Journal of the Georgian Geophysical Society, ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 21(1), 2018, pp.48-62

On the Connection of Monthly Mean of Some Simple Thermal Indices and Tourism Climate Index with the Mortality of the Population of Tbilisi City Apropos of Cardiovascular Diseases

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

[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]Tbilisi State Medical University
[3]Georgian State Teaching University of Physical Education and Sport

ABSTRACT

The comparative analysis of the connection of eight simple thermal indices and Tourism Climate Index (TCI) 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.

Key Words: Bioclimatic index, thermal comfort, bioclimatic stress, meteorological parameters

Introduction

Human health in essence depends on the means of her life (50 - 55 %), then from the environmental conditions (25 - 30 %), and finally - from the efforts of medicine [1]. Different anthropogenic loads on the living environment of people increase the risks of action on their health and life [1-5].

Studies of weather conditions, climate change, quality of atmospheric air, and also of different helio-geophysical and space factors for the human organism, are conducted in many countries of the world [6-11].

Significant number of works is devoted to the study of influence on the human health of separate meteorological and helio-geophysical elements, parameters of space weather, and also of their combinations: air temperature [1,4,10, 12], humidity, wind speed, atmospheric pressure, solar activity (Wolf's number), the geomagnetic fields , solar radiation, the cosmic rays [1, 12-20], light ions [1,21-24], aerosols [1,25], ozone [1,26-28], other air toxic admixtures and etc. [1,3-5]. Thus, are well known as the effects of a significant increase in the mortality of population with the strong cold and the extreme heat [29-32].

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 [33-37].

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 - WBGT, Tourism Climate Index - TCI) and others [33-43].

Complex thermal indices are 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. [41,44-48]).

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 [1,2,10,19,20,32,34,38,40,49,50].

For example, in the works [40,50] results of studying the connection of average-daily values of equivalent-effective temperature in Tbilisi with the mortality of the population of this city from the cardiovascular diseases are represented. It 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 work [32] that the relationship between the average monthly air temperature in Kutaisi (Georgia) 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).

The results of a study of the effect of the annual changeability of air temperature, surface ozone concentration and neutron component of galactic cosmic ray intensity on the mortality of the population of Tbilisi city in 1984-2010 are presented in the work [19]. In particular, it was found that within the variation range the contribution of the studied parameters to mortality variability is as follows: a random component of air temperature - 8.5%, real values of surface ozone concentration and cosmic ray intensity - 20.9% and 16.5%, respectively.

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 [20,34,39,51]. In this case usually is used the standard scale and categories of the majority of these indices, used 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, are represented below.

Material and methods

The data of M. Nodia Institute of Geophysics about the mean monthly decade mortality for reasons the cardiovascular diseases in Tbilisi for 1 million inhabitants from 1980 through 1992 (below – Mortality), and also data of agency on the environment about the mean and mean max monthly values of air temperature - T (°C), mean and mean min air relative humidity – RH (%), and wind speed - V (m/sec) during the indicated period of time were used in the work.

The analysis of data with the aid of the standard methods of mathematical statistics [52] was conducted. All 156 cases were analyzed (months).

The following designations besides intelligible will be used below: Range – variation scope (Max – Min); σ - standard deviation; σ_m - standard error (68% - confidence interval of mean values); C_v = 100·σ/Average - coefficient of variation (%); CONF-L and CONF-U - 99% upper and lower levels of the confidence interval of the average correspondingly; R - coefficient of linear correlation; R^2 – coefficient of determination, α - the level of significance.

The connection of Mortality with 8 simple thermal indices, and also with the Tourism Climate Index was studied in the work [40,53-69]. The values of simple thermal indices were calculated both according to mean monthly data of the above indicated meteorological parameters and by the mean monthly data about their values in 13 hours (below - Mean and Mean_Max correspondingly).

Information about eight simple thermal indices and Tourism Climate Index formulas, abbreviations, scales and category are presented in tables 1 and 2.

Table 1.

Eight simple thermal indices formula, scales and category

Equivalent-Effective Temperature [40,53]: $EET = 125 \cdot Lg(1+0.02 \cdot T+0.0001 \cdot (T-8) \cdot (RH-60)-0.0045 \cdot (33-T) \cdot V^{0.5})$, °C		Effective Temperature [54,55]: $ET = 37-(37-T)/(0.68-0.0014 \cdot RH+1/(1.76+1.4 \cdot V^{0.75})) -0.29 \cdot T \cdot (1-0.01 \cdot RH)$, °C	
<1	Sharply coldly	<1	Very cold
1-8	Coldly	1-9	Cold
9-16	Moderately coldly	9-17	Cool
17-22	Comfortably	17-21	Comfortable
23-27	Warmly	21-23	Warm
>27	Hotly	23-27	Hot
		>27	Very Hot
Effective Temperature [56-58]: $TE = T-0.4 \cdot (T-10) \cdot (1-RH/100)$, °C		Humindex [59]: $HI = T+0.5555 \cdot (e-10)$, °C	
< 16.1	Cool	<30	Comfortable
16.1-20	Comfortable	30÷40	Warm
20.1-24	Slightly humid	40÷45	Hot
> 24	Humid	45÷55	Very hot
		>55	Extreme hot
Equivalent temperature [60-62]: $TEK = T+1.5 \cdot e$, °C		Wet-Bulb-Globe-Temperature [63]: $WBGT = 0.567 \cdot T+0.393 \cdot e+3.94$, °C	
<18	Very cold	<18	Comfortable
18÷24	Cold	18÷24	Warm
24÷32	Cool	24÷28	Hot
32÷44	Comfortable	28÷30	Very hot
44÷56	Warm	>30	Extreme hot
>56	Hot		
Temperature - Humidity Index [64]: $THI = T - (0.55-0.0055 \cdot RH) \cdot (T-14.5)$, °C		Cooling Power [65-67]: $CP = (0.26+0.34 \cdot V^{0.622}) \cdot (36.5-T)$, $Mcal/cm^2/sec$	
<-40	Extreme cold	0÷4	Hot-sultry-uncomfortable
-40÷-20	Very high cold	5÷9	Warm-comfortable
-10÷-1.8	High cold	10÷19	Mild-pleasant
-1.8÷13	Moderate cold	20÷29	Cool
13÷15	Low cold	30÷39	Cold-Slightly uncomfortable
15÷20	No discomfort	40÷49	Moderately – very uncomfortable
20÷26.5	Hot	50÷59	Unpleasantly – extremely cold
26.5÷30	Very hot	60÷70	Unbearably cold
>30	Extreme hot		
T – air temperature, °C; RH – air relative humidity, %; V - wind speed, m/sec; e - water vapor pressure, hPa °C in this table is so-called perceptible temperature.			

Table 2.

Tourism Climate Index formula, scale and category

Tourism Climate Index [20,68,69]: TCI = 2· [(4·Cld)+Cla+(2·R)+(2·S)+W]			
TCI	Category	TCI	Category
90 ÷ 100	Ideal	40 ÷ 49	Marginal
80 ÷ 89	Excellent	30 ÷ 39	Unfavorable
70 ÷ 79	Very Good	20 ÷ 29	Very Unfavorable
60 ÷ 69	Good	10 ÷ 19	Extremely Unfavorable
50 ÷ 59	Acceptable	- 30 ÷ 9	Impossible
Cld is a daytime comfort index, consisting of the mean maximum air temperature Ta, max (°C) and the mean minimum relative humidity RH (%), Cla is the daily comfort index, consisting of the mean air temperature (°C) and the mean relative humidity (%), R is the precipitation index, S is the daily sunshine duration index, and W is the mean wind speed index. In contrast to other climate indices, every contributing parameter is assessed. Because of a weighting factor (a value for TCI of 100), every factor can reach 5 points. TCI values >= 80 are excellent, while values between 60 and 79 are regarded as good to very good. Lower values (40 – 59) are acceptable, but values < 40 indicate bad or difficult conditions for understandable to all tourism.			

For studying the possibility of applying of the standard scales and categories of the above indicated indices as the bioclimatic indicator in monthly time scale the data of table 3 are used.

Table 3.

Repetition of mean monthly decade mortality from the cardiovascular diseases in Tbilisi to 1 million inhabitants in 1980-1992 on the different levels of mortality (%) [70]

Low	**Lowered**	**Moderate**	**Increased**	**High**	**Extreme**
<75	>75-95	>95-115	>115-135	>135-155	>155
3.21	27.56	38.46	23.08	7.05	0.64

Below, the different rate of bioclimatic comfort or discomfort of environment for the people was evaluated according to the values of mortality ≤115 and > 115 respectively.

Results and discussion

Results in Table 4-6 and Fig. 1-11 are presented.

In Table 4 the statistical characteristics of eight simple thermal indices, TCI and Mortality in Tbilisi in 1980-1992 are presented. In the upper part of Table 4 the statistical data about the mean monthly values of eight thermal indices, and in the lower part - analogous data for 13 hours are represented. Data about TCI and Mortality respectively - mean monthly and mean monthly decade (led to the ten-day period, since in the months a different quantity of days).

In correspondence with Table 1 scale of thermal indices the following ranges cover:
EET: <1÷ >27°C; ET: <1÷ >27°C; TE: < 16.1 ÷> 24°C; THI: <-40÷>30°C; TEK: <18÷>56°C; HI: <30÷>55°C; WBGT: <18÷>30°C; CP: 0-4÷60-70 $Mcal/cm^2/sec$.

Table 4.

The statistical characteristics of eight simple thermal indices, TCI and Mortality

Parameter	EET	ET	TE	THI	TEK	HI	WBGT	CP	TCI	Mortality
	Mean									
Average	8.7	10.4	12.5	13.1	29.5	13.5	15.6	13.1	65.2	106.1
Min	-8.8	-4.1	-0.1	0.7	6.0	-3.9	5.2	5.6	38.0	69.0
Max	21.6	22.4	23.5	23.5	56.9	31.5	26.5	26.2	89.0	167.8
Range	30.4	26.5	23.6	22.8	50.8	35.4	21.3	20.6	51.0	98.8
St Dev	8.8	7.4	7.0	6.7	15.4	10.8	6.5	4.5	13.5	19.0
σ_m	0.7	0.6	0.6	0.5	1.2	0.9	0.5	0.4	1.1	1.5
C_v (%)	100.7	71.2	56.0	51.0	52.3	79.6	41.6	34.6	20.7	17.9
CONF-L	6.9	8.8	11.0	11.7	26.2	11.2	14.2	12.2	62.3	102.1
CONF-U	10.6	12.0	14.0	14.5	32.8	15.9	17.0	14.1	68.1	110.2
	Mean_Max									
Average	13.9	15.3	16.7	17.2	36.0	19.5	19.1	9.9	65.2	106.1
Min	-2.9	***0.3***	***2.9***	4.2	***8.9***	-1.1	***6.8***	1.7	38.0	69.0
Max	26.1	***27.5***	***27.7***	27.1	***65.1***	39.2	***30.9***	23.1	89.0	167.8
Range	29.0	***27.2***	***24.8***	23.0	***56.2***	40.3	***24.1***	21.4	51.0	98.8
St Dev	8.2	7.5	7.0	6.4	16.3	11.7	7.0	4.9	13.5	19.0
σ_m	0.7	0.6	0.6	0.5	1.3	0.9	0.6	0.4	1.1	1.5
Cv (%)	58.7	49.1	41.9	37.3	45.3	59.8	36.7	49.5	20.7	17.9
CONF-L	12.2	13.7	15.2	15.8	32.5	17.0	17.6	8.9	62.3	102.1
CONF-U	15.7	16.9	18.2	18.6	39.5	22.0	20.6	11.0	68.1	110.2

The comparison of Tables 1 and 4 shows that the complete range of the standard scale of thermal indices only the mean monthly values for 13 hours of the following indices cover: **ET**, **TE**, **TEK** and **WBGT** (Table 4, **Bold**, ***Italic***).

Table 5.

Correlation matrix of the investigated parameters. Right side – Mean_Max monthly values of eight simple thermal indices; left side - Mean monthly values of eight simple thermal indices.

$\alpha(R) \leq 0.001$

Parameter		**Mean_Max**									
		EET	**ET**	**TE**	**THI**	**TEK**	**HI**	**WBGT**	**CP**	**TCI**	**Mortality**
Mean	**EET**	1	1.00	0.99	0.99	0.99	0.99	0.99	-0.96	0.80	-0.69
	ET	1.00	1	0.99	0.99	0.99	0.99	0.99	-0.97	0.77	-0.69
	TE	0.99	0.98	1	1.00	0.99	1.00	1.00	-0.93	0.79	-0.68
	THI	0.99	0.98	1.00	1	0.99	1.00	1.00	-0.92	0.80	-0.68
	TEK	0.99	0.98	0.99	0.99	1	1.00	1.00	-0.94	0.74	-0.68
	HI	0.99	0.99	1.00	1.00	1.00	1	1.00	-0.93	0.76	-0.68
	WBGT	0.99	0.99	1.00	1.00	1.00	1.00	1	-0.94	0.76	-0.68
	CP	-0.92	-0.95	-0.87	-0.86	-0.89	-0.88	-0.88	1	-0.69	0.67
	TCI	0.77	0.74	0.77	0.78	0.72	0.74	0.74	-0.61	1	-0.50
	Mortality	-0.69	-0.69	-0.68	-0.68	-0.68	-0.68	-0.68	0.64	-0.50	1

As follows from Table 5 practically direct functional connection is observed between all eight simple thermal indices. The minimum absolute value of the coefficient of linear correlation for the mean monthly values of thermal indices is equal to 0.86, maximum - 1. For the mean monthly values of thermal indices in 13 hours linear correlation between them is higher ($0.92 \le |R| \le 1$). Somewhat below value R between TCI and thermal indices ($0.61 \le |R| \le 0.78$ and $0.69 \le |R| \le 0.80$ in the case of the mean monthly and mean monthly values of thermal indices in 13 hours respectively), which indicates the nonlinearity of the relationship between them.

It also follows from Table 5 that 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. In this case let us note that the level of correlation of mortality with the simple thermal indices ($0.64 \le |R| \le 0.69$) much the same as with the mean monthly maximum and mean monthly air temperature, and also with Cla (R = -0.65, -0.66 and -0.63 respectively [20]).

Fig. 1-9 presents visual information about the values of mortality in different ranges of the standard scale of simple thermal indices and TCI. In particular, it is clearly evident from these Figures that in the case of the mean monthly values of simple thermal indices in 13 hours is covered the larger range of the standard scale of these indices, than in the case of their mean monthly values (analogous information is represented above in Table 4).

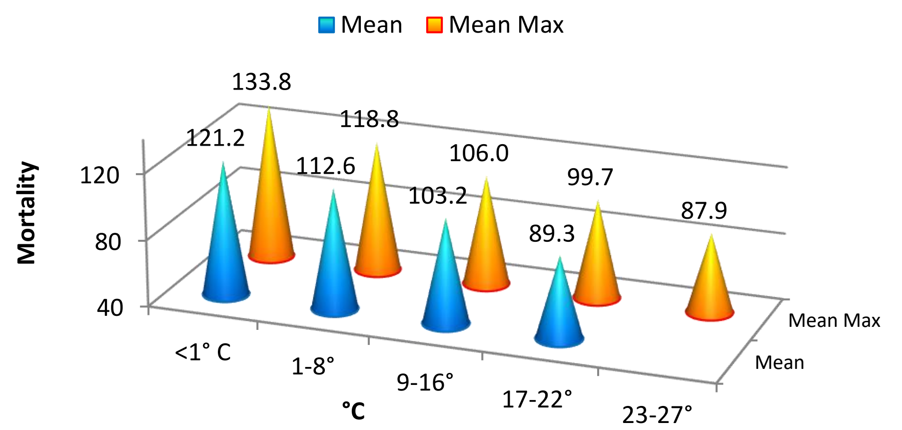

Fig. 1. Values of Mortality to the different range of EET

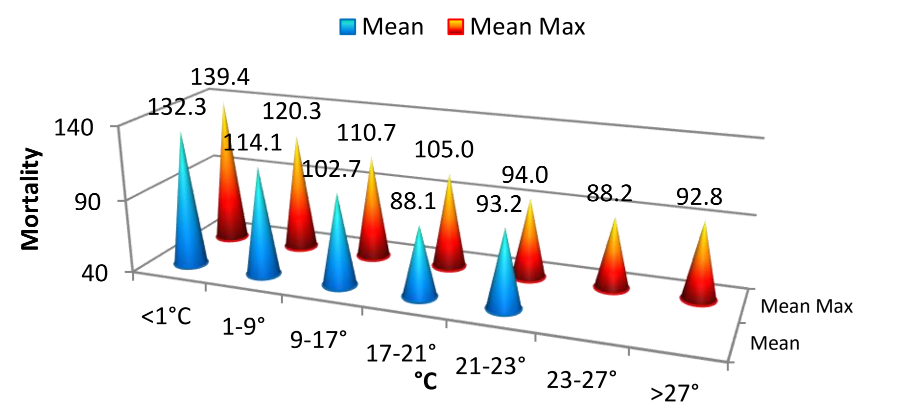

Fig. 2. Values of Mortality to the different range of ET

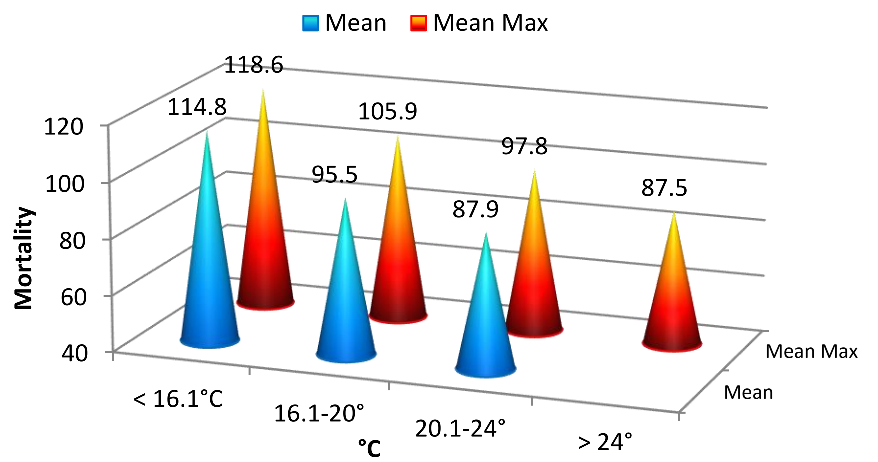

Fig. 3. Values of Mortality to the different range of TE

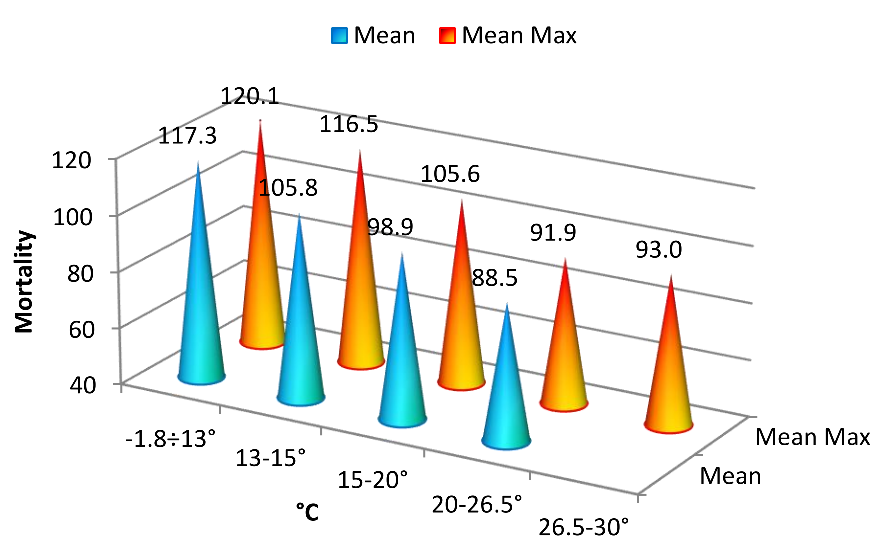

Fig. 4. Values of Mortality to the different range of THI

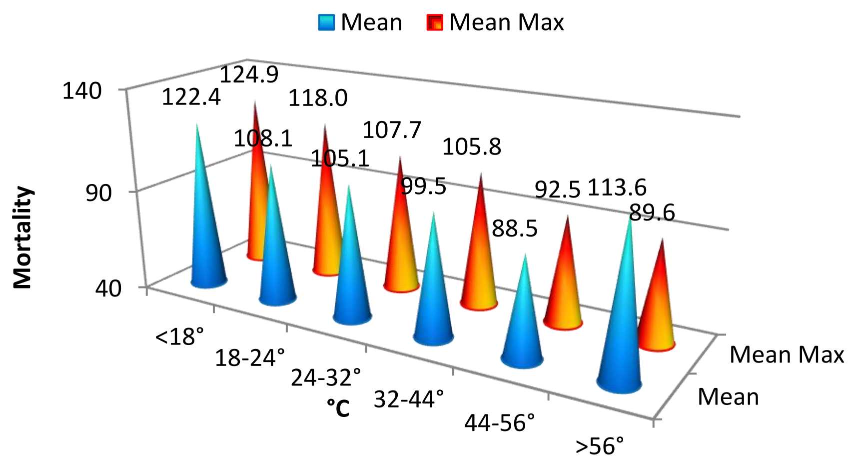

Fig. 5. Values of Mortality to the different range of TEK

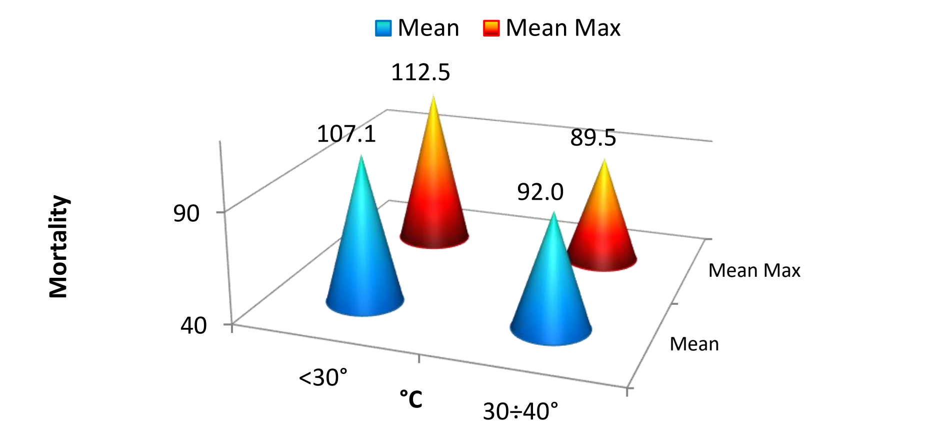

Fig. 6. Values of Mortality to the different range of HI

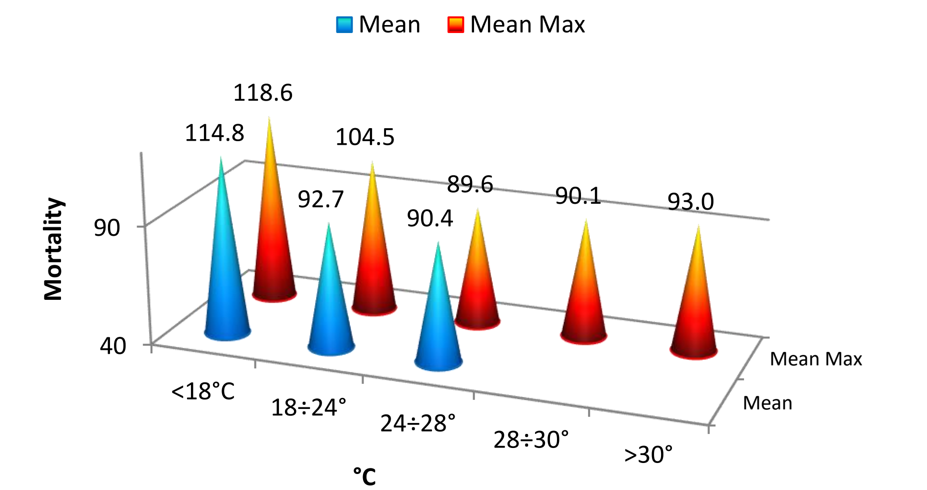

Fig. 7. Values of Mortality to the different range of WBGT

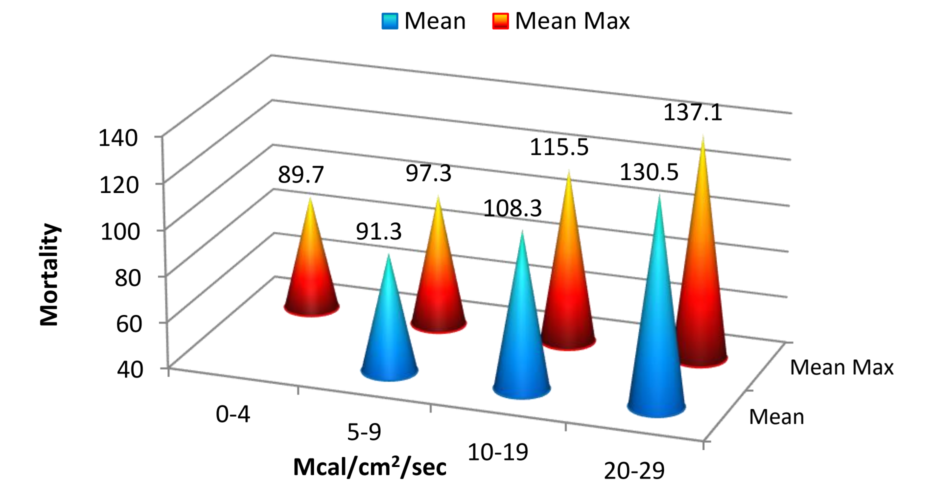

Fig. 8. Values of Mortality to the different range of CP

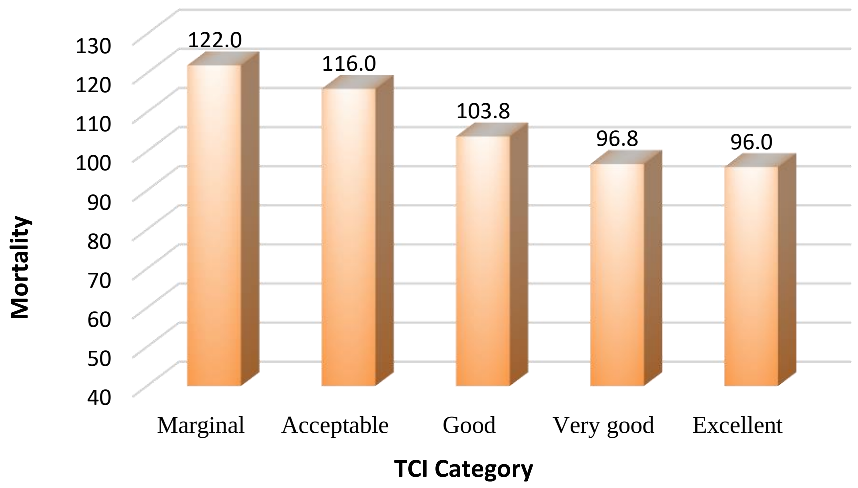

Fig. 9. Values of Mortality to the different range of TCI

As it was noted above, the complete range of the standard scale of thermal indices cover mean monthly values for 13 hours of such indices as: ET, TE, TEK and WBGT (Fig. 2,3,5 and 7; in the case with TEK complete range of the standard scale it is covered also for its mean monthly values, Fig. 5).

It also follows from Fig. 2,3,5 and 7 that classical form the distributions of mortality over the scale ranges of thermal indices (reduction in the mortality from the gradations with the low uncomfortable values of the scale to the comfortable, and by further increase of the mortality in the gradations with the high uncomfortable values of the scale) for ET, TEK и WBGT are observed. However, the distribution of mortality over the scale ranges ET (Fig. 2) better corresponds the distribution of mortality along its levels (table 3). Thus, the most representative for the description bioclimatic situation appears air effective temperature ET in 13 hours by Missenard [54,55].

As far as TCI is concerned, this index, without being especially thermal, in the limits of its standard scale also completely adequately corresponds to the bioclimatic situation of environment for the so-called "average tourist" (Fig. 9).

Table 6.

Coefficients of the equation of the regression of connection TCI with different simple thermal indices. $\alpha(R^2) \leq 0.001$

Parameter	**$TCI = a \cdot x^3 + b \cdot x^2 + c \cdot x + d$**				
	a	b	c	d	R^2
EET_Max	-0.0108	0.336	- 0.6953	45.537	0.8418
ET_Max	-0.0134	0.4872	- 2.8911	50.285	0.8366
TE_Max	-0.0154	0.6195	- 5.1183	56.928	0.8566
THI_Max	-0.0203	0.86	- 8.681	70.445	0.8587
HI_Max	-0.003	0.1198	0.2755	43.804	0.8546
TEK_Max	-0.0009	0.0727	- 0.5586	42.12	0.8411
WBGT_Max	-0.0135	0.6225	- 6.4081	62.42	0.8533
CP_Max	0.0297	- 1.126	10.403	48.413	0.6158

Finally, Table 6 presents the data about the values of the coefficients of the equation of the regression of the connection between the average monthly values of simple thermal indices 13 hours and

TCI. Fig. 11 and 12 depict two graphic examples of these connections (respectively - TCI and ET, TCI and CP).

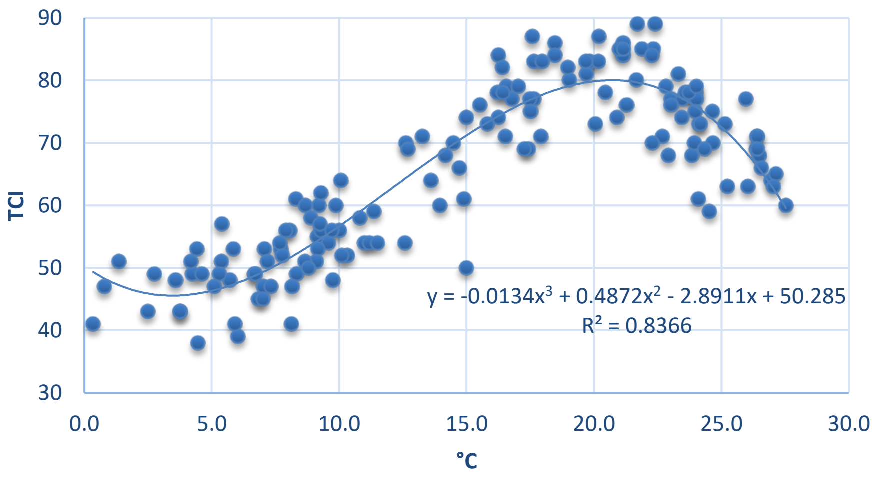

Fig. 10. Connection between TCI and ET_Max

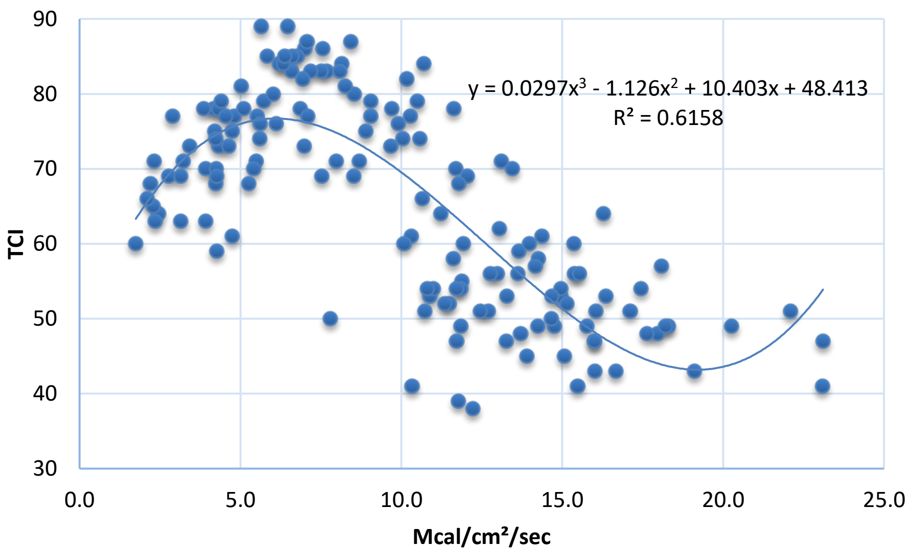

Fig. 11. Connection between TCI and CP_Max

As it follows from the indicated Table and the Figures, connection TCI with the simple thermal indices is satisfactorily described by the third power polynomial. Thus, if it is necessary, using values of simple thermal indices in the first approximation, it is possible to estimate values of TCI.

Conclusion

As a whole, all eight simple thermal indices and Tourism Climate Index adequately correspond to the degree of the bioclimatic comfort of environment for the "average person" and "average tourist" - with an increase in the level of comfort the mortality diminishes. Most representative for this purpose is Missenard air effective temperature in 13 hours.

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ზოგიერთი მარტივი თერმული ინდექსების და ტურიზმის კლიმატური ინდექსის საშუალო თვიური მნიშვნელობის კავშირი თბილისის მოსახლეობის სიკვდილობასთან (გამოწვეული გულ-სისხლძარღვთა დაავადებებით)

ა. ამირანაშვილი, ნ. ჯაფარიძე, ქ. ხაზარაძე

რეზიუმე

წარმოდგენილია შედარებითი ანალიზი რვა მარტივი თერმული ინდექსის და ტურიზმის კლიმატური ინდექსისა და თბილისის მოსახლეობის სიკვდილობას (გამოწვეული გულ-სისხლძარღვთა დაავადებებით) შორის. მარტივი თერმული ინდექსის მნიშვნელობა იანგარიშება საშუალო თვიური და საშუალო თვიური 13 ს. მეტეოროლოგიური ელემენტების გამოყენებით.

ყველა შესწავლილი მარტივი თერმული ინდექსებს შორის შეიმჩნევა პრაქტიკულად პირდაპირი, ფუნქციონალური დამოკიდებულება წრფივი კორელაციურ კოეფიციენტზე არა ნაკლებ 0.86.
მარტივი თერმული ინდექსების ტურიზმის კლიმატურ ინდექსებთან (ტკი) დამოკიდებულება არაწრფივია და აქვს მესამე რიგის პოლინომის სახე.
შესწავლილია სტანდარტული შკალების და ხსენებული ინდექსების კატეგორიის გამოყენება ბიოკლიმატური მაჩვენებლად თვიური მასშტაბის დროში.
მთლიანობაში, ყველა ინდექსი ადეკვატურად შეესაბამება გარემოს ბიოკლიმატური კომფორტის ხარისხს ადამიანებისთვის - კომფორტის დონის ზრდასთან ერთად სიკვდილობა მცირდება.
ყველაზე მეტად რეპრეზეტატულია ამ მიზნისათვის ჰაერის 13 ს. ეფექტური ტემპერატურა მისენარდის მიხედვით.

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

Резюме

Представлен сравнительный анализ связи восьми простых термальных индексов и климатического индекса туризма (КИТ) с месячной смертностью населения города Тбилиси по поводу сердечно-сосудистых заболеваний. Значения простых термальных индексов рассчитывались с использованием среднемесячных и средних месячных за 13 часов данных метеорологических элементов. Между всеми изученными простыми термальными индексами наблюдается практически прямая функциональная связь с коэффициентом линейной корреляции не ниже 0.86. Связь простых термальных индексов с КИТ нелинейная и имеет вид полинома третьей степени.
Изучена возможность использования стандартных шкал и категорий указанных индексов в качестве биоклиматического показателя в месячном масштабе времени. В целом, все индексы адекватно соответствуют степени биоклиматической комфортности окружающей среды для людей – с ростом уровня комфортности смертность убывает. Наиболее же репрезентативной для этой цели является эффективная температура воздуха по Миссенарду за 13 часов.