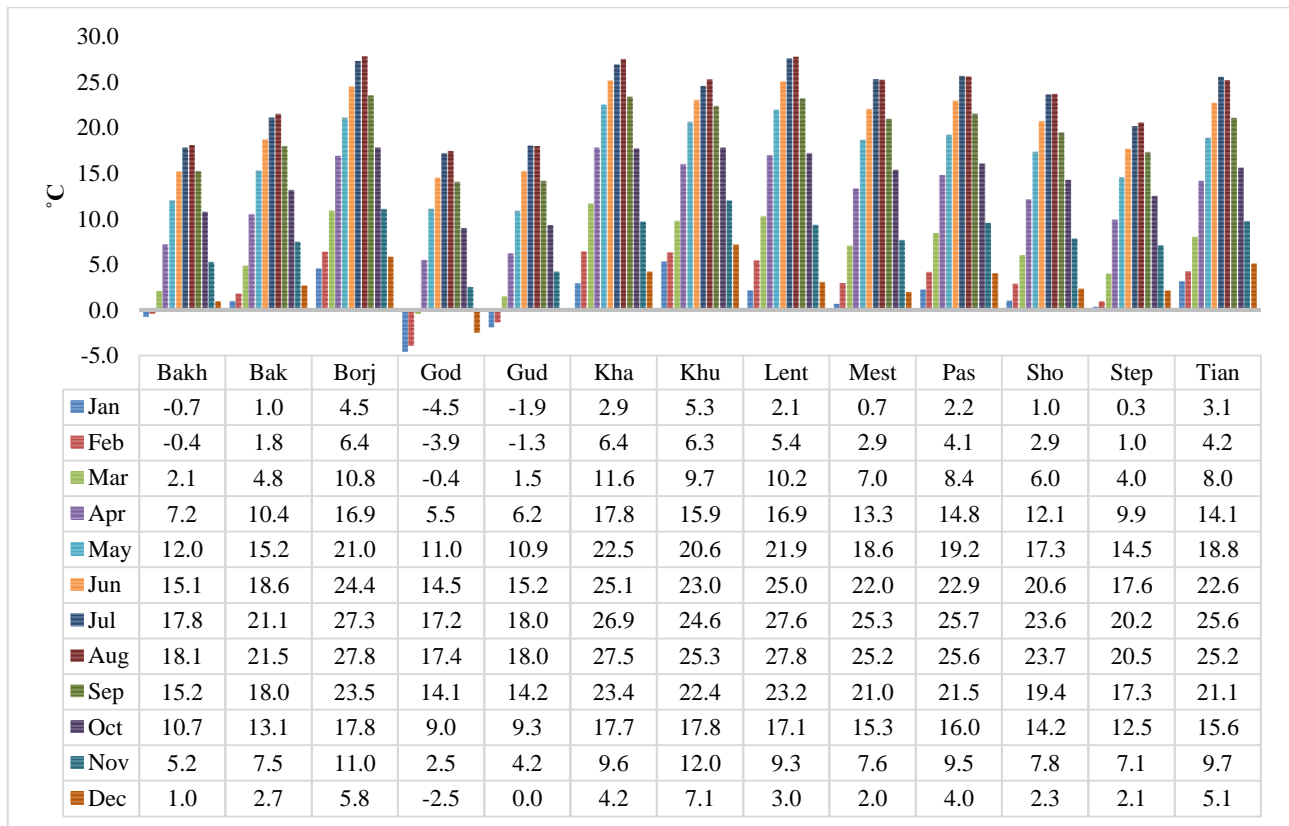


Fig. 1.  $T_{max}$  monthly mean values of in thirteen locations of Georgia in 1956-2015.

The intra-annual distribution of  $T_{max}$  values for all 13 investigations points of Georgia are presented on Fig. 1. The smallest  $T_{max}$  values for all points during January are detected. The  $T_{max}$  greatest values for Bakhmaro, Bakuriani, Borjomi, Goderdzi, Khaishi, Khulo, Lentekhi, Shovi and Stepantsminda during August are fixed; for Mestia, Pasanauri and Tianeti – during July, and for Gudauri – during July and August (Fig. 1).

The information on the changeability of the  $\Delta T_{max}$  values of in separate points is presented below (Fig. 2).

The variability of the mean monthly max air temperature is observed for 13 points of Georgia in 69 cases (including 66 cases - an increase and only for 3 cases - a decrease in  $\Delta T_{max}$  values).

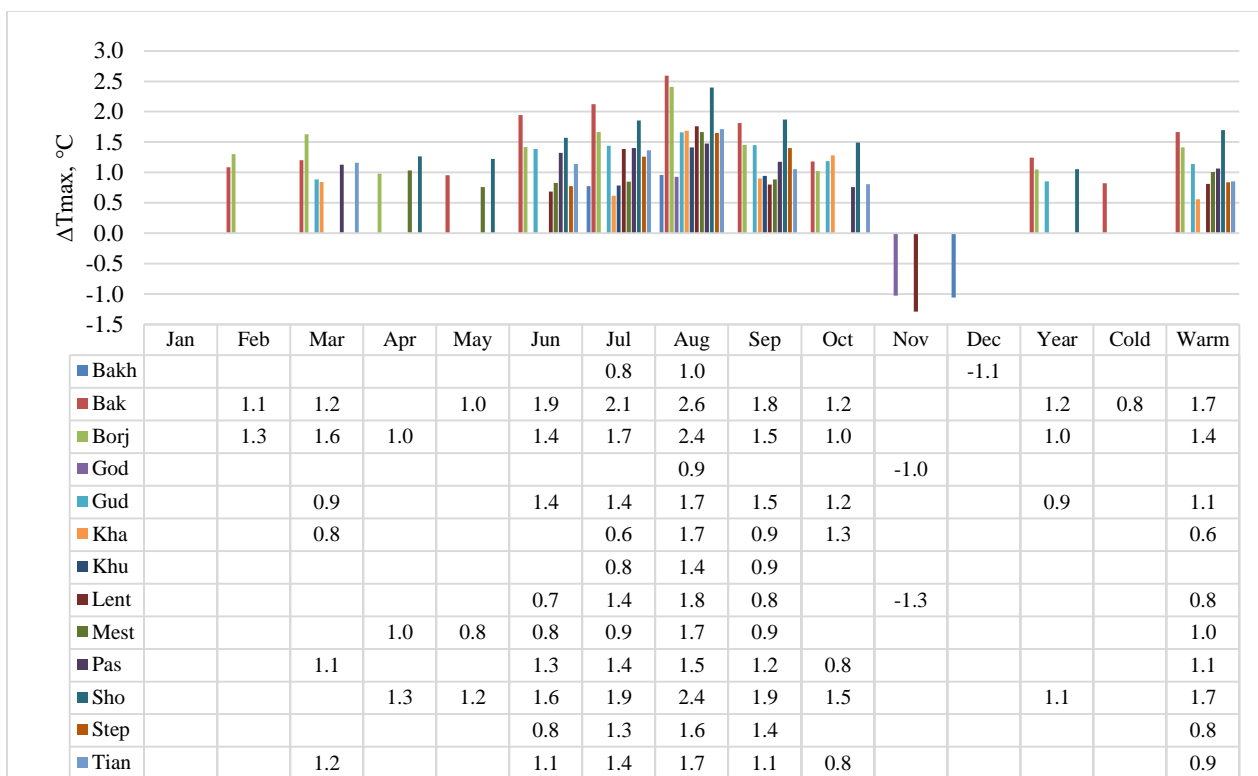


Fig. 2. Difference between the  $T_{max}$  mean values for 1986-2015 and 1956-1985 in thirteen locations of Georgia

The variations of the  $\Delta T_{max}$  values in the separate points are the following: Bakhmaro - increase of the values of  $\Delta T_{max}$  (July, August), decrease (-1.1 °C, December); Bakuriani - increase (February, March, May-October, mean annual, cold and warm seasons mean); Borjomi - increase (February-April, June-October, mean annual and warm season mean); Goderdzi - increase (August), decrease (-1.0 °C, November); Gudauri - increase (March, June-October, mean annual and warm season mean); Khaishi - increase (March, July-October, warm season mean); Khulo - increase (July-September); Lentekhi - increase (July-September, warm season mean), decrease (-1.3 °C, November); Mestia - increase (April-September, warm season mean); Pasanauri - increase (March, June-October, warm season mean); Shovi - increase (April-October, mean annual and warm season mean); Stepantsminda - increase (June-September, warm season mean); Tianeti - increase (March, June-October, warm season mean).

Totally, the  $\Delta T_{max}$  values change from -1.3 °C (Khulo, November) to 2.6 °C (Baruriani, August), amplitude - 3.9 °C.

### *Air mean relative humidity*

The mean annual, half year and monthly min and max air relative humidity (RH) data are available in Table 3 and on Fig. 3.

The range of variability of the RH mean values for the indicated stations is as follows: Mean Year - from 69.4 % (Stepantsminda) to 86.9 % (Goderdzi); Mean Cold - from 65.7 % (Stepantsminda) to 88.4 % (Goderdzi); Mean Warm - from 72.2 % (Mestia) to 85.4 (Goderdzi); Min - from 38.2 % (Khulo) to 61.3 % (Goderdzi); Max - from 91.0 % (Bakhmaro, Bakuriani) to 100 % (Goderdzi, Lentekhi).

The intra-annual distribution of RH values for all indicated investigations points of Georgia are presented in Fig. 3. The RH smallest values for all points during January are observed (62.8 %, Stepantsminda). The RH greatest values for Goderdzi (91.1 %) in February are fixed (Fig. 3).

Table 3. The mean monthly min, mean monthly max and mean seasonal RH (%) values in thirteen locations of Georgia in 1956-2015.

Location	Mean Year	Mean Cold	Mean Warm	Min	Max
Bakhmaro	74.1	73.3	74.8	50.0	91.0
Bakuriani	78.4	78.9	78.0	56.0	91.0
Borjomi	77.9	80.4	75.5	55.3	94.2
Goderdzi	86.9	88.4	85.4	61.3	100
Gudauro	74.2	71.4	76.9	47.2	91.7
Khaishi	77.8	81.2	74.4	48.0	97.0
Khulo	71.4	69.8	73.0	38.2	92.0
Lentekhi	80.2	85.2	75.2	48.6	100
Mestia	75.8	79.5	72.2	53.0	97.9
Pasanauri	75.2	75.9	74.5	56.0	92.0
Shovi	78.3	80.0	76.5	57.3	92.6
Stepantsminda	69.4	65.7	73.2	43.0	96.0
Tianeti	80.8	83.1	78.5	61.0	98.7

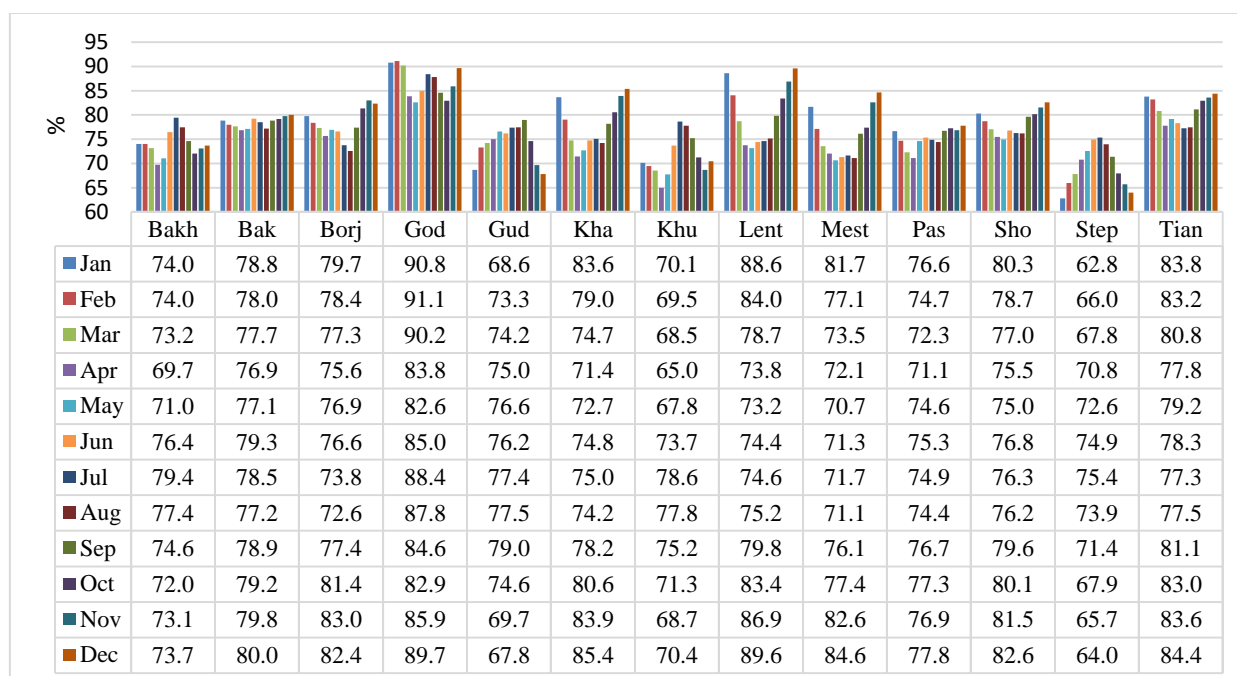


Fig. 3. The monthly mean values of relative humidity in thirteen locations of Georgia in 1956-2015.

The changeability of the  $\Delta RH$  values of in separate points is presented on the Fig. 4.

The variability of the monthly mean air relative humidity is detected for all investigated points in 86 cases (including 79 cases - an increase and only for 7 cases - a decrease of  $\Delta RH$  values).

The changeability of the  $\Delta RH$  values in the separate points is the following: Bakhmaro - increase of the  $\Delta RH$  values (January-June, October-December, mean annual and cold season mean), decrease (-2.5 %, August); Bakuriani - increase (January, February, April-June, October, December, mean annual, cold and warm seasons mean); Borjomi - increase (all month and seasons, except July, August and November); Goderdzi - increase (all month and seasons, except September); Gudauro - increase (January, February, mean annual and cold season mean); Khaishi - increase (January, March-June, November, December, mean annual and cold season mean); Khulo - increase (January, June, October, mean annual and cold season mean); Lentekhi - increase (January, November, cold season mean); Mestia - increase (January, November, December) decrease (March, April, August, September, mean annual and warm season mean); Pasanauri - increase (January, February, mean annual and cold season mean); Shovi - increase (January, February,

October, mean annual and cold season mean), decrease (August and September); Stepantsminda - increase (all month and seasons, except July, August and September); Tianeti - increase (all month and seasons).

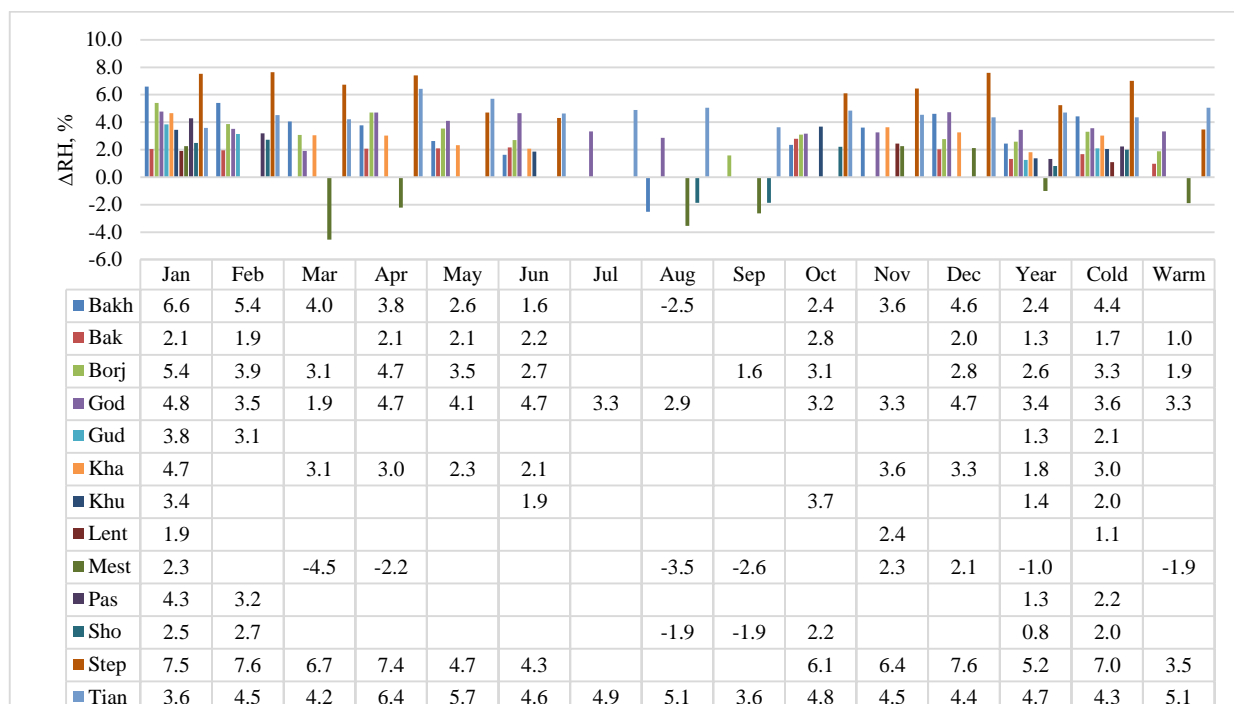


Fig. 4. Difference between the RH mean values for 1986-2015 and 1956-1985 in thirteen locations of Georgia

Completely, the  $\Delta RH$  values change from -4.5 % (Mestia, March) to 7.6 % (Stepantsminda, February, December), and the amplitude is 12.1 %.

### Total Cloud Cover

The mean annual, half year and monthly min and max total cloud cover amount (CC) data in are available from Table 4 and Fig. 5.

Table 4. The mean monthly min, mean monthly max and mean seasonal values of total cloud cover amount in thirteen locations of Georgia in 1956-2015.

Location	Mean Year	Mean Cold	Mean Warm	Min	Max
Bakhmaro	6.0	6.1	6.0	2.2	9.0
Bakuriani	6.1	6.1	6.1	2.0	9.1
Borjomi	6.2	6.4	6.0	2.3	9.1
Goderdzi	6.8	6.9	6.8	3.0	10
Gudauri	5.4	5.1	5.7	1.8	8.5
Khaishi	5.5	5.8	5.1	1.6	9.0
Khulo	6.1	6.1	6.0	2.0	9.0
Lentekhi	6.3	6.3	6.3	3.0	9.1
Mestia	6.1	6.3	5.9	2.0	9.1
Pasanauri	5.4	5.3	5.6	1.8	9.0
Shovi	6.4	6.5	6.4	2.0	10
Stepantsminda	5.4	4.9	5.9	1.8	9.0
Tianeti	5.7	5.8	5.6	2.0	9.0

The range of variability of the CC mean values for the indicated stations is as follows: Mean Year - from 5.4 (Gudauri, Pasaauri, Stepantsminda) to 6.8 (Goderdzi); Mean Cold - from 4.9 (Stepantsminda) to 6.9 (Goderdzi); Mean Warm - from 5.1 (Khaishi) to 6.8 (Goderdzi); Min - from 1.6 (Khaishi) to 3.0 (Goderdzi, Lentekhi); Max - from 8.5 (Gudauri) to 10 (Goderdzi, Shovi).

The intra-annual distribution of CC values for all indicated investigations points of Georgia is presented on Fig. 5 d. The smallest CC values for all points during August are fixed (4.4, Khaishi).

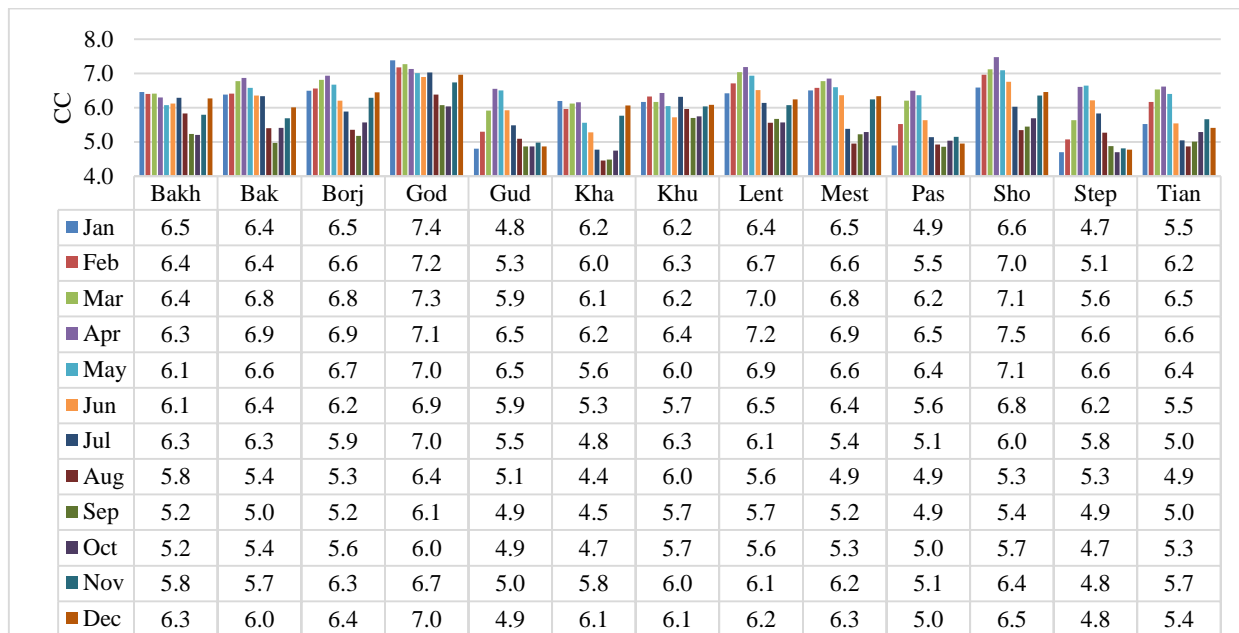


Fig. 5. Total cloud cover monthly mean values of in thirteen locations of Georgia in 1956-2015.

The CC greatest values for Shovi (7.5) are detected in April (Fig. 5).

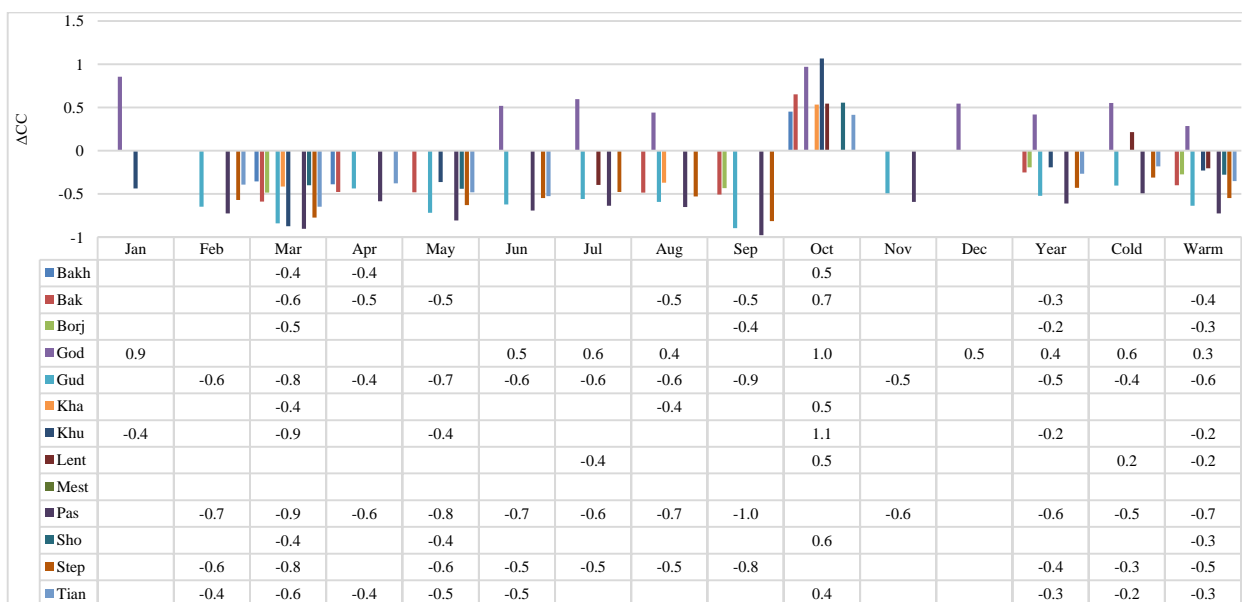


Fig. 6. Difference between the mean values of total cloud cover for 1986-2015 and 1956-1985 in thirteen locations of Georgia

The  $\Delta CC$  values variation in separate points is presented on Fig. 6. The variability of the mean monthly total cloud cover is detected for 12 investigated points (except Mestia) in 60 cases (including 48 cases - a decrease and for 12 cases - an increase in  $\Delta CC$  values).

The changeability of the  $\Delta RH$  values in the separate points is the following: Bakhmaro - decrease of the  $\Delta CC$  values (March, April), increase (October); Bakuriani - decrease (March-May, August, September, mean annual and warm seasons mean), increase (October); Borjomi - decrease (March, September, mean annual and warm season mean); Goderdzi - increase (all month and seasons, except February-May, September and November); Gudauri - decrease (all month and seasons, except January, October and December); Khaishi - decrease (March, August), increase (October); Khulo - decrease (January, March, May, mean annual and warm season mean), increase (October); Lentekhi - decrease (July and warm season mean), increase (October and cold season mean); Mestia – no changes; Pasanauri - decrease (all month and seasons, except January, October and December); Shovi - decrease (March, May and warm season mean), increase (October); Stepantsminda - decrease (all month and seasons, except January, April, October-December); Tianeti - decrease (February-June, mean annual, cold and warm seasons mean), increase (October).

### *Atmospheric precipitation sum*

The mean monthly annual, half year and monthly min and max P values are available in Table 5 and Fig. 7.

Table 5. monthly min, monthly max and mean monthly seasonal P (mm) values in thirteen locations of Georgia in 1956-2015.

Location	Mean Year	Mean Cold	Mean Warm	Min	Max
Bakhmaro	130	154	107	9.8	554
Bakuriani	70	59	82	0.5	283
Borjomi	55	48	62	1.5	181
Goderdzi	110	115	104	7.7	361
Gudauri	128	106	151	0	536
Khaishi	102	108	96	1.0	670
Khulo	117	149	84	0.5	628
Lentekhi	107	110	104	1.3	556
Mestia	82	76	88	1.0	284
Pasanauri	82	59	105	0	353
Shovi	98	85	111	3.4	444
Stepantsminda	62	34	89	0	252
Tianeti	64	42	85	0	277

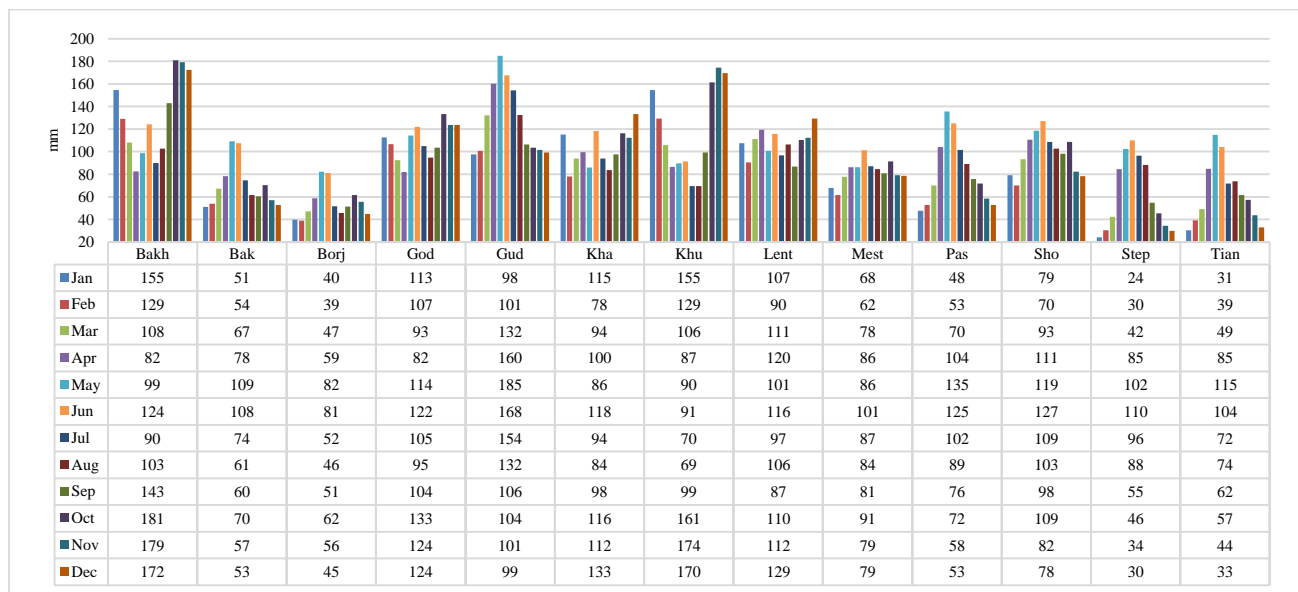


Fig. 7. Precipitation monthly mean values of in thirteen locations of Georgia in 1956-2015.



The variability range of the P mean values for the indicated stations is as follows: Mean Year - from 55 mm (Borjomi) to 130 mm (Bakhmaro); Mean Cold - from 34 mm (Stepantsminda) to 154 mm (Bakhmaro); Mean Warm - from 62 mm (Borjomi) to 151 mm (Gudauri); Min - from 0 mm (Gudauri, Pasanauri, Stepantsminda and Tianeti) to 9.8 mm (Bakhmaro); Max - from 181 mm (Borjomi) to 670 mm (Khaishi).

The intra-annual distribution of P values for all indicated investigations points of Georgia are presented in Fig. 7. The P smallest values for Stepantsminda during January are observed (24 mm). The P greatest values for Gudauri (185 mm) in May are observed (Fig. 7).

The changeability data of the  $\Delta P$  values in separate points is presented in Fig. 8. The variability of the atmospheric precipitation monthly mean sum is observed for 11 investigated points (except Bakhmaro, and Bakuriani) in 25 cases (including for 12 cases - an increase and for 13 cases - a decrease of  $\Delta P$  values).

The changeability of the  $\Delta P$  values in the separate points is the following: Bakhmaro and Bakuriani (no changes); Borjomi - decrease (June and December); Goderdzi - decrease (March, April mean annual and warm season mean); Gudauri - increase (August, October and cold season mean), decrease (September); Khaishi - increase (April and May); Khulo - increase (January, September, mean annual, cold and warm seasons mean); Lentekhi - increase (May and June), decrease (September); Mestia - increase (mean annual and cold season mean); Pasanauri - increase (August, October and cold season mean); Shovi - increase (October); Stepantsminda - decrease (July, September), increase (October); Tianeti - decrease (March, May-July, September, mean annual and warm seasons mean).

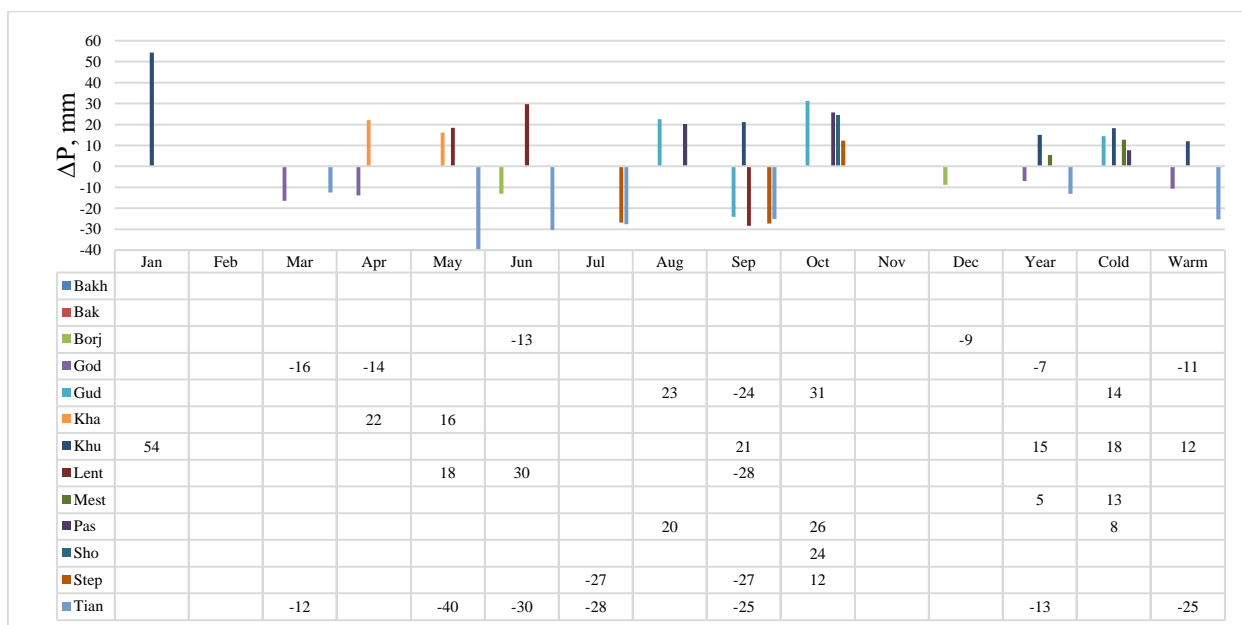


Fig. 8. Difference between the P mean values during 1986-2015 and 1956-1985 in thirteen locations of Georgia

### Mean wind speed

The mean annual, half year and monthly min and max wind speed (V) data are available in Table 6 and also on Fig. 9.

The range of variability of the V mean values for the indicated stations is as follows: Mean Year - from 0.3 m/sec (Lentekhi) to 4.8 m/sec (Goderdzi); Mean Cold - from 0.2 m/sec (Lentekhi) to 5.4 m/sec (Goderdzi); Mean Warm - from 0.4 m/sec (Lentekhi) to 4.2 m/sec (Goderdzi); Min - 0 m/sec (for all stations); Max - from 2.1 m/sec (Lentekhi) to 10.7 m/sec (Goderdzi).

The intra-annual distribution of V values for all indicated investigations points of Georgia are presented on Fig. 9. The smallest V values for all points during January and December are observed (0.1 m/sec, Lentekhi). The greatest values of V for Goderdzi (6.1 m/sec) in January are also fixed (Fig. 9).

Table 6. The monthly mean min, monthly mean max and mean seasonal V (m/s) values in thirteen locations of Georgia in 1956-2015.

Location	Mean Year	Mean Cold	Mean Warm	Min	Max
Bakhmaro	1.7	2.2	1.3	0.0	5.7
Bakuriani	1.3	1.1	1.5		5.2
Borjomi	0.7	0.5	0.8		2.2
Goderdzi	4.8	5.4	4.2		10.7
Gudauri	1.2	1.1	1.2		3.4
Khaishi	0.9	0.7	1.2		3.7
Khulo	1.9	2.0	1.7		4.0
Lentekhi	0.3	0.2	0.4		2.1
Mestia	0.5	0.3	0.7		2.2
Pasanauri	1.1	1.1	1.2		2.9
Shovi	1.1	1.0	1.1		2.9
Stepantsminda	1.7	1.8	1.6		6.1
Tianeti	1.2	1.2	1.2		4.6

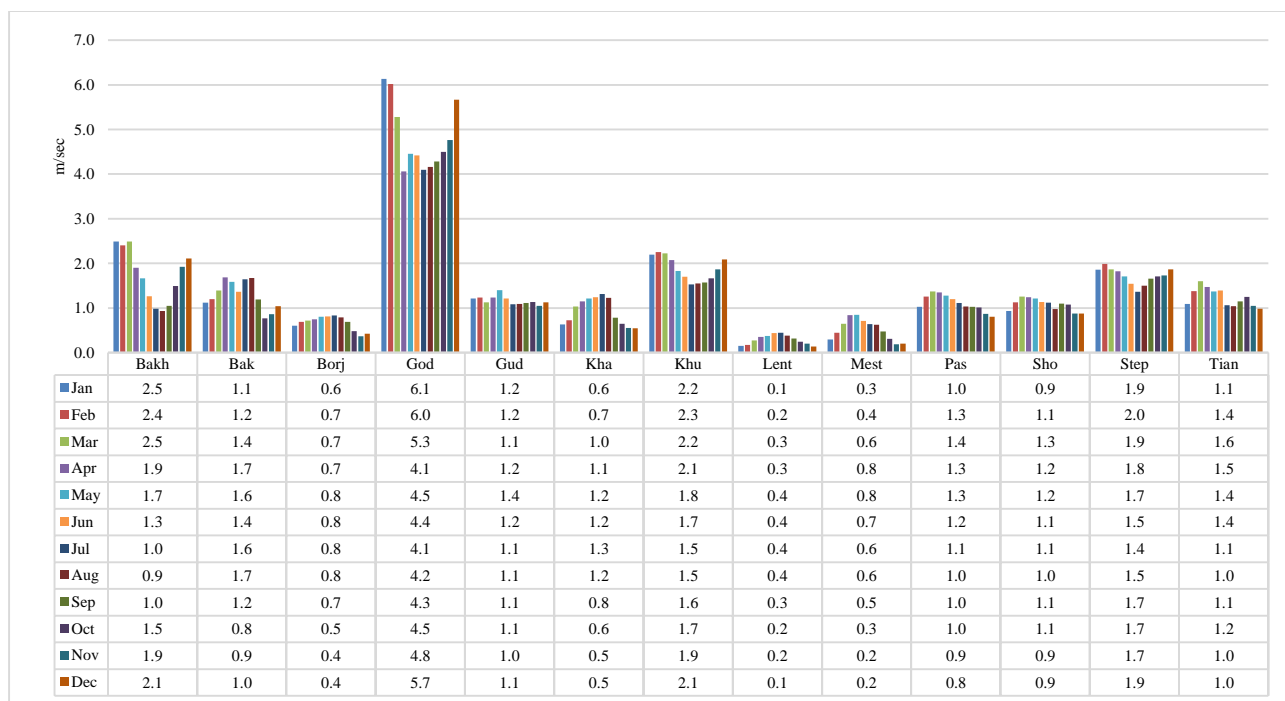


Fig. 9. Wind speed monthly Mean values in thirteen locations of Georgia in 1956-2015.

The changeability of the  $\Delta V$  values of in separate points is presented on Fig. 10. The variability of the monthly mean values of wind speed is detected for all 13 investigated points in 145 cases (including 141 cases - a decrease and only for 4 cases, Bakhmaro - an increase of  $\Delta V$  values).

The changeability of the  $\Delta V$  values in the separate points is the following: Bakhmaro – increase (January, March, May and June); all another station, except Shovi – decrease (all months, mean annual, cold and warm seasons mean); Shovi - decrease (all months, except April, June and October, mean annual, cold and warm seasons mean).

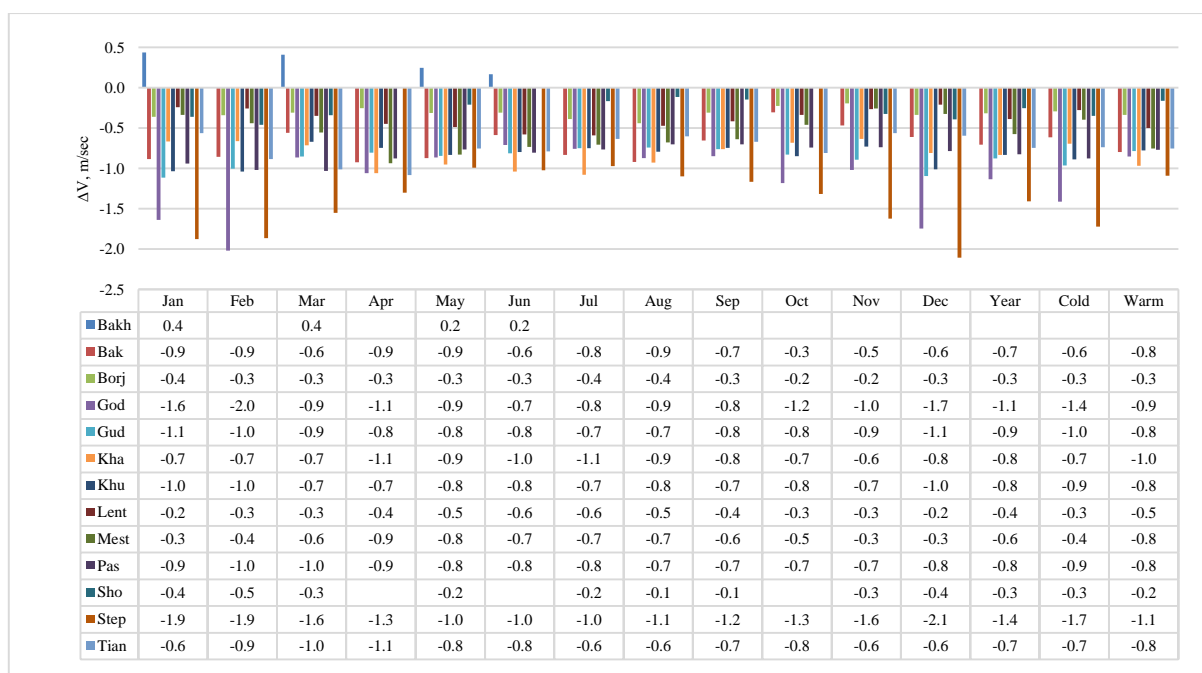


Fig. 10. Difference between the V mean values during 1986-2015 and 1956-1985 in thirteen locations of Georgia

Finally, we note that the greatest changes of all other investigated climatic parameters in 1986-2015 compared to 1956-1985 underwent wind speed, the least - atmospheric precipitation. The reasons for such changes are the subject of further research for the studied mountain regions of Georgia.

Data of this work are used in [40].

## Conclusion

The analysis confirms once again the earlier obtained results and formulated conclusions on the diversity of climatic conditions of Georgia and their uniqueness. Accordingly, this stimulates the need for the even more detailed study of climatic and associated bioclimatic conditions and their variability in different geographic regions of Georgia, both in terms of impact on public health and in terms of development of various sectors of the national economy of the state, including health resorts - tourism industry.

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# დასვენების კლიმატურ ინდექსში შემავალი მეტეოროლოგიური პარამეტრების ცვალებადობა საქართველოს სხვადასხვა მთიან რეგიონში 1956-2015 წლებში

ა. ამირანაშვილი, ლ. ქართველიშვილი, ნ. კუტალაძე,  
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## რეზიუმე

წარმოდგენილია საქართველოს ცამეტ მთიან რეგიონში (ბახმარო, ბაკურიანი, ბორჯომი, გოდერძი, გუდაური, ხაიში, ხულო, ლენტეხი, მესტია, ფასანაური, შოვი, სტეფანწმინდა, თიანეთი) დასვენების კლიმატურ ინდექსთან დაკავშირებული მეტეოროლოგიური პარამეტრების სტატისტიკური მონაცემები (ჰაერის საშუალო თვიური მაქსიმალური ტემპერატურა, ჰაერის საშუალო თვიური ფარდობითი ტენიანობა, ღრუბლის საფარი, ატმოსფერულ ნალექთა ჯამი, ქარის სიჩქარე) 1956 წლიდან 2015 წლამდე. კერძოდ, შესწავლილი იქნა მითითებული მეტეოროლოგიური პარამეტრების ცვალებადობა 1986–2015 წლებში 1956 ÷ 1985 წლებთან შედარებით ზემოთ ჩამოთვლილი პუნქტებისთვის.

## **Изменчивость метеорологических параметров, ассоциированных с климатическим индексом отдыха в различных горных районах Грузии в 1956-2015 гг.**

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## Резюме

Представлены статистические данные о метеорологических параметрах, ассоциированных с климатическим индексом отдыха (среднемесячная максимальная температура воздуха, среднемесячная относительная влажность воздуха, облачный покров, месячная сумма осадков, скорость ветра) в тринадцати горных районах Грузии (Бахмаро, Бакуриани, Боржоми, Годердзи, Гудаури, Хаиши, Хуло, Лентехи, Местия, Пасанаури, Шови, Степанцминда, Тианети) в период с 1956 по 2015 гг. В частности, изучена изменчивость указанных метеорологических параметров в 1986÷2015 гг. по сравнению с 1956÷1985 гг. для перечисленных выше пунктов.