e-ISSN 2667-9973
p-ISSN 1512-1127

საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

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ტომი 24 , № 1

JOURNAL OF THE GEORGIAN GEOPHYSICAL SOCIETY

Physics of Solid Earth, Atmosphere, Ocean and Space Plasma

Vol. 24 , № 1

Tbilisi

2021

e-ISSN 2667-9973
p-ISSN 1512-1127

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JOURNAL OF THE GEORGIAN GEOPHYSICAL SOCIETY

Physics of Solid Earth, Atmosphere, Ocean and Space Plasma

Editor-in-chief: T. Chelidze

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The Journal is devoted to all branches of the Physics of Solid Earth, Atmosphere, Ocean and Space Plasma. Types of contributions are: research papers, reviews, short communications, discussions, book reviews, announcements, conference reports.

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Tel.: 233-28-67; Fax: (99532) 2332867; e-mail: tamaz.chelidze@gmail.com; avtandilamiranashvili@gmail.com;
geophysics.journal@tsu.ge

Publication schedule and subscription information:

The journal is issued twice a year. The subscription price for print version is 30 $ in year.
Subscription orders should be sent to editor's address. Free online access is possible:
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Тел: 233-28-67; 294-35-91; Fax: (99532)2332867; e-mail: tamaz.chelidze@gmail.com; avtandilamiranashvili@gmail.com;
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Порядок издания и условия подписки:

Журнал издается дважды в год. Годовая подписная цена для печатной версии - 30 долларов США.
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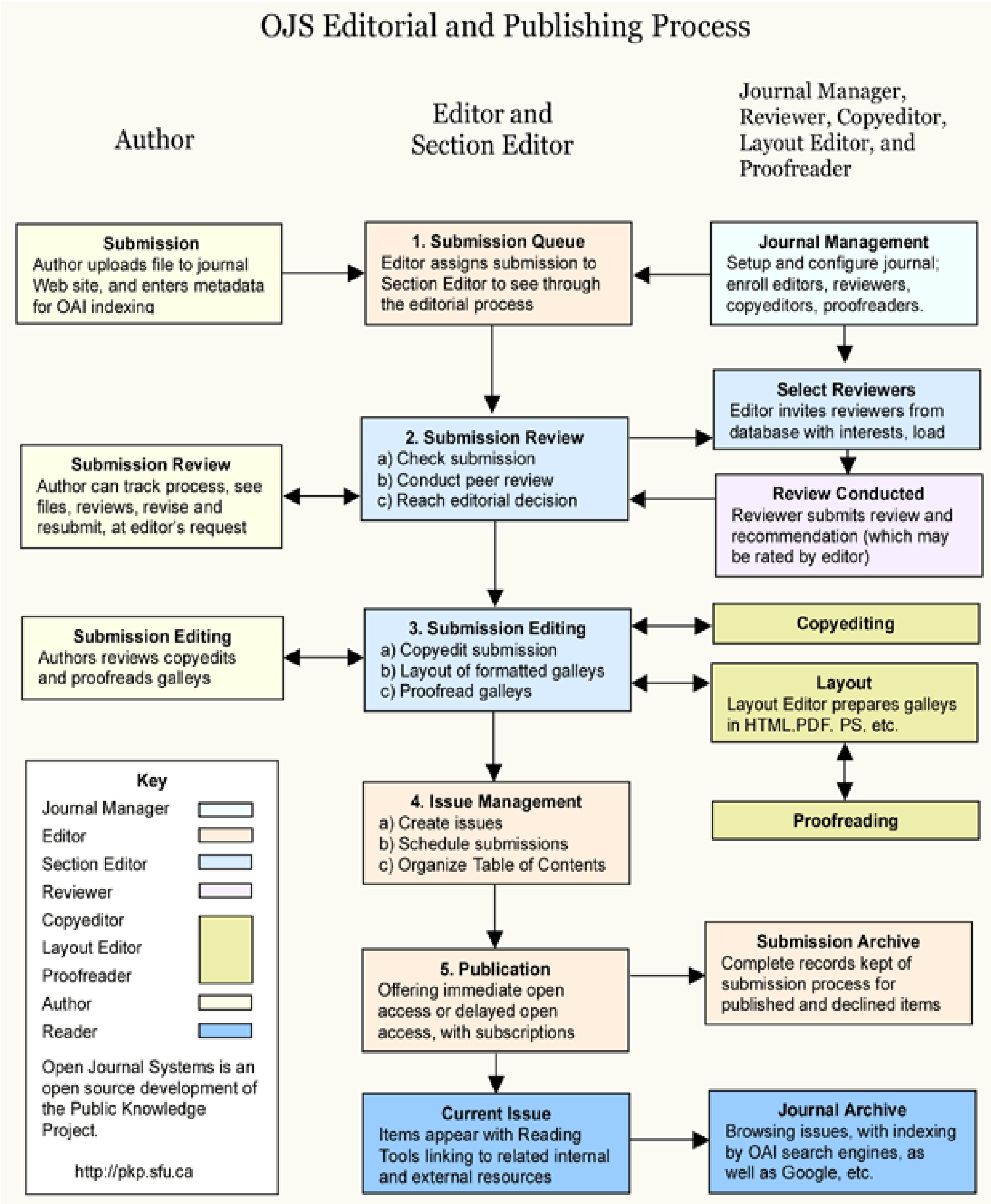

Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(1), 2021, pp. 5-10

Magnetic Declination Statistics (Dusheti 1935-1989) and Deep Self-Learning Model

Tengiz V. Kiria, Abesalom A. Esakia, Manana M. Nikolaishvili, Elene D. Lomadze

Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

ABSTARCT

Nowadays, there are many new instruments available for studying the parameters of the Earth's magnetic field with higher precision and more discretization. Moreover, data processing techniques have been developing on strong mathematical basis. The paper presents a rather long-term (1935 - 1950, total 19332 records) data of Dusheti Observatory on the statistics of magnetic declination (1) and considers the possibilities of so called machine learning (ML), a widespread method nowadays. It gives hypotheses to prove certain hidden regularities and periodicity of some geomagnetic parameters and determines so called "storages" of high statistical reliability, which are the etalon samples we use to build attribution function by use of so called Adam Deep Learning network (2).

Key words: *Earth's magnetic field, Adam Deep Learning network.*

Preamble

It is required to carry out certain statistical works in order to study a kind of long-term statistics as described in this work. We decided it was necessary to build standard variation series for magnetic declinations on the basis of months and years. Namely, it is important to make time period observations on variation series, also on separate series for 2σ and 3σ (3) parts. These two series turn out to be interesting in the annual point of view. It is highly essential to identify the density distribution of the statistical data in these clusters and whether they show any distribution regularities or behavior in dynamics.

Obviously, there is always an objectivity degree problem (equipment defects, etc.) in data. Consequently, it is required to exclude subjective statistics and there are numerous techniques for that. Nowadays, softwares with filtration tasks have been highly developed among computer technologies. Our data have undergone strict filtration processes. Of course, main informative anomalies have been preserved that is definitely significant.

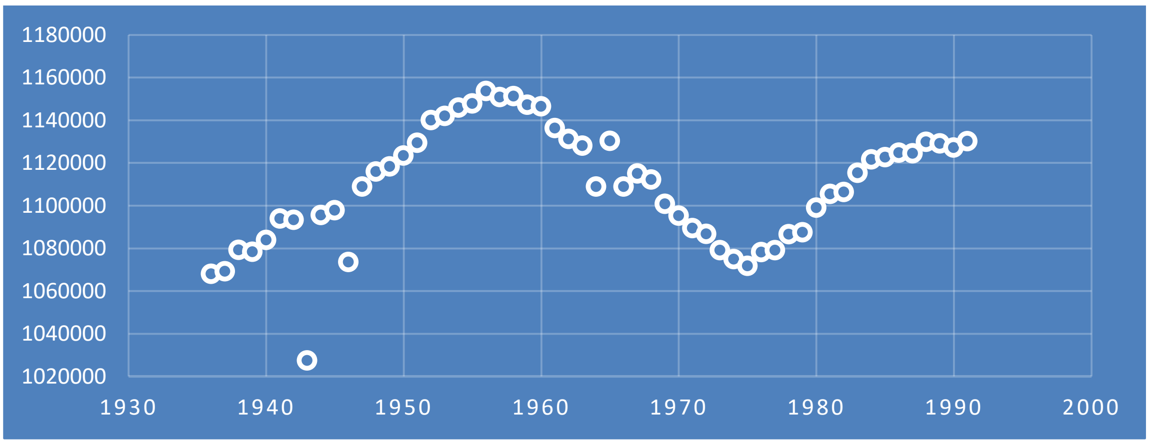

Fig. 1. Dynamics of average annual magnetic declination values (1936 - 1991).

The average annual values in *Figure 1* have periodic and regular structure. There is an exception of the Dusheti Observatory data of 1941-1942 and 1964-1966 in the average annual value point of view. These two episodes are conceivable, though, due to quite objective reasons, they might be a result of strong influence of artificial anomaly nearby the equipment location. We may conclude that, according to the figure, the average annual values have approximately 40-year cycles. Additionally, so called wave behavior has been revealed.

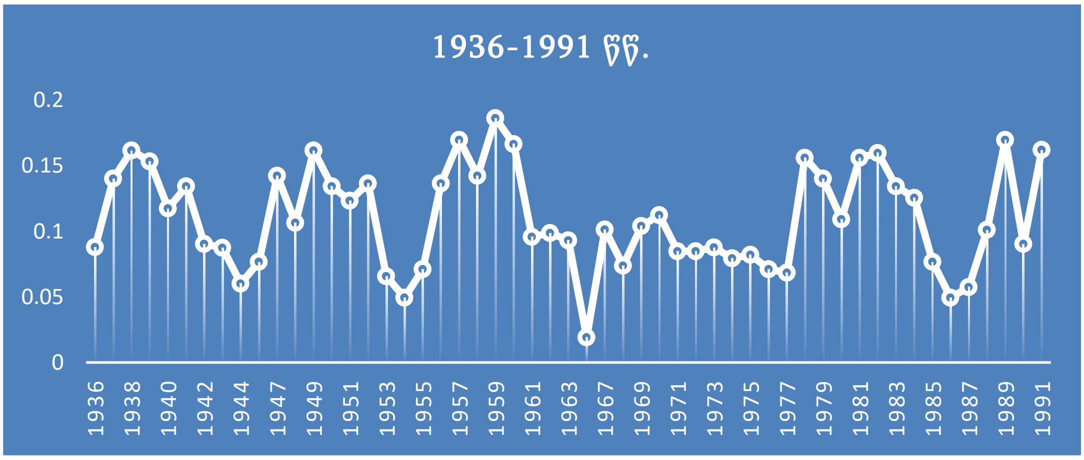

Fig. 2. Quantitative time period analysis of 2σ order anomalies of the magnetic field declination during 1936-1991.

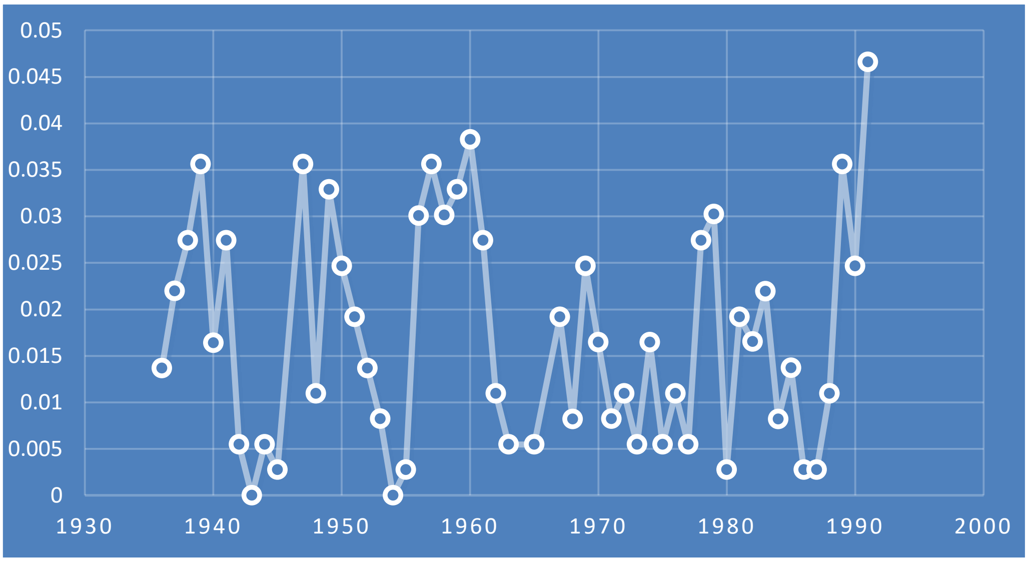

Fig. 3. Quantitative time period analysis of 3σ order anomalies of the magnetic field declination during 1936-1991.

Figure 2 shows shares of more than 2σ anomalies in a concrete year among the whole annual data. In 1936, for example, among the whole data the anomalies were declined from average value by more than 2σ altogether in 8% cases. Like this, in 1959 the number of such anomalies makes only 20% of the annual data. The issue of anomaly measurements according to the distinguished years is quite informative by frequency calculations in this figure.

Figure 3 shows shares of more than 3σ anomalies in a concrete year among the whole annual data. Here, statistical stability is under doubt and verification of statistical hypotheses of strong anomaly zones is prevented as far as their reliability is doubtful. There a question arises: why? It is due their limited involvement with all the data. However, from 1936 to 1960 their share is more than in 1960-1985, whereas at the end of the 80-s of the past century, processes similar to the ones in 1936-1960 take place.

From *Figures 1, 2* and *3* we may conclude that there is an alternation of rise (more dynamics) and fall in the magnetic declination. We are interested in the proceeding of the data till now. Does the magnetic declination parameter maintain its characteristics? Additionally, it is noteworthy to mention that there an alternation of average declination takes place from year to year, an average of so called *Up* and an average of so called *Down*. For example, so called Up-s and Down-s (frequent alternations of rise and fall) according to months must be a potential to build a good forecasting model.

If we bring in the following marks for our magnetic declination statistics:

$$X_{i\ ,} \qquad where\ (i\ is\ changed\ 1{:}\,19332\ )$$

we can build the following matrix:

Let us make components from previous 30 data in time for each *i* member. Our task is to find such F function, which will find links between any X_i and previous 30 records.

In this way we receive:

$$F(X_i, X_{i+1}, X_{i+2} \ldots X_{i+30}) \cong X_{i+31} \qquad (1)$$

The whole machine learning theory considers optimization of *F*, which uses different algorithms. In this paper we will consider Adam Optimization Algorithm for Deep Learning (1).

The normalized learning sampling for Formula (1) in the form of a real table is given as follows:

X1	**X2**	**X3**	**..**	**..**	**..**	**X29**	**X30**	**X(31)**
2899	2898	2893	..	..	..	2922	2925	2921
2898	2893	2898	..	..	..	2925	2921	2920
2893	2898	2902	..	..	..	2921	2920	2917
2898	2902	2908	..	..	..	2920	2917	2917
2902	2908	2918	..	..	..	2917	2917	2920
2908	2918	2930	..	..	..	2917	2920	2913
..	..	..	..	..	..	..	..	..
2917	2911	2912	..	..	..	2925	2925	2925
2911	2912	2910	..	..	..	2925	2925	2919

Finally, we received a learning sampling with 30 inputs and one output.

A significant detail in the algorithm is the one, which can find links between each reading and its predecessor 30 data. In this case we will construct such a model, which will enable us to make an optimal prognosis by every 30 predecessor reading by means of Adam network.

$$w_{t+1} = (1 - \lambda)w_t - \eta \nabla f_t(w_t) \quad (2)$$

As we know, in Adam algorithm, optimization of (1) is a solution to equation (2) for each necessary iteration (usually, there are 1000 iterations) for weight sampling, where λ is a parameter guiding the weight drop. Of course, here we have L2 regularization for decreasing unjustified weights, which is based on so called penalty principle, finally, on search function modification to have L2 -norm weight vector (4).

Table 1. Matrix of confusion (clarity) of the prognosis by 30-day predecessors of 1936-1991 magnetic field declination.

Target output:	Network output:									
	<2851	2851 .. 2887.6	2887.6 .. 2924.2	2924.2 .. 2960.8	2960.8 .. 2997.4	2997.4 .. 3034	3034 .. 3070.6	3070.6 .. 3107.2	3107.2 .. 3143.8	3143.8 .. 3180.4
2851 .. 2887.6	0	0	2	1	0	0	0	0	0	0
2887.6 .. 2924.2	0	0	65	158	1	0	0	0	0	0
2924.2 .. 2960.8	0	0	0	1810	70	0	0	0	0	0
2960.8 .. 2997.4	0	0	0	197	1813	37	0	0	0	0
2997.4 .. 3034	0	0	0	2	444	1224	73	0	0	0
3034 .. 3070.6	0	0	0	0	1	100	1598	142	0	0
3070.6 .. 3107.2	0	0	0	0	1	3	90	2624	165	2
3107.2 .. 3143.8	0	0	0	0	0	0	0	105	1432	39
3143.8 .. 3180.4	0	0	0	0	0	0	0	2	401	494
3180.4 .. 3217	0	0	0	0	0	0	0	1	3	25

Table 1 shows the qualitative assessment of the obtained prognostic model according to their interval (cluster) distribution. More exactly, here we have real and false coincidences of prognostic and real data, which are expressed quantitatively and by clusters.

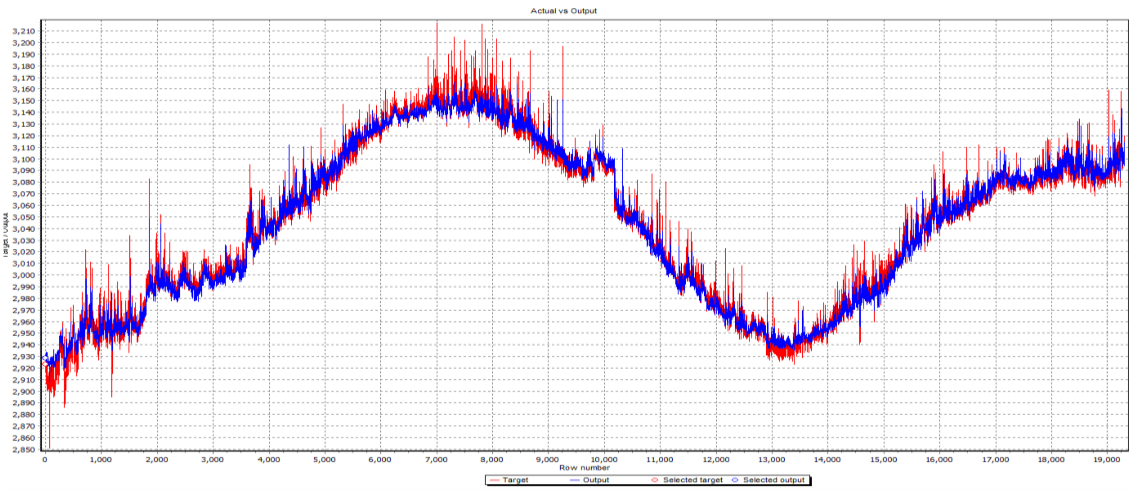

Fig. 4. Scheme of the prognosis by 30-day predecessors of 1936-1991 magnetic field declination.

Figure 4 clearly shows the compatibility between learning sampling and prognostic model. The real data are given in red colour and the prognostic values are shown in blue. It is obvious that the values of the strong anomalies, which took place in 1940-1950, are not reliable. However, taking into account these anomalies, the model revealed similar strong anomalies of the same order more accurately at the end of 1980-s. Finally, we have following characteristics for the constructed model:

	Target	Output	AE	ARE
Mean:	3042.505371	3041.840249	5.740834	0.001887
Std Dev:	68.173232	67.271728	5.886604	0.001927
Min:	2851	2908.161365	0.000849	2.71E-07
Max:	3217	3171.404207	101.941242	0.033066

Correlation: 0.992766
R-squared: 0.98506

The obtained result makes it clear that there is a tight correlation (0.992766) between the value of magnetic declination of any day and its predecessor 30-day data. The corrected determination coefficient 0.98506 means that our prognostic model, taking into account the predecessor 30 days, forecasts the probable value of the following day declination by nearly 99% on the eve.

Conclusion

The statistical study of the Dusheti Observatory (overall 19332 readings, y.y.1935-1950) shows that the dynamics of average annual values is characterized with 45-year cycle. Here statistically stable periodicity of increase of magnetic declination variations is distinguished. Namely, increase from minimal meaning to peak value needs approximately 15 years. There was a peak of such variation in 1952 and during the following 15 years a decrease took place. Further on, similar increase was observed during the next 15 years.

Taking into consideration, in our work we constructed an Adam deep learning network and received a high reliability prognostic model. The obtained model can be used for every-day forecasting as well as for more long-term prognoses.

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მაგნიტური (დუშეთი 1935-1989 წ.წ.) მიხრილობის სტატისტიკა და ღრმა თვითსწავლებადი მოდელი

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რეზიუმე

ნაშრომში წარმოდგენილია დუშეთის ობსერვატორიის მაგნიტური მიხრილობის საკმაოდ ხანგრძლივ (1935 – 1950 წ.წ., სულ 19332 ანათვალი) მონაცემთა ჯერ სტატისტიკური, ხოლო შემდეგ დღეისათვის ფართოდ გავრცელებული ე. წ. მანქანური სწავლების (ML) მეთოდის შესაძლებლობები. მოყვანილია ჰიპოთეზები ზოგიერთი გეომაგნეტური პარამეტრისთვის გარკვეული ფარული კანონზომიერებების და პერიოდულობის დასასაბუთებლად. დადგენილია მაღალი სტატისტიკური მდგრადობის მქონე ე. წ. „მეხსიერებები“. სწორედ ესაა ეტალონური ნიმუშები, რომელსაც ე. წ ადამის ღრმა სწავლების ქსელის გამოყენებით მიკუთვნების ფუნქციის ასაგებად ვიყენებთ.

Статистика магнитного склонения (Душети, 1935-1989 гг.) и модель глубокого самообучения

Т.В. Кириа, А.А. Эсакиа, М.М. Николайшвили, Э.Д. Ломадзе

Реферат

В статье представлены довольно длительные (1935 - 1950 г.г., всего 19332 отсчета) данные магнитного склонения обсерватории Душети, сначала статистические, а затем, широко используемые, методом машинного обучения (ML). Приводятся гипотезы для обоснования определенных скрытых закономерностей и периодичности некоторых геомагнитных параметров.

С высокой статистической стабильностью установлена т. н. "устоичивость". Это те стандартные образцы, которые мы используем с помощью сети глубокого самобучения Адама для построения функции принадлежности.

Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(1), 2021, pp. 11-17

The Sharle Statistical Structure

[1]Zurab S. Zerakidze, [2]Jemal K. Kiria, [2]Tengiz V. Kiria

[1]Gori State Teaching University
e-mail: zura.zerakidze@mail.ru
[2]M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University
e-mail: kiria51@yahoo.com

ABSTRACT

In this paper the consistent criteria for testing Hypothesis for the Sharle statistical structure are defined. It is shown that the necessary and sufficient conditions for the existence of these critical are considered. Also the necessary and sufficient conditions for the existence of such criteria for the Sharle strongly statistical structure.

Key words: Consistent criterion, statistical structures.

I. The Sharle statistical structure.

Definition 1.1 we will say that X random value is (see [1]-[6]) the Sharle distribution if this density given by formula

$$f_{sh}(x) = f(x) + \frac{1}{\sigma}\left[\frac{S_k(X)}{6}\cdot Z_u \cdot (U^3 - 3U) + \frac{E_x(X)}{24}\cdot Z_u \cdot (U^4 - 6U^2 + 3)\right]$$

$f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-m)^2}{2\sigma^2}}$, $\quad U = \frac{x-m}{\sigma}$, $\quad Z_u = \frac{1}{\sqrt{2\pi}} e^{-\frac{U^2}{2}}$,
$s_k(x)$ - asymmetry, $E_x(X)$-exess
Let (E,S) – be a measurable spase. Let

$$\mu(A) = \int_A f_{Sh}(x)dx, \quad A\epsilon L(R)$$

Probability Sharle given on $(R, L(R))$, vohere $f_{sh}(x)$ be spectral density Sharle and $L(R)$ Lebesgue σ - algebra in R. Let $\{\mu_i, i\epsilon I\}$ the corresponding Sharle probability measures.

Definition 1.2. An Object $\{E, S, \mu_h, h\epsilon H\}$ is called a Sharle statistical structure.

Definition 1.3. A Sharle statistical structure $\{E, S, \mu_h, h\epsilon H\}$ is called orthogonal (singular) if a family of Sharle probability measures $\{\mu_i, i\epsilon I\}$ constricts of pairwise singular measures $(i,e.\ \mu_{h'}\perp\mu_{h''}\ \ \forall h' \neq h'')$.

Definition 1.4. Sharle statistical structure $\{E, S, \mu_h, h\epsilon H\}$ is called weakly separable if then exists a family of S-measurable sets $\{X_h, i\epsilon I\}$ Such that the relations are fulfilled:

$$\mu_h(X_{h'}) = \begin{cases} 1, & if\ h = h' \\ 0, & if\ h \neq h' \end{cases}$$

Definition 1.5. A Sharle statistical structure $\{E, S, \mu_h, h\epsilon H\}$ Is called separable if there exists a family of S-measurable sets $\{X_h, h\epsilon H\}$ Such that the relations are fulfilled:

1. $\mu_h(X_{h'}) = \begin{cases} 1, & if\ h = h' \\ 0, & if\ h \neq h' \end{cases}$
2. $\forall h,\ h' \in H\ card(X_h \cap X_{h'}) < c\ \ if\ h \neq h'$

Where c denotes the continuum power

Definition 1.6 A Sharle statistical structure $\{E, S, \mu_h, h\epsilon H\}$ is called strongly separable if there exists a disjoint family of S-measurable sets $\{X_h, h\epsilon H\}$ such that the relations are fulfilled:

$$\mu_h(X_h) = 1, \forall i \in I.$$

Remark 1.1 from strong separability there follows separability there follows orthogonality but not vice versa.

Example 1.1 let *E=RxR* (where $R = (-\infty, +\infty)$ and *L (RxR)* be a lebesgue σ- algebra of subsets of *RxR*. As a set of hypotheses consider the set *H=R*. let $X_h = \{(-\infty < x < +\infty), y = h, h \in R\}$. And let

$$\mu(A) = \int_A f_{Sh}(x)dx$$

Be the Sharle linear measures on $X_h, h\epsilon R$

The Sharke statistical structure $\{R \times R, L(R \times R), \mu_h, h \in R\}$ is continuum strongly separable statistical structure.

Let H be the set of hypotheses and let $B(H)$ be σ-algebra of subsets of H which contains all finite subsets of H.

Definition 1.7. we will say that the statistical structure $\{E, S, \mu_h, h\epsilon H\}$ admits a consistent criterium for hypotheses testing if there exist at least one measurable mapping

$$\delta: (E, S) \to \big(H, B(H)\big),$$

Such that

$$\mu_h(\{x: \delta(x) = h\}) = 1,\ \ \forall h \in H.$$

The notion and corresponding construction of consistent criteria for hypotheses testing was introduced and studied by Z. Zerakidze (see [5]).

Remark 1.2. if the Sharle statistical structure $\{E, S, \mu_h, h\epsilon H\}$ admits a consistent criterion for hypothesis testing, then the Sharle statistical structure $\{E, S, \mu_h, h\epsilon H\}$ is strongly separable but not vice versa.

(see example 1.1).

Example 1.2. let $E = R \times R \times R = R^3$, let S be a Borel σ-algebra on R^3. let take S-measurable sets

$$X_h = \begin{cases} -\infty < x < +\infty, \quad -\infty < y < +\infty, \quad z = h\ if\ h \leq [0,1]; \\ x = h - 2, -\infty < y < +\infty, -\infty < z < +\infty, if\ h \in [2,3]; \\ -\infty < x < +\infty, \quad y = h - 4, -\infty < z < +\infty, if\ h \in [4,5]; \end{cases}$$

and assume that μ_h are plane Sharle measures on X_h Then the Sharle statistical structure $\{R^3, S, \mu_h, h \in [0,1] \cup [2,3] \cup [4,5]\}$ is weakly separable, but not strongly separable.

Example 1.3 let $E = [0,1] \times [0,1]$, let $B = [0,1] \times [0,1]$, be a Borel σ-algebra of subsets of E. As a set of hypotheses consider the set $H = [0,1] \cup [2,3]$ let us take the $B = [0,1] \times [0,1] -$ measurable sets

$$X_h = \begin{cases} 0 \leq x \leq 1, \quad y = h, \quad if\ h \in [0,1]; \\ x = h - 2, 0 \leq y \leq 1, \ \ if\ h \in [2,3]; \end{cases}$$

and denote by $\mu_h, h \in [0,1] \cup [2,3]$ linear, normed, Sharle measures on X_h. Then the Sharle statistical structure $\{[0,1] \times [0,1], B([0,1] \times [0,1]), \mu_h, h \in [0,1] \cup [2,3]\}$, is a separable statistical structure. Suppose that it admits a consistent criterium for hypotheses testing

$$\delta: ([0,1] \times [0,1], B([0,1] \times [0,1])) \to (H, B(H)),$$

with

$$\mu_h(\{x: \delta(x) = h\}) = 1, \ \ \forall h \in [0,1] \cup [2,3].$$

Let's introduce sets $A_1 = \{x: \delta(x) \in [0,1]\}$ and $A_2 = \{x: \delta(x) \in [2,3]\}$ it is clear that A_1 and A_2 $B([0,1] \times [0,1])$ measurable Sets and we have

$\mu_h(A_1 \cap \{[0,1] \times \{h\}) = 1 \ \ \forall h \in [0,1]$ and

$\mu_h(A_2 \cap \{h - 2\} \times [0,1]) = 1 \ \ \forall h \in [2,3]$

Further, according to the Fubin theorem we conclude that $\mu(A_1) = 1$ and $\mu(A_2) = 1$ (where μ is the Sharle plane measure).

From here, taking into account that $A_1 \cap A_2 = \emptyset$ and $A_1 \cup A_2 = [0,1] \times [0,1]$ we verify that $\mu([0,1] \times [0,1]) = 2$ which contradicts rhe fact that $\mu([0,1] \times [0,1]) = 1$. Hence, the Sharle separable statistical structure does not admit a consistent criterium for hypotheses testing.

Theorem 1.1 let $\{E, S, \mu_{h_i}, i \epsilon N\}$ $(N = 1,2, \dots, n, \dots.)$ Be on orthogonal Sharle statistical structure, then this statistical structure admit a consistent criterium for hypotheses testing.

Proof due to the singulatito of Sharle statistical structure $\{E, S, \mu_h, n \epsilon N\}$ there exists the family of S-measurable sets $\{X_{ik}\}$ such that for any $i \neq k$: | $\mu_{h_k}(X_{i_k}) = 0$ and $\mu_{h_i}(E - X_{ik}) = 0$, Therefore if consider the sets

$$X_i = \bigcup_{k \neq i} (E - X_{ik}),$$

we get $\mu_{h_i}(X_i) = 0$, Hence, $\mu_{h_i}(E - X_i) = 1$. On the other hand, for $k \neq i$ we have $\mu_k(E - X_i) = 0$, It means that the Sharle statistical structure $\{E, S, \mu_{h_i}, i \in N\}$ is weakly seperable. Therefore, there exists the family of S-measurable sets $\{X_{h_i}\ i \in N\}$ such, that

$$\mu_{h_i}(X_{h_i}) = \begin{cases} 1, & \text{if } i = j \\ 0, & \text{if } i \neq j \end{cases}$$

Consider now the sets

$$\bar{X}_{h_i} = X_{h_i} - \left(X_{h_i} \bigcap \left(\bigcup_{k \neq 0} X_{h_k} \right) \right), i \in N$$

It is obvious that these sets are S-measurable disjocht sets and

$$\mu_{h_i}(\bar{X}_{h_i}) = 1,\ \forall i \in N$$

Wet us define the mapping

$$\delta: (E, S) \rightarrow (H, B(H))$$

in the following way: $\delta(\bar{X}_i) = h_i, \forall i \in N$.

Then we have

$\{x: \delta(x) = h_i\} = \bar{x}_i$

and

$\mu_{h_i}(\bar{X}_{h_i}) = \mu_{h_i}(\{x: \delta(x) = h_i\}) = 1,\ \forall i \in N$

Hence δ is a consistent viterion for hypo theses testing.

2. The consistent oriterion for hypotheses testing of Sharle strongly separgble statistical stractares.

Let $\{\mu_{\mathrm{h}}, h \in H\}$ be Sharle prebabality measares defined on the measurable space (E, S), For each $h \in \mathrm{H}$ denote by $\bar{\mu}_{\mathrm{h}}$ the completion of the measure μ_{h} and denote by dom($\bar{\mu}_{\mathrm{h}}$) the σ-algebra of all $\bar{\mu}_{\mathrm{h}} -$ measurable sabsets of E. Let

$$S_1 = \bigcap_{h \epsilon H} \mathrm{dom}(\bar{\mu}_{\mathrm{h}})\ .$$

Definition 2.1. A Sharle statistical structure $\{E, S_1, \bar{\mu}_{\mathrm{h}}, h \epsilon H\}$ is called strongly separable if there exists the family of S_1 -measurable sets $\{z_h, h \epsilon H\}$ such that the relations are fulfilled:

1 $\bar{\mu}_h(z_h) = 1, \forall h \in H;$

2 $Z_{h_1} \cap z_{h_n} = \emptyset\ \forall h_1 \neq h_2;$

3 $\bigcup_{h \epsilon H} z_h = E.$

Definiteon 2.2. We will say that the orthogonal Sharle statistical structure admits a consistent criterion for testing hypothesis if there exists at least one measurathe mapping

$$\delta: (E, S_1) \rightarrow (H_1 B(H))\text{ , such that}$$

$$\bar{\mu}_h(\{x: \delta(x) = h\}) = 1,\ \forall h \in H.$$

Theorem 2.1 in order that the Sharle statistical structure $\{E, S_1, \bar{\mu}_{\mathrm{h}}, h \epsilon H\}$, $\mathrm{card} H = c$ admitted a consistent criterion for hypotheses testing it is necessary and sufficient that this statistical structure was strongly separable (see definition 2.1).

Proof. Necessity. The existence of a consistent criterion for hypothesis testing (see definition 2.2) means that there exist at least one measurable mapping

$$\delta:(E,S_1)\to(H,B(H))$$

Such that

$$\bar{\mu}_h(\{x:\delta(x)=h\})=1,\forall h\epsilon H.$$

Denoting $z_h=\{x:\delta(x)=h\}$ for $h\epsilon H$ we get:

1) $\bar{\mu}_h(z_h)=\bar{\mu}_h(\{x:\delta(x)=h\})=1,\forall h\epsilon H;$
2) $z_{h_1}\cap z_{h_2}=\emptyset \quad \{x:\delta(x)=h_1\}\cap\{x:\delta(x)=h_2\} \quad \forall h_1\neq h_2, \quad h_1,h_2\epsilon H;$
3) $\bigcup_{h\in H} Z_h=\{x:\delta(x)\epsilon H\}=E$

Sufficiency, since the Sharle statistical structure $\{E,S_1,\bar{\mu}_{\mathrm{h}},h\epsilon H\}$ Is strongly separable (see definition 2.1.) there exist a family $\{z_{\mathrm{h}},h\epsilon H\}$ of elements of the σ-algebra

$$S_1=\bigcap_{h\epsilon H} dom(\bar{\mu}_h).$$

Such that

1) $\bar{\mu}_h(z_h)=1,\forall h\epsilon H;$
2) $z_{h_1}\cap z_{h_2}=\emptyset \quad \forall h_1\neq h_2;$
3) $\bigcup_{h\in H} Z_h=E$

For $x\epsilon E$ we put

$$\delta(x)=h$$

Where h is a unique hypothesis from the H for which $x\epsilon Z_h$ the existence and uniqueness of such hypothesis h can be proved using conditions 2) and 3)

Take now $y\epsilon B(H)$. Then

$$\{x:\delta(x)\epsilon y\}\epsilon\bigcup_{h\in y} Z_h$$

We have to show that

$$\{x:\delta(x)\epsilon y\}\epsilon dom(\bar{\mu}_{h_0})$$

For each $h_0\epsilon H$

If $h_0\epsilon y$ then

$$\{x:\delta(x)\epsilon y\}\epsilon\bigcup_{h\in y} Z_h=Z_{h_0}\bigcup\left(\bigcup_{h\in y-\{h_0\}} Z_h\right)$$

On the one hand the conditions 1), 2) and 3) follows that

$$Z_{h_0}\epsilon S_1$$

On the other hand the inclusion

$$\bigcup_{h\in y-\{h_0\}} Z_h\subseteq(E-Z_0)$$

Implies that

$$\bar{\mu}_{h_0}\left(\bigcup_{h\in y-\{h_0\}} Z_h\right) \leq \bar{\mu}_{h_0}(E - Z_0) = 0$$

And hence

$$\bar{\mu}_{h_0}\left(\bigcup_{h\in y-\{h_0\}} Z_h\right) = 0.$$

And hence

$$\bigcup_{h\in y-\{h_0\}} Z_h \in dom(\bar{\mu}_{h_0}).$$

Since $dom(\bar{\mu}_{h_0})$ Is σ-algebra, we conclude that

$$\{x: \delta(x)\epsilon y\} = Z_{h_0} \cup \left(\bigcup_{h\in y-\{h_0\}} Z_h\right) \in dom(\bar{\mu}_{h_0}).$$

If $h_0 \notin y$ Then

$$\{x: \delta(x)\epsilon y\}\epsilon \bigcup_{h\in y} Z_h \subseteq (E - Z_{h_0})$$

And we conclude that

$$\bar{\mu}_h(\{x: \delta(x) \in y\}) = 0.$$

The last relation implies that

$$\{x: \delta(x)\epsilon y\}\epsilon dom(\bar{\mu}_{h_0}), \forall y \in B(H).$$

Thus we have shown the validity of the relation

$$\{x: \delta(x)\epsilon y\}\epsilon dom(\bar{\mu}_{h_0})$$

For an arbitrary $h_0 \in H$ Hence,

$$\{x: \delta(x)\epsilon y\}\epsilon \bigcap_{h\in H} dom(\bar{\mu}_h) = S_1$$

We have shown that the map

$$\delta: (E, S_L) \to (H, B(H))$$

Is measurable map

Since $B(H)$ contains all singletons of H, we ascertain that $\bar{\mu}_h(\{x: \delta(x) = h\}) = \bar{\mu}_h(z_h) = 1, \forall h \in H.$

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შარლეს სტატისტიკური სტრუქტურები

ზ. ზერაკიძე, ჯ. ქირია, თ. ქირია

რეზიუმე

სტატიაში აგებულია შარლეს ძლიერად და სუსტად განცალებადი სტრუქტურები, რომელთათვისაც არ არსებობს ჰიპოთეზათა შემოწმების ძალდებული კრიტერიუმი. ამავე სტატიაში განხილულია უფრო ფართე σ-ალგებრა და ახალი განმარტება ძლიერად განცალებადი სტატისტიკური სტრუქტურები, რომელებისათვის ყოველთვის არსებობს ჰიპოთეზა შემოწმების ძალდებული კრიტერიუმი.

Статистические структуры Шарлье

З. С. Зеракидзе, Дж. К. Кириа, Т. В. Кириа

Резюме

В статье построены сильно и слабо разделимые статистические структуры Шарлье, для которых не существует состоятельных критериев для проверки гипотез. Далее строится более широкая σ −алгебра и по новому определены сильно разделимые статистические структуры Шарлье, для которых всегда существуют состоятельные критерии для проверки гипотез.

Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(1), 2021, pp. 18-24

The Consistent Criteria for Hypotheses Testing for Sharle Statistical Structure

[1]Zurab S. Zerakidze, [2]Jemal K. Kiria, [2]Tengiz V. Kiria

[1]Gori State Teaching University
e-mail: zura.zerakidze@mail.ru
[2]M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University
e-mail: kiria51@yahoo.com

ABSTRACT

In this paper, we define Sharle statistical Structure such that the probability of any kind of error is zero for given criterion. The necessary and sufficient conditions for the existence of such criteria are given.

Key words: *Consistent criterion, statistical structures*.

I. Introduction

Statistics of random processes is used in various fields of science and technology (for example, in theoretical physics, genetic, economics, radio physics, geophysics).

When using random processes as models of real phenomena, the question of determining the probabilistic characteristics of the processes arises. To determine these characteristics should be use statistical methods. Among the problems of statistics, a class of problems is distinguished in which the number of observations is unique.

Despite the uniqueness of observation, is many cases, one can authentically determine the values of unknown distribution parameters or reliably choose one of an infinite number of competing hypotheses about the exact form of the distribution. In the case when a parameter or hypothesis is determined by one observation reliably, it is said that for it there exists a consistent estimate of parameter or a consistent criterion for hypothesis testing. This article is devoted to the question a consistent criterion for hypothesis testing for Sharle statistical structure.

It is said that an error of the h-th kind of the δ criterion accors, if the criterion rejects the main hypothesis of Ha. The following probability $\{\alpha_h(\delta) = \mu_h(\{x: \delta(r) \neq h\})$ Is called the probability of an erroe of the h-th kind for a given criterion δ. Example 1 nd 2 show a general trend-when we decrease one of the probabilities of an error, the other, as a rule, increases.

Example 1.1 Consider the case when there are two simple hypheses h_1 and h_2 about the distribution of population and criterion $\delta: R^n \to \{h_1, h_2\}$ such that $\delta(x) \equiv h_1$ then the probability of an error of the first kind is zero $\alpha_1 = \mu_{h_1}(\{x: \delta(r) \neq h_1\}) = 0$ and the probability of an error of the second kind is equal to one $\alpha_2 = \mu_{h_2}(\{x: \delta(r) \neq h_2\}) = 1$.

Example 1.2. There are observations from the normal distribution in R with variation one and different means $a \in R$ And two simple hypotheses $H_1 = \{a = 0\}$ And $H_2 = \{a = 1\}$ consider the following criteria

$$\delta(x) = \begin{cases} H_1 \, if \;\; x \leq c; \\ H_2 \, if \;\; x \leq c, \end{cases}$$

From $c \in R$. It obvious that with the increase of the number c the probability of an error of the first type decreases, and the probability of an error of the second kind increases.

2. The consistent criteria for hypotheses testing of Sharle statistical structure let (E,S) – be a measurable space. The following definitions are taken from ([1] – [7])

Definition 2.1. we will say that X random value is the Sharle (see [7]) distribution if this density given by formul

$$f_{sh} = f(x) + \frac{1}{\sigma}\left[\frac{S_k(x)}{6} \cdot Z_u \cdot (u^3 - 3u) + \frac{E_x(x)}{24} Z_u \cdot (u^4 - 6u^2 + 3)\right] \quad (1)$$

$$f_x = \frac{1}{\sqrt{2\pi}\sigma} \cdot e^{-\frac{(x-m)^2}{2\sigma^2}} \qquad u = \frac{x-m}{\sigma} \quad Z_u = \frac{1}{\sqrt{2\pi}} \cdot e^{-\frac{u^2}{2}}$$

$S_k(x)$ - asymmetry, $E_x(x)$ - excess

Let

$$\mu(A) = \int_A f_{sh}(x)dx, \qquad A \epsilon L(R)$$

Probability Sharle given on $(R, L(R))$ where $f_{sh}(x)$ Be spectral density Sharle and $L(R)$lebesgue σ −algebra in R.

Let $\{\mu_{i,}\ i \epsilon I\}$ the corresponding Sharle probability measures .

Definition 2.2. an object $\{E, S, \mu_i,\ i \epsilon I\}$ is called a Sharle statistical structure.

Definition 2.3. a Sharle statistical structure $\{E, S, \mu_i,\ i \epsilon I\}$ Is called orthogonal (singular) if a family of Sharle probability measures $\{\mu_{i,}\ i \epsilon I\}$ Consists of pairwise singular measures (i.e. $\mu_i \perp \mu_j,\ \forall\, i \neq j$).

Example 2.1 let $E = [0, 1]$ S be a Borel σ −algebra of subsets of $[0, 1]$.

Let $\mu_1(B) = 2l\left(B \cap \left[0, \frac{1}{2}\right]\right)$, $\mu_2(B) = 2l\left(B \cap \left[\frac{1}{2},\ 1\right]\right)$ and $\mu_3(B) = 3l\left(B \cap \left[0,\ \frac{1}{3}\right]\right)$ BCS., where L lebesgue measure on S. then $\mu_1 \perp \mu_2$ And $\mu_1 \perp \mu_3$ But $\mu_2 \perp \mu_3$ is not orthogonal to μ_3.

Definition 2.4. A Sharle statistical structure $\{E, S, \mu_i,\ i \epsilon I\}$ is called weakly separable if there exists a family of S-measurable sets $\{X_i,\ \ i \in I\}$ such that the relations are fulfilled:

$$\mu_i(X_j) = \begin{cases} 1, & if \;\; i = j \\ 0, & if \;\; i \neq j \end{cases}$$

Definition 2.5 A Sharle statistical structure $\{E, S, \mu_i,\ i \epsilon I\}$ Is called separable if there exists a family of S-measurable sets $\{X_i,\ \ i \in I\}$ Such that the relations are fulfilled:

1) $\mu_i(X_j) = \begin{cases} 1, & if \ i = j \\ 0, & if \ i \neq j \end{cases}$

2) $\forall \ i,j \in I \quad card \ (X_i \cap X_i) < c$ if $i \neq j$,

Where c denotes the continuum power.

Definition 2.6. A Sharle statistical structure $\{E, S, \mu_i, \ i\epsilon I\}$ is called strongly separable if there exists a disjoint family of S-measurable sets $\{X_i, \ i \in I\}$ such that the relations are fulfilled: $\mu_i(X_i) = 1, \ \forall \ i \in I$

Remark 2.1. From strong separability there follows separability there follows weak separability and from weak separability there follows orthogonality but not vice versa.

Remark 2.2. On an arbitrary set E of continuum power one can define a Sharle orthogonal statistical structure having the maximal possible power equal to 2^{2^c} and Sharle weakly separable statistical structure having the maximal possible power equal to 2^c, and a Sharle strongly statistical structure with the maximal possible power equal c, where c is continuum power.

Lemma 2.1. If a Sharle statistical structure $\{E, S, \mu_i, \ i\epsilon I\}$ Is separable then it is orthogonal.

Proof. If a Sharle statistical structure $\{E, S, \mu_i, \ i\epsilon I\}$ is separable, then there exists S-measurable sets $\{X_i, \ i \in I\}$ Such that

$$\mu_i(X_j) = \begin{cases} 1, & if \ i = j \\ 0, & if \ i \neq j \end{cases} \quad i,j \in I$$

Since $\mu_i(X_i) = 1, \ \forall \ i \in I$ and $\mu_j(X_i) = 0, \ \forall \ i \in I$ We have $\mu_i(E - X_i) = 0$. Hence, the measurable μ_i and μ_j Are orthogonal.

The notion and corresponding construction of consistent criteria for hypotheses testing was introduced and studied by Z.Zerakidze (see [6]).

Definition 2.7 We consider the concept of the hypothesis as any assumption that determines the form of the distribution on population.

Definition 2.8. A statical criterion is any measurable mapping $\delta \ (E, S) \to (H, B(H))$ where H be the set of hypotheses and $B(H)$ be σ-algebra of subsets of H which contains all finite subsets of H.

Definition 2.9. We will say that the Sharle statistical structure $\{E, S, \mu_h, \ h\epsilon I\}$ admits a consistent criterion for hypothesis testing if there exists at least one measurable mapping

$$\delta \ (E, S) \to (H, B(H))$$

Such that

$$\mu_h: (x: \delta \ (x) = h \ ) = 1 \quad \forall \ h \in H$$

Definition 3.0. the probability

$$\alpha_h(\delta) = \ \mu_h: (x: \delta \ (x) \ \neq h \ )$$

Is called the probability of error of the h-th type for a given criterion….

Definition 3.1 we will say that the Sharle statistical structure $\{E, S, \mu_i, \ i\epsilon I\}$ admits a consistent criterion for hypothesis testing of any parametric function is for any real bounded measurable function

$$g: \ (H, B(H)) \to (R, B(R))$$

There exists at least one measurable function

$$f : (E, S) \rightarrow (R, B(R))$$

Such that

$$\mu_h: (x: f\ (x) = g(h)\ ) = 1 \quad \forall\ h\ \in H$$

Definition 3.1. We will say that the Sharle statistical structure $\{E, S, \mu_i,\ i\epsilon I\}$ admits an unbiased criterion for hypothesis testing if for any real bounded function

$$g : (H, B(H)) \rightarrow (R, B(R))$$

There exists at least one measurable function

$$f : (E, S) \rightarrow (R, B(R))$$

Such that

$$\int_E\ f\mu_h(dx) = g(x)\ ,\ \ \forall\ h\ \in H$$

Theorem 2.1. Let the Sharle statistical structure $\{E, S, \mu_h,\ h\epsilon I\}$ Admit a consistent criterion for hypothesis testing of any parametric function, then the Sharle statistical structure $\{E, S, \mu_h,\ h\epsilon I\}$ Is weakly separable.

Theorem 2.2. Let the Sharle statistical structure $\{E, S, \mu_h,\ h\epsilon I\}$Admit a consistent criterion for hypothesis testing, then the statistical structure $\{E, S, \mu_h,\ h\epsilon I\}$ Admits a consistent criterion for hypothesis testing of any parametric function, which in turn, implies the existence of an unbiased criterion for hypothesis testing.

Theorem 2.1. Since the Sharle statistical structure $\{E, S, \mu_h,\ h\epsilon I\}$ Admits a consistent criteria of hypothesis any parametric function, denote by $f(x)$ one of the corresponding consistent criterion for indicator $I_{h'}(h)$. Hence, for the sets

$$\{x: f_h\ (x) = I_{h'}(h)\} = X_h$$

We have

$$\mu_{h'}(h) = \begin{cases} 1, & if\ \ h' = h \\ 0, & if\ \ h' \neq h \end{cases}$$

The Sharle statistical stricture $\{E, S, \mu_h,\ h\epsilon I\}$ is weakly separable.

Proof Theorem 2.2. Since Sharle statistical structure $\{E, S, \mu_h,\ h\epsilon I\}$ admits a consistens criteria of hypothesis testing there existing measurable mapping

$$\delta : (E, S) \rightarrow (H, B(H))$$

Such that

$$\mu_h\ (x: \delta\ (x) = h\ \ ) = 1 \quad \forall\ h\ \in H$$

Let

$$g: (H, B(H)) \to (R, B(R))$$

Be any real, bounded, measurable function and define the function δ_g as follows:

$$\delta_g = g(\delta(x))$$

Then we obtaim $\{x: \delta_g = g(h)\} = \{x: \delta(x) = h\}$

$$\mu_h (x: \delta (x) = g(h)) = \mu_h (x: \delta (x) = h) = 1 \quad \forall \ h \in H \quad \text{and}$$

$$\int_E f\mu_h(dx) = g(x) \ , \ \forall \ h \in H$$

Theorem 2.3. If the Sharle statistical structure $\{E, S, \mu_h, \ h\epsilon I\}$ Admits a consistent δ criteria of hypothesis testing then this statistical structure $\{E, S, \mu_h, \ h\epsilon I\}$ is strongly separable, but not versa.

Proof. Since the Sharle statisitical stricture admits a consisten criterion of hypothesis testing there existing δ measersble maping

$$\delta : (E, S) \to (H, B(H))$$

Such that

$$\mu_h (x: \delta (x) = h) = 1 \quad \forall \ h \in H$$

Let $X_h = \{x: \delta (x) = h\} = 1.$ $\quad X_h \cap X_{h'} = \emptyset, \quad \forall \ h \neq h'$ and

$$\mu_h(X_h) = \mu_h(x: \delta (x) = h) = 1 \quad \forall \ h \in H$$

Theorem 2.4. The Sharle statistical structure $\{E, S, \mu_h, \ h\epsilon I\}$ admit a consistent criteria for hypothesis testing if and only if the probability of error of any kind is equal to zero for the criterion δ.

Proof. Necessity since the sharle statistical structure $\{E, S, \mu_h, \ h\epsilon I\}$ admit a consistent criterion for hypothesis testing, there exists a measurable maping

$$\delta : (E, S) \to (H, B(H))$$

Such that

$$\mu_h\{x: \delta (x) = h \} = 1 \quad \forall \ h \in H$$

There for

$$\alpha_h(\delta) = \mu_h: (x: \delta (x) \neq h) = 0 \, , \quad \forall \ h \in H$$

Sufficiency since thes probability of error of any kind is equal to zero, we have

$$\alpha_k(\delta) = \mu_h: (x: \delta (x) \neq h) = 0 \, , \quad \forall \ h \in H$$

On the ather hand

$$\{x: (\delta(x) = h) \cup (x: \delta(x) \neq h)\} = E$$

and

$$\mu_h[(x: (\delta(x) = h) \cup (x: \delta(x) \neq h)] = \mu_h(E) = 1$$

and

$$\mu_h[(x: \delta(x) = h) \cup (x: \delta(x) \neq h)] =$$
$$=\mu_h(x: \delta(x) = h) + \mu_h(x: \delta(x) \neq h)] = \mu_h(x: (\delta(x) = h) = 1, \ \forall h \in H$$

Example 2.1. let $E = R \times R$ (where $R = (-\infty, +\infty)$ and $B(R \times R)$ be a Borel σ-algebra of subsets of $R \times R$. As a set of hypotheses consider the se $H = Q^+$, where Q^+ is the set of positive rational nambers.

Let $X_h = \{-\infty < x < +\infty, y = h, h \in Q^+\}$

And let

$$\mu_h(A) = \int_A f_{sh}(x)dx$$

be the Sharle linear measures on X_h, $h \in Q^+$.

The Sharle statistical structure $X_h = \{R \times R, \mathrm{B}(R \times R), \mu_h, h \in Q^+\}$ is countable Sharle strongly separabele statistical structure.

If we now define the mapping

$$\delta: (R \times R, B(R \times R) \to (Q^+, B(Q^+))$$

By the formula

$$\delta(X_h) = h, \qquad h \in Q^+$$

We get

$$\mu_h(\{x: \delta(x) = h\}) = 1, \qquad \forall h \in Q^+$$

Thus, this Sharle statistical structure $\{R \times R, B(R \times R), \forall h \in Q^+\}$ admits a consistent criterion for hypothesis testing.

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ჰიპოთეზათა შემოწმების ძალდებული კრიტერიუმები შარლეს სტატისტიკური სტრუქტურებისათვის

ზ. ზერაკიძე, ჯ. ქირია, თ. ქირია

რეზიუმე

სტატიაში განმარტებულია შარლეს სტატისტიკური სტრუქტურები. აგებულია ისეთი შარლეს სტატისტიკური სტრუქტურა, რომლისთვისაც ჰიპოთეზათა შემოწმების ძალდებული კრიტერიუმისათვის ყველა რიგის შეცდომის ალბათობა ნულის ტოლია.

Состоятельные критерии для проверки гипотез статистических структур Шарлье

З. С. Зеракидзе, Дж. К. Кириа, Т. В. Кириа

Резюме

В этой статье мы определяем статистическую структуру Шарлье так, что вероятность любого вида ошибки равна нулю для данного критерия. Приведены необходимые и достаточные условия существования таких критериев.

Journal of the Georgian Geophysical Society, ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(1), 2021, pp. 25-36

Modeling the Distribution of Hailstones by Mean Max Sizes on the Territory of Kakheti (Georgia) using Data of the Freezing Level in the Atmosphere and Radar Measurements

[1]Avtandil G. Amiranashvili, [2]Nana R. Bolashvili, [2]Zaza M. Gulashvili, [1]Nino K. Jamrishvili, [2]Nikoloz E. Suknidze, [1]Khatia Z. Tavidashvili

M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University, 1 M Alexsidze Str 0160, Tbilisi, Georgia, avtandilamiranashvili@gmail.com

Vakhushti Bagrationi Institute of Geography of Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia

ABSTRACT

Results of modeling of the distribution of hailstones by mean max diameter (D) on the territory of Kakheti (Georgia) using data of the freezing level in the atmosphere and radar measurements of hail max sizes in clouds are presented.
Maps of the distribution of hail by the average maximum diameter in the territory of Kakheti for individual months, from April to September, have been built. The vertical distribution of D on the indicated territory in the range of heights from 0.11 to 3.84 km was studied.

Key words*: *Hail, map of hail distribution by size.

Introduction

Hail phenomena occur in many regions of the world [1-3], including Georgia [4-7]. Annual global losses of agricultural products from hail damage range from 4 to 18% of the harvest, and in monetary terms, they exceed 11 billion US dollars [https://www.meteorf.ru/activity/activ/antigrad/obs-info/]. At the same time, with regard to damage from hail, Georgia is one of the most hail-hazardous countries in the world. Therefore, the problem of hail in this country is devoted to numerous works covering a wide range of studies, such as climatology of hail [5,8-15], radar observation on hail processes [16-19], theoretical and experimental studies of the mechanisms of hail formation [20-22], methods of impact on hail processes [18,23,24], analysis of impact results [25-28], etc.

To solve various problems of scientific or applied significance (the impact of climate change on hail processes, comparison of experimental data on hailstorms with theoretical models of hail processes, assessment of the expected damage from hailstorms, planning of work on active impacts on hail processes, etc.), detailed information on the spatial-temporary characteristics of hail distributions and its sizes on different locations is necessary. Corresponding ground-based network studies (the number of days with hail per year, determination of the size of hail, their structure, kinetic energy, etc.) have been widely carried out and are being carried out both in different countries of the world [2,3,29-34] and in Georgia [1,4,5-15].

To construct of spatial-temporary maps of the distribution of hail processes, data from radar observations of convective clouds are also used [3,16,19,22,25,35-37]. In particular, in the paper [19] presents the results of a statistical analysis of such parameters of hail processes for separate municipalities of

Kakheti in the period from 2016 to 2019, as: the maximum height of hail clouds, the maximum diameter of hailstone in clouds, the number of hail clouds of various categories, repetition of hail clouds of various categories, the mean hail hazard relative ratio G. It was found that during the study period , the greatest hail hazard was observed in the Gurjaani municipality (G = 1.74), and the smallest in the Dedoplistskaro municipality (G = 0.39).

This work is a continuation of the study [19]. Results of modeling of the distribution of hailstones by mean max sizes on the territory of Kakheti (Georgia) using data of the freezing level in the atmosphere and radar measurements of hail sizes in clouds are presented below.

Study area, material and methods

Study area – Kakheti region of Georgia. Data of meteorological radar "METEOR 735 CDP 10 - Doppler Weather Radar" of Anti-hail service of Georgia about the max diameter of hailstones in the clouds (cm) - radar products HAILSZ (Size) [38] - are used.

Period of observation: April-September, 2016-2019. The area of shielded from the hail territory - 11 309.5 km^2.

The expected diameter of hailstones falling out to the earth's surface according to the Zimenkov-Ivanov model of hail melting in the atmosphere [1,39-41] by taking into account the radar data about their max diameter in the clouds and freezing level in atmosphere was calculated [42, 43].

To calculate the mean max diameter of hailstones (D) on the surface of the earth, the territory of Kakheti was divided into 465 squares, the range of heights was 0.11 ÷ 3.84 km. The monthly average values of the max sizes of hailstones and their 99% values of the lower and upper levels of the average were calculated.

The initial dimensions of hailstones in clouds from April to September in Table 1 are presented.

Table 1. The statistical characteristics of hailstones in the clouds above Kakheti territory by mean max diameter from April to September 2016-2019 (cm).

Parameter	April	May	June	July	August	September
Mean	1.17	1.69	1.97	1.97	1.27	1.79
Min	0.16	0.09	0.09	0.29	0.09	0.20
Max	2.55	4.30	4.83	3.58	4.05	3.58
Range	2.40	4.21	4.74	3.29	3.96	3.38
St Dev	0.65	0.90	0.96	0.82	0.94	0.87
σ_m	0.10	0.06	0.07	0.09	0.22	0.11
99%_Low	0.91	1.53	1.79	1.73	0.70	1.49
99%_Upp	1.42	1.84	2.16	2.21	1.84	2.08

GIS technologies to construct maps of the distribution of hailstones by size near the surface of the earth in the territory of Kakheti were used.

For the data analysis the standard statistical methods are used. The following designations of statistical information are used below: Mean – average values; Min – minimal values; Max - maximal values; Range - Max – Min; St Dev - standard deviation; σ_m - standard error; %; 99% _Low and 99%_Upp – 99% of lower and upper levels of the mean accordingly.

Results

Results in Fig. 1-12 and Table 2,3 are presented.

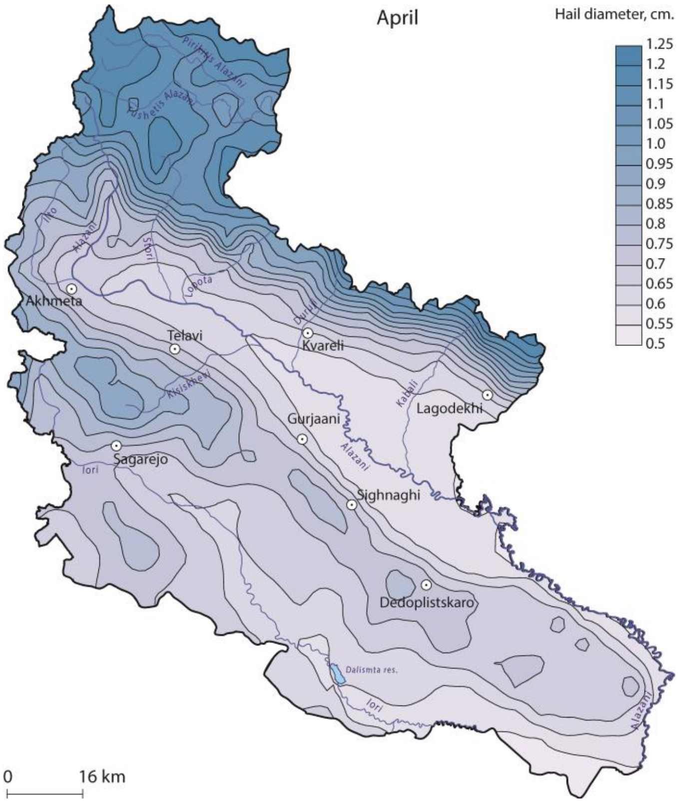

Fig. 1. Distribution of hailstones by mean max diameter on the territory of Kakheti in April.

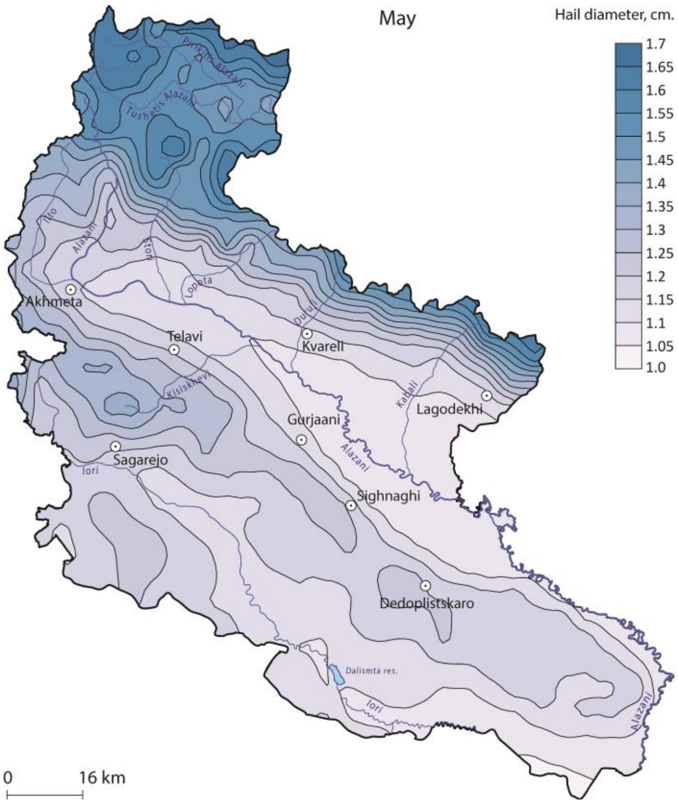

Fig. 2. Distribution of hailstones by mean max diameter on the territory of Kakheti in May.

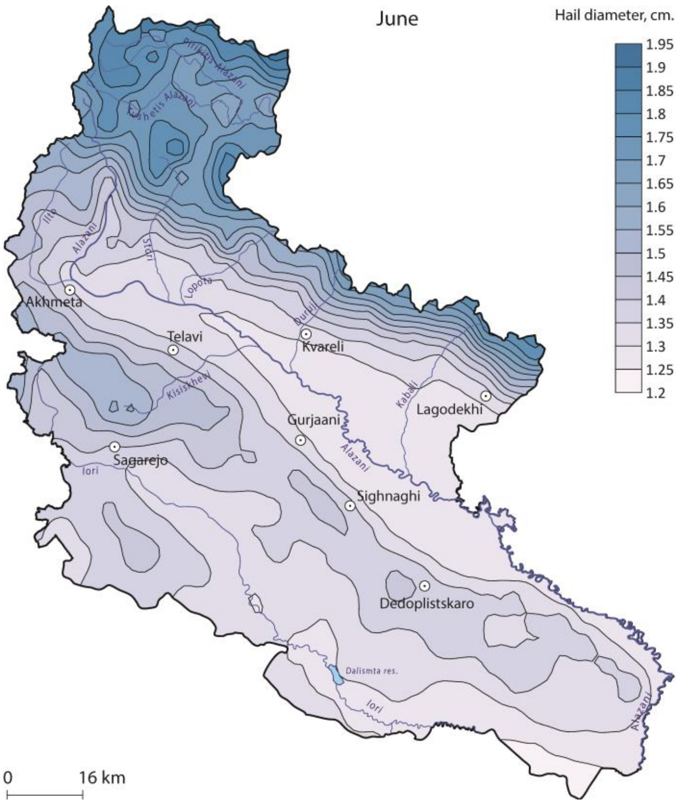

Fig. 3. Distribution of hailstones by mean max diameter on the territory of Kakheti in June.

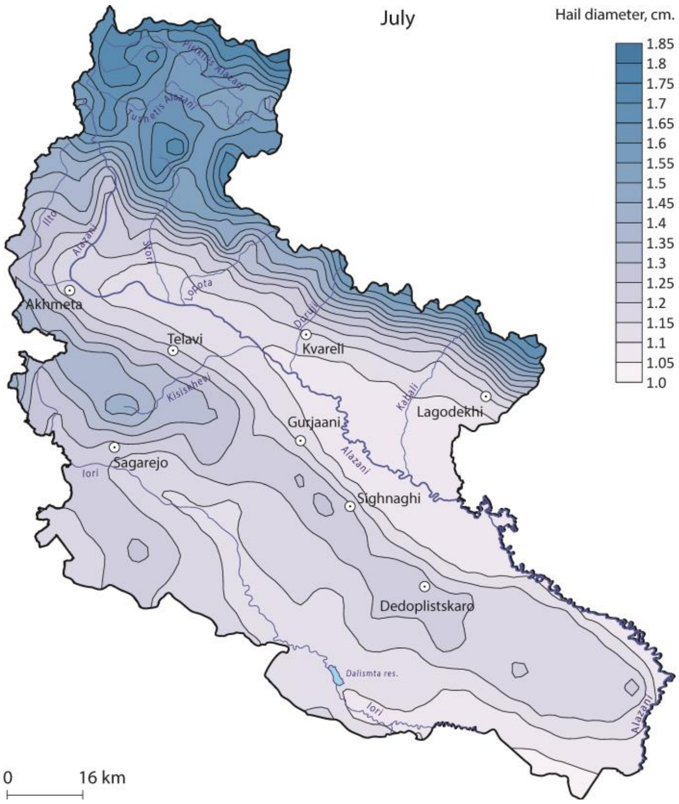

Fig. 4. Distribution of hailstones by mean max diameter on the territory of Kakheti in July.

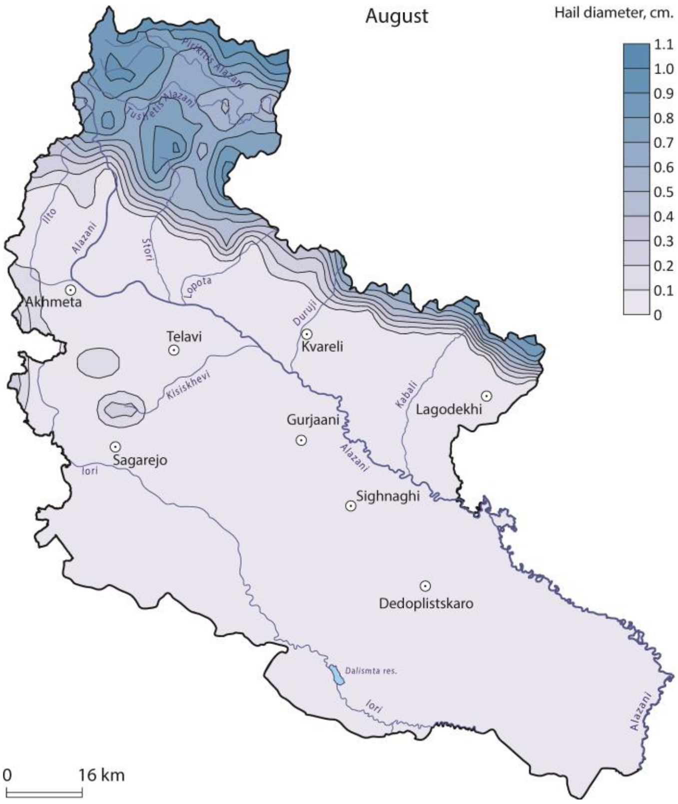

Fig. 5. Distribution of hailstones by mean max diameter on the territory of Kakheti in August.

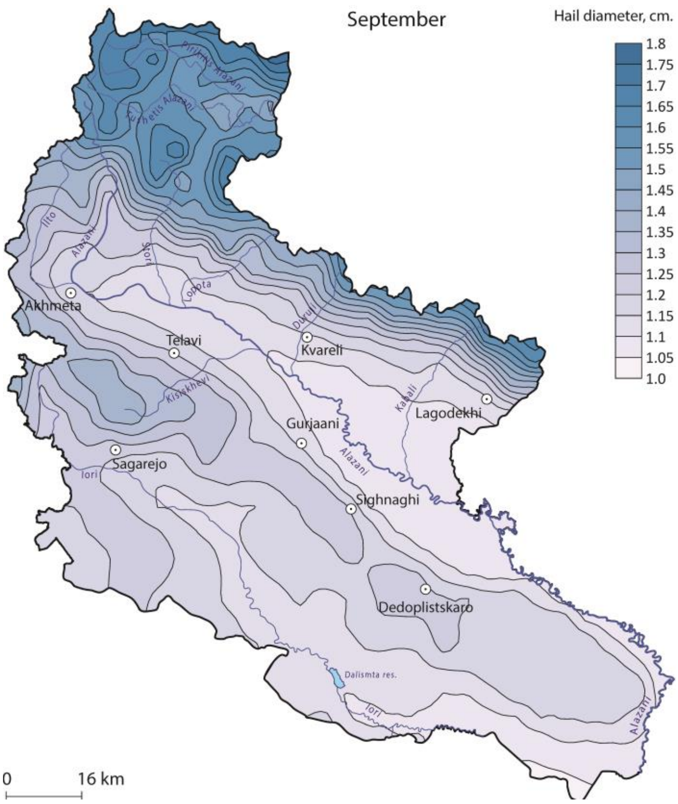

Fig. 6. Distribution of hailstones by mean max diameter on the territory of Kakheti in September.

Fig. 1-6 clearly demonstrated distribution of hailstones by mean max diameter on the territory of Kakheti from April to September.

The statistical characteristics of hailstones by mean max diameter on the earth surface in Kakheti from April to September in Table 2 and 3 are presented. In particular, as follows from Table 2,3 mean values of D to full Kakheti territory change from 0.12 cm (August) to 1.41 cm (June), mean values of D_99%_Low change from 0 cm (August) to 1.17 cm (June) and mean values of D_99%_Upp – from 1.06 cm (August) to 1.65 cm (June).

Table 2. The statistical characteristics of hailstones by mean max diameter on the earth surface in Kakheti from April to June.

Month	**April**			**May**			**June**		
Parameter	**99%_Low**	**Mean**	**99%_Upp**	**99%_Low**	**Mean**	**99%_Upp**	**99%_Low**	**Mean**	**99%_Upp**
Mean	0.29	0.75	1.09	1.02	1.23	1.42	1.17	1.41	1.65
Min	0.00	0.52	0.92	0.82	1.05	1.26	0.96	1.24	1.49
Max	0.91	1.17	1.42	1.53	1.69	1.84	1.75	1.94	2.12
Range	0.91	0.65	0.50	0.72	0.65	0.58	0.79	0.70	0.64
St Dev	0.29	0.18	0.14	0.17	0.15	0.14	0.17	0.15	0.14
σm	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
99%_Low	0.25	0.73	1.07	1.00	1.21	1.40	1.15	1.39	1.63
99%_Upp	0.32	0.78	1.11	1.04	1.24	1.43	1.19	1.43	1.66

Table 3. The statistical characteristics of hailstones by mean max diameter on the earth surface in Kakheti from July to September.

Month	**July**			**August**			**September**		
Parameter	**99%_Low**	**Mean**	**99%_Upp**	**99%_Low**	**Mean**	**99%_Upp**	**99%_Low**	**Mean**	**99%_Upp**
Mean	0.88	1.25	1.58	0.00	0.12	1.06	0.81	1.24	1.61
Min	0.59	1.04	1.40	0.00	0.00	0.82	0.54	1.05	1.46
Max	1.60	1.86	2.11	0.42	1.11	1.72	1.49	1.79	2.09
Range	1.01	0.82	0.71	0.42	1.11	0.90	0.95	0.75	0.63
St Dev	0.22	0.18	0.15	0.02	0.26	0.20	0.21	0.16	0.14
σm	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01
99%_Low	0.85	1.23	1.56	0.00	0.09	1.04	0.79	1.22	1.60
99%_Upp	0.90	1.27	1.60	0.00	0.15	1.08	0.84	1.26	1.63

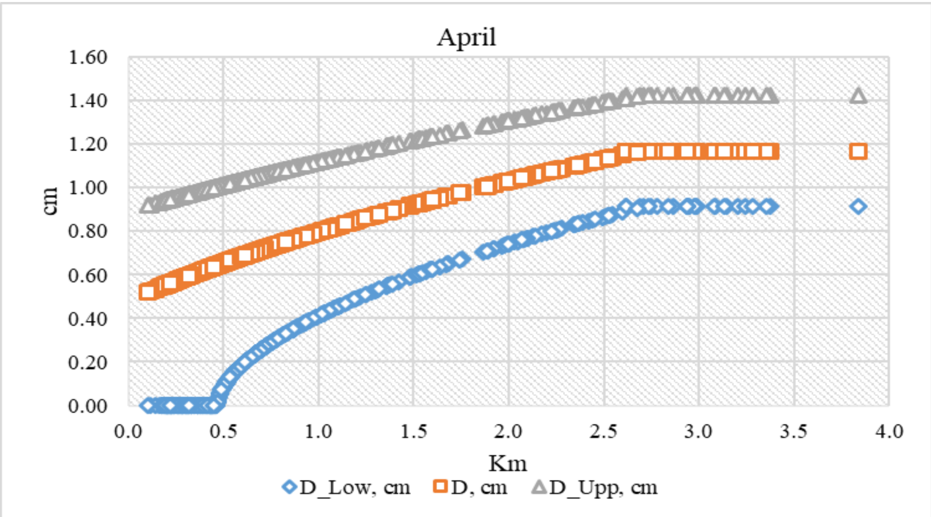

Fig. 7. Vertical distribution of mean max diameter of hailstones and their 99% lower and upper levels in Kakheti in April.

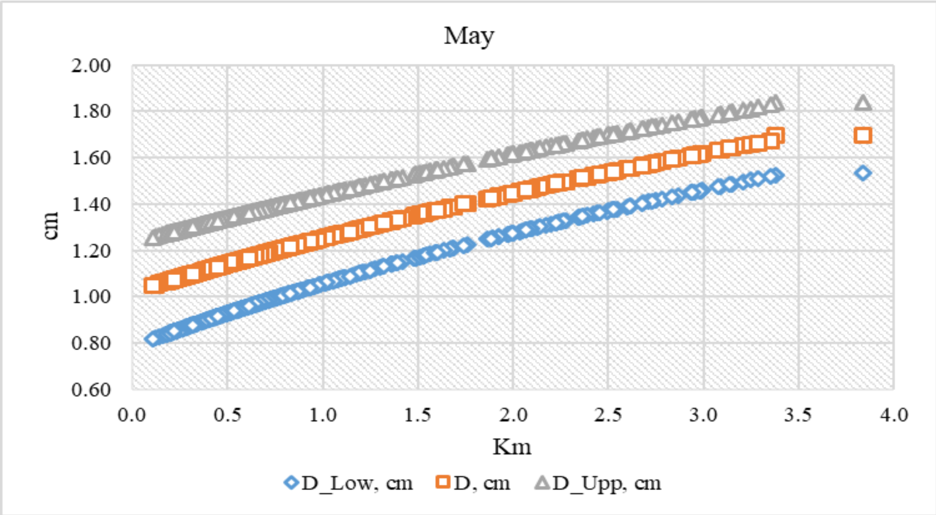

Fig. 8. Vertical distribution of mean max diameter of hailstones and their 99% lower and upper levels in Kakheti in May.

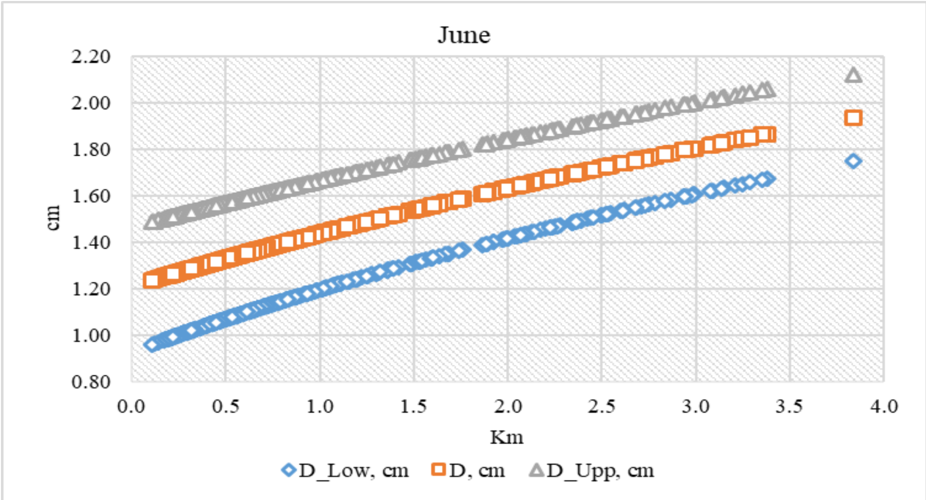

Fig. 9. Vertical distribution of mean max diameter of hailstones and their 99% lower and upper levels in Kakheti in June.

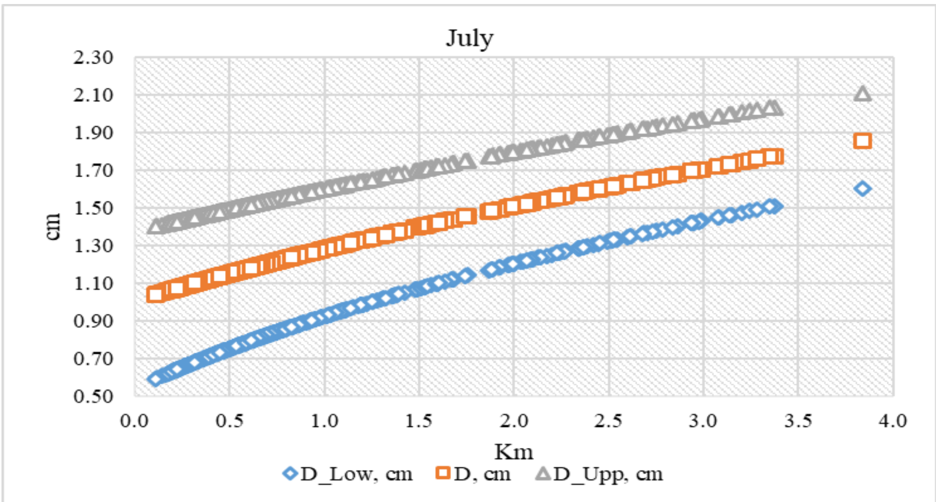

Fig. 10. Vertical distribution of mean max diameter of hailstones and their 99% lower and upper levels in Kakheti in July.

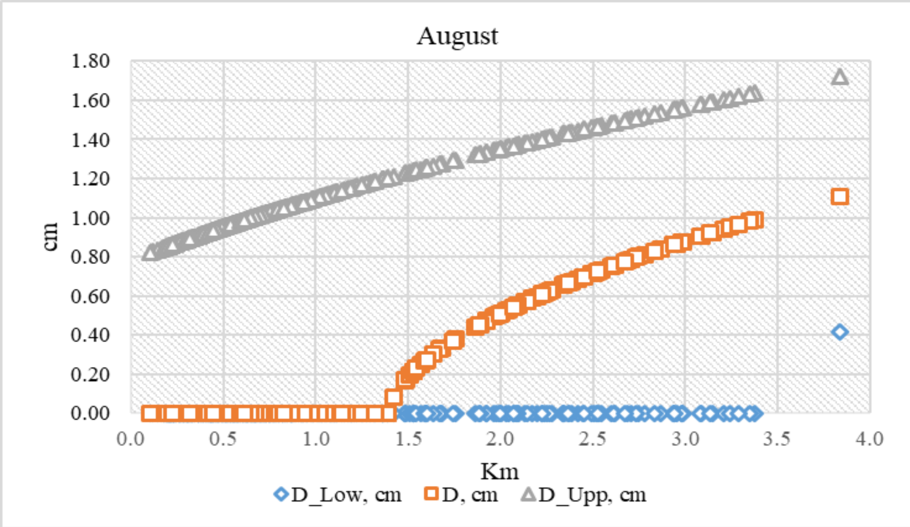

Fig. 11. Vertical distribution of mean max diameter of hailstones and their 99% lower and upper levels in Kakheti in August.

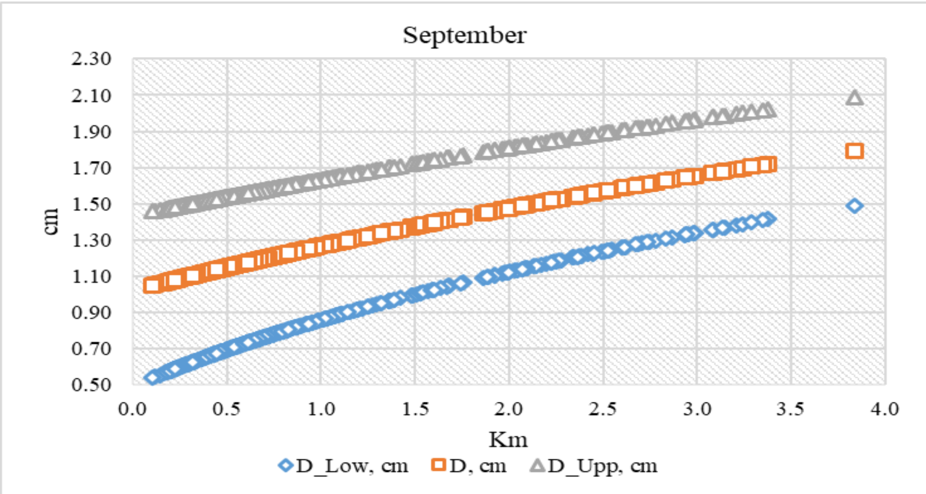

Fig. 12. Vertical distribution of mean max diameter of hailstones and their 99% lower and upper levels in Kakheti in September.

In Fig. 7-12 vertical distribution of mean max diameter of hailstones and their 99% lower and upper levels in Kakheti from April to September are presented. In particular, Fig. 5-12 and Table 2, 3 shows, that the variability of the mean maximum hail diameter on the territory of Kakheti in the range of heights from 0.11 to 3.84 km is as follows:

- **D_99%_Low.** April: 0÷0.91 cm; May: 0.82÷1.53 cm; June: 0.96÷1.75 cm; July: 0.59÷1.60 cm; August: 0÷0.42 cm; September: 0.54÷1.49 cm.
- **D.** April: 0.52÷1.17 cm; May: 1.05÷1.69 cm; June: 1.24÷1.94 cm; July: 1.04÷1.86 cm; August: 0÷1.11 cm; September: 1.05÷1.79 cm.
- **D_99%_Upp.** April: 0.92÷1.42 cm; May: 1.26÷1.84 cm; June: 1.49÷2.12 cm; July: 1.40÷2.11 cm; August: 0.82÷1.72 cm; September: 1.46÷2.09 cm.

Conclusion

In the near future, we plan to study the statistical characteristics of the mean max size of hailstones for the municipalities of Kakheti as well as modeling the damage from hail to vineyards, wheat and corn in the agricultural regions of Kakheti.

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კახეთის ტერიტორიაზე საშუალი მაქსიმალური ზომების მიხედვით სეტყვის განაწილების მოდელირება ატმოსფეროში გაყინვის დონისა და რადარის გაზომვების მონაცემების გამოყენებით

ა. ამირანაშვილი, ნ. ბოლაშვილი, ზ. გულაშვილი,
ნ. ჯამრიშვილი, ნ. სუქნიძე, ხ. თავიდაშვილი

რეზიუმე

წარმოდგენილია სეტყვის განაწილების მოდელირების შედეგები საშუალო მაქსიმალური ზომების მიხედვით კახეთის ტერიტორიისათვის ატმოსფეროში გაყინვის დონისა და ღრუბლებში სეტყვის მაქსიმალური ზომების შესახებ რადიოლოკაციური გაზომვების მონაცემების გამოყენებით.

შედგენილია სეტყვის განაწილების რუკები საშუალო მაქსიმალური ზომების მიხედვით კახეთის ტერიტორიისთვის ცალკეულ თვეებში აპრილიდან სექტემბრამდე. შესწავლილია D - ს ვერტიკალური განაწილება აღნიშნული ტერიტორიისთვის 0.11 - დან 3.84 - კმ- მდე სიმაღლეების დიაპაზონში.

Моделирование распределения по средним максимальных размерам града на территории Кахетии (Грузия) с использованием данных об уровне замерзания в атмосфере и радиолокационных измерений

А.Г. Амиранашвили, Н. Р. Болашвили, З.М. Гулашвили,
Н. К. Джамришвили, Н. Э. Сукнидзе, Х. З. Тавидашвили

Резюме

Представлены результаты моделирования распределения градин по средним максимальным размерам на территории Кахетии (Грузия) с использованием данных об уровне промерзания в атмосфере и радиолокационных измерений максимальных размеров града в облаках.

Построены карты распределения града по средним максимальным размерам на территории Кахетии для отдельных месяцев, с апреля по сентябрь. Изучено вертикальное распределение D на указанной территории в диапазоне высот от 0.11 до 3.84 км

Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(1), 2021, pp. 37-43

Numerical Simulation of Dust Distribution in City Tbilisi Territory in the Winter Period

[1,2]Aleksandre A. Surmava, [3]Leila V. Gverdsiteli, [2]Liana N. Intskirveli, [2]Natia G. Gigauri

[1]M. Nodia Institute of Geophysics at the Iv. Javakhishvili Tbilisi State University, 1, M. Aleksidze Str., 0160, Tbilisi, Georgia, e-mail: aasurmava@yahoo.com
[2]Institute of Hydrometeorology at the Georgian Technical University, 150-a D.Agmashenebeli Ave, 0112 Tbilisi, Georgia, e-mail: intskirvelebi2@yahoo.com
[3]Georgian Technical University, 7, Kostava str., Tbilisi, Georgia, e-mail: l.gverdtsiteli@gtu.ge

ABSTRACT

Dust propagation at Tbilisi city territory in the winter period during western background light wind is modeled and analyzed using 3D regional model of atmospheric process evolution and via combined integration of admixtures transfer and diffusion equations. The motor transport moving at city streets and highways is the main source of atmosphere pollution. Basic peculiarities featuring dust spatial propagation processes under complex terrain conditions are explored. The role of complex terrain in the passive admixture's diffusion process is studied, urban zones with high dust pollution level are established, and the differences between air pollution spatial distribution in winter and summer seasons are determined. Time intervals, when high dust pollution level of the air is formed or air self-purification process occurs, are defined. Time and spatial change of dust concentration in the lower part of the atmospheric boundary layer is studied. It is obtained that 0.8-1.5 maximum allowable concentration (MAC) is registered at 9 AM and 6 PM at Gldani and Temqa district territories situated in the central and northeastern parts of the city.

Key words: *Numerical modeling, pollution source, dust distribution, western background wind, winter season.*

Introduction.

Tbilisi is one of the largest cities of the South Caucasus, an administrative and touristic center of Georgia. Tbilisi city relief is highly complex. City is confined from the west and the east by high-mountain massifs; from the north the narrow Mtkvari River gorge, and from the south the lowland territory connects it with the external space. Based on theoretical assumptions we suppose that the local air circulations formed under the influence of the city atmosphere don't promote city atmosphere self-purification process. Indeed, according to atmospheric air monitoring network data and other studies the dust concentration in Tbilisi atmosphere frequently reaches and, in some cases, exceeds maximum allowable concentrations (MAC) [1-7].

In order to elaborate air quality substantiated recommendations and carry out practical measures it is necessary to study theoretically the features of polluting agents time and spatial distribution in city atmosphere, especially during unfavorable meteorological conditions.

In the presented work, with the purpose of further extension of carried out researches [8-11], city atmosphere pollution level in winter period is studied via numerical modeling under conditions of western background light wind. A numerical model is used to describe the development of atmospheric processes and the spread of pollutants in the Caucasus [8].

Brief description of problem statement.

The 30,6x24 sq. km area of Tbilisi and surrounding territories is considered. In order to mathematically correctly describe the dynamic fields of atmosphere and meteorological parameters under conditions of complex terrain of the city a relief-following coordinate system (t, x, y, $\zeta = (z - \delta) / h$) is used. Here t is time, x and y are coordinates directed along parallel and meridian, ζ is a vertical non dimensional coordinate, $\delta(x,y)$ is a relief height above sea level), h = H - δ – troposphere thickness, $H(t,x,y)$ – tropopause height.

The equation for dust concentration change in the selected coordinate system will be written in the following form

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+(\tilde{w}-\frac{w_0}{h})\frac{\partial C}{\partial \zeta}=\frac{\partial}{\partial x}\mu\frac{\partial}{\partial x}+\frac{\partial}{\partial y}\mu\frac{\partial}{\partial y}+\frac{1}{h^2}\frac{\partial}{\partial \zeta}\nu\frac{\partial C}{\partial \zeta}+F \quad , \qquad (1)$$

where, C – ingredients concentration; u, v, w and $\tilde{w}$ wind velocity components along the x, y, z and ζ axes, w_o – dust deposition rate, $F(t,x,y,\zeta)$ dust dissipation rate in the atmosphere by the source, μ and ν – coefficients of horizontal and vertical turbulence. Wind velocity components and coefficients of turbulence are calculated through numerical integration of equations given in [8] and formulas determining the coefficient of turbulence.

Dust dissipation in the free atmosphere and surface layer of the atmosphere is modeled through numerical integration of equation (1), using respective initial and boundary conditions. Numerical grid steps along the x and y axes equal to 300 and 400 m, and vertical step in the free atmosphere is 1/31 that roughly corresponds to 300 m. In the 100 m thick surface layers of the atmosphere a vertical step varies from 0.5 to 15 m, while time step is 1 sec. Calculations are made for 3-day period. A case of western light background wind under dry weather conditions of January is considered. Wind velocity varies from 1 m/sec (at 100 m height above the ground) to 20 m/sec (in the tropopause at 9 km altitude). Relative atmosphere humidity is 50%.

It is assumed that the atmosphere is polluted by a dust originated at city mains and streets due to motor transport traffic. Its quantity changes in time and is determined according to assessment of continuous surveillance materials and transport traffic intensity.

Numerical modeling results

Spatial distribution of dust concentration and wind velocity, obtained through calculation at 2, 100 and 600 m height from the earth surface, when t = 3 and 6 h, is shown in Fig. 1. Concentration is given in the units of one-off maximum allowable concentration (MAC = 0.5 mg/m^3).

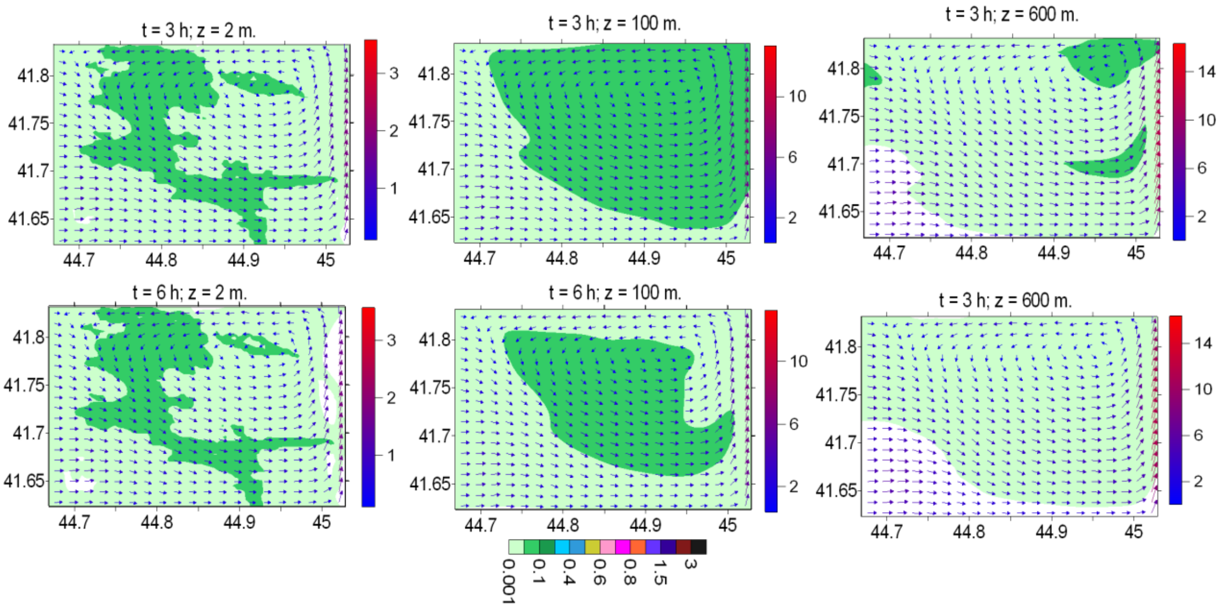

Fig. 1. Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 3 and 6 h, at 2, 100 and 600 m height from the earth surface.

It is seen from Fig. 2 that in time interval from 3h to 6h the dust concentration at 2 m height from the earth surface is practically constant and slightly varies within 0.001-0.1 MAC. 0.01 MAC concentration is obtained at less urbanized territories adjacent to the city. At the central and densely populated (urbanized) territories of the city, dust concentration varies from 0.01 to 0.1 MAC. In the surface layer of the atmosphere dust concentration growths with height increase and at 100 m height it changes within 0.01-0.1MAC in the major part of the atmosphere. Afterwards dust concentration reduces with the further height increase and at 600 m height its value doesn't exceed 0.01 MAC. If we compare spatial distribution and quantitative values of concentration, we come to conclusion that the pollution level in nighttime hours of summer barely exceeds that obtained in winter period.

After t = 6 h, the quantity of dust hitting the atmosphere increases along with quick growth of motor transport traffic intensity and rapid pollution of city atmosphere begins. When t = 9h, during first "rush-hour" situation, at 2 m height above the ground dust concentration is high in the proximity of city mains located in the northern part (Gldani, Temka districts) and the central (Vake and Saburtalo districts) parts of the city. Surface distribution of concentration obtained through calculations considerably differs from that obtained in summer period [12]. Maximum concentration value 1.2 MAC is obtained in the surroundings of the crossroad of Sarajishvili, Guramishvili avenues and Kerch street. Maximum value at Vazha-Pshavela and I. Chavchavadze avenues of Vake and Saburtalo districts equals to 0.7 MAC, while highest concentration at A. Tsereteli Avenue of Didube district reaches 0.9 MAC.

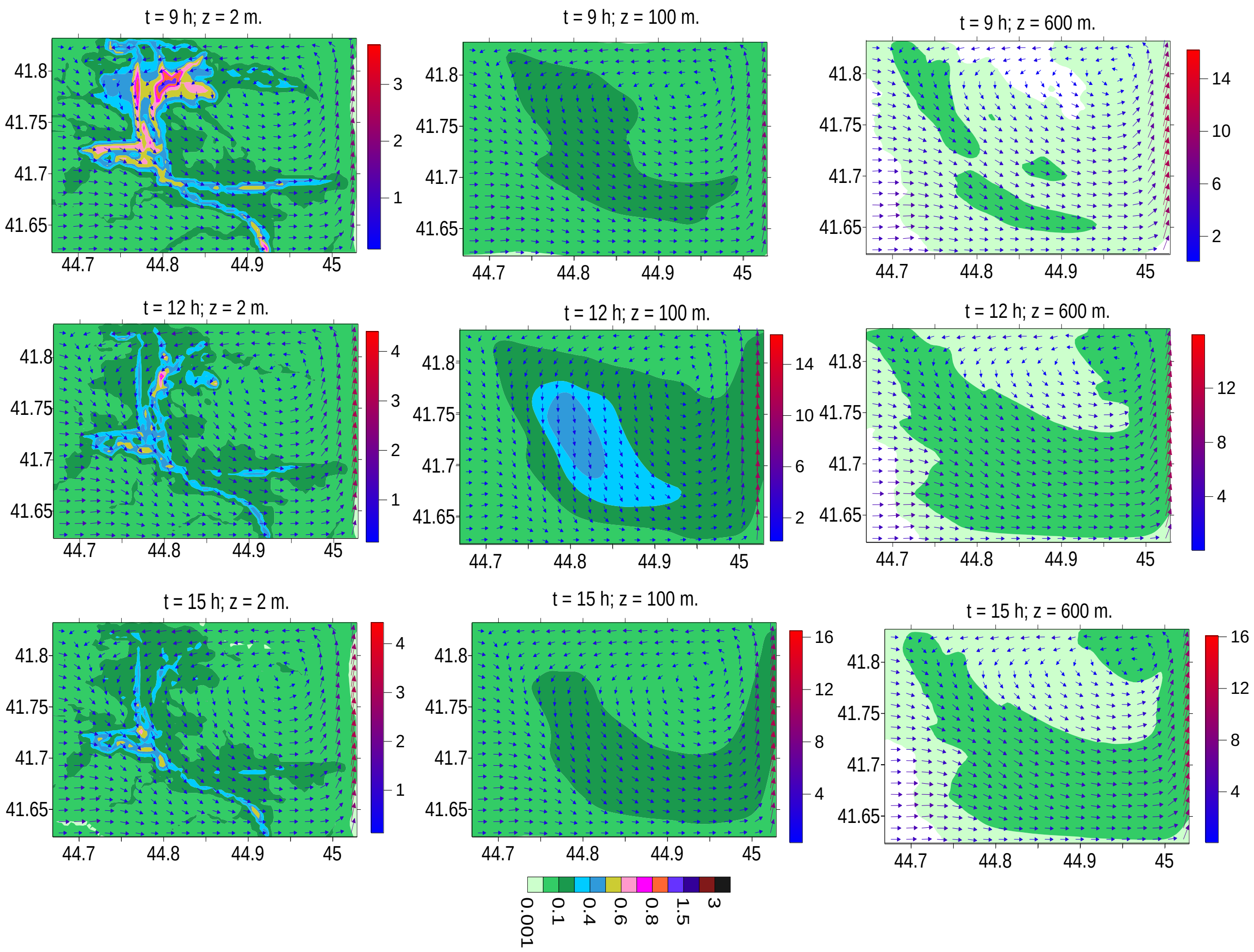

Fig. 2. Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 9, 12 and 15 h, at 2, 100 and 600 m height from the earth surface.

In the time range from 10 AM to midday, under conditions of motor transport traffic constant intensity and dust dissipation constant speed, in the high pollution level area a considerable reduction of concentration is obtained at 2 m height (Fig. 2). Concentration decrease lasts until 3 PM. When t = 12 and 15 h, maximum concentration values vary within 0.6-0.8 MAC interval. The mentioned maximum concentrations are obtained at different urban territories distanced from each other, namely in Temka and Saburtalo districts.

At 100 m from the earth surface a dust is distributed above urbanized territories of the city and its concentration values are equal to 0.3 MAC. The only exception is the concentration values (0.5 MAC) obtained at quite large territories above the central part of the city, when t = 12 h. At 600 m height above the ground the concentration doesn't exceed 0.1 MAC.

After 3 PM, at z = 2 m height, the second stage of dust pollution level increase begins, which lasts up to 8 PM (Fig. 3). Dust pollution level increases in 1 km thick area of the atmospheric boundary layer. This growth is especially intensive in the lower part of the surface layer in the surroundings of city mains located in the center of the city and its peripheries. In the northern part of Tbilisi (surroundings of Temka and Gldani districts), at 2 m height, dust concentration maximum value reaches and even exceeds 1 MAC, while in the central and southern parts of the city the maximum value equals to 0.8 MAC. At suburban areas, dust concentrations are within 0.2 MAC.

Dust vertical turbulent and convective transfer processes occur along with the increase of its surface concentration. Dust concentration growth in the upper part of the surface layer runs with approximately 3-hour phase lag. As a result, maximum concentration value, which is equal to 0.6 MAC is obtained at 100 m height, when t = 21h. At 600 m height from the earth surface dust pollution level is virtually unchanged and is less than 0.1 MAC.

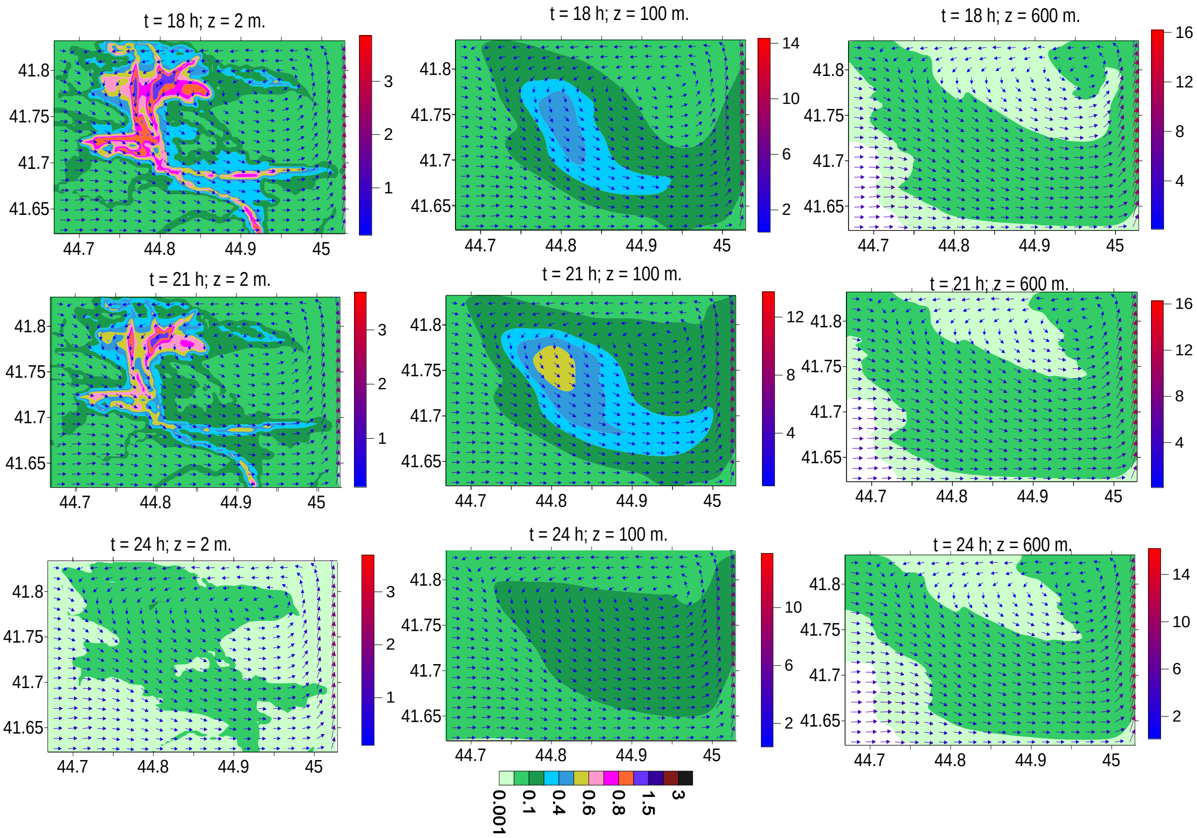

Fig. 3. Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 18, 21 and 24 h, at 2, 100 and 600 m height from the earth surface

After t = 20h the stage of surface concentration reduction begins, which lasts up to t = 24h. Concentration value by this time is within 0.1 MAC at urbanized territory. At 100 m height from the earth surface, dust concentration roughly equals to 0.2 MAC. Calculations show that in case of constant wind, dust transfer and diffusion process has quasiperiodic character with 24h period.

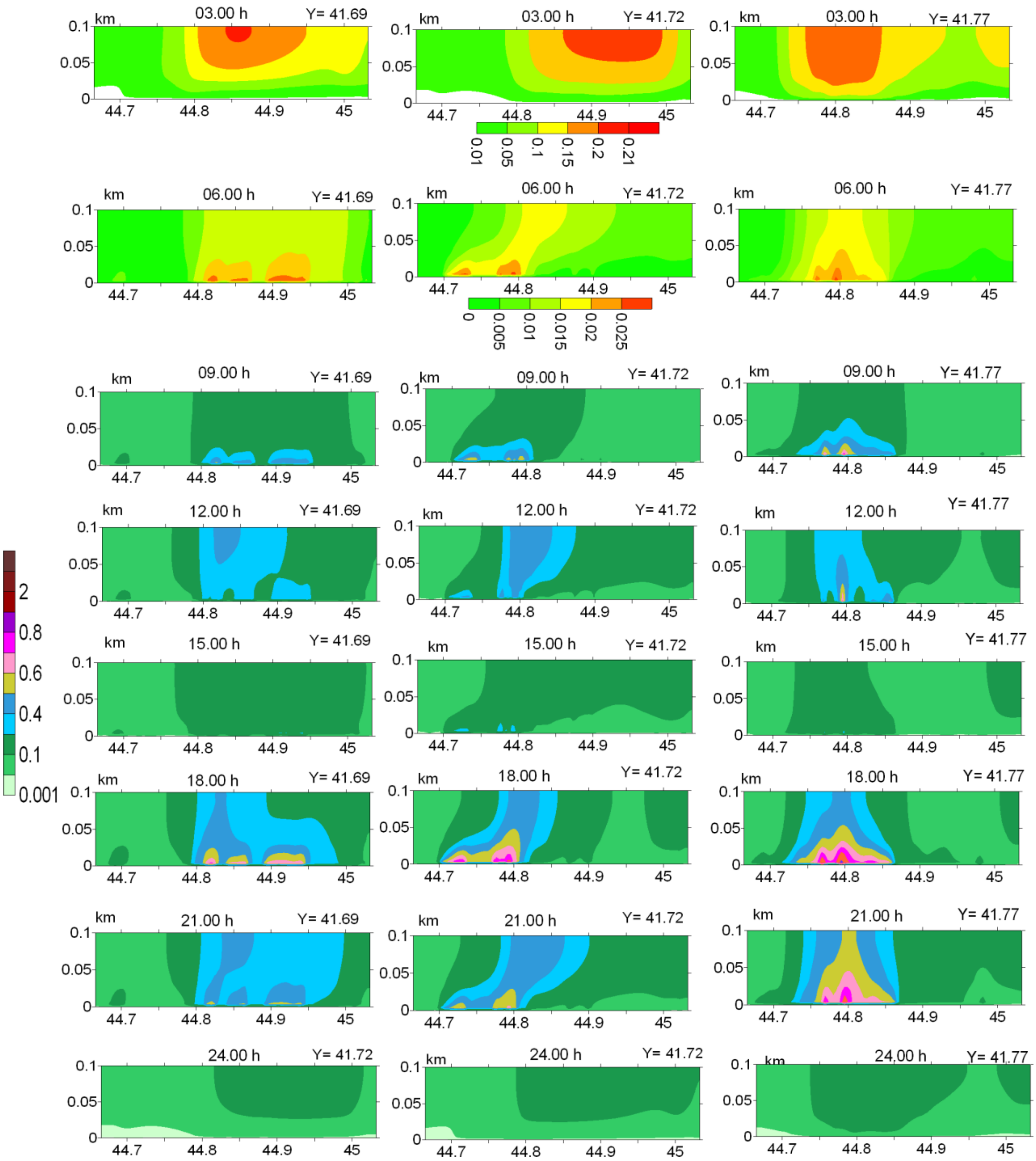

Fig. 4. Dust concentration (MAC) distribution within a day in the surface layer of atmo-sphere in three vertical planes located along the parallel (Y= 41.69°, Y=41. 72° and Y=41. 77°).

In Fig. 4 there is shown dust concentration vertical distribution in the surface layer of atmosphere, in three vertical cross-sections drawn along the parallel, with three hour time interval. It is seen from Fig. 4 that from the midnight to 6 AM an atmospheric dust is transferred to the upper part of the surface layer of atmosphere. From t = 6h dust pollution areas start to form near the underlying surface. At following points of time, a surface dust is propagated in vertical and horizontal direction. Intensive vertical dust transfer starts at t = 18h and lasts until t = 21h. Dust cloud form points at the convective mechanism of its origination. Prevailing directions of dust propagation are seen in Fig. 4 and from there we can determine respective dynamic processes causing dust transfer. We can conclude that local circulation processes at the same territory may have different character at different points of time, namely advective, convective or turbulent-diffusive.

Conclusion

Motor transport-induced dust pollution change kinematics in winter period at the territory of Tbilisi is explored in case of western background wind. Diurnal pattern of dust spatial distribution and its propagation peculiarities are studied. Through analysis of wind velocity and concentration fields it is obtained that spatial distribution of heavily dust polluted areas depends on city mains location, on one hand and on dynamic impact of relief, and local circulation systems formed by daily change of thermal regime at underlying surfaces, on the other.

Comparison of dust concentration spatial and time distribution in winter period with that obtained through calculation for summer one, shows not only their similarity, but also points at substantial qualitative difference between them. Distinctions are manifested in different location of high dust pollution areas, maximum dust pollution level occurrence time, and dust vertical and horizontal distribution. Differences between concentration distribution in case of the same background wind can be explained by the seasonal character of local hydrometeorological fields formation. In particular, Tbilisi city relief, in case of western background light wind, generates local cyclonic vortex in winter, and anticyclone vortex in summer. These vortices, due to diurnal change of thermodynamic fields in the surface layer of atmosphere, experience periodic variations of shape, velocity field and location during a day. The mentioned circumstance has an effect on dust transfer-diffusion process and causes differences in spatial distribution of concentration fields between the winter and summer periods.

Acknowledgment. The work is performed with the support of grant project №FR-3667-18 of Shota Rustaveli National Science Foundation of Georgia.

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ქ. თბილისის ტერტორიაზე ზამთარში მტვრის გავრცელების რიცხვითი მოდელირება

ა. სურმავა’, ლ. გვერდწითელი, ლ. ინწკირველი, ნ. გიგაური

რეზიუმე

ატმოსფერული პროცესების ევოლუციის 3D რეგიონალური მოდელისა და მინარევების გადატანა - დიფუზიის განტოლების ერთობლივი ინტეგრირებით რიცხობრივად მოდელირებული და გაანალიზებულია მტვრის გავრცელება ქ. თბილისის ტერიტორიაზე ზამთრის პერიოდში დასავლეთის ფონური სუსტი ქარის დროს. ატმოსფეროს დაბინძურების ძირითად წყაროს წარმოადგენს ქალაქის ქუჩებსა და მაგისტრალებზე მოძრავი ავტოტრანსპორტი. გამოკვლეულია ძირითადი თავისებურებანი რომლებიც ახასიათებენ რთული რელიეფის პირობებში მტვრის სივრცეში გავრცელების პროცესს. შესწავლილია რთული რელიეფის როლი პასიური მინარევების დიფუზიის პროცესში, დადგენილია ქალაქის მაღალი დამტვერიანების ზონები, აღმოჩენილია განსხვავებები რომლებიც არსებობენ ზამთრისა და ზაფხულის სეზონებში ატმოსფერული ჰაერის დამტვერიანებების სივრცულ განაწილებებს შორის. განსაზღვრულია დროის ინტერვალები, როდესაც ფორმირდება ჰაერის მაღალი დამტვერიანება ან ხდება ჰაერის თვითდასუფთავების პროცესი. შესწავლილია ატმოსფეროს სასაზღვრო ფენის ქვედა ნაწილში მტვრის კონცენტრაციის დროსა და სივრცეში ცვლილება. მიღებული იქნა, რომ 0.8 - 1.5 ზღვრულად დასაშვები კონცენტრაცია (ზდკ) მიიღება დღის 9 და 18 -ზე ქალაქის ცენტრალურ და ჩრდილო -აღმოსავლეთ ნაწილებში მდებარე გლდანისა და თემქის რაიონის ტერიტორიებზე.

Численное Моделирование Распространения Пыли Зимой на территории г. Тбилиси

А. Сурмава, Л. Гвердцители, Л. Инцкирвели, Н. Гигаури

Резюме

Исследовано распространение пыли на территории города Тбилиси в зимний период при фоновом слабом западном ветре с использованием региональной трехмерной модели эволюции атмосферных процессов 3D и интегрирования уравнения переноса-диффузии примесей. В модели автомобильный транспорт рассматривается как основной нестационарный источник загрязнения, от которого в атмосферу выбрасывается пыль. Путем численного моделирования показано, что процесс загрязнения атмосферного воздуха пылью протекает в четыре этапа и зависит от интенсивности автомобильного движения, микрорельефа города и расположения автомобильных магистралей. Исследованы особенности распространения пыли в зимний период года, роль сложного рельефа при диффузии пыли, определены зоны высокого запыленности, выявлены различия между пространственными распределениями пыли в зимний и летный периоды года. Определены интервалы времени, когда формируются зоны высокого запыления воздуха или происходит самоочищения городского воздуха. Получено, что зоны высокой запыленности с концентрациями 0.8-1.5 предельно допустимая концентраций формируются с 9 ч. утра до 6 ч вечера на территориях Глданского и Темкинского районов.

Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(1), 2021, pp. 44-62

Holiday Climate Index in Kakheti (Georgia)

[1]Avtandil G. Amiranashvili, [2]Liana G. Kartvelishvili

[1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia
*1, M. Alexidze Str., 0160, Tbilisi, Georgia, e-mail:*avtandilamiranashvili@gmail.com
[2]National Environmental Agency of Georgia

ABSTRACT

Data about long-term monthly average values of Holiday Climate Index (HCI) for 12 locations of Kakheti (Akhmeta, Dedoplistskaro, Gombori, Gurjaani, Kvareli, Lagodekhi, Omalo, Sagarejo, Shiraki, Telavi, Tsnori and Udabno) are presented. For 6 stations of this region (Dedoplistskaro, Gurjaani, Kvareli, Lagodekhi, Sagarejo and Telavi) detailed analysis of the monthly, seasonally and annually HCIs values over a 60-year period (1956-2015) are carried out. Comparison of monthly values of HCI and Tourism Climate Index (TCI) for four points of Kakheti (Dedoplistskaro, Kvareli, Sagarejo and Telavi) based on data from 1961 to 2010 are carried out.

Key Words: *Bioclimate, Tourism Climate Index, Holiday Climate Index*.

Introduction

Weather and climate are two factors that in many respects influence on tourism development. Many climate indices for tourism have been applied in past research [1-6]. The most widely known and applied index is the Tourism Climate Index (TCI) proposed by Mieczkowski [7]. In south Caucasus countries, monthly value of TCI be calculated in Georgia, first for Tbilisi [8], then for many other locations of Caucasus (Armenia, Azerbaijan, North Caucasus etc.) [9-16]. For example, the statistical characteristics of the monthly mean, annual and half year values of tourism TCI and its components for four points of Kakheti (Telavi, Dedoplistskaro, Kvareli and Sagarejo) in the period from 1961 through 2010 in [14, 16] are represented. In particular, the changeability of the indicated bioclimatic parameters into 1986÷2010 in comparison with 1961÷1985 is studied, and also the trends of values of TCI for higher enumerated points are investigated.

Despite the TCI's wide application, it has been subject to substantial critiques [17]. The four key deficiencies of the TCI include: (1) the subjective rating and weighting system of climatic variables; (2) it neglects the possibility of an overriding influence of physical climatic parameters (e.g., rain, wind); (3) the low temporal resolution of climate data (i.e., monthly data) has limited relevance for tourist decision-making; and (4) it neglects the varying climatic requirements of major tourism segments and destination types (i.e., beach, urban, winter sports tourism).

To overcome the above noted limitations of the TCI, a Holiday Climate Index (HCI) was developed to more accurately assess the climatic suitability of destinations for tourism. The word "holiday" was chosen to better reflect what the index was designed for (*i.e.*, leisure tourism), since tourism is much broader by definition ("Tourism is a social, cultural and economic phenomenon which entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes" [18-23].

Results of comparison of the holiday climate index and the tourism climate index in Tbilisi are presented in [24]. Comparison of the values and categories of the Tourism Climate Index and Holiday

Climate Index in Tbilisi shows that the intra-annual variation of both indices is similar and has a bimodal form. However, given that the TCI is calculated for the so-called "average tourist" (regardless of gender, age, physical condition), the value and category of this index is lower than the HCI values and categories. In general, HCI more adequately determines the bioclimatic state of the environment for the development of various types of tourism than TCI [24]. The detailed information on the variability of the monthly values of the Holiday Climate Index (HCI) in Tbilisi in 1956-2015 in [25] are presented. It also presents data on the interval forecast of variability of HCI values in Tbilisi for the next few decades.

This study develops a long-term average of HCI for 12 stations of Kakheti region of Georgia (Akhmeta, Dedoplistskaro, Gombori, Gurjaani, Kvareli, Lagodekhi, Omalo, Sagarejo, Shiraki, Telavi, Tsnori and Udabno), detailed analysis of the monthly, seasonally and annually HCIs values over a 60-year period (1956-2015) for 6 stations of this region (Dedoplistskaro, Gurjaani, Kvareli, Lagodekhi, Sagarejo and Telavi) and comparison of monthly values of HCI and TCI for four points of Kakheti (Dedoplistskaro, Kvareli, Sagarejo and Telavi) based on data from 1961 to 2010.

Study Area, Material and Methods

Study area - Kakheti region of Georgia (below - Kakheti). Kakheti is located in the eastern part of Georgia. Area - 11375 km^2, population - 314.7 thous. pers., (including of urban - 71.4 thous. pers.), the capital of region - Telavi (population - 19.8 thous. pers.) [www.geostat.ge].

A visit to Kakheti can be a fascinating experience because of its beautiful mountain landscapes, stunning regions, ancient world temples and monasteries, picturesque valleys and rivers and home to amber grapes that grows under the warmth of the sun. Kakheti is not only famous as a tourism destination, but it is also locally recognized as Georgia's center for winemaking.

Studies for 12 locations of Kakheti (Akhmeta, Dedoplistskaro, Gombori, Gurjaani, Kvareli, Lagodekhi, Omalo, Sagarejo, Shiraki, Telavi, Tsnori and Udabno) are carried out.

Fig. 1 depicts the map of the arrangement of the indicated meteorological stations. Table 1 presents information about coordinates and heights of these 12 meteorological stations, whose data were used in the work. These stations that are located from 223 to 1880 meters above sea level and are open to fresh and pure air because of this.

Fig.1. Locations of 12 meteorological stations in Kakheti.

Table 1. Coordinates and heights of the 12 meteorological stations in Kakheti.

Location (Abbreviation)	Latitude, N°	Longitude, E°	Height, m, a.s.l.
Akhmeta (Akhm)	42.02	45.22	567
Dedoplistskaro (Ded)	41.47	46.08	800
Gombori (Gom)	41.86	45.20	1085
Gurjaani (Gur)	41.75	45.80	410
Kvareli (Kvar)	41.97	45.83	449
Lagodekhi (Lagod)	41.82	46.30	362
Omalo	42.38	45.63	1880
Sagarejo (Sag)	41.73	45.33	802
Shiraki (Shir)	41.40	46.33	555
Telavi (Tel)	41.93	45.48	568
Tsnori	41.63	46.02	223
Udabno (Udab)	41.50	45.47	750

In this work the Holiday Climate Index (HCI) is used. The HCI uses five climatic variables related to the three facets essential to tourism (table 2): thermal comfort (TC), aesthetic (A), and physical (P) facet. The five climatic variables used for the HCI input are maximum air temperature and relative humidity (TC), cloud cover (A), precipitation and wind (P) [12].

The HCI score is calculated according to the following formula: $\mathbf{HCI = 4 \cdot T + 2 \cdot A + 3 \cdot R_d + 1 \cdot W}$. In tables 2-4 components of Holiday Climate Index, HCI's rating scheme and HCI's category are presented.

Table 2. Components of Holiday Climate Index (HCI).

Facet	Climatic Variable	Index Weighting (%)
Thermal Comfort (TC)	Dry-bulb Temperature (°C): Maximum Temperature (°C)	40%
	Relative Humidity (%): Mean RH	
Aesthetic (A)	Cloud Cover (%)	20%
Physical (P)	Amount of Rain (mm)	30%
	Wind Speed (km/h)	10%

Table 3. HCI's Rating Scheme.

Rating	T - Effective Temperature (°C)	A - Daily Cloud Cover (%)	R_d - Daily Precipitation (mm)	W - Wind Speed (km/h)
10	23÷25	11÷20	0	1÷9
9	20÷22; 26	1÷10; 21÷30	<3	10÷19
8	27÷28	0; 31÷40	3÷5.99	0; 20÷29
7	18÷19; 29÷30	41÷50		
6	15÷17; 31÷32	51÷60		30÷39
5	11÷14; 33÷34	61÷70	6÷8.99	
4	7÷10; 35÷36	71÷80		
3	0÷6	81÷90		40÷49
2	-5÷-1; 37÷39	90÷99	9÷12	
1	<-5	100		
0	>39		>12	50÷70
-1			>25	
-10				>70

Table 4. HCI's Category.

HCI Score	Category (Abbreviation)	HCI Score	Category (Abbreviation)
90÷100	Ideal	**40÷49**	Marginal (Marg.)
80÷89	Excellent (Excell.)	**30÷39**	Unfavorable
70÷79	Very Good	**20÷29**	Very Unfavorable
60÷69	Good	**10÷19**	Extremely Unfavorable
50÷59	Acceptable (Accept.)	**9÷-9; -10÷-20**	Impossible

For the 12 indicated localities the long-term monthly average values of HCI with the use data of Georgian National Environmental Agency are calculated. For 6 stations of this region (Dedoplistskaro, Gurjaani, Kvareli, Lagodekhi, Sagarejo and Telavi) detailed analysis of the monthly, seasonally and annually HCIs values over a 60-year period (1956-2015) are carried out. Comparison of monthly HCI and TCI values for four points of Kakheti (Dedoplistskaro, Kvareli, Sagarejo and Telavi) based on data from 1961-2010 are carried out [14,16].

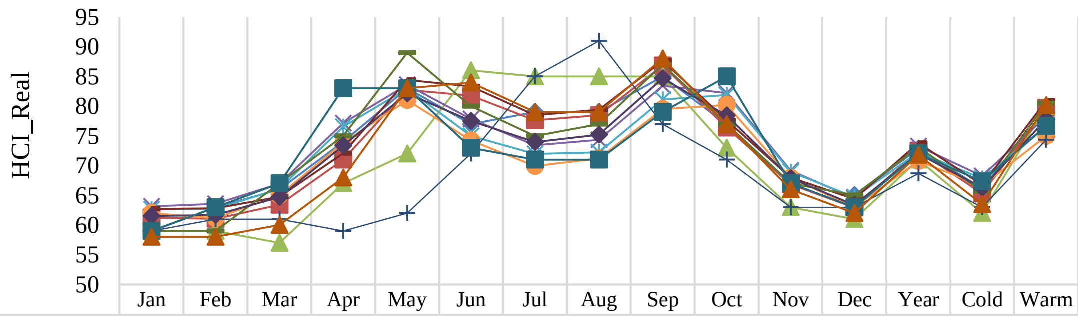
In the work analysis of data is carried out with the use of the standard statistical analysis methods. The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; 99%_Low and 99%_Upp - Low and Upper levels of 99% confidence interval of mean values; R^2 - coefficient of determination; R - coefficient of linear correlation.

Results and discussion

Results in the Table 4-18 and Fig. 2-17 are presented.

1. Basic information about HCI for 12 points of Kakheti.

Data about long-term mean of HCI real values at 12 locations of Kakheti in Fig. 2 are presented.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Akhm	59	63	66	74	83	77	79	79	85	77	67	65	73	66	80
Ded	61	61	63	71	83	82	78	78	87	76	67	63	73	65	80
Gomb	59	59	57	67	72	86	85	85	85	73	63	61	71	62	80
Gur	63	64	67	77	84	78	73	74	83	82	69	64	73	68	78
Kvar	63	63	66	77	83	75	72	72	81	82	69	65	72	68	77
Lagod	62	61	65	74	81	74	70	71	80	80	68	63	71	67	75
Omalo	59	61	61	59	62	72	85	91	77	71	63	63	69	63	74
Sag	63	63	65	72	84	83	78	79	88	78	68	64	74	67	81
Shir	59	59	67	75	89	80	75	77	87	77	67	65	73	66	81
Tel	62	62	65	73	82	78	74	75	85	78	68	63	72	66	78
Tsnori	59	63	67	83	83	73	71	71	79	85	67	63	72	67	77
Udab	58	58	60	68	83	84	79	79	88	77	66	62	72	64	80

Fig. 2. Mean of HCI real values at 12 locations of Kakheti.

As follows from Fig. 2 mean monthly values of HCI change from 57 (Gombori, March, Acceptable) to 91 (Omalo, August, Ideal). The variability of HCI values for individual items is as follows: Akhmeta (59, January – 85, September), Dedoplistskaro (61, January, February – 87, September), Gombori (57, March – 86, June), Gurjaani (63, January – 84, May), Kvareli (63, January, February – 83, May), Lagodekhi (61, February – 81, May), Omalo (59, January, April – 91, August), Sagarejo (63, January, February – 88, September), Shiraki (59, January, February – 89, May), Telavi (62, January, February – 85,September), Tsnori (59, January – 85, October, Udabno (58, January, February – 88, September).

Table 5. Linear correlation coefficient between separated stations on the mean monthly values of HCI (R min = 0.60, α = 0.05; R min = 0.56, α = 0.075; R min = 0.52, α = 0.10; R min = 0.47, α = 0.15).

Location	Akhm	Ded	Gomb	Gur	Kvar	Lagod	Omalo	Sag	Shir	Tel	Tsnori	Udab
Akhm	1	0.97	0.87	0.92	0.89	0.90	0.64	0.97	0.97	0.97	0.82	0.96
Ded	0.97	1	0.91	0.91	0.87	0.89	0.64	1.00	0.96	0.98	0.75	1.00
Gomb	0.87	0.91	1	0.71	0.64	0.66	0.85	0.90	0.78	0.82	0.52	0.93
Gur	0.92	0.91	0.71	1	0.99	0.99	0.38	0.92	0.95	0.97	0.94	0.89
Kvar	0.89	0.87	0.64	0.99	1	1.00	0.32	0.88	0.93	0.95	0.96	0.85
Lagod	0.90	0.89	0.66	0.99	1.00	1	0.35	0.90	0.94	0.96	0.94	0.87
Omalo	0.64	0.64	0.85	0.38	0.32	0.35	1	0.62	0.48	0.53	0.22	0.67
Sag	0.97	1.00	0.90	0.92	0.88	0.90	0.62	1	0.96	0.98	0.76	0.99
Shir	0.97	0.96	0.78	0.95	0.93	0.94	0.48	0.96	1	0.98	0.84	0.94
Tel	0.97	0.98	0.82	0.97	0.95	0.96	0.53	0.98	0.98	1	0.85	0.97
Tsnori	0.82	0.75	0.52	0.94	0.96	0.94	0.22	0.76	0.84	0.85	1	0.72
Udab	0.96	1.00	0.93	0.89	0.85	0.87	0.67	0.99	0.94	0.97	0.72	1

Linear correlation coefficient between separated station on the mean monthly values of HCI changes as follows (Table 5). Akhmeta: 0.64 (Omalo) - 0.97 (Dedoplistskaro, Sagarejo, Shiraki, Telavi); Dedoplistskaro: 0.64 (Omalo) – 1.00 (Sagarejo, Udabno); Gombori: 0.52 (Tsnori) – 0.93 (Udabno); Gurjaani: 0.38 (non sign, Omalo) – 0.99 (Kvareli, Lagodekhi); Kvareli: 0.32 (non sign, Omalo) – 1.00 (Lagodekhi); Lagodekhi: 0.35 (non sign, Omalo) – 1.00 (Kvareli); Omalo: 0.22 (non sign, Tsnori) – 0.85 (Gombori); Sagarejo: 0.62 (Omalo) – 1.00 (Dedoplistskaro); Shiraki: 0.48 (Omalo) – 0.98 (Telavi); Telavi: 0.53 (Omalo) – 0.98 (Dedoplistskaro, Sagarejo, Shiraki); Tsnori: 0.22 (non sign, Omalo) – 0.96 (Kvareli); Udabno: 0.67 (Omalo) – 1.00 (Dedoplistskaro).

Distribution of mean monthly values of TCI for 12 locations of Kakheti by a ninth power of polynomial ($R^2 \geq 0.978$) are described. Coefficients of the equation of the regression of the intra-annual motion of mean monthly values of HCI for these points in Table 6 are presented.

Table 6. Coefficients of the equation of the regression of the intra-annual motion of mean monthly values of HCI for 12 points of Kakheti.

Equation of regress., coefficients	$HCI = a{\cdot}X^9+b{\cdot}X^8+c{\cdot}X^7+d{\cdot}X^6+e{\cdot}X^5+f{\cdot}X^4+g{\cdot}X^3+h{\cdot}X^2+i{\cdot}X+j$, (X-Month)										
	a	b	c	d	e	f	g	h	i	j	R^2
Akhm	-7.05E-05	3.81E-03	-8.54E-02	1.02E+00	-7.08E+00	2.82E+01	-6.12E+01	6.11E+01	-9.50E+00	4.65E+01	0.978
Ded	-2.35E-04	1.35E-02	-3.26E-01	4.37E+00	-3.52E+01	1.76E+02	-5.40E+02	9.72E+02	-9.25E+02	4.08E+02	0.996
Gom	-6.56E-05	3.78E-03	-9.19E-02	1.23E+00	-9.81E+00	4.79E+01	-1.41E+02	2.38E+02	-2.10E+02	1.33E+02	0.979
Gur	4.62E-05	2.70E-03	6.75E-02	9.38E-01	7.94E+00	4.22E+01	1.39E+02	2.69E+02	2.74E+02	1.09E+02	0.996
Kvar	2.38E-06	-2.91E-04	1.31E-02	-2.93E-01	3.67E+00	-2.67E+01	1.12E+02	-2.56E+02	2.88E+02	-5.82E+01	0.990
Lagod	-4.37E-05	2.44E-03	-5.61E-02	6.80E-01	-4.68E+00	1.81E+01	-3.67E+01	3.36E+01	-7.02E+00	5.81E+01	0.993
Omalo	1.57E-04	-9.07E-03	2.22E-01	-3.00E+00	2.44E+01	-1.23E+02	3.82E+02	-6.99E+02	6.78E+02	-2.00E+02	0.990
Sag	4.92E-05	2.88E-03	7.19E-02	9.99E-01	8.46E+00	4.49E+01	1.48E+02	2.87E+02	2.92E+02	1.16E+02	0.997
Shir	1.22E-04	7.16E-03	1.79E-01	2.49E+00	2.11E+01	1.12E+02	3.68E+02	7.14E+02	7.27E+02	2.89E+02	0.984
Tel	-1.46E-04	8.30E-03	-1.98E-01	2.59E+00	-2.02E+01	9.72E+01	-2.85E+02	4.89E+02	-4.45E+02	2.23E+02	0.993
Tsnori	2.22E-04	-1.31E-02	3.31E-01	-4.69E+00	4.06E+01	-2.20E+02	7.40E+02	-1.45E+03	1.49E+03	-5.31E+02	0.996
Udab	-2.79E-04	1.61E-02	-3.93E-01	5.30E+00	-4.31E+01	2.17E+02	-6.71E+02	1.22E+03	-1.16E+03	4.95E+02	0.997

In Table 7 information about distribution types of mean monthly values of HCI at 12 locations of Kakheti are provides.

As follows from this Table in general bimodal distribution type of HCI is observed (10 locations from 12). For stations Akhmeta, Dedoplistskaro, Sagarejo, Shiraki and Telavi the first and second extremum in HCI distribution fall on May and September respectively; for stations Gurjaani, Kvareli and Lagodekhi - on May and September-October; for Tsnori - on April-May and October and for Udabno - on May-June and September.

For Gombori unimodal distribution type of HCI with plateau in June-September is observed; for Omalo - unimodal distribution type with maximum in August.

Table 7. Distribution types of mean monthly values of HCI at 12 locations of Kakheti.

<table>
<tr><th>Location</th><th>Distribution type</th><th>First extremum</th><th>Second extremum</th><th>Location</th><th>Distribution type</th><th>First extremum</th><th>Second extremum</th></tr>
<tr><td>Akhmeta</td><td rowspan="2">Bimodal</td><td rowspan="2">May</td><td rowspan="2">Sep</td><td>Omalo</td><td>Unimodal</td><td colspan="2">Aug</td></tr>
<tr><td>Dedoplistskaro</td><td>Sagarejo</td><td rowspan="5">Bimodal</td><td rowspan="3">May</td><td rowspan="3">Sep</td></tr>
<tr><td>Gombori</td><td>Unimodal, plateau</td><td colspan="2">June-Sept</td><td>Shiraki</td></tr>
<tr><td>Gurjaani</td><td rowspan="3">Bimodal</td><td rowspan="3">May</td><td rowspan="3">Sep-Oct</td><td>Telavi</td></tr>
<tr><td>Kvareli</td><td>Tsnori</td><td>Apr-May</td><td>Oct</td></tr>
<tr><td>Lagodekhi</td><td>Udabno</td><td>May-Jun</td><td>Sep</td></tr>
</table>

In Table 8 and 9 data about categories of mean monthly and seasonal values of HCI at 12 locations of Kakheti in cold and warm period are presented.

Table 8. Categories of mean monthly and seasonal values of HCI at 12 locations of Kakheti in cold period.

<table>
<tr><th>Location</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Cold</th><th>Year</th></tr>
<tr><td>Akhmeta</td><td>Accept.</td><td rowspan="2">Good</td><td rowspan="2">Good</td><td rowspan="3">Very Good</td><td rowspan="12">Good</td><td rowspan="12">Good</td><td rowspan="12">Good</td><td rowspan="6">Very Good</td></tr>
<tr><td>Dedoplistskaro</td><td>Good</td></tr>
<tr><td>Gombori</td><td>Accept.</td><td>Accept.</td><td>Accept.</td></tr>
<tr><td>Gurjaani</td><td rowspan="3">Good</td><td rowspan="5">Good</td><td rowspan="9">Good</td><td rowspan="3">Excell.</td></tr>
<tr><td>Kvareli</td></tr>
<tr><td>Lagodekhi</td></tr>
<tr><td>Omalo</td><td>Accept.</td><td rowspan="4">Very Good</td><td>Good</td></tr>
<tr><td>Sagarejo</td><td>Good</td><td rowspan="5">Very Good</td></tr>
<tr><td>Shiraki</td><td>Accept.</td><td>Accept.</td></tr>
<tr><td>Telavi</td><td>Good</td><td rowspan="2">Good</td></tr>
<tr><td>Tsnori</td><td rowspan="2">Accept.</td><td>Excell.</td></tr>
<tr><td>Udabno</td><td>Accept.</td><td>Very Good</td></tr>
</table>

Table 9. Categories of mean monthly and seasonal values of HCI at 12 locations of Kakheti in warm period.

<table>
<tr><th>Location</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Warm</th></tr>
<tr><td>Akhmeta</td><td rowspan="2">Very Good</td><td rowspan="2">Excell.</td><td>Very Good</td><td rowspan="2">Very Good</td><td rowspan="2">Very Good</td><td rowspan="6">Excell.</td><td rowspan="3">Excell.</td></tr>
<tr><td>Dedoplistskaro</td><td rowspan="2">Excell.</td></tr>
<tr><td>Gombori</td><td>Good</td><td>Very Good</td><td>Excell.</td><td>Excell.</td></tr>
<tr><td>Gurjaani</td><td rowspan="3">Very Good</td><td rowspan="3">Excell.</td><td rowspan="4">Very Good</td><td rowspan="3">Very Good</td><td rowspan="3">Very Good</td><td rowspan="4">Very Good</td></tr>
<tr><td>Kvareli</td></tr>
<tr><td>Lagodekhi</td></tr>
<tr><td>Omalo</td><td>Accept.</td><td>Good</td><td>Excell.</td><td>Ideal</td><td>Very Good</td></tr>
<tr><td>Sagarejo</td><td rowspan="3">Very Good</td><td rowspan="5">Excell.</td><td rowspan="2">Excell.</td><td rowspan="5">Very Good</td><td rowspan="5">Very Good</td><td rowspan="3">Excell.</td><td rowspan="2">Excell.</td></tr>
<tr><td>Shiraki</td></tr>
<tr><td>Telavi</td><td rowspan="2">Very Good</td><td rowspan="2">Very Good</td></tr>
<tr><td>Tsnori</td><td>Excell.</td><td>Very Good</td></tr>
<tr><td>Udabno</td><td>Good</td><td>Excell.</td><td>Excell.</td><td>Excell.</td></tr>
</table>

As follows from these Tables, categories of mean monthly and seasonal values of HCI at 12 locations of Kakheti changes from Acceptable to Ideal.

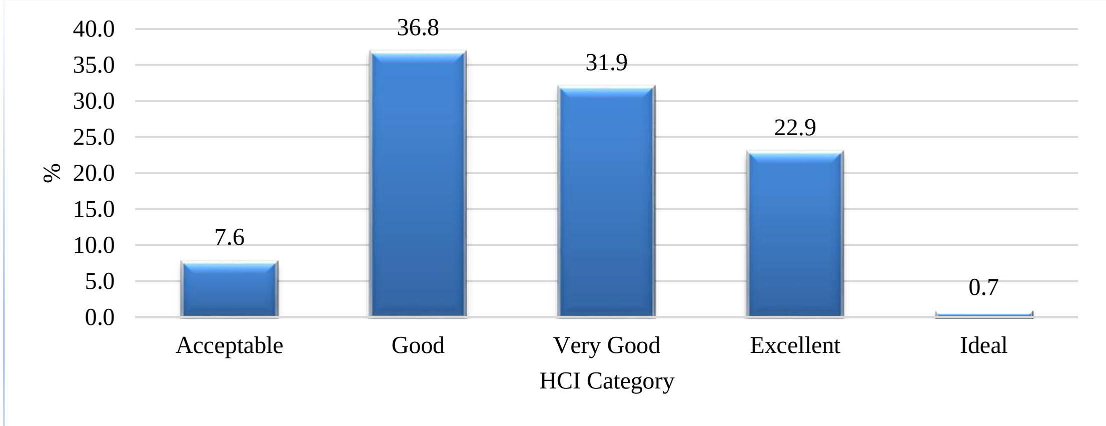


Fig. 3. Repetition of mean monthly HCI category at 12 locations of Kakheti.

In Fig. 3 information about repetition of mean monthly HCI category at 12 locations of Kakheti is presented. So, as follows from Tables 8, 9 and Fig. 3 in Kakheti there are favorable conditions for the development of tourism and resorts throughout the year.

2. Analysis of HCI and HCI components at 6 points of Kakheti in 1956-2015.

Detailed analysis of HCI and HCI components at 6 points of Kakheti from 1956 to 2015 in Fig. 4-15 and Tables 10-15 are presented.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded Min	53	55	52	53	59	69	65	65	75	60	53	54	69	60	74
Ded Max	69	69	72	89	93	91	85	89	93	89	80	73	76	70	85
Gur Min	57	54	56	57	66	59	65	56	67	64	54	54	69	63	71
Gur Max	67	74	77	91	91	85	79	81	91	96	82	73	76	73	82
Kvar Min	56	54	56	61	67	61	61	56	58	59	58	56	69	63	70
Kvar Max	71	73	83	91	91	83	79	81	89	95	84	74	75	72	83
Lagod Min	56	43	54	46	62	56	59	48	62	52	54	49	63	62	63
Lagod Max	69	73	83	91	89	84	78	81	89	93	86	74	74	72	81
Sag Min	53	56	52	51	60	71	69	69	73	60	52	54	70	62	75
Sag Max	71	75	77	89	93	91	85	87	95	91	86	74	78	72	85
Tel Min	53	55	53	57	67	61	63	68	71	60	55	54	69	63	72
Tel Max	72	71	77	89	91	86	79	81	93	96	84	73	75	72	81

Fig. 4. Min and Max values of HCI at 6 locations of Kakheti in different months and season in 1956-2015.

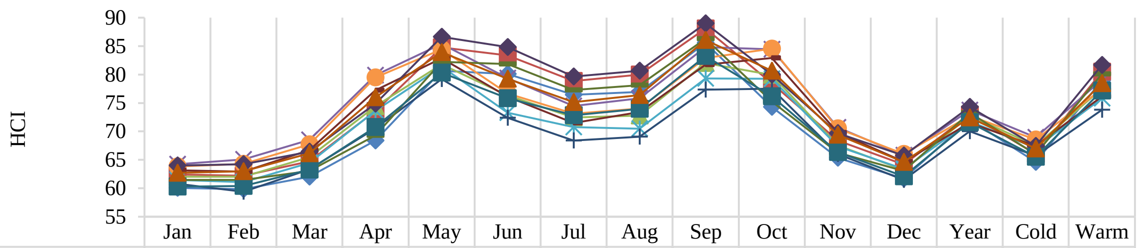
In Fig. 4 and Tables 10,11 data about Min and Max values of HCI and these categories at 6 locations of Kakheti in different months and season in 1956-2015 are presented. As follows from these Fig. and Tables values of HCI in 6 locations of Kakheti changes from 43 (Lagodekhi, February, Marginal) to 96 (Telavi, October, Ideal).

Table 10. Categories of Min and Max values of HCI at 6 locations of Kakheti in cold period in 1956-2015.

<table>
<tr><th>Location</th><th>Parameter</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Cold</th><th>Year</th></tr>
<tr><td>Ded</td><td>Min</td><td rowspan="4">Accept.
Good</td><td>Accept.</td><td rowspan="4">Accept.
Very Good</td><td>Good</td><td rowspan="12">Accept.
Excell.</td><td rowspan="6">Accept.
Very Good</td><td rowspan="12">Good
Very
Good</td><td rowspan="8">Good
Very Good</td></tr>
<tr><td>Ded</td><td>Max</td><td>Good</td><td>Excell.</td></tr>
<tr><td>Gur</td><td>Min</td><td rowspan="4">Accept.
Very Good</td><td>Good</td></tr>
<tr><td>Gur</td><td>Max</td><td>Ideal</td></tr>
<tr><td>Kvar</td><td>Min</td><td>Accept.</td><td rowspan="4">Accept.
Excell.</td><td rowspan="4">Accept.
Ideal</td></tr>
<tr><td>Kvar</td><td>Max</td><td>Very Good</td></tr>
<tr><td>Lagod</td><td>Min</td><td>Accept.</td><td>Marg.</td><td>Marg.</td></tr>
<tr><td>Lagod</td><td>Max</td><td>Good</td><td>Very Good</td><td>Very Good</td></tr>
<tr><td>Sag</td><td>Min</td><td rowspan="4">Accept.
Very Good</td><td rowspan="4">Accept.
Very Good</td><td rowspan="4">Accept.
Very Good</td><td rowspan="4">Good
Ideal</td><td rowspan="4">Accept.
Very Good</td><td rowspan="2">Very Good</td></tr>
<tr><td>Sag</td><td>Max</td></tr>
<tr><td>Tel</td><td>Min</td><td>Good</td></tr>
<tr><td>Tel</td><td>Max</td><td>Very Good</td></tr>
</table>

Table 11. Category of Min and Max values of HCI at 6 locations of Kakheti in warm period in 1956-2015.

<table>
<tr><th>Location</th><th>Parameter</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Warm</th></tr>
<tr><td>Ded</td><td>Min</td><td>Accept.</td><td>Accept.</td><td>Good</td><td>Good</td><td>Good</td><td>Very Good</td><td rowspan="6">Very Good
Excell.</td></tr>
<tr><td>Ded</td><td>Max</td><td>Excell.</td><td>Ideal</td><td>Ideal</td><td>Excell.</td><td>Excell.</td><td>Ideal</td></tr>
<tr><td>Gur</td><td>Min</td><td>Accept.</td><td rowspan="4">Good
Ideal</td><td>Accept.</td><td rowspan="4">Good
Very Good</td><td rowspan="4">Accept.
Excell.</td><td>Good</td></tr>
<tr><td>Gur</td><td>Max</td><td>Ideal</td><td>Excell.</td><td>Ideal</td></tr>
<tr><td>Kvar</td><td>Min</td><td>Good</td><td>Good</td><td>Accept.</td></tr>
<tr><td>Kvar</td><td>Max</td><td>Ideal</td><td>Excell.</td><td>Excell.</td></tr>
<tr><td>Lagod</td><td>Min</td><td>Marg.</td><td>Good</td><td>Accept.</td><td>Accept.</td><td>Marg.</td><td>Good</td><td>Good</td></tr>
<tr><td>Lagod</td><td>Max</td><td>Ideal</td><td>Excell.</td><td>Excell.</td><td>Very Good</td><td>Excell.</td><td>Excell.</td><td>Excell.</td></tr>
<tr><td>Sag</td><td>Min</td><td rowspan="4">Accept.
Excell.</td><td rowspan="4">Good
Ideal</td><td>Very Good</td><td>Good</td><td rowspan="4">Good
Excell.</td><td rowspan="4">Very Good
Ideal</td><td rowspan="4">Very Good
Excell.</td></tr>
<tr><td>Sag</td><td>Max</td><td>Ideal</td><td>Excell.</td></tr>
<tr><td>Tel</td><td>Min</td><td>Good</td><td>Good</td></tr>
<tr><td>Tel</td><td>Max</td><td>Excell.</td><td>Very Good</td></tr>
</table>



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded 99%_Low	60	60	62	68	81	80	76	77	86	74	65	62	72	65	79
Ded 99%_Upp	62	62	65	74	85	83	79	80	88	78	68	64	73	66	80
Gur 99%_Low	62	62	65	74	82	76	72	73	82	80	68	63	73	68	77
Gur 99%_Upp	64	65	69	80	85	79	74	76	85	84	71	66	74	69	79
Kvar 99%_Low	61	61	64	74	81	73	71	70	79	79	67	63	72	67	76
Kvar 99%_Upp	64	64	68	79	84	77	73	74	83	85	71	66	73	69	77
Lagod 99%_Low	61	59	63	71	79	72	68	69	77	78	66	61	70	66	74
Lagod 99%_Upp	63	63	67	77	83	76	72	73	82	83	70	65	71	67	76
Sag 99%_Low	61	61	63	69	82	82	77	78	86	75	66	63	73	66	80
Sag 99%_Upp	64	64	66	75	87	85	80	81	89	80	70	66	74	67	82
Tel 99%_Low	60	60	63	71	80	76	73	74	83	76	66	62	72	66	77
Tel 99%_Upp	63	63	66	76	84	79	75	76	86	81	69	65	72	67	78

Fig. 5. Low and Upper levels of 99% confidence interval of mean values of HCI at six locations of Kakheti in 1956-2015.

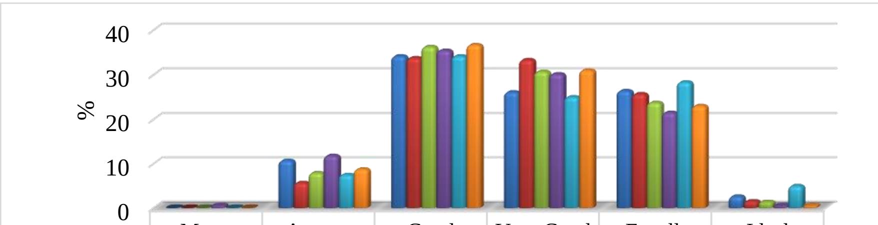
Table 12. Category of Low and Upper levels of 99% confidence interval of mean values of HCI at 6 locations of Kakheti in cold period in 1956-2015.

<table>
<tr><th>Location</th><th>Parameter</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Cold</th><th>Year</th></tr>
<tr><td>Ded</td><td>99%_Low</td><td rowspan="12">Good</td><td rowspan="6">Good</td><td rowspan="12">Good</td><td rowspan="2">Very Good</td><td rowspan="2">Good</td><td rowspan="12">Good</td><td rowspan="12">Good</td><td rowspan="12">Very Good</td></tr>
<tr><td>Ded</td><td>99%_Upp</td></tr>
<tr><td>Gur</td><td>99%_Low</td><td rowspan="2">Excell.</td><td>Good</td></tr>
<tr><td>Gur</td><td>99%_Upp</td><td>Very Good</td></tr>
<tr><td>Kvar</td><td>99%_Low</td><td>Very Good</td><td rowspan="6">Good Very Good</td></tr>
<tr><td>Kvar</td><td>99%_Upp</td><td>Excell.</td></tr>
<tr><td>Lagod</td><td>99%_Low</td><td>Accept.</td><td>Very Good</td></tr>
<tr><td>Lagod</td><td>99%_Upp</td><td>Good</td><td>Excell.</td></tr>
<tr><td>Sag</td><td>99%_Low</td><td rowspan="4">Good</td><td>Very Good</td></tr>
<tr><td>Sag</td><td>99%_Upp</td><td>Excell.</td></tr>
<tr><td>Tel</td><td>99%_Low</td><td>Very Good</td><td rowspan="2">Good</td></tr>
<tr><td>Tel</td><td>99%_Upp</td><td>Excell.</td></tr>
</table>

Table 13. Category of Low and Upper levels of 99% confidence interval of mean values of HCI at 6 locations of Kakheti in warm period in 1956-2015.

<table>
<tr><th>Location</th><th>Parameter</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Warm</th></tr>
<tr><td>Ded</td><td>99%_Low</td><td>Good</td><td rowspan="6">Excell.</td><td rowspan="2">Excell.</td><td rowspan="6">Very Good</td><td>Very Good</td><td rowspan="4">Excell.</td><td>Very Good</td></tr>
<tr><td>Ded</td><td>99%_Upp</td><td>Very Good</td><td>Excell.</td><td>Excell.</td></tr>
<tr><td>Gur</td><td>99%_Low</td><td>Very Good</td><td rowspan="6">Very Good</td><td rowspan="4">Very Good</td><td rowspan="6">Very Good</td></tr>
<tr><td>Gur</td><td>99%_Upp</td><td>Excell.</td></tr>
<tr><td>Kvar</td><td>99%_Low</td><td rowspan="4">Very Good</td><td>Very Good</td></tr>
<tr><td>Kvar</td><td>99%_Upp</td><td>Excell.</td></tr>
<tr><td>Lagod</td><td>99%_Low</td><td>Very Good</td><td>Good</td><td>Good</td><td>Very Good</td></tr>
<tr><td>Lagod</td><td>99%_Upp</td><td>Excell.</td><td>Very Good</td><td>Very Good</td><td>Excell.</td></tr>
<tr><td>Sag</td><td>99%_Low</td><td>Good</td><td rowspan="4">Excell.</td><td rowspan="2">Excell.</td><td>Very Good</td><td>Very Good</td><td rowspan="4">Excell.</td><td rowspan="2">Excell.</td></tr>
<tr><td>Sag</td><td>99%_Upp</td><td>Very Good</td><td>Excell.</td><td>Excell.</td></tr>
<tr><td>Tel</td><td>99%_Low</td><td rowspan="2">Very Good</td><td rowspan="2">Very Good</td><td rowspan="2">Very Good</td><td rowspan="2">Very Good</td><td rowspan="2">Very Good</td></tr>
<tr><td>Tel</td><td>99%_Upp</td></tr>
</table>

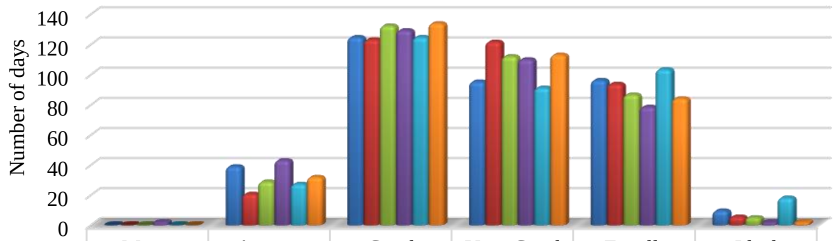
In Fig. 5 and Tables 12,13 information about 99%_Low and 99%_Upp levels of mean values of HCI and these categories at 6 locations of Kakheti in different months and season in 1956-2015 are presented. As follows from these Fig. and Tables values of HCI in 6 locations of Kakheti changes from 43 (Lagodekhi, February, Marginal) to 96 (Telavi, October, Ideal). As follows from these Fig. and Tables values of HCI in 6 locations of Kakheti changes from 59 (Acceptable) to 89 (Excellent).



	Marg.	Accept.	Good	Very Good	Excell.	Ideal
Ded	0.0	10.7	34.2	26.1	26.4	2.6
Gur	0.0	5.7	33.8	33.3	25.7	1.5
Kvar	0.0	7.9	36.3	30.7	23.8	1.4
Lagod	0.6	11.8	35.4	30.1	21.5	0.6
Sag	0.0	7.5	34.2	25.0	28.3	5.0
Tel	0.0	8.8	36.7	31.0	23.1	0.6

Fig. 6. Repetition of monthly values of TCI categories at six locations of Kakheti in 1956-2015.

In Fig. 6 data about repetition of monthly values of TCI category at six locations of Kakheti in 1956-2015 are presented. The variability of this repetition for separate locations of Kakheti is as follows: Dedoplistskaro (2,6%, Ideal – 34.2%, Good), Gurjaani (1,5%, Ideal – 33,8% Good), Kvareli (1,4%, Ideal – 36.3%, Good), Lagodekhi (0,6%, Marginal, Ideal – 35.4%, Good), Sagarejo (5,0%, Ideal – 34.2%, Good), Telavi (0,6%, Ideal – 36.7%, Good).



	Marg.	Accept.	Good	Very Good	Excell.	Ideal
Ded	0	39	125	95	96	10
Gur	0	21	123	122	94	6
Kvar	0	29	132	112	87	5
Lagod	2	43	129	110	79	2
Sag	0	27	125	91	103	18
Tel	0	32	134	113	84	2

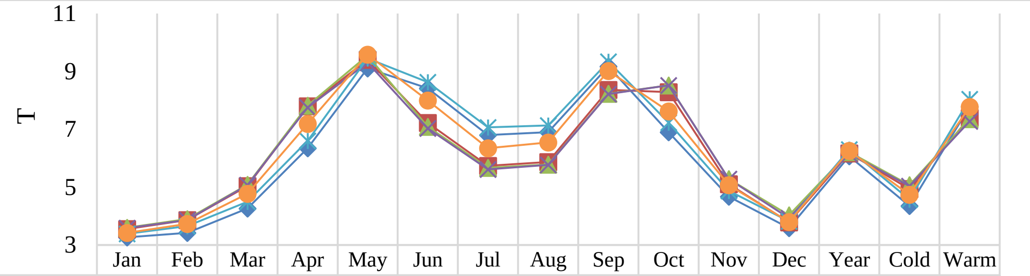
Fig. 7. Number of days in year of various categories of HCI at six locations of Kakheti in 1956-2015.

Respectively the variability of number of days in year of various categories of HCI for separate locations of Kakheti is as follows (Fig. 7): Dedoplistskaro (10, Ideal – 125, Good), Gurjaani (6, Ideal – 123, Good), Kvareli (5, Ideal – 132, Good), Lagodekhi 2, Marginal, Ideal – 129, Good), Sagarejo (18, Ideal – 125, Good), Telavi (2, Ideal – 134, Good).

In Table 14 and Fig. 8-11 data about Min, Max and mean values of HCI components at six locations of Kakheti are presented. As follows from these Table and Fig. the monthly values of HCI components changes from 0 (Rd, Lagodekhi) to 10 (all components, all locations). The monthly mean values of HCI components changes from 3.3 (T, Lagodekhi) to 10 (W, all locations besides Lagodekhi).

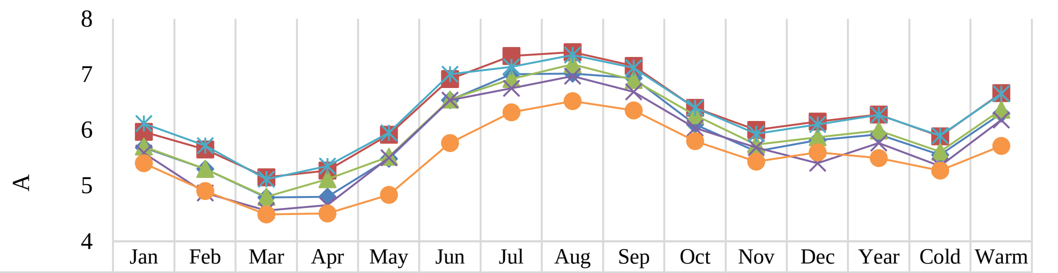
Table 14. Data of Min and Max values of HCI components at six locations of Kakheti.

Parameter	**All data**		**Mean monthly 1956-2015**		**All data**		**Mean monthly 1956-2015**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
	Dedoplistskaro				**Lagodekhi**			
T	2	10	3.3	9.2	2	10	3.6	9.3
A	2	10	4.8	7.0	2	10	4.6	7.0
Rd	5	10	8.4	9.0	0	10	7.7	9.0
W	9	10	9.8	10	8	10	9.6	9.9
	Gurjaani				**Sagarejo**			
T	2	10	3.6	9.4	2	10	3.4	9.5
A	3	10	5.2	7.4	3	10	5.1	7.4
Rd	2	10	8.1	9.0	2	10	8.3	9.0
W	10	10	10	10	9	10	9.9	10
	Kvareli				**Telavi**			
T	2	10	3.6	9.6	2	10	3.4	9.6
A	3	10	4.8	7.2	1	10	4.5	6.5
Rd	2	10	7.9	9.0	5	10	8.0	9.0
W	10	10	10	10	9	10	9.9	10



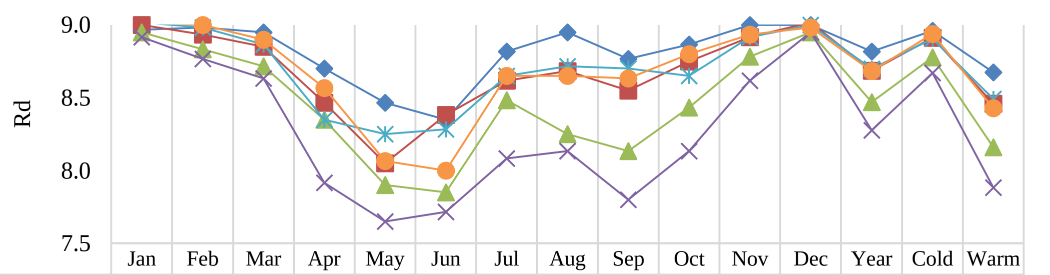
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded	3.3	3.4	4.3	6.4	9.1	8.4	6.8	6.9	9.2	6.9	4.7	3.6	6.1	4.4	7.8
Gur	3.6	3.9	5.0	7.8	9.4	7.2	5.7	5.9	8.4	8.3	5.1	3.8	6.2	4.9	7.4
Kvar	3.6	3.9	5.1	7.8	9.6	7.1	5.7	5.8	8.2	8.5	5.3	4.0	6.2	5.1	7.4
Lagod	3.6	3.9	5.1	7.8	9.3	7.0	5.6	5.8	8.2	8.5	5.3	3.9	6.2	5.0	7.3
Sag	3.4	3.7	4.5	6.6	9.5	8.6	7.1	7.1	9.3	7.2	4.9	3.8	6.3	4.6	8.0
Tel	3.4	3.7	4.8	7.2	9.6	8.0	6.4	6.6	9.0	7.6	5.1	3.8	6.3	4.7	7.8

Fig. 8. Mean monthly and seasonal values of T component of HCI at six locations of Kakheti in 1956-2015.



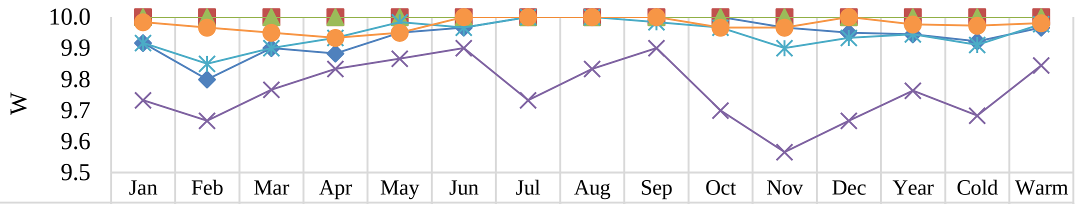
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded	5.7	5.3	4.8	4.8	5.5	6.5	7.0	7.0	6.9	6.1	5.6	5.8	5.9	5.6	6.3
Gur	6.0	5.7	5.2	5.3	5.9	6.9	7.3	7.4	7.2	6.4	6.0	6.2	6.3	5.9	6.7
Kvar	5.7	5.3	4.8	5.1	5.5	6.6	6.9	7.2	6.9	6.3	5.7	5.9	6.0	5.6	6.4
Lagod	5.6	4.9	4.6	4.7	5.5	6.5	6.8	7.0	6.7	6.0	5.7	5.4	5.8	5.4	6.2
Sag	6.1	5.7	5.1	5.4	6.0	7.0	7.1	7.4	7.1	6.4	5.9	6.1	6.3	5.9	6.7
Tel	5.4	4.9	4.5	4.5	4.8	5.8	6.3	6.5	6.4	5.8	5.4	5.6	5.5	5.3	5.7

Fig. 9. Mean monthly and seasonal values of A component of HCI at six locations of Kakheti in 1956-2015.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded	9.0	9.0	9.0	8.7	8.5	8.4	8.8	9.0	8.8	8.9	9.0	9.0	8.8	9.0	8.7
Gur	9.0	8.9	8.9	8.5	8.1	8.4	8.6	8.7	8.6	8.8	8.9	9.0	8.7	8.9	8.5
Kvar	9.0	8.8	8.7	8.4	7.9	7.9	8.5	8.3	8.1	8.4	8.8	9.0	8.5	8.8	8.2
Lagod	8.9	8.8	8.6	7.9	7.7	7.7	8.1	8.1	7.8	8.1	8.6	9.0	8.3	8.7	7.9
Sag	9.0	9.0	8.9	8.4	8.3	8.3	8.7	8.7	8.7	8.7	8.9	9.0	8.7	8.9	8.5
Tel	9.0	9.0	8.9	8.6	8.1	8.0	8.7	8.7	8.6	8.8	8.9	9.0	8.7	8.9	8.4

Fig. 10. Mean monthly and seasonal values of Rd component of HCI at six locations of Kakheti in 1956-2015.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded	9.9	9.8	9.9	9.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.9	9.9	10.0
Gur	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Kvar	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Lagod	9.7	9.7	9.8	9.8	9.9	9.9	9.7	9.8	9.9	9.7	9.6	9.7	9.8	9.7	9.8
Sag	9.9	9.9	9.9	9.9	10.0	10.0	10.0	10.0	10.0	10.0	9.9	9.9	9.9	9.9	10.0
Tel	10.0	10.0	10.0	9.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

Fig. 11. Mean monthly and seasonal values of W component of HCI at six locations of Kakheti in 1956-2015.

Intra-annual distribution of mean monthly values of T component of HCI at six locations of Kakheti (Fig. 8), as well HCI (Fig. 2, Table 7), bimodal distribution type of this parameter is observed. The first extremum of T component for all locations in May is observed (range of change: 9.1, Dedoplistskaro – 9.6, Kvareli, Telavi). The second extremum of T component for Dedoplistskaro, Sagarejo and Telavi in September is observed, for Gurjaani, Kvareli and Lagodekhi – in September-October. Range of change for Dedoplistskaro, Sagarejo and Telavi is as follow: 9.0, Telavi – 9.3, Sagarejo. Range of change for Gurjaani, Kvareli and Lagodekhi is as follow: 8.2, Kvareli, Lagodekhi – 8.5, Kvareli, Lagodekhi.

Intra-annual distribution of mean monthly values of A component of HCI at six locations of Kakheti (Fig. 9) unimodal distribution type of this parameter is observed. The Max values of A component for all locations, besides Dedoplistskaro, in August is observed (range of change: 6.5, Telavi – 7.4, Gurjaani, Sagarejo). In Dedoplistskaro unimodal distribution type with plateau of A value is observed (7.0, July-August).

Intra-annual variation of mean monthly values of Rd component of HCI at six locations of Kakheti (Fig. 10) is not very significant. Range of change for separate locations is as follow. Dedoplistskaro: 8.4, June – 9.0, November-March, August; Gurjaani: 8.1, May – 9.0, December, January; Kvareli: 7.9, May, June – 9.0, December, January; Lagodekhi: 7.7, May, June – 9.0, December; Sagarejo: 8.3, May, June –9.0, December – February; Telavi: 8.0, June – 9.0, December – February.

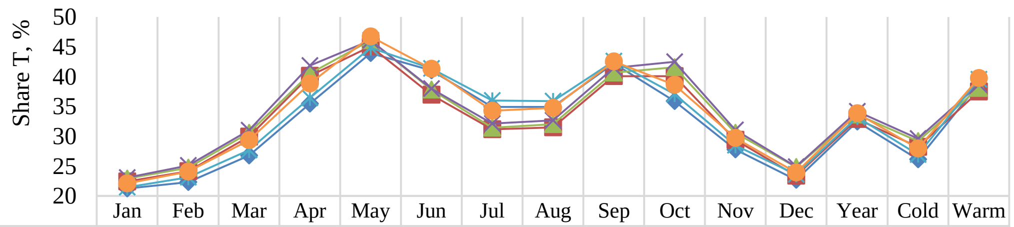
Intra-annual variation of mean monthly values of W component of HCI at six locations of Kakheti (Fig. 11) is not significant - range of change for all stations – from 9.6 to 10.0.

In Table 15 and Fig. 12-15 data about Min, Max and mean values of share of HCI components in HCI values at six locations of Kakheti are presented. As follows from these Table and Fig. the monthly values of share of HCI components changes from 0% (Share Rd, Lagodekhi) to 60.6% (Share T, Gurjaani, Lagodekhi). The monthly mean values of share of HCI components changes from 11.4% (Share W, Sagarejo) to 46.8% (Share T, Telavi).

Intra-annual distribution of mean monthly values of Share of T component of HCI value at six locations of Kakheti (Fig. 12), as well HCI and T (Fig. 2, 8, Table 7), bimodal distribution type of this parameter is observed. Range of change of Share of T component of HCI value for all stations (first extremum) is as follow: 44.0%, Dedoplistskaro – 46.8%, Telavi. Range of change of Share of T component of HCI value (second extremum) for Dedoplistskaro, Sagarejo and Telavi is as follow: 42.2%, Dedoplistskaro – 42.6%, Sagarejo. Range of change for Gurjaani, Kvareli and Lagodekhi is as follow: 40.1, Gurjaani – 42.5%, Lagodekhi.

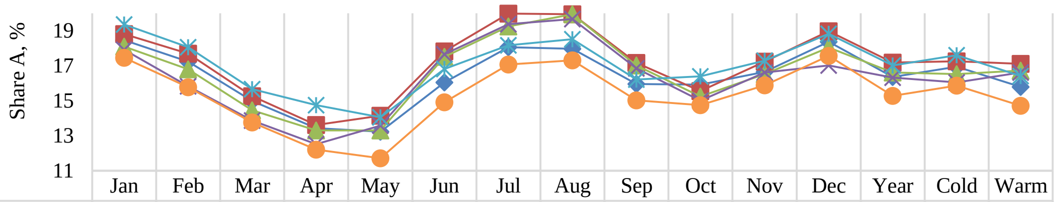
Table 15. Data of Min and Max values of share of HCI components in HCI value at six locations of Kakheti, (%)

Parameter	All data		Mean monthly 1956-2015		All data		Mean monthly 1956-2015	
	Min	Max	Min	Max	Min	Max	Min	Max
	Dedoplistskaro				Lagodekhi			
Share T	12.3	53.3	21.2	44.0	13.1	60.6	23.1	46.1
Share A	7.5	30.8	13.2	18.5	7.4	29.2	12.5	19.7
Share Rd	19.0	50.9	30.3	44.3	0	50.9	28.1	43.3
Share W	10.0	19.2	11.5	16.2	9.0	23.3	12.2	15.9
	Gurjaani				Sagarejo			
Share T	13.1	60.6	22.4	45.1	15.1	60.0	21.5	44.9
Share A	8.5	27.4	13.6	20.0	9.4	26.9	14.1	19.4
Share Rd	9.1	47.4	28.7	42.9	10.0	50.9	29.2	43.3
Share W	10.4	18.5	12.0	15.9	10.0	19.6	11.4	15.9
	Kvareli				Telavi			
Share T	12.1	60.0	22.9	46.1	14.5	54.8	22.1	46.8
Share A	7.5	27.3	13.3	19.9	3.6	27.4	11.7	17.6
Share Rd	10.0	49.1	28.5	43.0	20.5	50.9	29.3	44.1
Share W	10.5	18.5	12.1	16.0	10.2	18.9	11.8	16.3



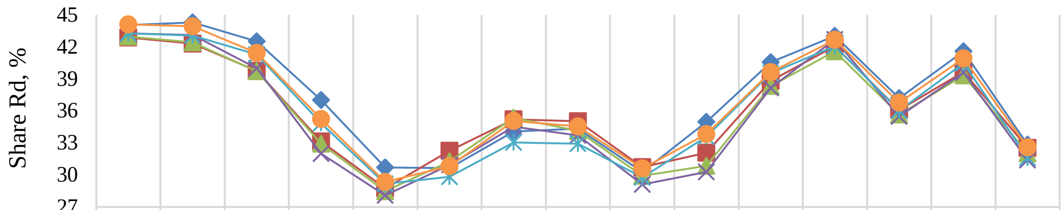
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded	21.2	22.3	26.8	35.5	44.0	41.1	35.0	34.9	42.2	35.9	27.8	22.7	32.4	26.1	38.8
Gur	22.4	24.2	30.0	40.1	45.1	37.0	31.2	31.5	40.1	40.1	29.4	23.4	32.9	28.3	37.5
Kvar	22.9	24.7	30.6	40.5	46.1	37.8	31.5	32.0	40.7	41.6	30.6	24.9	33.7	29.2	38.1
Lagod	23.1	25.1	31.0	41.9	46.1	38.0	32.1	32.7	41.5	42.5	31.1	24.9	34.2	29.6	38.7
Sag	21.5	23.1	27.7	36.4	44.9	41.4	36.0	35.9	42.6	37.1	28.5	23.6	33.2	26.9	39.5
Tel	22.1	24.1	29.4	38.9	46.8	41.3	34.3	34.8	42.5	38.6	29.8	23.9	33.9	28.0	39.8

Fig. 12. Share of mean monthly and seasonal values of T component in HCI value at six locations of Kakheti in 1956-2015.



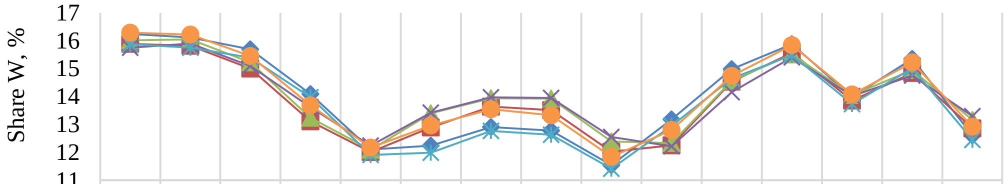
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded	18.5	17.2	15.0	13.4	13.2	16.0	18.1	18.0	16.0	15.9	16.7	18.4	16.4	16.9	15.8
Gur	18.8	17.7	15.3	13.6	14.2	17.8	20.0	19.9	17.2	15.5	17.2	19.0	17.2	17.3	17.1
Kvar	18.1	16.8	14.5	13.3	13.3	17.5	19.2	19.9	17.0	15.2	16.5	18.0	16.6	16.5	16.7
Lagod	17.9	15.8	13.9	12.5	13.6	17.7	19.4	19.7	16.9	15.0	16.6	17.0	16.3	16.0	16.6
Sag	19.4	18.1	15.7	14.8	14.1	16.8	18.2	18.5	16.2	16.4	17.3	18.8	17.0	17.6	16.4
Tel	17.5	15.8	13.8	12.2	11.7	14.9	17.1	17.3	15.0	14.8	15.9	17.6	15.3	15.9	14.7

Fig. 13. Share mean monthly and seasonal values of A component in HCI value in six locations of Kakheti in 1956-2015.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded	44.1	44.3	42.5	37.0	30.7	30.6	34.1	34.3	30.3	35.0	40.6	43.0	37.2	41.6	32.8
Gur	42.9	42.3	39.8	33.1	28.7	32.3	35.2	35.0	30.7	32.1	38.8	42.1	36.1	39.7	32.5
Kvar	43.0	42.4	39.7	32.9	28.5	31.3	35.4	34.1	29.9	30.9	38.3	41.6	35.7	39.3	32.0
Lagod	43.3	43.1	40.0	32.0	28.1	31.0	34.5	33.7	29.1	30.3	38.2	42.7	35.5	39.6	31.4
Sag	43.3	43.1	41.3	34.9	29.2	29.8	33.1	32.9	29.8	33.6	39.5	42.1	36.0	40.5	31.6
Tel	44.1	43.9	41.4	35.2	29.3	30.8	35.1	34.6	30.6	33.8	39.6	42.7	36.8	40.9	32.6

Fig. 14. Share mean monthly and seasonal values of Rd component in HCI value at six locations of Kakheti in 1956-2015.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Ded	16.2	16.1	15.7	14.1	12.1	12.2	12.9	12.8	11.5	13.2	15.0	15.9	14.0	15.3	12.6
Gur	15.9	15.8	15.0	13.1	12.0	12.9	13.6	13.5	12.0	12.3	14.5	15.6	13.9	14.8	12.9
Kvar	16.0	16.0	15.2	13.2	12.1	13.4	13.9	13.9	12.4	12.3	14.6	15.5	14.1	14.9	13.2
Lagod	15.7	15.9	15.1	13.6	12.2	13.4	14.0	13.9	12.5	12.2	14.2	15.4	14.0	14.8	13.3
Sag	15.9	15.7	15.4	14.0	11.9	12.0	12.8	12.6	11.4	12.9	14.6	15.5	13.7	15.0	12.4
Tel	16.3	16.2	15.5	13.7	12.2	13.0	13.5	13.3	11.8	12.8	14.7	15.8	14.1	15.2	12.9

Fig. 15. Share of mean monthly and seasonal values of W component in HCI value at six locations of Kakheti in 1956-2015.

Intra-annual distribution of mean monthly values of Share of A components of HCI value at six locations of Kakheti (Fig. 13), as well HCI, T and Share T (Fig. 2, 8, 12, Table 7), have a bimodal type. For Dedoplistskaro, Gurjaani, Kvareli and Telavi first extremum of Share of A distribution in January and December is observed, for Lagodekhi and Sagarejo – in January. The second extremum of this distribution for all stations in July-August is observed.

Range of change of Share of A component of HCI value for all stations (first extremum) is as follow: 17.5%, Telavi – 19.0%, Gurjaani; Lagodekhi and Sagarejo – 17.9% and 19.4% respectively. Range of change of Share of A component of HCI value for all stations (second extremum) is as follow: 17.1%, Telavi – 20.0%, Gurjaani.

Intra-annual distribution of mean monthly values of Share of Rd and Share of W components of HCI value at all locations of Kakheti (Fig. 14, 15) have a bimodal type. Whereinto for both distributions, the first and second extremumes coincide in time: December-February and July-August respectively. It should be noted that in both cases the summer extremum is significantly lower than the winter one.

Range of change of Share of Rd component of HCI value for all stations (first extremum) is as follow: 41.6%, Kvareli – 44.3%, Dedoplistskaro. Range of change of Share of Rd component of HCI value for all stations (second extremum) is as follow: 32.9%, Sagarejo – 35.4%, Kvareli.

Range of change of Share of W component of HCI value for all stations (first extremum) is as follow: 15.4%, Lagodekhi – 16.3%, Telavi. Range of change of Share of W component of HCI value for all stations (second extremum) is as follow: 12.6%, Sagarejo – 14.0%, Lagodekhi.

Range of change of different components of HCI for all station in year, cold and warm seasons is as follow respectively.

T component (Fig. 8). Year: 6.1, Dedoplistskaro – 6.3, Sagarejo, Telavi; cold season: 4.4, Dedoplistskaro – 5.1, Kvareli; warm season: 7.3, Lagodekhi – 8.0, Sagarejo.

A component (Fig. 9). Year: 5.5, Telavi – 6.3, Gurjaani, Sagarejo; cold season: 5.3, Telavi – 5.9, Gurjaani, Sagarejo; warm season: 5.7, Telavi – 6.7, Gurjaani, Sagarejo.

Rd component (Fig. 10). Year: 8.3, Lagodekhi – 8.8, Dedoplistskaro; cold season: 8.7, Lagodekhi – 9.0, Dedoplistskaro; warm season: 7.9, Lagodekhi – 8.7, Dedoplistskaro.

W component (Fig. 11). Year: 9.8, Lagodekhi – 10.0, Gurjaani, Kvareli, Telavi; cold season: 9.7, Lagodekhi – 10.0, Gurjaani, Kvareli, Telavi; warm season: 9.8, Lagodekhi – 10.0, all other locations.

Share of T component (Fig. 12, %). Year: 32.4, Dedoplistskaro – 34.2, Lagodekhi; cold season: 26.1, Dedoplistskaro – 29.6, Lagodekhi; warm season: 37.5, Gurjaani – 39.8, Telavi.

Share of A component (Fig. 13, %). Year: 15.3, Telavi – 17.2, Gurjaani; cold season: 15.9, Telavi – 17.6, Sagarejo; warm season: 14.7, Telavi – 17.1, Gurjaani.

Share of Rd component (Fig. 14, %). Year: 35.5, Lagodekhi – 37.2, Dedoplistskaro; cold season: 39.3, Kvareli – 41.6, Dedoplistskaro; warm season: 31.4, Lagodekhi – 32.8, Dedoplistskaro.

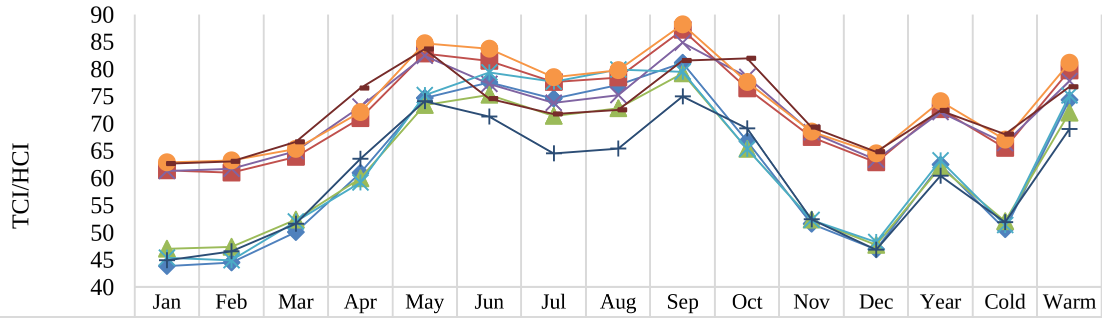
Share of W component (Fig. 15, %). Year: 13.7, Sagarejo – 14.1, Kvareli, Telavi; cold season: 14.8, Gurjaani, Lagodekhi – 15.3, Dedoplistskaro; warm season: 12.4, Sagarejo – 13.3, Lagodekhi.

3. Comparison of TCI and HCI at four location of Kakheti in 1961-2010.

Comparison of TCI and HCI values in many investigations are provided [17, 18, 20, 22, 23]. In Georgia, an analogous study conducted for Tbilisi [24].

Comparison of TCI and HCI at four location of Kakheti (Dedoplistskaro, Kvareli, Sagarejo and Telavi) in 1961-2010 is provided below (Fig. 16, 17, Table 16-18).

In Fig. 16 data about mean monthly and seasonal values of TCI and HCI at four locations of Kakheti in 1961-2010 are presented.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
TCI_Ded	44	44	50	61	75	78	75	77	81	67	52	47	62	51	74
HCI_Ded	61	61	64	71	83	81	78	78	87	76	68	63	73	66	80
TCI_Tel	47	47	52	60	73	75	71	73	79	65	52	48	62	52	72
HCI_Tel	61	62	65	73	82	77	74	75	85	79	68	63	72	66	78
TCI_Sag	45	45	52	59	75	79	78	80	80	65	52	48	63	51	75
HCI_Sag	63	63	65	72	85	84	78	80	88	78	69	65	74	67	81
TCI_Kva	45	47	52	64	74	71	65	65	75	69	52	47	60	52	69
HCI_Kvar	63	63	67	77	84	75	72	73	82	82	69	65	72	68	77

Fig. 16. Comparison of mean monthly and seasonal values of TCI and HCI at four location of Kakheti in 1961-2010.

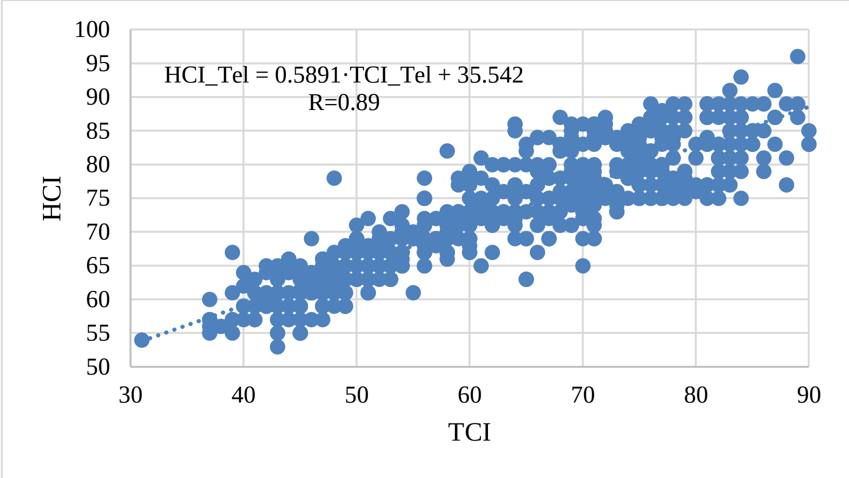


Fig. 17. Linear correlation and regression between monthly values of TCI and HCI in Telavi in 1961-2010.

HCI_Ded = 0.5886·TCI_Ded + 35.869, (R=0.93); HCI_Kvar = 0.584·TCI_Kvar + 37.127, (R=0.88);
HCI_Sag = 0.587·TCI_Sag + 36.969, (R=0.92); For all values of R, $\alpha<0.005$.

Comparison of the values and categories of the Tourism Climate Index [7] and Holiday Climate Index (Fig. 16, 17, Table 16-18) shows that the intra-annual variation of both indices is similar and has a bimodal form. Linear correlation between monthly values of TCI and HCI is high (Fig. 17, example for Telavi) and change from 0.88 (Kvareli) to 0.93 (Dedoplistskaro).

Table 16. Comparison of TCI and HCI categories at four location of Kakheti in cold period of year in 1961-2010.

<table>
<tr><th>Month</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Cold</th><th>Year</th></tr>
<tr><td>TCI_Ded</td><td rowspan="8">Marg.
Good</td><td rowspan="8">Marg.
Good</td><td rowspan="8">Accept.
Good</td><td rowspan="6">Good
Very
Good</td><td rowspan="8">Accept.
Good</td><td rowspan="8">Marg.
Good</td><td rowspan="8">Accept.
Good</td><td rowspan="8">Good
Very
Good</td></tr>
<tr><td>HCI_Ded</td></tr>
<tr><td>TCI_Tel</td></tr>
<tr><td>HCI_Tel</td></tr>
<tr><td>TCI_Sag</td></tr>
<tr><td>HCI_Sag</td></tr>
<tr><td>TCI_Kvar</td><td>Good</td></tr>
<tr><td>HCI_Kvar</td><td>Excell.</td></tr>
</table>

Table 17. Comparison of TCI and HCI categories at four location of Kakheti in warm period of year in 1961-2010.

<table>
<tr><th>Month</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Warm</th></tr>
<tr><td>TCI_Ded</td><td>Good</td><td rowspan="8">Very Good
Excell.</td><td>Very Good</td><td rowspan="6">Very Good</td><td rowspan="6">Very Good</td><td rowspan="2">Excell.</td><td rowspan="4">Very Good</td></tr>
<tr><td>HCI_Ded</td><td>Very Good</td><td>Excell.</td></tr>
<tr><td>TCI_Tel</td><td rowspan="4">Accept.
Very Good</td><td rowspan="2">Very Good</td><td rowspan="6">Very Good
Excell.</td></tr>
<tr><td>HCI_Tel</td></tr>
<tr><td>TCI_Sag</td><td>Very Good</td><td>Very Good</td></tr>
<tr><td>HCI_Sag</td><td>Excell.</td><td>Excell.</td></tr>
<tr><td>TCI_Kvar</td><td>Good</td><td rowspan="2">Very Good</td><td>Good</td><td>Good</td><td>Good</td></tr>
<tr><td>HCI_Kvar</td><td>Very Good</td><td>Very Good</td><td>Very Good</td><td>Very Good</td></tr>
</table>

Comparison of TCI and HCI categories shows, that in cold months, season and year HCI categories on 1-2 step higher than TCI categories (Table 16). Difference on 2 step in the following cases are observed: TCI_Marginal → HCI_Good, in January, February, December for all stations; TCI_Good →

HCI_Excellent, in October, for Kvareli. Difference on 1 step: TCI_ Acceptable → HCI_Good, in March, November, Cold season, for all stations; TCI_Good → HCI_Very Good in October for Dedoplistskaro, Telavi, Sagarejo and in year, for all stations.

Comparison of TCI and HCI categories in warm months and season shows, that HCI categories either the same than TCI categories, or 1-2 steps higher (Table 17).

Difference on 2 step in the following case is observed: TCI_ Acceptable → HCI_Very Good, in April for Telavi and Sagarejo.

Difference on 1 step: TCI_ Good → HCI_Very Good, in April, for Dedoplistskaro and Kvareli; in July, August and Warm season, for Kvareli; TCI_Very Good → HCI_ Excellent in May for all stations, in June for Dedoplistskaro and Sagarejo; in September, for Telavi, Sagarejo and Kvareli; in Warm season, for Sagarejo.

The same categories: Very Good, in June, for Telavi and Kvareli; in July and August, for Dedoplistskaro, Telavi and Sagarejo; in Warm season, for Dedoplistskaro and Telavi. Excellent, in September, for Dedoplistskaro.

Table 18. Comparison of Min and Max values of TCI and HCI and its category for four location of Kakheti in 1961-2010.

Parameter		**Value**	**Location/Month/Category**
TCI	Min	44	Dedoplistskaro, January, February, Marginal
	Max	81	Dedoplistskaro, September, Excellent
	Mean on Station	62	Good
HCI	Min	61	Good, Dedoplistskaro, January,February; Telavi, January
	Max	88	Sagarejo, September, Excellent
	Mean on Station	73	Very Good

In Table 18 comparison of Min and Max values of TCI and HCI and its category for four location of Kakheti is provided. As follows from this Table TCI value change from 44 (Dedoplistskaro, January, February, Marginal) to 81 (Dedoplistskaro, September, Excellent) and HCI value – from 61 (Good, Dedoplistskaro, January, February; Telavi, January) to 88 (Sagarejo, September, Excellent). Mean on the one station for TCI is 62 (Good) and for HCI - 73 (Very Good).

However, given that the TCI is calculated for the so-called “average tourist” (regardless of gender, age, physical condition), the value and category of this index is lower than the HCI values and categories. In general, HCI more adequately determines the bioclimatic state of the environment for the development of certain types of tourism (winter tourism, extreme tourism, etc.) than TCI.

Conclusion

In the future, we are planning a more detailed study of the climatic resources of this and other regions of Georgia for tourism, recreation and treatment (mapping the territory on HCI and TCI, long-term forecasting of HCI and TCI, determining other modern climatic and bioclimatic indicators for tourism, recreation and treatment, assessing the adequacy of bioclimatic indicators scales to human health, etc.).

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დასვენების კლიმატური ინდექსი კახეთში

ა.ამირანაშვილი, ლ.ქართველიშვილი

რეზიუმე

წარმოდგენილია მონაცემები დასვენების კლიმატური ინდექსის (დკი) მრავალწლიური საშუალო თვიური მნიშვნელობების შესახებ კახეთის 12 ადგილისთვის (ახმეტა, დედოფლისწყარო, გომბორი, გურჯაანი, ყვარელი, ლაგოდეხი, ომალო, საგარეჯო, შირაქი, თელავი, წნორი და უდაბნო). ამ რეგიონის 6 სადგურისთვის (დედოფლისწყარო, გურჯაანი, ყვარელი, ლაგოდეხი, საგარეჯო და თელავი) ჩატარებულია ყოველთვიური, სეზონური და წლიური დკი-ს მნიშვნელობების დეტალური ანალიზი 60 წლიანი პერიოდის განმავლობაში (1956-2015 წწ.). ჩატარებულია დკი-ს და ტურიზმის კლიმატური ინდექსის ყოველთვიური მნიშვნელობების შედარება კახეთის ოთხ პუნქტზე (დედოფლისწყარო, ყვარელი, საგარეჯო და თელავი) 1961-2010 წწ. მონაცემების საფუძველზე.

Климатический Индекс Отдыха в Кахетии (Грузия)

А.Г. Амиранашвили, Л. Г. Картвелишвили

Резюме

Представлены данные о многолетних среднемесячных значениях Климата Индекса Отдыха (КИО) для 12 населенных пунктов Кахетии (Ахмета, Дедоплисцкаро, Гомбори, Гурджаани, Кварели, Лагодехи, Омало, Сагареджо, Шираки, Телави, Цнори и Удабно). Для 6 станций этого региона (Дедоплисцкаро, Гурджаани, Кварели, Лагодехи, Сагареджо и Телави) проведен детальный анализ месячных, сезонных и годовых значений КИО за 60-летний период времени (1956-2015 гг.). Проведено сравнение месячных значений КИО и Климатического Индекса Туризма для четырех пунктов Кахетии (Дедоплисцкаро, Кварели, Сагареджо и Телави) по данным с 1961 по 2010 гг.

Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 24(1), 2021, pp. 63-76

Connection of Holiday Climate Index with Public Health (on Example of Tbilisi and Kakheti Region, Georgia)

[1]Avtandil G. Amiranashvili, [2]Aza A. Revishvili, [2,3]Ketevan R. Khazaradze, [3,4]Nino D. Japaridze

[1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia
avtandilamiranashvili@gmail.com
[2]Georgian State Teaching University of Physical Education and Sport, Tbilisi, Georgia
[3]Ministry of Internally Displaced Persons from Occupied Territories, Labour, Health and Social Affair of Georgia, Tbilisi, Georgia
[4]Tbilisi State Medical University, Tbilisi, Georgia

ABSTRACT

Study on connection of Holiday Climate Index (HCI) and its components and components ratings with public health (on Example of Tbilisi - mortality by cardiovascular deseases and Kakheti Region of Georgia - ambulance calls, hospitalization, total mortality are presented).
It is shown that, in general, all indicators adequately correspond to the degree of bioclimatic comfort of the living environment for people. In particular, the relationship between HCI and mortality in Tbilisi has the form of a second-degree polynomial, and in Kakheti - a third-degree polynomial. At the same time, with an increase in the degree of bioclimatic comfort to the category "Very good", there is a tendency for a decrease in mortality. With the transition to the "Excellent" category, there is a slight increase in mortality. A similar result for some components of the HCI and the ratings of these components was obtained.
It is proposed to make adjustments in determining the degree of comfort of bioclimatic index scales for the population, taking into account local social and climatic conditions.

***Key words*: *Holiday Climate Index (HCI), public health, ambulance calls, hospitalization, mortality*.**

Introduction

Studies of weather conditions, climate change, atmospheric air quality, and also of different heliogeophysical and space factors for the human organism, are conducted in many countries of the world [1-8].

A significant number of works are devoted to the study of the impact on human health of individual meteorological and heliogeophysical elements, space weather parameters, etc. In particular, these elements include: air temperature [5, 8-11], wind speed [11], humidity [12], atmospheric pressure [13], solar activity (Wolf's number) [12-15], the geomagnetic fields [16-18], solar radiation [9], the cosmic rays [9, 19], light ions [9, 20,21], aerosols [9, 22], ozone [9, 23], other air toxic admixtures and etc. [9, 24].

It is well known that the effects of a significant increase in the mortality of population with the strong cold and the extreme heat [25-31]. For determining the extent of comfort or discomfort of the human living environment for her health (so-called "average person") frequently are used different simple and complex thermal indices [32-36].

Simple thermal indices involve more than one meteorological parameter and consider the combined effects on human organism (air equivalent- effective temperature - EET, Wet-bulb-globe temperature - derived from energy budget models. Such indices are popular in recent years, for example: Physiologically Equivalent Temperature (PET), Standard Effective Temperature (SET), Physiological Subjective Temperature and Subjective Temperature (MENEX), the Universal Thermal Climate Index (UTCI) etc. [37-41]).

Action on the human organism by the higher indicated factors have different scales - from minute, hour, day, decade and month to the seasonal and annual [5,7,9,14,17,19,23,30,31,33,36,42-44]. For example, in the works [43,44] is obtained that the dependence of mortality on EET takes the classical form - the decrease of mortality from the gradation "Sharply Coldly" to "Comfortably" with further increase to the gradation "Warmly". It is found in the works [30,31] that the relationship between the average monthly air temperature in Kutaisi and Kakheti region and such indices of the health of population as the total number of emergency medical calls, cases of hospitalizations and deaths has the form of a third power polynomial. In general, in the warm months there is a decrease of the total number of emergency medical calls, cases of hospitalizations and deaths. In the hot months, there is a worsening in these indicators of health, comparable to the cold months of the year (increase of the emergency medical calls, cases of hospitalizations and deaths).

For the bioclimatic zoning of territories (including for evaluating the bioclimatic potential of health resort- tourist industry) frequently is used the mean monthly values of simple thermal indices [33,42,45,46].

The standard scale and categories of the majority of these indices is usually used in this case for describing the real (hour or day) bioclimatic situation. In the latter case, as a rule, with the monthly averaging of meteorological data occurs range reduction of the scale of thermal indices and decrease of its sensitivity for evaluating the degree of the bioclimatic comfort of environment for the people. Therefore, the numerical values of the standard scale of thermal indices always cannot coincide with the verbal description of the categories of these indices. The results of investigating the connection of eight simple thermal indices and Tourism Climate Index with the monthly mortality of the population of Tbilisi city apropos of the cardiovascular diseases, which made it possible to estimate the representativeness of the standard scales and categories of the indicated indices as the bioclimatic indicator in monthly time scale, were represented in [36].

In this work, comparative analysis of the connection of eight simple thermal indices and Tourism Climate Index (TCI) [47] with the monthly mortality of the population of Tbilisi city apropos of cardiovascular diseases is represented. The values of simple thermal indices were calculated with the use of mean monthly and mean monthly for 13 hours data of meteorological elements. Between all studied simple thermal indices practically direct functional connection with the coefficient of linear correlation not lower than 0.86 is observed. The connection of simple thermal indices with the TCI is nonlinear and takes the form of third power polynomial. The possibility of using the standard scales and categories of the indicated indices as the bioclimatic indicator in monthly time scale is studied. As a whole, all indices adequately correspond to the degree of the bioclimatic comfort of environment for the people - with an increase in the level of comfort the mortality diminishes. Most representative for this purpose is Missenard air effective temperature in 13 hours.

This work is a continuation of the study [36]. Results of investigation on connection of Holiday Climate Index (HCI) and its components and components ratings [48-51] with public health (on Example of Tbilisi - mortality by cardiovascular deseases and Kakheti Region of Georgia - ambulance calls, hospitalization, total mortality) are presented below.

Study Area, Material and Methods

Study area – Tbilisi and Kakheti region of Georgia (below - Kakheti).

In this work the Holiday Climate Index (HCI) is used. The HCI uses five climatic variables related to the three facets essential to tourism (table 2): thermal comfort (TC), aesthetic (A), and physical (P) facet. The five climatic variables used for the HCI input are maximum air temperature and relative humidity (TC), cloud cover (A), precipitation and wind (P) [48].

The HCI score is calculated according to the following formula [48]:

$$\mathbf{HCI = 4 \cdot T + 2 \cdot A + 3 \cdot R_d + 1 \cdot W.}$$

This formula uses the following bioclimatic indicators and ratings of these indicators. Thermal Comfort (TC) - effective temperature (°C) [47] – combination of maximum dry-bulb temperature and mean values of relative humidity (%), rating of TC is T; CC - daily cloud cover (%), rating of CC is A; DP - daily precipitation (mm), rating of DP is R_d; WS - wind speed (m/sec or km/hour), rating of WS is W. Values of all HCI components rating change from 0 to 10 [48-51]. Note that below the physical dimensions of the studied parameters are omitted.

In this work the data of HCI for Tbilisi is used [49]. For Kakheti, these data were averaged over six locations of this region (Dedoplistskaro, Gurjaani, Kvareli, Lagodekhi, Sagarejo and Telavi) [51].

The population health indicators are as follows. Mean monthly decade mortality by cardiovascular deseases – M; mean monthly decade values of ambulance colls - AC, hospitalization – H; total mortality – TM.

In the work analysis of data is carried out with the use of the standard statistical analysis methods. The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; Range: Max – Min; St Dev – standard deviation; C_v, % - coefficient of variation: $C_v = 100 \cdot$ St Dev/Mean; R^2 - coefficient of determination; R - coefficient of linear correlation; α - level of significance.

R(M), … etc. - coefficient of linear correlation between mortality, … etc. with mean monthly values of HCI componets and these ration respectivelly; α (R(M)), … etc. - the corresponding values of the significance level of the linear correlation coefficient.

Results

Results in Table 1-6 and Fig. 1-13 are presented.

Table 1. Statistical characteristics of mean monthly values of HCI and mean monthly decade mortality by cardiovascular deseases in Tbilisi in 1980-1990.

Variable	HCI	HCI Category	Mortality
Mean	73	Very Good	105
Min	53	Acceptable	70
Max	89	Excellent	168
Range	36		98
St Dev	8.7		17.3
Cv, %	11.9		24.7

In Table 1 statistical characteristics of mean monthly values of HCI and mean monthly decade mortality by cardiovascular deseases in Tbilisi in 1980-1990 is presented. As follows from this Table values of HCI change from 53 (category - Acceptable) to 89 (category - Excellent). Values of M change from 70 to 168.

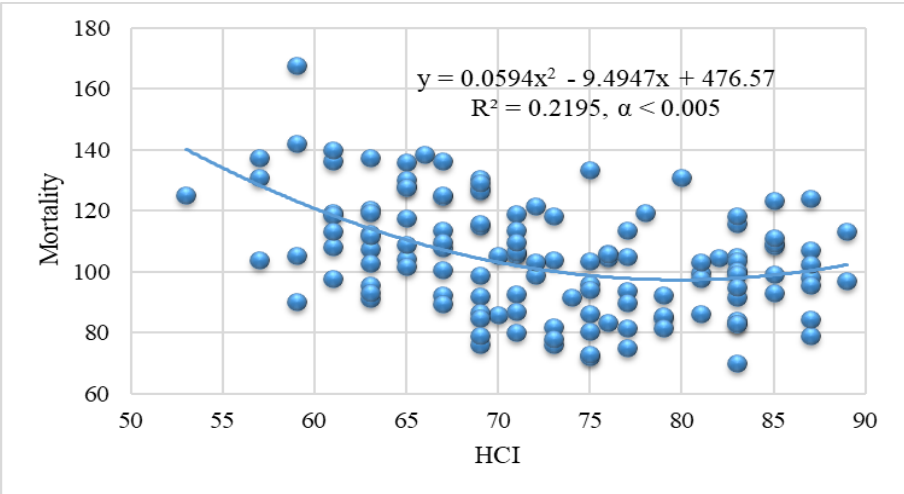

Fig.1. Connection between mean monthly values of HCI with mean monthly decade mortality by cardiovascular deseases in Tbilisi in 1980-1990.

Connection between mean monthly values of HCI with mean monthly decade mortality by cardiovascular deseases in Tbilisi (Fig. 1) has the form of a second degree polynomial. It should be noted that with an increase of the HCI values, in general, a decrease of mortality is observed. At the same time, at high values of HCI, mortality tends to increase.

This fact is also clearly demonstrated in Fig. 2. As follows from Fig. 2 in the range of HCI categories Acceptable – Very Good, mortality by cardiovascular deseases in Tbilisi decreases. With the transition of HCI categories from Very Good to Excellent - mortality increases. And although this growth is statistically insignificant, the some trend is still observed.

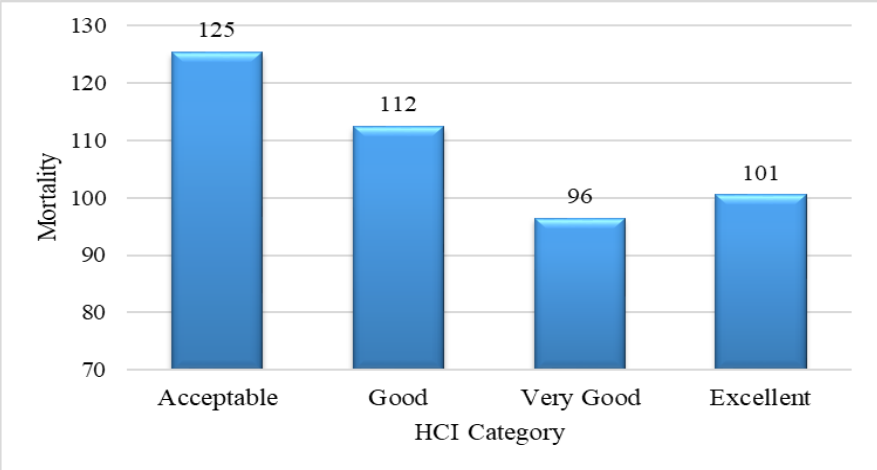

Fig.2. Mean monthly decade mortality by cardiovascular deseases at different HCI categories in Tbilisi in 1980-1990.

It should be noted that in our early studies [36, 42] it was found that the relationship between the Tourism Climate Index (TCI) and mortality by cardiovascular deseases in Tbilisi has an inverse linear relationship. At the same time, for both TCI categories Very good and Excellent, the mortality rate in Tbilisi was the same.

Table 2. Statistical characteristics of HCI components and ratings of these components in Tbilisi in 1980-1990.

Variable	**TC**	**T**	**CC**	**A**	**DP**	**R_d**	**WS**	**W**
Mean	19.2	6.2	5.9	5.6	40.1	8.9	0.9	10.0
Min	1.6	3	2.8	3	0.0	8	0.1	8
Max	34.1	10	9.0	9	158.7	10	1.9	10
Range	32.5	7.0	6.2	6.0	158.7	2	1.8	2
St Dev	9.4	2.1	1.2	1.2	33.4	0.3	0.4	0.2
Cv, %	48.8	33.3	19.5	21.8	83.4	3.6	44.2	2.5

In Table 2 statistical characteristics of HCI components and ratings of these components in Tbilisi in 1980-1990 are presented. As follows from this Table the variability of the investigated parameters is as follows. TC: – mean – 19.2, range of change – 1.6÷34.1; T: mean – 6.2, range of change – 3÷10; CC: mean – 5.9, range of change – 2.8÷9.0; A: mean – 5.6, range of change – 3÷9; DP: mean – 40.1, range of change – 0.0÷158.7; R_d: mean – 8.9, range of change – 8÷10; WS: mean – 0.9, range of change – 0.1÷1.9; W: mean – 10.0, range of change – 8÷10.

Table 3. Linear correlation coefficient between HCI components and ratings of these components with mean monthly decade mortality by cardiovascular deseases in Tbilisi in 1980-1990.

Variable	**TC**	**T**	**CC**	**A**	**DP**	**R_d**	**WS**	**W**
R(M)	-0.65	-0.36	0.25	-0.23	-0.14	0.09	-0.18	0.00
α (R(M))	<0.005	<0.005	0.005	0.01	0.10	no sign	0.05	no sign

In Table 3 information about linear correlation coefficient between HCI components and ratings of these components with mean monthly decade mortality by cardiovascular deseases in Tbilisi is presented. The largest value of the linear correlation coefficient between the values of M and the HCI components is -

0.65 (with TC), the smallest is -0.14 (with DP). The largest value of the linear correlation coefficient between the M values and the ratings of the HCI components is -0.36 (with T), the smallest is 0.0 (with W). Thus, the TC and T parameters make the main contribution to the mortality by cardiovascular deseases variability.

For example, in Fig. 3 shows a graph of the linear correlation between the values of TC and M.

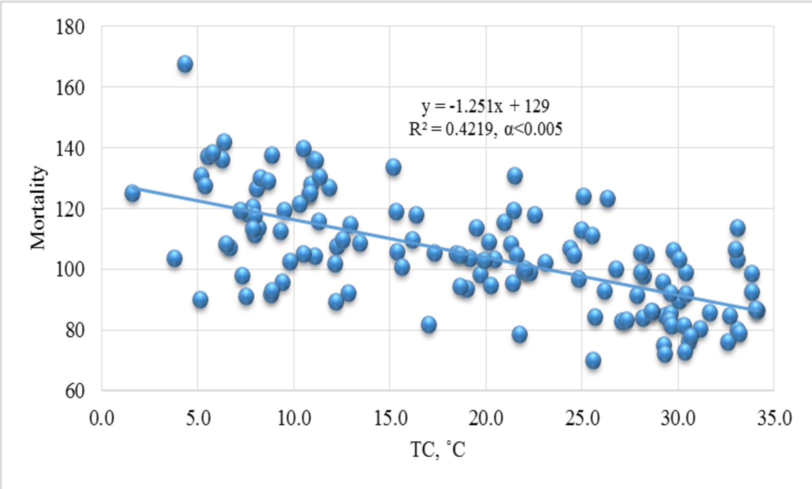

Fig.3. Connection between mean monthly values of TC with mean monthly decade mortality by cardiovascular deseases in Tbilisi in 1980-1990.

Connection between mean monthly values of T with mean monthly decade mortality by cardiovascular deseases in Tbilisi in Fig. 4 is presented. As follows from this Fig. coonection between indicated parameters has the form of a second degree polynomial (R^2 = 0.3078, α<0.005).

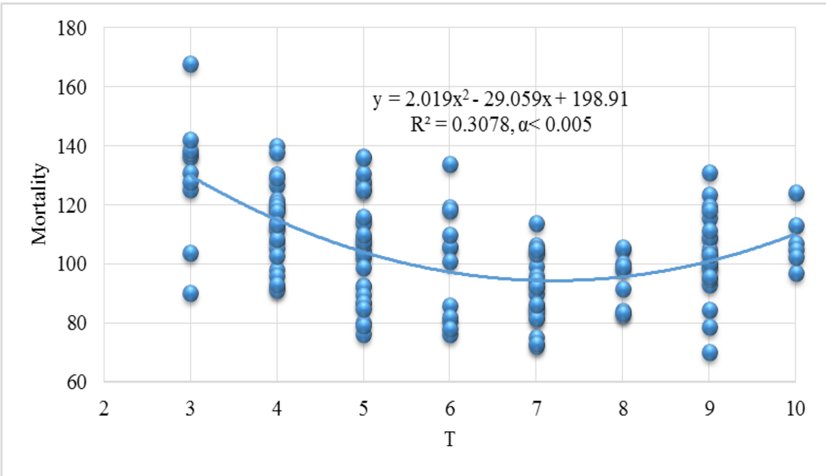

Fig.4. Connection between mean monthly values of T with mean monthly decade mortality by cardiovascular deseases in Tbilisi in 1980-1990.

Note that the second degree polynomial describes the relationship between M and T better than linear regression (R = -0.36, or R^2 = 0.1239, α<0.005, Table 3). Fig. 4 also implies that, in general, with an increase in the values of T, mortality decreases, with the exception of values of T> 9 (some increase in mortality). This fact determines the connection between HCI and M in the case of the HCI category "Excellent" (some increase in mortality, Fig.2).

The statistical characteristics of mean monthly values of HCI and mean monthly decade values of ambulance calls, hospitalization and total mortality in Kakheti in 2013 and 2015 in Table 4 are presented.

Table 4. Statistical characteristics of mean monthly values of HCI and mean monthly decade values of ambulance calls, hospitalization and total mortality in Kakheti in 2013 and 2015.

Variable	HCI	Ambulance Calls	Hospitalization	Total mortality
Mean	71	1753	435	15
Min	62	1184	296	8
Max	84	2265	623	26
Range	22	1081	326	18
St Dev	6.8	335.8	79.0	4.2
Cv, %	9.6	19.1	18.2	28.0

As follows from this Table values of HCI change from 62 (category Good) to 84 (category Excellent). Values of ambulance calls change from 1184 to 2265, hospitalization - from 296 to 623, total mortality - from 8 to 26.

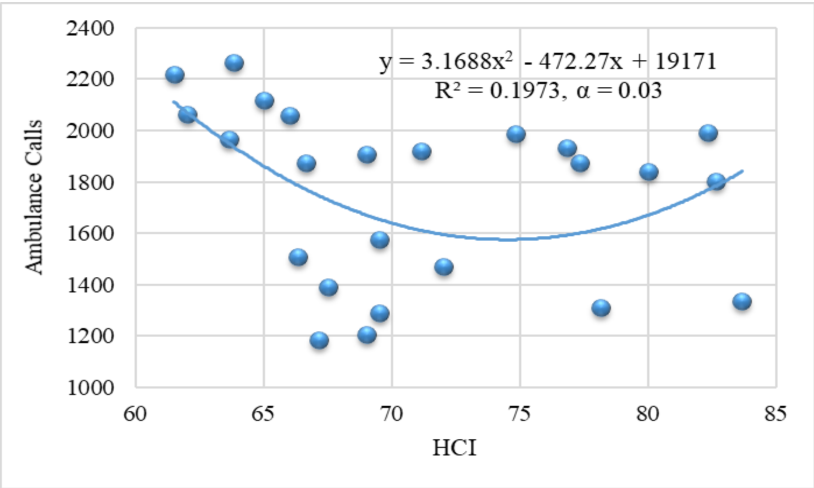

Fig.5. Connection between mean monthly values of HCI with mean monthly decade value of ambulance calls in Kakheti in 2013 and 2015.

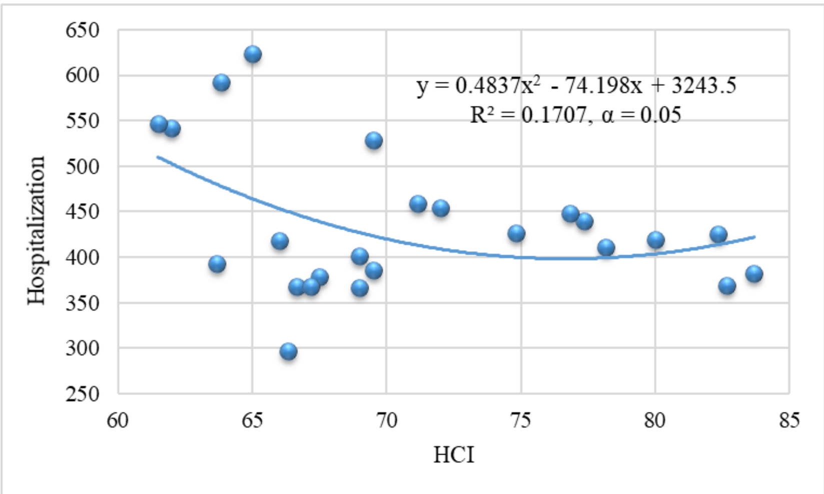

Fig.6. Connection between mean monthly values of HCI with mean monthly decade value of hospitalization in Kakheti in 2013 and 2015.

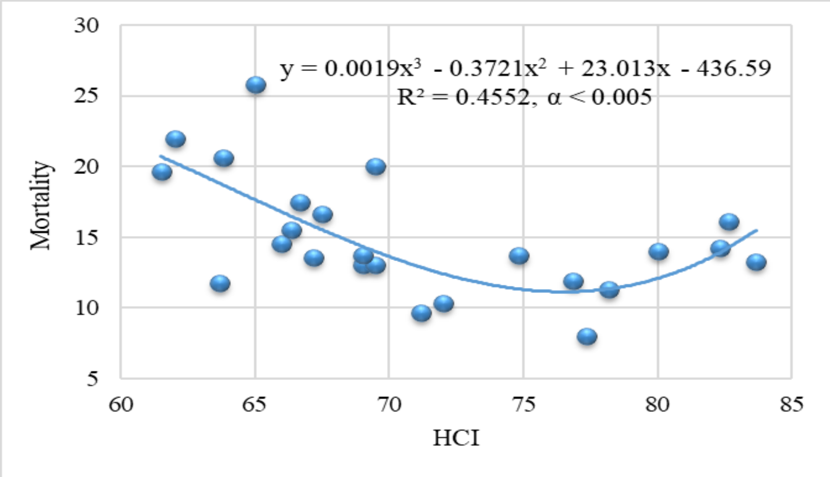

Fig.7. Connection between mean monthly values of HCI with mean monthly decade value of total mortality in Kakheti in 2013 and 2015.

In Fig. 5-7 connection between mean monthly values of HCI with mean monthly decade value of ambulance calls, hospitalization and total mortality in Kakheti are presented. As follows from these Fig. all the indicated connections have the form of a second degree polynomial (as in the case of Tbilisi, Fig.1). That is, in general with an increase of HCI values, there is a decrease of the values of AC, H and TM, and with the HCI category Excellent), their slight increase.

Table 5. Statistical characteristics of HCI components and ratings of these components in Kakheti in 2013 and 2015.

Variable	TC	T	CC	A	DP	R_d	WS	W
Mean	19.8	6.0	5.8	5.8	73.6	8.5	1.0	10
Min	6.3	3.3	3.8	3.8	17.0	6.5	0.8	10
Max	33.8	9.8	8.0	8.0	202.1	9.0	1.3	10
Range	27.5	6.5	4.2	4.2	185.1	2.5	0.5	0
St Dev	9.4	1.8	1.2	1.2	48.8	0.6	0.1	0
Cv, %	47.3	30.3	20.7	20.7	66.3	7.6	11.7	0.0

In Table 5. statistical characteristics of HCI components and ratings of these components in Kakheti in 2013 and 2015 are presented. As follows from this Table the variability of the investigated parameters is as follows. TC: – mean – 19.8, range of change – 6.3÷33.8; T: mean – 6.0, range of change – 3.3÷9.8; CC: mean – 5.8, range of change – 3.8÷8.0; A: mean – 5.8, range of change – 3.8÷8.0; DP: mean – 73.6, range of change – 17.0÷202.1; R_d: mean – 8.5, range of change – 6.5÷9.0; WS: mean – 1.0, range of change – 0.8÷1.3; W: mean – 10, range of change – 10÷10.

Table 6. Linear correlation coefficient between HCI components and ratings of these components with mean monthly decade values of ambulance colls, hospitalization and total mortality in Kakheti in 2013 and 2015.

Variable	TC	T	CC	A	DP	R_d	WS	W
R(AC)	-0.37	-0.20	-0.30	-0.30	-0.28	0.28	0.05	0.00
α (R(AC))	0.075	0.35	0.15	0.15	0.2	0.2	no sigh	no sigh
R(H)	-0.06	-0.29	-0.24	-0.24	-0.17	0.22	-0.22	0.00
α (R(H))	no sign	0.15	0.26	0.26	no sign	0.30	0.30	no sign
R(TM)	-0.57	-0.46	-0.22	-0.22	-0.25	0.26	0.35	0.00
α (R(TM))	0.005	0.02	0.30	0.30	0.24	0.22	0.1	no sigh

In Table 6 data about linear correlation coefficient between HCI components and ratings of these components with mean monthly decade values of ambulance colls, hospitalization and total mortality in Kakheti are presented.

The largest value of the linear correlation coefficient between the values of AC and the HCI components is -0.37 (with TC), the smallest is 0.05 (with WS). The largest value of the linear correlation coefficient between the AC values and the ratings of the HCI components is -0.30 (with A), the smallest is 0.0 (with W).

The largest value of the linear correlation coefficient between the values of H and the HCI components is -0.24 (with CC), the smallest is -0.06 (with TC). The largest value of the linear correlation coefficient between the H values and the ratings of the HCI components is -0.29 (with T), the smallest is 0.0 (with W).

The largest value of the linear correlation coefficient between the values of TM and the HCI components is -0.57 (with TC), the smallest is -0.22 (with CC). The largest value of the linear correlation coefficient between the TM values and the ratings of the HCI components is -0.46 (with T), the smallest is 0.0 (with W).

For example, in Fig. 8-13 shows a graphs of the connections between the values of TC and T with values of ambulance calls, hospitalization and total mortality in Kakheti.

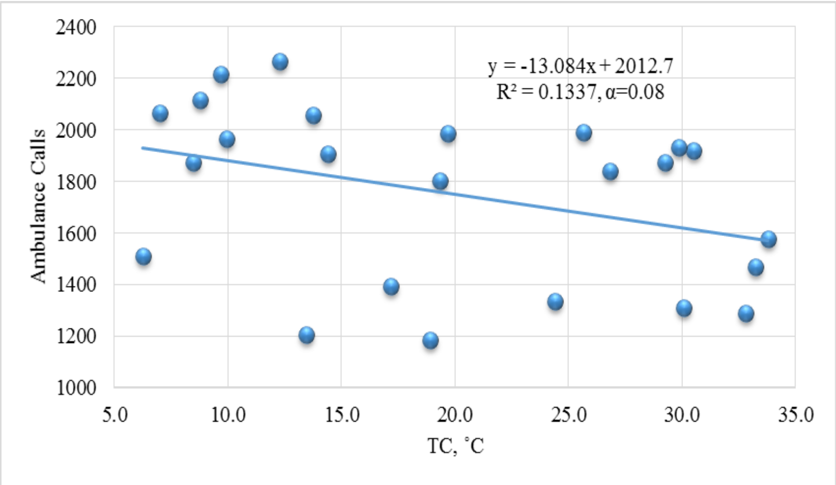

Fig.8. Connection between mean monthly values of TC with mean monthly decade value of ambulance calls in Kakheti in 2013 and 2015

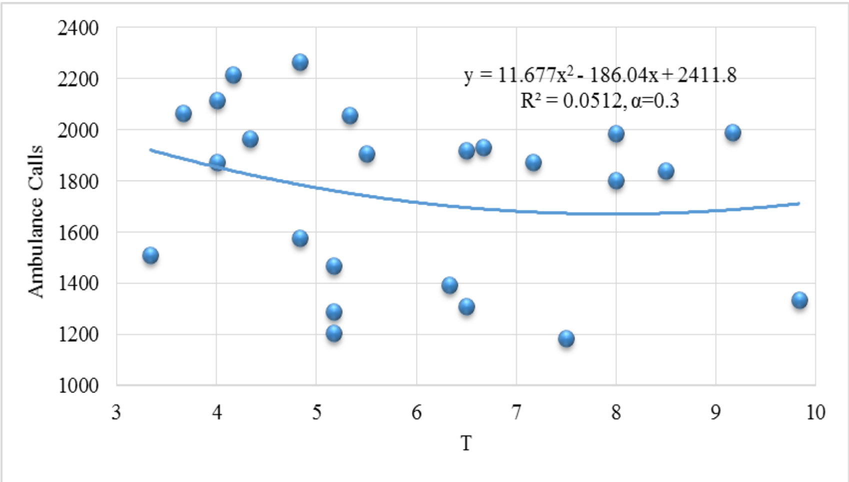

Fig.9. Connection between mean monthly values of T with mean monthly decade value of ambulance calls in Kakheti in 2013 and 2015.

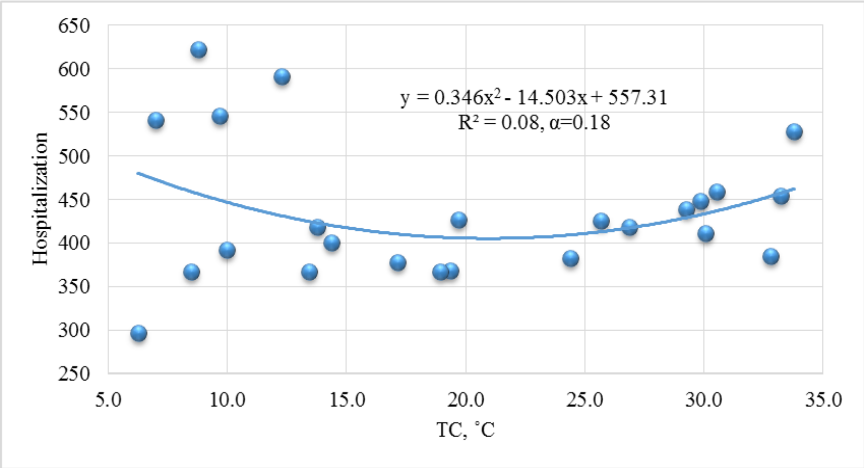

Fig.10. Connection between mean monthly values of TC with mean monthly decade value of hospitalization in Kakheti in 2013 and 2015.

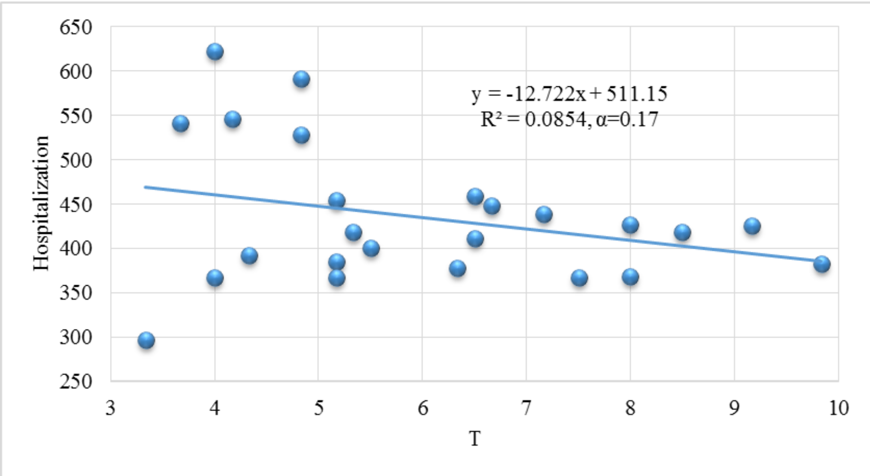

Fig.11. Connection between mean monthly values of T with mean monthly decade value of hospitalization in Kakheti in 2013 and 2015.

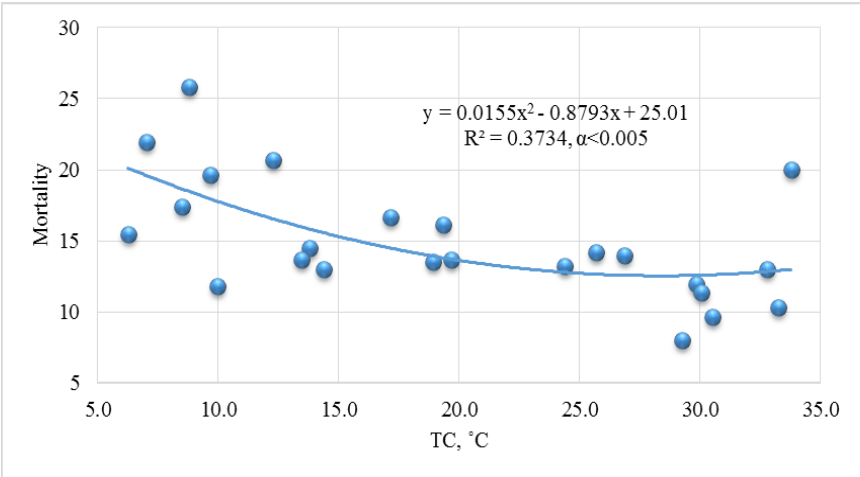

Fig.12. Connection between mean monthly values of TC with mean monthly decade value of total mortality in Kakheti in 2013 and 2015.

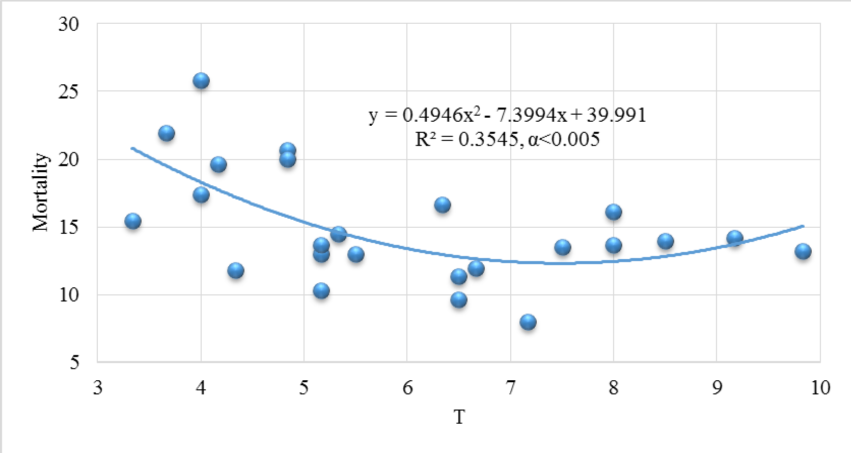

Fig.13. Connection between mean monthly values of T with mean monthly decade value of total mortality in Kakheti in 2013 and 2015.

So, the relationship between the values of TC and AC is inverse linear, and between T and AC - a polynomial of the second degree (Fig. 8 and 9); the relationship between the values of TC and H is a polynomial of the second degree, and between T and H - inverse linear (Fig. 10 and 11); the relationship between the values of TC and TM and T and TM are a polynomial of the second degree (Fig. 11 and 13).

Thus, the relationship between the HCI and the health indicators of the population in Tbilisi and Kakheti is in general similar to the classical form of mortality distribution according to the scale of thermal indices (a decrease in mortality from gradations with low uncomfortable values of the scale to comfortable ones, and then there is an increase in mortality in gradations with high uncomfortable values scale) [36].

Therefore, in our opinion, it is desirable to make adjustments in determining the degree of comfort of the HCI scale (as well as scales of other bioclimatic indices), taking into account local social and climatic conditions.

Conclusion.

In the future, we are planning to envisage conducting similar studies for other regions of Georgia.

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დასვენების კლიმატური ინდექსის კავშირი ადამიანის ჯანმრთელობასთან (თბილისის და კახეთის რეგიონის მაგალითზე)

ა. ამირანაშვილი, ა.რევიშვილი, ქ. ხაზარაძე, ნ. ჯაფარიძე

რეზიუმე

წარმოდგენილია დასვენების კლიმატური ინდექსის (დკი), მისი კომპონენტებისა და ამ კომპონენტების რეიტინგების ადამიანის ჯანმრთელობასთან კავშირის გამოკვლევა (თბილისის მაგალითზე - სიკვდილიანობა გულსისხლძარღვთა დაავადებების გამო და კახეთის რეგიონში - სასწრაფო სამედიცინო დახმარების გამოძახების, ჰოსპიტალიზაციის, საერთო სიკვდილიანობის რაოდენობა).

ნაჩვენებია, რომ მთლიანობაში ყველა მაჩვენებელი ადეკვატურად შეესაბამება ადამიანების საარსებო გარემოს კომფორტულობის ხარისხს. კერძოდ, დკი-ს კავშირს სიკვდილიანობასთან თბილისში აქვს მეორე ხარისხის პოლინომის, ხოლო კახეთში- მესამე ხარისხის პოლინომის სახე. ამავე დროს, ბიოკლიმატური კომფორტულობის ხარისხის ზრდისას დონემდე “ძალიან კარგი” დაიკვირვება სიკვდილიანობის შემცირების ტენდენცია. კომფორტულობის დონეზე “შესანიშნავი” გადასვლისას აღინიშნება სიკვდილიანობის გარკვეული მატება. ანალოგიური შედეგია მიღებული დკი-ს ზოგიერთი კომპონენტისა და მათი რეიტინგებისათვის.
შემოთავაზებულია მოსახლეობის ბიოკლიმატური კომფორტულობის ხარისხის სკალის განსაზღვრის კორექტირების ჩატარება ადგილობრივი სოციალური და კლიმატური პირობების გათვალისწინებით.

Связь климатического индекса отдыха со здоровьем людей (на примере Тбилиси и Кахетинского региона, Грузия)

А.Г. Амиранашвили, А. А. Ревишвили, К. Р. Хазарадзе, Н. Д. Джапаридзе

Резюме

Представлено исследование связи Климатического Индекса Отдыха (КИО), его компонент и рейтингов этих компонент на здоровье людей (на примере Тбилиси - смертность от сердечно-сосудистых заболеваний и Кахетинского региона Грузии – количество вызовов скорой медицинской помощи, госпитализаций, общей смертности).
Показано, что в целом все показатели адекватно соответствуют степени биоклиматической комфортности среды обитания для людей. В частности, связь КИО со смертностью в Тбилиси имеет вид полинома второй степени, а в Кахетии – полинома третьей степени. При этом, с повышением степени биоклиматической комфортности до категории “Очень хорошая” наблюдается тенденция уменьшения смертности. С переходом на уровень комфортности с категорией “Превосходная” отмечается некоторый рост смертности. Аналогичный результат получен для некоторых компонент КИО и рейтингов этих компонент.
Предлагается внести корректировки в определение степени комфортности шкал биоклиматических индексов для населения с учетом местных социальных и климатических условий.

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ტომი 24 , № 1

ჟურნალი იბეჭდება საქართველოს გეოფიზიკური საზოგადოების პრეზიდიუმის დადგენილების საფუძველზე

ტირაჟი 30 ცალი

JOURNAL OF THE GEORGIAN GEOPHYSICAL SOCIETY

Physics of Solid Earth, Atmosphere, Ocean and Space Plasma

Vol. 24, № 1

Printed by the decision of the Georgian Geophysical Society Board

Circulation 30 copies

ЖУРНАЛ ГРУЗИНСКОГО ГЕОФИЗИЧЕСКОГО ОБЩЕСТВА

Физика Твердой Земли, Атмосферы, Океана и Космической Плазмы

Том 24, № 1

Журнал печатается по постановлению президиума Грузинского геофизического общества

Тираж 30 экз

Tbilisi-თბილისი-Тбилиси
2021