Assessment of bioclimatic comfort of the Krasnodar Krai

D Gura1,3, M Kuzyakina2, I Gribkova1

1Kuban State Technological University, 2, Moskovskaya str., 350042, Krasnodar, Russia
2Kuban State University, 149, Stavropol'skaya str., Krasnodar, 350040, Russia
3Kuban State Agrarian University named after I.T. Trubilin, 13, Kalinina str., 350044, Krasnodar, Russia

E-mail: gda-kuban@mail.ru

Abstract. The paper identifies bioclimatic comfort zones of the Krasnodar Krai. The studied bioclimatic indices take into account the combined influence of temperature, wind speed, relative humidity, atmospheric pressure, solar radiation in various combinations. The geoinformation analysis of the following bioclimatic indices was carried out: effective temperature, equivalent effective temperature, bioclimatic active temperature, radiation equivalent effective temperature, and a comprehensive indicator of the level of pathogenic weather in the Krasnodar Krai. The pathogenic weather index is the only index considered in this paper that takes into account atmospheric pressure. Comfortable months for living in the Krasnodar Krai have been established, as well as areas of the Krasnodar Krai that are favorable for living at any time of the year. However, peak values are not necessarily adverse. During these periods, sometimes healthy people experience an improvement in mood and a surge of strength, while overworked ones respond by aggravation of their condition. Thus, the Krasnodar Krai was divided into 4 comfort zones: Azov-Black Sea, Black Sea, South-East foothill and continental.

1. Introduction
The most informative indicator of the effect of weather on a person is the pathogenicity index. It takes into account: air temperature, air humidity, atmospheric pressure and wind speed.

Calculation of bioclimatic indicators is useful for determining the best time, for example, for climatological treatment, human sunbathing. It is commonly known that a sharp change in weather, magnetic storms, and other climatic peaks affect the human body. Moreover, conditionally healthy people react, as a rule, by raising their mood, increasing their working capacity, while conditionally unhealthy people, on the contrary, fall into depression, despondency, chronic diseases worsen in them.

Thus, the studies carried out made it possible to reveal some features of the natural conditions of the Krasnodar Krai and analyze the influence of climatic and meteorological factors on the spatial and temporal distribution of the degree of comfort of the territory using actual statistical material.

Average long-term (average monthly) observations of air temperature, relative air humidity, wind speed and atmospheric pressure were taken from freely distributed data by the global forecasting system of the National Oceanic and Atmospheric Administration (GFS NOAA) for the following 30 settlements that are uniformly located across the territory of the Krasnodar Krai: Abinsk, Adler, Anapa, Armavir, Belorechensk, Gelendzhik, Goryachy Klyuch, Gulkevichi, Dzhubga, Yeysk,
Kanevskaya, Korenovsk, Krasnodar, Kropotkin, Krymsk, Kurganinsk, Kushchevskaya, Labinsk, Mostovskoy, Novokubansk, Novorossiysk, Primorsko-Akhtarsk Slavyansk-na-Kubani, Sochi, Temryuk, Timashevs, Tikhoretsk, Tuapse, Ust-Labinsk, Hadyzhensk.

The calculations were carried out according to 5 main known bioclimatic indicators: effective temperature, equivalent effective temperature, biologically active temperature, radiation equivalent effective temperature, and pathogenicity index of weather conditions.

2. Materials and Methods

The effective temperature characterizes the heat sensation of the human body in undressed form.

The same heat sensation can be experienced with the most diverse combinations of meteorological elements. Experimentally, a number of combinations of temperature and relative humidity were established, at which the effect of heat transfer and heat perception will be the same. They are expressed in degrees of temperature of still air saturated with water vapor, i.e. in degrees of effective temperature.

There are about 10 different formulas for its calculation [1-5], but the Missenard’s formula (1) is considered classical [5]:

$$ET_M = T - 0.4(T - 10) \left(1 - \frac{f}{100}\right),$$  \hspace{1cm} (1)

where $T$ – air temperature, degrees; $f$ – relative humidity, %.

Equivalently effective temperature characterizes the heat sensation of the human body when dressed. Usually the formula developed by Missenard is also used for its calculation (2) [5]:

$$EET_M = 37 - \left(\frac{T}{0.68 - 0.0014f + \frac{1}{1.76 + 1.4w^{0.75}}}\right) - 0.29T \left(1 - \frac{f}{100}\right),$$  \hspace{1cm} (2)

where $T$ – air temperature, degrees; $f$ – relative humidity, %; $w$ – wind speed, m/s.

The equivalent-effective temperature index is used for climate treatment [6].

Biologically active temperature takes into account the effect of radiation reflected by the Earth’s surface; it is also used in agriculture as a parameter characterizing the period of active vegetation of crops.

In calculations, the Tsitsenko formula (3) was used.

$$BAT = 0.8(0.8 \cdot EET + 7) + 9,$$  \hspace{1cm} (3)

where EET – equivalent effective temperature.

Radiation equivalent effective temperature - a measure of the thermal sensation of a naked person exposed to solar radiation. It is used in climatotherapy for microclimatic assessment of locations for climatotherapy procedures (sunbathing).

To calculate the radiation equivalent effective temperature, there are two formulas, one of which (4) is not applicable for calculations due to the complexity of data collection.

Whereas the second formula (5) developed by E.G. Golovina and V.I. Rusanov is recommended for assessing REET [7].

$$REET = 120 \cdot \lg \left(1 + 0.02T + 0.01(T - 8)(f - 60)\right) - 0.045(33 - T)\sqrt{w} + 185B,$$  \hspace{1cm} (4)

where $T$ – air temperature, degrees; $f$ – relative humidity, %; $w$ – wind speed, m/s; $B$ – solar radiation absorbed by the surface of the body, kW/m$^2$.

$$REET = 0.83 \cdot EET + 12,$$  \hspace{1cm} (5)

where EET – equivalent effective air temperature, degrees.

To assess the degree of the irritant action of weather changes on the body, the meteorological pathogenicity index proposed by Boksha is used [8]. This index is the sum of the pathogenicity indices of different meteorological variables and is called the pathogenicity index of the meteorological
situation (6).

\[ J = I_T + I_h + I_w + I_{\Delta p} + I_{\Delta T} \]  

(6)

where \( J \) – general pathogenicity index; \( I_T \) – pathogenicity index of air temperature; \( I_h \) – moisture pathogenicity index; \( I_w \) – pathogenicity index of wind speed; \( I_{\Delta p} \) – pathogenicity index of changes in atmospheric pressure; \( I_{\Delta T} \) – pathogenicity index of changes in air temperature.

Component pathogenicity indices are calculated using the following formulas (7–11):

The pathogenicity index of air temperature is calculated according to the system of equations (7):

\[
\begin{align*}
I_T &= 0.2(18 - T)^2, \text{ when } T \leq 18; \\
I_T &= 0.2(T - 18)^2, \text{ when } T > 18,
\end{align*}
\]

(7)

where \( T \) – average daily air temperature in °C.

The moisture pathogenicity index is calculated by the formula (8):

\[ I_h = \frac{10(h - 70)}{20} \]

(8)

where \( h \) – average daily relative air humidity in %.

The pathogenicity index of wind speed - according to the formula (9):

\[ I_w = 0.2w^2, \]

(9)

where \( w \) – average daily wind speed in m/s.

The pathogenicity index of atmospheric pressure changes is determined by the formula (10):

\[ I_{\Delta p} = 0.06(\Delta p)^2 \]

(10)

where \( \Delta p \) – day-to-day change in average daily atmospheric pressure in mmHg/day.

The day-to-day temperature variability is determined, on the one hand, by the annual cycle of temperature, and on the other, by circulation processes. In the annual cycle of temperature, a slight day-to-day change is observed. Large day-to-day changes in air temperature create uncomfortable conditions for humans.

The pathogenicity index of changes in air temperature (formula (11)):

\[ I_{\Delta T} = 0.06(\Delta T)^2 \]

(11)

where \( \Delta t \) – day-to-day change in average daily air temperature in °C/day.

3. Results

Figure 1 shows the results of the geoinformation analysis of the effective temperature in the Krasnodar Krai, calculated according to the formula of A. Missenard (1).
Figure 1. Maps of the effective temperature (comfort level) of the Krasnodar Krai according to the formula of A. Missenard.

The most comfortable temperature was only in September on the sea coast (both the Black Sea and the Sea of Azov) and in June at the foothills of the Caucasus - Mostovskoy and Absheron districts.

Figure 2 shows cartographic material on the geoinformation analysis of equivalent effective temperature calculated by the formula of A. Missenard (2).

Figure 2. Maps of the equivalent effective temperature (comfort level) of the Krasnodar Krai according to the formula of A. Missenard.
There is almost no absolutely comfortable equivalent effective temperature in the Krasnodar Krai. In June, a high level of comfort is observed in the northwestern part of the Krasnodar Krai. Whereas in July - in the southeast: Absheron, Mostovskoy, Otradnensky areas, i.e. at the foothills of the Caucasus.

From June to September, the average level of comfort is observed throughout the Krasnodar Krai, in May it is moderate, in October and April it is low, uncomfortable equivalent effective temperature is observed from November to March.

However, it should be noted that in March, October and November in the municipalities of Tuapse and Sochi, the level of comfort is an order of magnitude better than in the rest of the Krasnodar Krai.

The figure shows the spatial distribution of the biologically active temperature calculated by the Tsitsenko’s formula (3).

Figure 3. Maps of biologically active temperature (comfort level) of the Krasnodar Krai according to Tsitsenko’s formula.

In the summer months, the biologically active temperature has an uncomfortable level, because air temperature rises too much. The most comfortable level is observed in the continental part of the Krasnodar Krai in April and October, while along the Black Sea coast - in November, and the Sea of Azov - in April. These periods are considered the most favorable for farming and agricultural work [9].

Maps of radiation equivalent effective temperature are presented in Figure 4. The values of radiation equivalent effective temperature are calculated according to formula 5.

Outdoor sun baths are shown in March in the Sochi region, in November - on the Black Sea coast from Tuapse to Adler, in April - throughout the Krasnodar Krai, in October - also throughout the territory, except for the Kushchevsky region, and in May – at the mountain-foothill part of the region: from Goryachiy Klyuch to the Absheron, Otradnensky and Mostovskoy regions and the mountainous part of the Sochi municipality, in the Taman Peninsula, as well as on the Black Sea coast from Anapa to Tuapse.
Figure 4. Maps of radiation equivalent effective temperature of the Krasnodar Krai. The weather pathogenicity index is the first of the studied indices that takes into account atmospheric pressure. In addition, it is aimed more at stating sharp changes in indicators than at the adverse weather conditions themselves.

On critical days, subjectively healthy people often experience an improvement in mood, overestimate their capabilities.

Overworked people begin to exaggerate difficulties, show a tendency to affective and asteroid reactions, increased aggressiveness, or, on the contrary, try to avoid social contacts.

Figure 5 shows the geographic information analysis of the index of the pathogenic effect of the weather, calculated according to the chain of formulas 6-11.
As you can see from the obtained cartographic material, critical days in the Krasnodar Krai mostly occur in the winter months of the year, and in the northwestern part of the Krai, the pathogenic effect lasts until March, and ends in Sochi region in January. At this time, people need to be especially careful.

4. Discussion
Analyzing all of the above indicators, we can conclude that the territory of the Krasnodar Krai has a regular climatic heterogeneity in the following comfort zones:
- “Black Sea” zone along the Black Sea coast from the Gelendzhik municipal district to the Sochi municipal district;
- “Azov-Black Sea” zone along the Black Sea coast from the Novorossiysk municipality to Anapa municipality, as well as along the Azov coast from the Temryuk region to Yeisk;
- “Southeast piedmont” zone in the Southeast of the Krasnodar Krai from the Absheron region to the Mostovskoy and Otradnensky regions;
- “Continental” zone, which includes the rest of the predominantly flat part of the Krasnodar Krai.

However, the climate comfort here is determined by the absence of sudden changes during the changing seasons, smooth transitions between months without stress for the human body. Whereas the peak values of comfort indices in a healthy person are associated with surges of strength and energy. The question of an absolutely comfortable or absolutely uncomfortable area of the Krasnodar Krai remains open for discussion.

5. Conclusions
It was found that the most favorable regions of the Krasnodar Krai for the climate-friendly life is the Black Sea coast from Tuapse to Sochi. It is caused by a combination of factors.

Comparing the studied indicators of climatic comfort on the territory of the Krasnodar Krai, we can say that June and September are the most comfortable months throughout the whole territory of the Krasnodar Krai.
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