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MEDICAL AND DEMOGRAPHIC CONSEQUENCES OF CLIMATE CHANGE AND THE ASSESSMENT OF COMFORT LEVEL OF WEATHER-CLIMATIC CONDITIONS IN THE VOLGA FEDERAL DISTRICT

ABSTRACT. The paper provides a brief analysis of research on the impact of global climate change on human health. Using Tatarstan as an example, the paper discusses medical and demographic consequences of the extreme heat wave of the summer of 2010. Assessment of the Volga Federal District (VFD) bioclimate conducted with the help of certain biometeorological parameters allowed evaluating modern global and regional changes of weather-climatic conditions. The main emphasis was placed on spatial and temporal analysis of both the integral pathogenicity index (*I*) and its individual components for the district territory. In VFD, aggravating weather conditions increase from southwest to northeast. Summer months are associated with comfort weather conditions. In winter, the air temperature pathogenicity index and interdiurnal temperature fluctuations contribute the greatest to *I*; in summer, the role of cloudiness and humidity pathogenicity indices increases. The contribution of wind speed and interdiurnal pressure fluctuations to *I* is insignificant in all seasons. Analysis of the frequency distribution of *I* showed that comfort weather conditions (over 50 % of cases) occur in May–August, aggravating weather conditions occur in March-Appril, and harsh weather conditions in more than 50 % of cases occur in January–February and November–December. Calculation of biometeorological indices allows forecasting risk of thermal hazard under extreme meteorological conditions.

KEY WORDS: climate change, population mortality, biometeorological indices, bioclimatic comfort level.

INTRODUCTION

A characteristic feature of our time is the widespread awareness of the importance of global environmental change. Currently, climate change factors are considered along with other known risk factors for human health – environmental pollution, food insecurity, deterioration of the quality of drinking water, etc. [WHO, 2003; Sovremennyye..., 2006; Global..., 2007; Revich, 2007; IPCC 2013].

The recent decades have been the warmest recorded on our planet. The increase in global temperature of the Earth and the Northern and Southern Hemispheres, compared to the 1891–1900 level, has reached 1.08, 1.30, and 0.87 °C, respectively, in 2015, for the first time surpassing the "1 °C" mark [Byulleten…, 2015; Perevedentsev et al., 2015].

One of the direct consequences of global warming is the increase in the number of days with abnormally high temperature. Exposure to elevated temperature affects adversely primarily the more sensitive population groups, i.e., the elderly, children, and patients with high blood pressure and chronic respiratory disease or heart disease, causing heat stroke and meteotropic body reaction (exacerbation of chronic disease).

Modern research shows that weather (especially high air temperature) affects the mortality much stronger than previously thought. In years with an abnormally high air temperature mortality increases significantly in all age groups, especially among the elderly suffering from chronic diseases of the cardiovascular and/or respiratory systems [WHO, 2003; Malkhazova, 2006; Chazov, Boitsov, 2012].

Analysis of morbidity and mortality in 1961–1990 suggests that 166,000 deaths worldwide are associated with warming. According to the World Health Organization (WHO), climate change currently accounts for about 0.3 % of all deaths and 55×10^6 person-years of disability per year (0.4 % of global disability) [Revich, Maleev, 2011].

The extreme temperature rise in urban areas is especially dangerous. There has been even described the effect of "heat islands" located usually in urban centers with tall office buildings and paved area and a small share of open land, green spaces, and water surfaces. Thus, heat becomes a risk factor not only for the most vulnerable groups (elderly, young children, low-income people), but also for the employees of numerous government agencies, banks, and other offices located in city centers [Revich, Maleev, 2011]. As a rule, increased mortality in summer is observed in cities no later than the day after the extremely high temperatures. The use of air conditioners does not reduce mortality; during heat waves, it continues to be high.

The Roshydromet assessment report [Vtoroi otsenochnyi…, 2014] examined the effects of recent climate change (warming) in the territory of Russia. It drew attention to the increase in the recurrence rate (frequency) and magnitude of heat waves – long periods (within season) with extremely high temperatures. It has been demonstrated that continuous hot weather causes an increase in the number of deaths and diseases of the circulatory system (heart attack), cerebrovascular disease (stroke), respiratory diseases, diseases of endocrine system (diabetes), etc. [Haynes et al., 2004.; Revich et al., 2012]. The duration of heat waves affects the population greater in general than the value of maximum temperature, although for the elderly, the temperature factor is very important.

There were several recorded heat waves (e.g., in Moscow in 2001 and 2003) and the disastrous heat wave of summer 2010 in the European part of Russia due to a blocking anticyclone lasting for 55 days, from June through mid-August. It resulted in a dry and very hot weather. Throughout the entire July, air temperature rose above 30 °C, reaching 39.6 °C in Kazan, which is the upper limit of air temperature oscillation for this location. The heat wave dramatically weakened only with the passage of the cyclone from west at the end of the second decade of August [Analiz usloviy..., 2011]. The heat wave that continued through the first half of August resulted in the most significant increase in mortality, more than 1.5 times compared to August 2009, in a number of regions and republics of the European part of Russia. The main cause of increased mortality of the population was circulatory system diseases (34,000 out of 54,000 total cases). This is supported by the data on the mortality structure during heat waves. [Revich, Maleev, 2011; Vtoroi otsenochnyi…, 2014].

High temperatures in summer months have been observed in recent years in many cities in Europe and the US, which led to a significant number of additional deaths. For example, in Chicago in 1995, the heat wave has caused more than 500 cases of heat-related deaths [Witman et al., 1997]. Furthermore, in August 2003 in Western Europe, the heat wave resulted in more than 70,000 additional deaths [Fouillet et al., 2008].

It has been suggested that global warming could double the number of very hot days in the temperate zones. Global warming will greatly increase the frequency of heat waves [IPPC..., 2013]. For example, in the UK, the summer of 1976 was extremely hot. It was an extremely rare event then, but in the current half-century (up to 2050) such an event will take place every 5–6 years [McMichael et al., 2002].

According to climate models forecast scenarios, warming will continue in the XXI century (Kislov et al., 2008; Ekologo-geograficheskiye…, 2011). The effects of climate warming on the population may be different in the northern and southern regions, as southerners are better adapted to the heat. The greatest impact can be expected in areas where high temperatures are not recorded regularly.

According to the US Environmental Protection Agency [Global..., 2007], the temperature threshold at which mortality begins increasing significantly varies for different US regions. Such spatial-temporal assessments may be also valuable for Russia and other countries of the temperate zone.

Calculations [Strategichesky prognoz…, 2005] suggest that increase in the number of days with high temperatures in the summer period can occur practically in the entire territory of the Russian Federation. It means that almost in all settlements of Russia, except in the south, even a brief heat wave, i.e., temperatures above 29 °C, can lead to an increase in the number of hospitalizations and deaths.

We have undertaken a comprehensive study, including assessment of the Volga Federal District (VFD) bioclimate, its impact on human health, identification of potential areas of climatic resources of the territory, and the assessment of the comfort level of the environment under modern global and regional climate change [IPCC, 2013; Vtoroi otsenochnyi …, 2014; Perevedentsev, 2014, 2015].

MEDICAL AND DEMOGRAPHIC CONSEQUENCES OF CLIMATE CHANGE IN THE TERRITORY OF TATARSTAN

Analysis of medical records for 8 years (2008–2015) in the territory of Tatarstan showed that during the extreme heat of the summer 2010 (July–August), there was a sharp increase in the number of deaths, i.e., 2,528 more deaths compared to July–August of 2009. The effects of the heat in August 2010 were more devastating than in July 2010 (Table 1, Figure 1).

Thus, there was a 52.4 % increase in mortality in August 2010 compared to August 2009; the

Table 1. The rate of summer mortality in the Republic of Tatarstan in 2008–2015 (number of deaths per 100,000 population)

Month	Year							
	2008	2009	2010	2011	2012	2013	2014	2015
June	115.6	110.6	109.9	103.3	99.3	99.3	95.8	110.7
July	111.9	102.6	119.6	112.1	103.6	102.9	101.9	96.0
August	101.7	94.9	144.6	102.8	98.3	95.5	97.0	92.6

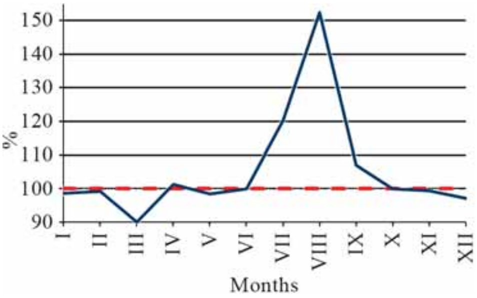

Fig. 1. Monthly mortality rate of the Tatarstan population in 2010 (solid line) and in 2009 (dashed line).

extreme heat of summer of 2010 had a direct negative effect on the Tatarstan population. There was another heat wave in the VFD in July-August 2016 as a result of a continuous blocking anticyclone.

BIOCLIMATIC ASSESSMENT METHODS AND THE COMFORT LEVEL OF THE TERRITORY

One of the most important meteorological factors that cause morbid meteotropic reactions are interdiurnal changes in temperature, pressure, humidity, wind speed, oxygen density, etc. [Isaev, 2001]. Assessment of the human body response to external stimuli is based on medical statistics on ambulance calls, morbidity, and mortality; assessment of the comfort level of weather conditions is conducted based on various biometeorological indices [Revich, Maleev, 2011; Revich, Shaposhnikov, 2012; Shartova et al., 2014].

Currently, there are a significant number of approaches and methods of evaluation of the environmental comfort level [Tkachuk, 2012], which is basically is the assessment of the bioclimatic comfort level, i.e., calculation of bioclimatic indices characterizing features of the thermal structure of the environment and determining, first of all, human thermal perception [Hentschel, 1988; Isaev 2001, Evelina et al., 2014].

Expert assessments [Rukovodstvo..., 2008, Vinogradov, 2012; Vtoroi otsenochnyi …, 2014; Emelina et al., 2014] suggest that the most universal and available for different regions of the country primary meteorological characteristics required for assessment, which most reliably represent the bioclimatic comfort level of the territory, are the parameters used in this work and listed below.

Effective temperature (ET) – characterizes heat or cold perception by the human body, which is determined by A. Missenard's method. The most comprehensive is the algorithm modified by R. Steadman [Steadman, 1994].

Equivalent-effective temperature (EET) – a combination of meteorological parameters, which produces the same thermal effect as still air at 100 % relative humidity and a certain temperature; determined by A. Missenard's method adjusted by B. Eizenstat [Eizenstat, 1964]. Frequency of *EET* in the interval 17–22 °C characterizes potential climatic resources of the territory.

Weather severity index (S) (humidity cooling as per Hill and wind chill as per Bodman) – characterizes the severity of weather and potential duration of a person's presence and activity outdoors.

Description of these parameters, their estimation algorithms, and interpretation of the obtained results are provided in works on the bioclimatic comfort level [Zolotokrylin et al., 1992; Vinogradov, 2012; Gamburtsev, Sigachyov 2012; Vtoroi otsenochnyi…, 2014; Emelina et al., 2014.; Emelina et al., 2015.; Shartova et al., 2015].

The ***integral meteorological pathogenicity index I*** proposed by V. Boksha and B. Bogutsky [Boksha, Bogutsky, 1980] was calculated to evaluate short-term effects of weather conditions on human health:

$$I = I_t + I_f + I_v + I_n + I_{\Delta p} + I_{\Delta t},$$

where I_t – temperature pathogenicity index: $I_t = 0.02 *(18 - t)^2$ at a temperature of less than or equal to 18 °C; $I_t = 0.02\ (t - 18)$ for

$t > 18$ °C; t – daily average temperature, $I_{\Delta t}$ – interdiurnal temperature pathogenicity index Δt; I_f – humidity pathogenicity index; f – daily average relative humidity (%); I_V – wind pathogenicity index; V – daily average wind speed (m/s); I_n – cloudiness pathogenicity index, which is determined on a 11-point scale; n – point cloud; $I_{\Delta p}$ – pathogenicity index of the interdiurnal atmospheric pressure change Δp.

In practice, the following working formula is used to calculate I (in points):

$$I = 10\frac{f-70}{20} + 0{,}2V^2 + 0{,}06n^2 +$$

$$+ 0{,}06(\Delta p)^2 + 0{,}3(\Delta t)^2 + I_t.$$

The authors of the method [Boksha, Bogutsky, 1980] suggested three grades of the meteorological pathogenicity index (Table 2).

Table 2. Grades of the meteorological pathogenicity index

Pathogenicity index	0–9	10–24	24
Weather conditions	Optimal (comfort)	Excitant	Acute

Bioclimatic assessments are based on methods for measuring impacts of different weather systems on human health, primarily, interdiurnal fluctuations of meteorological parameters [Isaev, 2001; Rukovodstvo…, 2008; Vinogradov, 2012]. The absolute values of interdiurnal changes in air temperature Δt (C°), atmospheric pressure P (hPa), and the value of the partial density of oxygen $\left(\rho_{O_2}\right)$ were estimated based on the All-Russian Research Institute of Hydrometeorological Information data for the VFD 19 weather stations for 1966–2010. The evaluation of I and its individual components was carried out for 12 months using current meteorological observations for 1966–2013. First, the formula's components were calculated based on the daily average data and then their multi-annual average values were calculated for each of the VFD 19 weather stations, which allowed performing assessment of the annual pattern and territorial differences in I. The section below presents the results of the calculations of some bioclimatic parameters listed above.

RESULTS AND DISCUSSION

The distribution of the estimated bioclimatic parameters in the VFD territory allowed us to evaluate the quality of the human living environment in the modern period.

Statistical analysis of the interdiurnal fluctuations of meteorological parameters showed that in January, most interdiurnal ***air temperature*** fluctuations Δt (°C) are within the range of 0–4.0 °C (60 %); in July in about 60 % of cases, these differences occur in the range of 0–2.0 °C. A similar situation is characteristic of ***atmospheric pressure*** Δp (hPa). Thus, in January in 60 % of cases, it does not exceed 6 hPa; in July, fluctuations of Δp in 61 % of cases occur in the range of 0–2.7 hPa. Thus, the bulk of the interdiurnal fluctuations of meteorological parameters have a relatively small numerical value and only in 29 % of cases in January Δp exceeds 8 hPa, and Δt in 14 % of cases exceeds 8 °C, which has an adverse effect on humans [Isaev, 2001]. In summer, these parameters are considerably milder and large fluctuations are rarely observed.

Calculation of the partial oxygen density $\left(\rho_{O_2}\right)$ showed that in winter, the air is saturated with oxygen to a greater extent than in summer. There is a pronounced seasonal variation. The ρ_{O_2} values averaged over the VFD 19 stations vary from 283.1 g/m^3 (July) to 324.4 g/m^3 (January). The annual average ρ_{O_2} value is 303.7 g/m^3. In January, it increases from 321 g/m^3 to 328 g/m^3 from southwest to northeast. In July, the contour lines of the ρ_{O_2} values assume the zonal pattern and the oxygen content in the air is increasing northward from 280 g/m^3 to 285 g/m^3. In other months, there is also a northward increase in this parameter, which means that it is easier to breathe in the northern part than in the southern part of the region, where air masses are less oxygenated.

The distribution of the ***effective temperature in the territory of the region*** (Fig. 2) shows

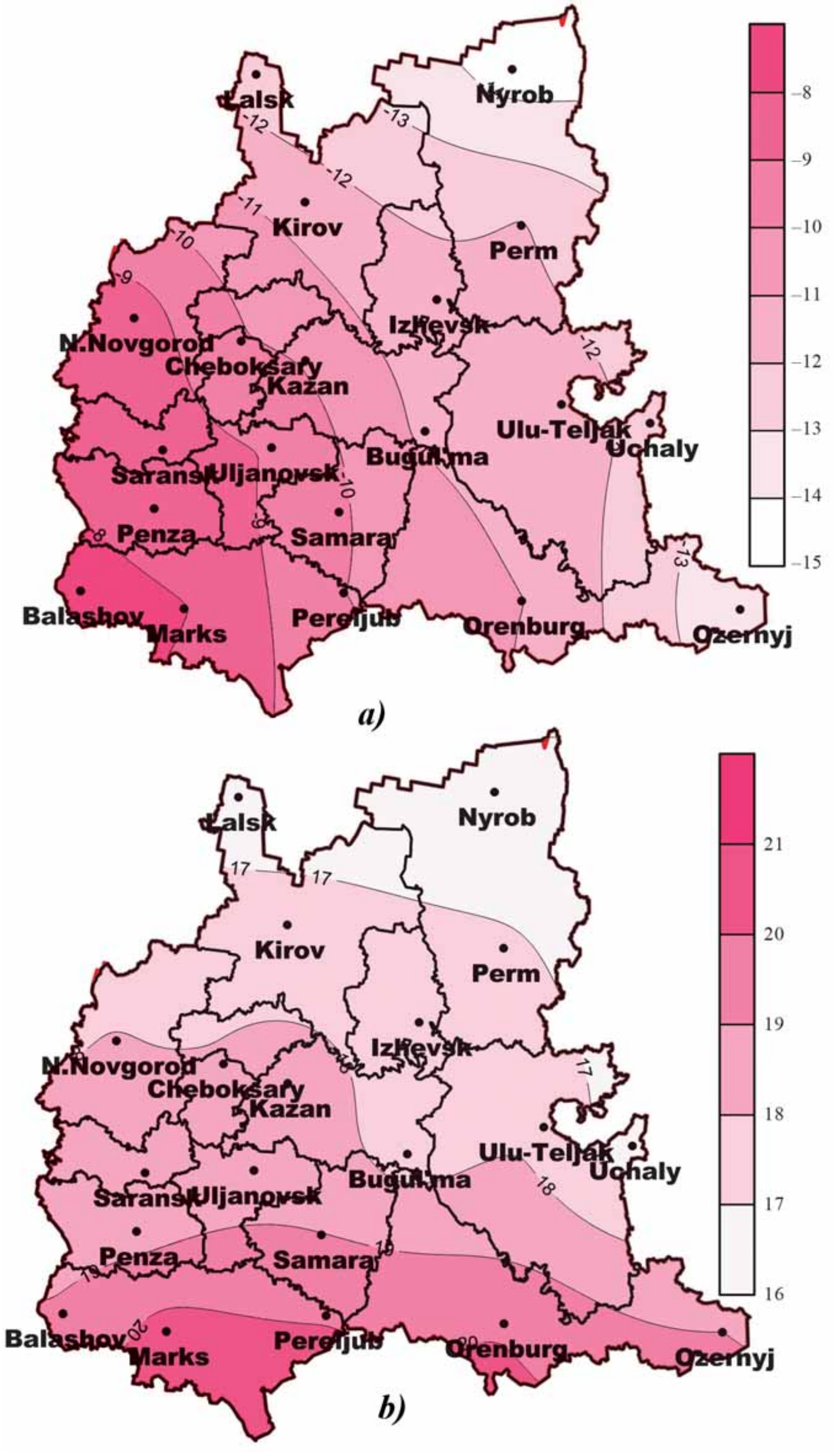

Fig. 2. Effective temperature *(ET),* °C: a) January; b) July

significant differences both in the territory and the seasons of the year. *ET* averaged over the VFD territory varies within the year from –10.7 °C (January) to 18.1 °C (July) (annual average value is 4.0 °C). The lowest *ET* values are observed in the northeastern part (Nyrob), where in January, *ET* = –14.5 °C and in July, *ET* = 16.1 °C (annual average value is 1.0 °C). In the far southwestern part of the region (Marks, near Saratov), the *ET* values are the highest (in January, *ET* = –8.0 °C and in July, *ET* = 20.4 °C (annual average value is 6.5 °C).

The Steadman's effective temperature averaged over the region varies throughout the year from –5.0 °C (January) to 24 °C (July). The probability of exceeding the minimum threshold of thermal safety ($ET_S < 18$°C) is highest in July; frequency (%) of values $ET_S \leqslant 18$°C is 63.0, 25.1, 9.3, 25.7, and 73.9 % in May, June, July, August, and September, respectively. From this perspective, the likelihood of comfortable weather (reduced risk of thermal hazard) is higher in May and September than in summer months. In the territory, this index increases markedly from south to north. Thus, in July, it increases from 3 % in the southern part of the region to 24 % in the northeast.

Frequency of values was calculated for the following ranges: < 18 °C – minimal risk; 18–22 °C – average risk; 23–28 °C – high risk; and >28 °C – extreme risk. The results averaged over the VFD are presented in Table 3.

The minimal risk of thermal hazard is observed in May and September; the thermal hazard risk increases significantly during summer months, especially in July, within the ranges 23–28 °C and > 28 °C. The risk of thermal hazard significantly diminishes from south to north.

Frequency of the number of days with values of Eizenstat equivalent-effective temperature in the 17.3–21.7 °C range (comfortable weather) is the highest in July (23.0 %). Monthly distribution of the probability of occurrence of comfortable weather is as follows: 6.2 % (May), 16.0 % (June), 23.0 % (July), 14.0 % (August), and 2.4 % (September). Probability of comfortable weather is the greatest in the southern part of the VFD and the lowest in the northern part (Fig. 3). Calculation of the *EET* linear trend slope coefficients shows a weak increase in the number of days with a comfortable weather.

Calculation of *the* ***Bodman weather severity index*** during the cold period shows that mild winters are the most common condition for the VFD territory. The most likely situation is when winter is either moderately or mildly harsh (Table 4). The highest values of the Bodman index are observed in January and its maximum values are characteristic of the northeastern part of the territory.

Evaluation of ***the integral I index and its components*** for the VFD shows that the territory exhibits a well-defined annual pattern with the maximum in November-February, which characterizes weather conditions as harsh (*I* is greater than 24 across-the-board); in March, April, September, and October, aggravating weather conditions are formed at most stations (*I* varies from 10 to 24); and only

Table 3. Average frequency (%) of different ET_S ranges in summer period

Range of ET_S,°C	Month				
	V	V	V	V	V
<18	63.0	63.0	63.0	63.0	63.0
18–22	22.8	22.8	22.8	22.8	22.8
23–28	16.4	16.4	16.4	16.4	16.4
>28	1.0	1.0	1.0	1.0	1.0

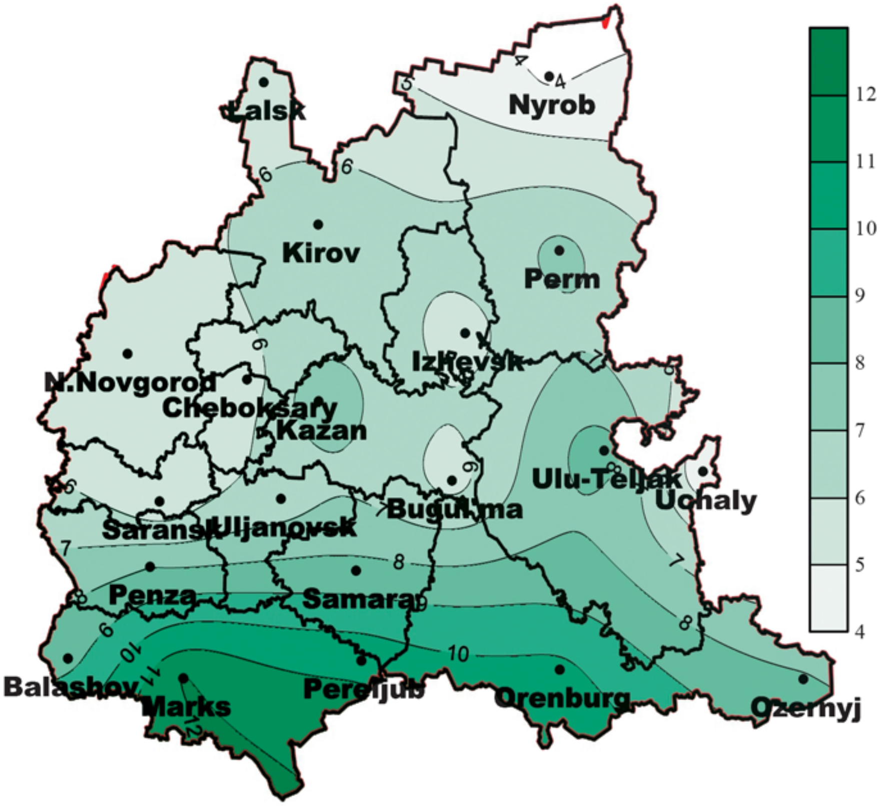

Fig. 3. Distribution of the multi-annual average number of days with comfortable *EET* in July

in summer months, weather is comfortable at most stations, with the exception of the northern part (Lalsk, Nyrob). Of course, this is only the average climate pattern, which sometimes can vary greatly. Notable territorial differences in the distribution of *I* in the district should also be noted: for the most part of the year, there are aggravating and harsh weather conditions in the northern and northeastern parts of the VFD (Lalsk, Nyrob); in the southwestern part of the district (Balashov), comfortable weather is present from May through September. The acute weather is usually formed in the cold time of the year under active synoptic conditions with rapid movement of air masses and weather fronts,

Table 4. Frequency (%) of the Bodman index averaged over the VFD territory, by ranges

Scale of weather "severity"	Month				
	XI	XII	I	II	III
B < 1	0.8	0.0	0.0	0.0	0.8
1 < B < 2	62.5	36.7	26.8	29.8	60.6
2 < B < 3	33.2	50.6	54.6	54.6	33.6
3 < B < 4	3.1	11.0	15.4	13.0	4.5
4 < B < 5	0.3	1.4	2.6	2.3	0.5
5 < B < 6	0.1	0.2	0.5	0.3	0.1

resulting in significant short-term changes of meteorological parameters, low temperature background, and high relative humidity.

Analysis of *the* ***component indices of pathogenicity*** (components of the formula) by months was conducted using data from three stations located in different geographical conditions: Nyrob (northeast), Kazan (center), and Balashov (southwest). In winter, the air temperature pathogenicity indices I_t (temperature deviation from the optimum) and $I_{\Delta t}$, due to large interdiurnal fluctuations in temperatures, provide contribute most to I; in Balashov, the most important factor is the humidity pathogenicity index I_f. During summer months in Kazan and Balashov, comfortable weather conditions are prevalent and the influence of the individual indices is insignificant. Among them, the role of the cloudiness and humidity pathogenicity indices is important, while that of wind speed and the contribution of interdiurnal pressure fluctuations is small. In the extreme northeastern part of the district (Nyrob), where natural conditions are most severe, even in July, the overall index is 10.6 and the largest contribution to pathogenicity comes from humidity, cloudiness, and interdiurnal temperature fluctuations.

Frequency of occurrence of weather conditions by the ranges of *the pathogenicity index* (0–9, 10–24, and > 24) is presented in Table 5 which shows the data averaged for the VFD based on the calculations performed for all stations.

Table 5. Frequency of the pathogenicity index

Months	Ranges of*I*values		
	0–9	9.1–24	> 24
I	0.0	9.3	90.7
II	0.0	16.1	83.9
III	3.7	53.8	42.6
IV	32.5	53.6	13.9
V	52.1	41.6	6.3
VI	62.3	34.5	3.2
VII	67.0	30.9	2.1
VIII	57.8	38.2	4.0
IX	39.4	49.7	10.9
X	16.4	55.4	28.2
XI	1.1	32.1	66.8
XII	0.1	12.4	87.5

Comfortable weather conditions prevail in May–August (frequency is greater than 50 %); aggravating weather conditions prevail in March–April and October, and harsh weather conditions prevail in January-February and November–December. Comfortable weather conditions are characteristic of the southern part of the VFD; the index (0–9) decreases from 70 % to 50 % from south to north.

Thus, assessment of medical and demographic impacts of climate change and the comfort level of weather and climatic conditions in the VFD territory has shown that:

- due to the summer heat wave in 2010 in the territory of Tatarstan, there has been a sharp increase in the number of deaths (over 50 %);
- the most adverse climatic conditions are formed in the northeastern part of the VFD; during the year, the integral pathogenicity index varies from 35.5–50.3 (January) to 14.3 to 5.7 (July); the largest contribution to the integral index are made by the components that depend on the temperature deviation from the optimal, interdiurnal temperature fluctuations, humidity, and cloudiness.
- comfortable weather conditions, on average for the VFD, are prevalent in May–August (more than 50 % of cases), while aggravating conditions are characteristic of October and March–April, and harsh conditions occur in November and February.

CONCLUSION

According to forecasts, climate change in the XXI century will have an impact on humans, mostly aggravating existing health problems. The Climate Doctrine of the Russian Federation [Klimaticheskaya…, 2009] considers a range of issues associated with adaptation of the population and economy to the occurring and future climate change in the interest of sustainable development of the country. The relevance of the problem is substantiated by the fact that the Strategy for activities in the field of hydrometeorology for the period up to 2030 (2010) emphasizes the need to develop forecasts that include assessment of the influence of various meteorological parameters on specific diseases, taking into account aspects of climate change. Early adoption of measures would allow the country to minimize the risk of thermal hazard and decrease the number of additional deaths and exacerbation of chronic diseases. The results presented in the paper indicate that it is necessary to consider the risks to human health, especially in extreme weather conditions. The authors are continuing research in this area by using other biometeorological indices to assess the comfort level of weather and climatic conditions in the VFD territory for the population living in the present and in the future under global and regional climate change.

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