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Meteorological Parameters and Hypertensive Crisis Risk: a Longitudinal Study for Prediction Model Developing

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ABSTRACT

INTRODUCTION. Integrating climatotherapy into health resort therapy for arterial hypertension in diverse landscapes has the potential to yield positive effects, if used in target groups and preventing the occurrence of meteopathic reactions, including a hypertensive crisis (HC). While the impact of natural healing factors on the human body has been previously studied, the utilization of modern mathematical approaches in developing HC models has enabled accurate predictions and timely prevention of HC during adverse weather periods.

AIM. To analyze publicly available meteorological data time series to construct a mathematical model for predicting high-risk situations of HC based on the influence of climatic factors on patients with arterial hypertension. This model would identify unfavorable periods for hypertensive patients staying in health resorts throughout the year, allowing for timely therapeutic and preventive measures to prevent HC during these periods.

MATERIALS AND METHODS. The study was conducted over a 22-month period, from January 1, 2019 to October 31, 2020, in Gelendzhik and Novorossiysk, renowned resort destinations located on the Black Sea coast of the Caucasus. These regions have a dry and subtropical climate. Meteorological data were obtained from Gelendzhik and Novorossiysk weather stations, and ambulance calls data were collected from Gelendzhik (12,268 calls) and Novorossiysk (12,226 calls), resulting in a total of 24,494 ambulance calls.

The model was calculated using the maximum likelihood method through nonlinear logit regression. Key factors for the model included the main indicators of climate[1] and geomagnetic conditions[2]. The logistic regression method exhibited a sensitivity of 56.0 % and a specificity of 77.3 %, with an overall accuracy of 76.0 %.

RESULTS. According to the developed predictive model, the winter season has no more than 75.0 % of days associated with a low risk of hypertension, decreasing to 59.0 % in spring. However, the proportion increases to 89.0 % in summer and reaches 77.0 % in autumn. Model adequacy checks indicated a high degree of relevance, with Q (model quality) ranging between +0.64 and –0.117, and $p > 0.3$.

CONCLUSION. The developed logistic regression models provide more accurate calculations of individual risks for developing complications of hypertension and offer the opportunity to formulate individual strategies for patients. These models contribute to the field of climatotherapy and enhance the understanding of the impact of climatic factors on hypertensive patients, facilitating targeted interventions and improved management of hypertensive crises.

KEYWORDS: seasons, likelihood functions, climatotherapy, logistic models, weather, hypertension, prognosis, spa treatment, meteorological factors.

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[1] Source of meteorological factors data. Available at: www.gismeteo.ru or http://www.kubanmeteo.ru/index.php/podrazdeleniya/set-meteostantsij (accessed: 02.07.2023)
[2] Geomagnetic activity data source: http://spaceweather.izmiran.ru

Метеорологические параметры и риск развития гипертонического криза: лонгитюдное исследование для разработки модели прогнозирования

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РЕЗЮМЕ

ВВЕДЕНИЕ. Включение климатотерапии в состав санаторно-курортного лечения артериальной гипертензии (АГ) в различных местностях, обладающих характеристиками природного лечебного ресурса, может дать положительный эффект в целевых группах при условии предотвращении возникновения метеопатических реакций, в том числе гипертонического криза (ГК). Влияние природных лечебных факторов на организм человека изучалось и ранее, но использование современных цифровых технологий построения моделей риска возникновения ГК позволяет точно прогнозировать и своевременно предотвращать ГК в неблагоприятные погодные периоды.

ЦЕЛЬ. На основе анализа временных рядов общедоступных метеорологических данных построить математическую модель для прогнозирования периодов высокого риска ГК на основе влияния климатических факторов на пациентов с АГ. Данная модель позволит выявить неблагоприятные периоды пребывания пациентов с АГ в санаторно-курортных учреждениях в течение года, что позволит своевременно проводить лечебно-профилактические мероприятия по предупреждению ГК в эти периоды.

МАТЕРИАЛ И МЕТОДЫ. Лонгитюдное следование проводилось в течение 22 месяцев, с 1 января 2019 г. по 31 октября 2020 г., в Геленджике и Новороссийске — городах, расположенных на Черноморском побережье Северного Кавказа. В этих регионах преобладает сухой субтропический климат. Метеорологические данные были получены с метеостанций городов Геленджик и Новороссийск. Данные о вызовах скорой помощи также были собраны в Геленджике (12 268 вызовов) и Новороссийске (12 226 вызовов), в результате чего суммарно было изучено 24 494 вызова скорой помощи. Математическая модель была построена с использованием метода максимального правдоподобия посредством нелинейной логит-регрессии. Ключевыми факторами для модели стали основные показатели климата и геомагнитной обстановки. Метод логистической регрессии показал чувствительность 56,0 % и специфичность 77,3 % с общей точностью 76,0 %.

РЕЗУЛЬТАТЫ. На основании разработанной прогностической модели в зимний сезон приходится не более 75,0 % дней, связанных с низким риском ГК, число которых снижается до 59,0 % в весенний период. Однако доля увеличивается до 89,0 % летом и достигает 77,0 % осенью. Проверки адекватности модели показали высокую степень релевантности с К (качество модели) в диапазоне от +0,64 до −0,117 и $p > 0,3$.

ЗАКЛЮЧЕНИЕ. Разработанные модели логистической регрессии обеспечивают более точные расчеты индивидуальных рисков развития осложнений АГ и дают возможность сформулировать индивидуальные стратегии для пациентов. Эти модели вносят свой вклад в область климатотерапии и улучшают понимание влияния климатических факторов на пациентов с АГ, облегчая целенаправленные вмешательства и улучшая лечение ГК.

КЛЮЧЕВЫЕ СЛОВА: сезонность, функция максимального правдоподобия, климатотерапия, логистические модели, погода, артериальная гипертония, прогноз, санаторно-курортное лечение, метеорологические факторы.

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1. INTRODUCTION

Arterial hypertension is a leading cause of high mortality from cardiovascular diseases [1–4]. Today, medical professionals consider approximately 14 risk factors for arterial hypertension when making a diagnosis [4, 5]. It is important to note that there are other factors, including psychological, genetic, and climatic factors, that impact the course of the disease. However, these factors are not widely utilized in medical practice due to their high cost, the complexity of performing diagnostic procedures, or the challenge of calculating an integral indicator that can provide an unequivocal and sufficiently accurate diagnostic outcome [5]. Nevertheless, these factors still hold significant importance and contribute to the development and progression of the disease.

According to estimates from the World Health Organization (WHO), the adverse effects of climate factors are currently responsible for approximately 150,000 premature deaths worldwide and 55 million person-years of disability per year on average. These figures account for approximately 0.3 % and 0.4 % of the global rates of mortality and disability, respectively. Furthermore, climate factors have a significant impact on cardiovascular diseases, particularly arterial hypertension, as well as other health conditions [6–8].

Previous studies have identified the main weather conditions that induce meteopathic reactions in Moscow region [9]. These reactions are influenced by both terrestrial and space weather factors, including atmospheric pressure, atmospheric air temperature, atmospheric air humidity, atmospheric electric field strength, and magnetic storms [10]. Meteopathic reactions can manifest through various symptoms, such as a decline in general well-being, significant fluctuations in blood pressure leading to a hypertensive crisis (HC), headache, myalgia and arthralgia, heart pain, acute coronary syndrome, angina pectoris, changes in partial oxygen tension in the inhaled air (PO2 atm), variations in atmospheric electrical activity, and extreme weather events like floods, droughts, hurricanes, among others. Additionally, environmental pollution resulting from the transformation of substances due to insolation, high temperature, forest fires, as well as the impact of physical factors like noise and vibration, also play a role in meteopathic reactions [8, 10, 11].

The clinical guidelines for physicians regarding the treatment of arterial hypertension emphasize the importance of lifestyle interventions for all patients, regardless of the stage, degree of the disease, or whether they are receiving pharmacological therapy or not [5]. In line with a personalized approach to treatment and prevention, non-drug methods should be incorporated, and comprehensive rehabilitation treatment should be carried out in sanatoria and spas [9, 11].

Currently, there is a significant demand for personalized forecasting methods for meteopathic reactions, which can worsen the course of hypertensive disease and increase the risk of complications during spa treatment [10, 12]. While we cannot control weather conditions, we can predict periods with a higher risk of HC. Patients from northern and eastern regions are particularly susceptible to this risk [1]. With this in mind, our study aims to construct a mathematical model by analyzing time series of publicly available meteorological data. This model would allow us to predict high-risk situations of HC related to the impact of climatic factors on the patient's body. By identifying unfavorable periods for patients with arterial hypertension staying in health resorts throughout the year, we can implement timely therapeutic and preventive measures to prevent the development of HC during these periods.

The digitalization of spa medicine, in general, would enable us to address these objectives at a new level, significantly enhancing the effectiveness of spa treatment in the country and establishing a competitive position for spa facilities in the global market.

2. AIM

To analyze publicly available meteorological data time series to construct a mathematical model for predicting high-risk situations of HC based on the influence of climatic factors on patients with arterial hypertension.

3. MATERIAL AND METHODS

3.1. Study design

The study was conducted from January 01, 2019 until October 31, 2020, in Gelendzhik (44° 36'N 38° 08'E) and Novorossiysk (44°43'N 37°46'E). The study utilized data from the website www.gismeteo.ru. The number of medical care requests for the specific condition under study amounted to 24,494, with 64.6 % of the patients being women and 35.4 % being men. Among the patients, 84.4 % were over the age of 65, with an average age of 59.9 years (± 10.2 years). The race of the patients was reported as white, and their ethnicity was noted as non-Caucasian.

Seasonal dependence of emergency care attendance for HC was studied.

The study was supported by the Independent Local Ethics Committee of the Federal State Budgetary Institution "National Medical Research Centre for Rehabilitation and Balneology" of the Ministry of Health of the Russian Federation (Minutes No. 4, dated April 16, 2017). The study protocol adhered to the principles outlined in the Declaration of Helsinki. The researchers obtained a de-identified primary dataset from the emergency room staff in response to a written request. The reports contained information about the reasons for seeking emergency care.

The information used in the study was collected from the daily reports of all ambulance sub-stations that provided medical services to patients residing in the study area. These reports allowed for the identification of patients within the city and region. Additionally, patients were categorized according to the length of their residence in the region, which could be established by the name and tariff code of the insurance company. The dataset included data on patients aged 18 and older, with further categorization based on age (over or under 65), sex (male or female), race, and length of residence (0–5 years or more than 5 years) in the study area. The researchers also had the opportunity to identify patients who were permanent residents of other territories, but were in the region for seasonal work or tourism, based on payment rate codes provided by insurance companies.

3.2. Climatological data and geographical area

The meteorological data used in the study were obtained from the website gismeteo.ru and from meteorological stations located in Gelendzhik and «Vulan» sanatorium and resort complex (44°36' north latitude, 38°53' east longitude). The emergency medical data was collected from Gelendzhik and Novorossiysk (44°36' north latitude, 38°08' east longitude; 44°43' north latitude, 37°46' east longitude). These cities are situated in a lowland area within a dry subtropical zone. The altitude ranges from 10 to 60 meters above sea level. The region experiences 2416 hours of sunshine per year. The weather patterns are variable in winter and stable in summer. Summers are warm, with an average monthly temperature of 22.9 °C in July. Sunny weather predominates during summers (70–80 %), while rainy weather accounts for approximately 5 % and hot and humid weather comprises about 10 % of the period. The relative humidity in the area is generally low, ranging from 55 % to 70 %. Winters are moderately mild, with temperatures around -3.9 °C in January. Weather with temperature transitions through 0 °C occurs in about 40–45 % of cases, and moderately frosty weather accounts for approximately 10–20 % of the period. Figure 1 displays the annual heliomagnetic temperatures.

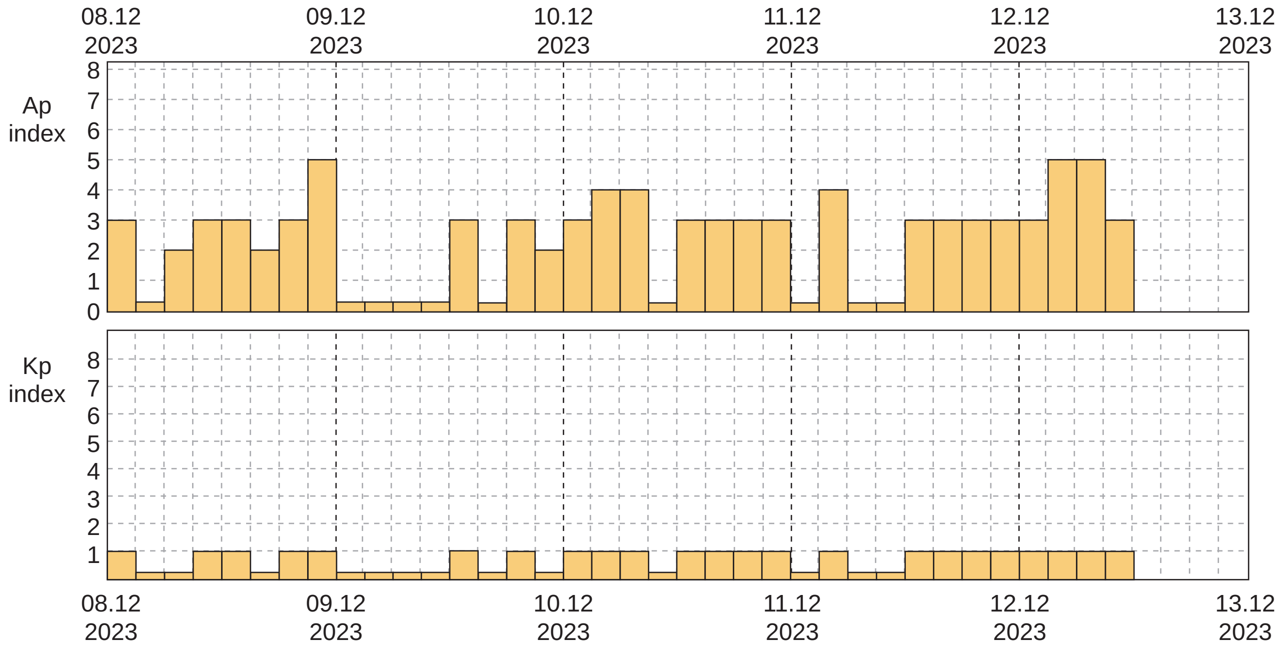

Fig. 1. Map of geomagnetic activity for the period October 16–21, 2022 (The upper diagram displays the Ap-index, the lower diagram — the Kp-index) (source: http://spaceweather.izmiran.ru)

According to data from Rosstat (Federal State Statistics Service) in 2017, Krasnodar Territory, which encompasses Gelendzhik and Novorossiysk, had a total of 5,483,567 patients. Among them, 46.4 % were men, and 79.6 % belonged to the urban population. The regional mortality rate was recorded as 1,253.1 per 100,000 populations, with mortality from circulatory diseases reaching 536.6 cases per 100,000 individuals. The gross regional product in Krasnodar Territory was reported as 301,436 RUB, while the average per capita income was 28,788 RUB per person. These income figures are close to the averages for the Russian Federation[1].

According to the Federal State Statistics Service (Rosstat), in 2021 Gelendzhik had a population of 75,504 people, while Novorossiysk had a population of 340,800. The Southern Federal District, which includes the region, experiences a high level of migration. In 2021, there were approximately 143,919 people migrating within the district annually. Additionally, there were more than 250,000 people migrating from the Southern Federal District to other regions of the Russian Federation each year. The region also sees a significant level of international migration[2].

3.3 Inclusion criteria

- Such patients are to be 18 years of age or older at the time of seeking medical care;
- Such patients are required to have lived in Gelendzhik or Novorossiysk continuously for at least 5 years;
- Such patients should be diagnosed with «Hypertensive crisis» in accordance with the recommendations of the Russian Society of Cardiology[3] [5].

3.4 Exclusion criteria

- Patients under the age of 18 at the time of seeking medical care.
- Patients who refused to participate in the study.
- Patients whose diagnosis of «Hypertensive crisis» was associated with the consumption of cocaine, amphetamines, an overdose of ephedrine, and/or norepinephrine.
- Patients with pre-eclampsia during pregnancy.

3.5 Statistical analysis and data processing

To construct the risk models, we employed a nonlinear logit regression model with a stepwise variable inclusion using the maximum likelihood method, as described in the previous studies [13–15]. It is important to note that the model was based on anonymized data, and therefore adjustments for different calendar events (such as public, church, and family holidays, vacations, etc.) were not applied. The risk of disease occurrence was quantitatively assessed using the odds ratio (OR) in the presence or absence of the disease under investigation [13–15]. To construct risk models, we implemented a nonlinear logit regression with a stepwise inclusion of variables using the maximum likelihood method [13–15].

If the probability p was less than 0.5, we assumed that the event would not occur; otherwise, the event was not expected [16]. The χ^2-test was used to assess the significance of the risk of pathology, and a 95 % confidence interval was calculated for the odds ratio [17, 18].

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[1] Federal state statistics service (2017) Russian statistical Yearbook. Moscow. Available at: https://rosstat.gov.ru/bgd/regl/b17_13/Main.htm (In Russ.)
[2] Federal state statistics service (2021) Russian statistical Yearbook. Moscow. Available at: https://eng.rosstat.gov.ru/storage/mediabank/Ejegodnik_2021(1).pdf (In Russ.)
[3] Arterial hypertension in adults. Clinical guidelines (2020) Russian Journal of Cardiology 25(3):3786. (In Russ.) http://dx.doi.org/10.15829/1560-4071-2020-3-3786

When the regression coefficient is positive, it indicates that the odds ratio (OR) is greater than one, suggesting an increase in the chances of the disease with an increase in the predictor level. Conversely, a negative regression coefficient signifies an odds ratio (OR) less than one, indicating a decrease in the risk of disease with an increase in the predictor level [19, 20]. The exponential coefficient of the regression equation (bx) shows how many times the chances of the predicted disease (e.g., hypertensive crisis) will change when the factor level increases by one [21, 22].

Preliminary processing and analysis of the time series data were conducted using the ARIMA (Autoregressive Integrated Moving Average) method. A short-term model (7 days) for the development of HC was built using the ARIMA prediction method [23, 24]. The short-term forecasting (7 days) was conducted with the Almon distributed lag method [23, 24].

The significance of the differences was considered at $p < 0.05$ [25]. The research results were processed using software such as Statistica for Windows, v. 8.0 (StatSoft Inc., USA) and Microsoft Excel (Microsoft, USA).

4. RESULTS

It was found that reliance on emergency medical aid in the case of hypertensive crisis (HC) is associated with weather factors. However, only weak correlations between the onset of HC and weather factors were found, such as atmospheric pressure, daytime air temperature, and K-index. The long-term observation data recording the parameters used to build the model are provided above. The variables that were found ruled out the possibility of constructing reliable predictive models. This situation can be explained by the non-linear response of the human organism to weather factors, the presence of several adaptation phases, the absence of a clearly leading factor, and the superposition and accumulation of changes throughout the year.

In addition, we analyzed the frequency of ambulance calls in Gelendzhik during 2019 and the first 10 months of 2020. It was observed that in summer, there was a lower incidence of HC compared with spring and autumn, with an accuracy rate of 33.0 %. Seasonal statistics on weather factors and ambulance calls are presented in Figures 2–4. Since the geoclimatic characteristics of Novorossiysk and Gelendzhik are similar, identical results were obtained.

Drawing on these findings, we developed a logistic regression model using the main indicators of climate and geomagnetic conditions as factors to predict an increase in the risk of developing HC in the studied population. Table 1 presents the indicators included in the calculation along with their corresponding symbols: (1) daytime air temperature (T); (2) atmospheric pressure (Atm); (3) relative humidity (Hum); (4) K-index (K-ind). The model was constructed using daily mean temperatures and their standard deviations, calculated from the baseline data measured every 3 hours (from 9:00 to 18:00).

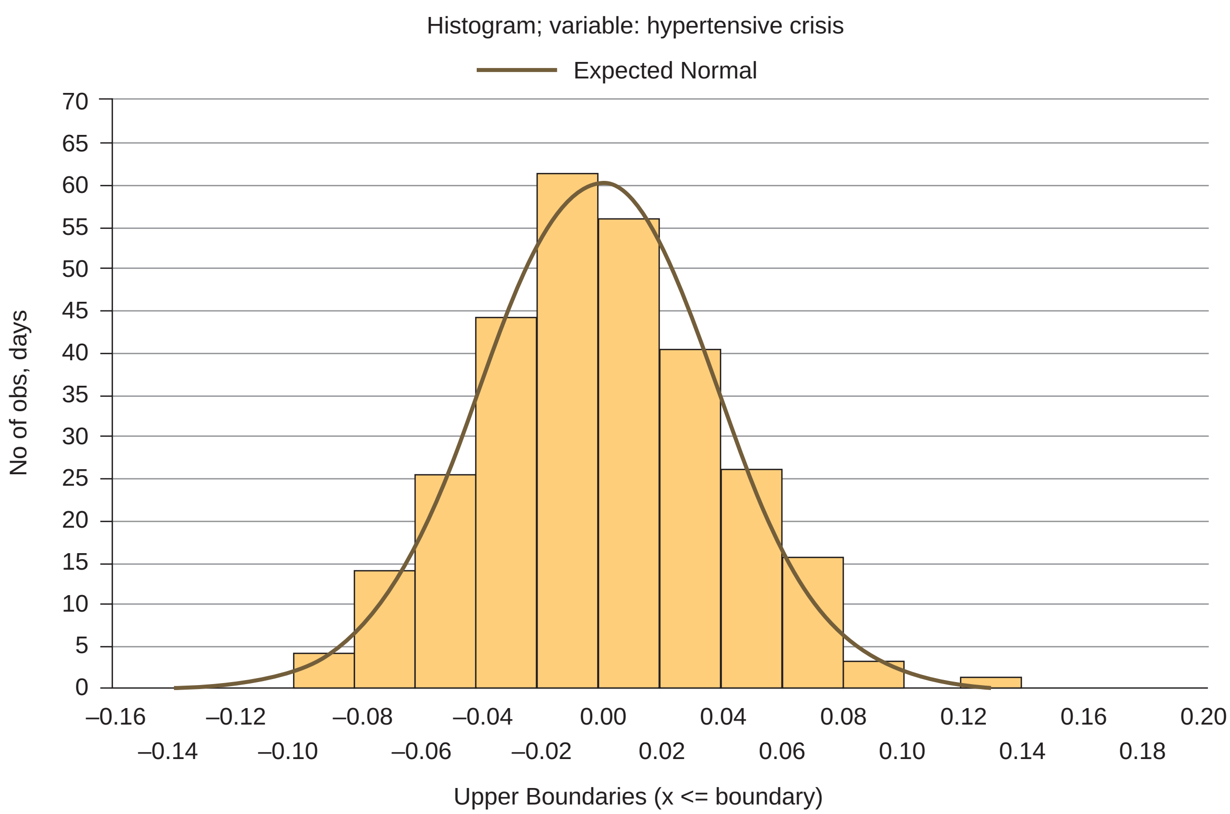

Fig. 2. Days with high risk of (below the red line) hypertensive crisis development in Gelendzhik, calculated using the logistic regression ($n = 604$)

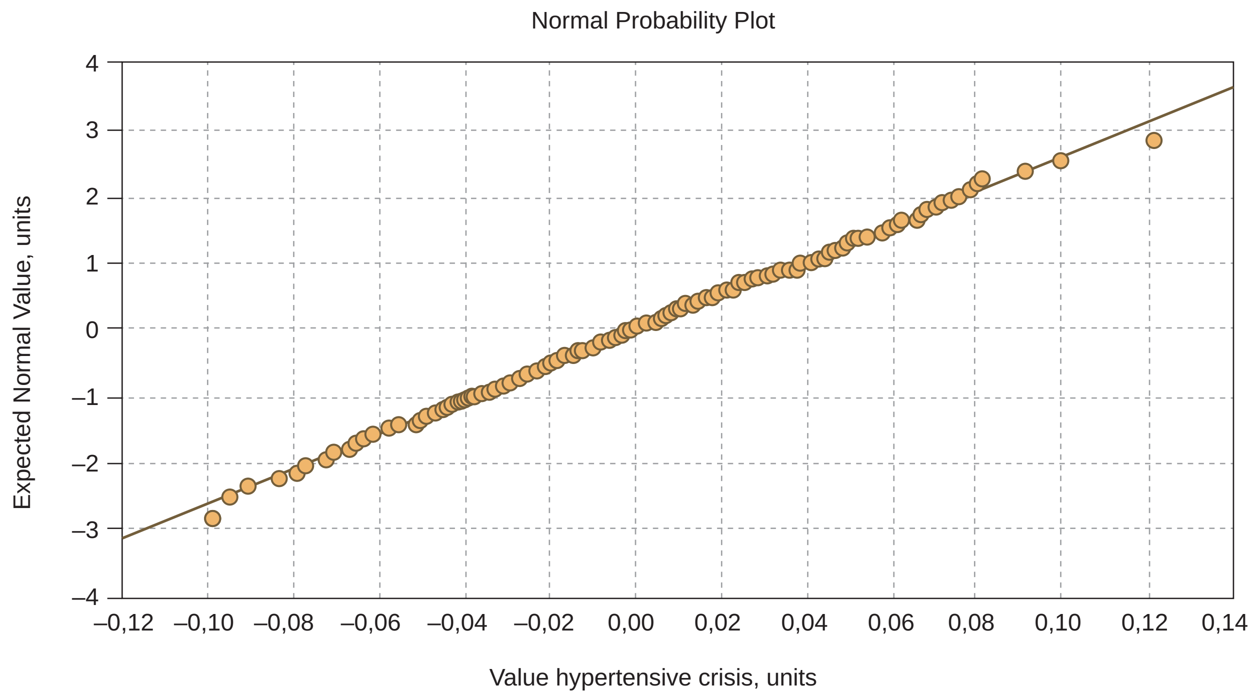

Fig. 3. Histogram of the residuals of the ARIMA model: hypertensive crisis

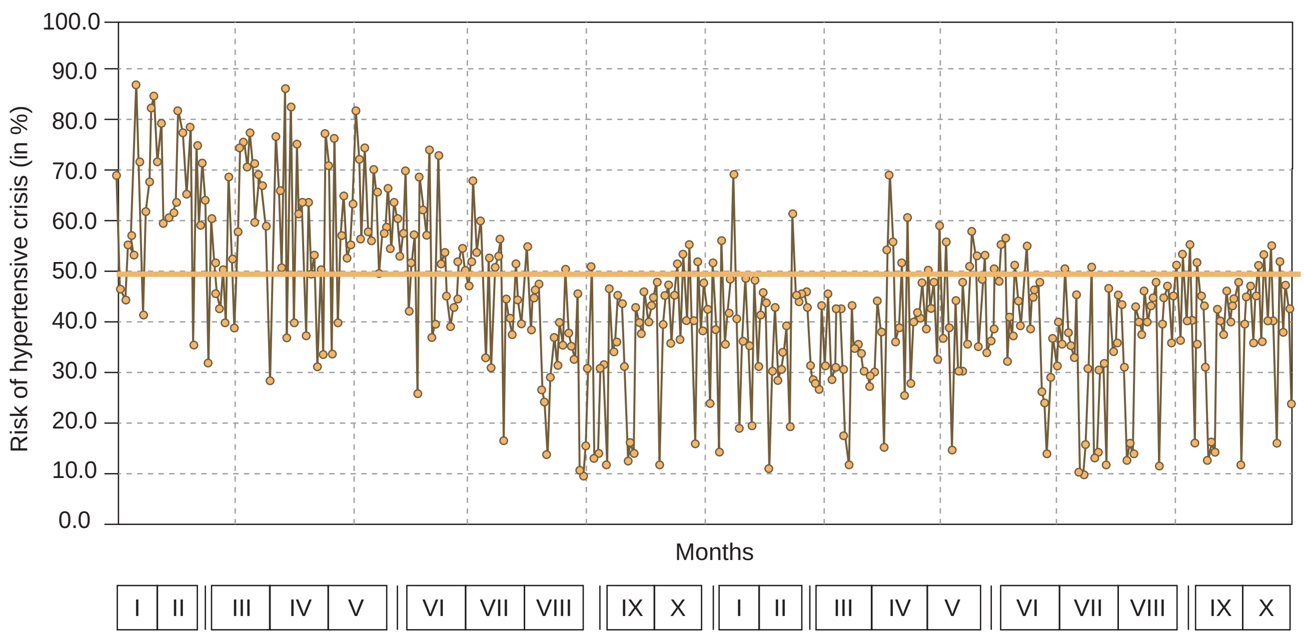

Fig. 4. Normal probability plot of ARIMA model residuals: hypertensive crisis

Table 1. Model of logistic regression analysis of the risk of developing a hypertensive crisis

Indicators	E ± SE	OR (e^b)	Used coefficient	*p*
Free term of logistic regression (B0)	19.4 ± 10.2	–	–	0.03
T, °C	–0.07 ± 0.002	1.07	0.07	0.001
Atmospheric pressure, mmHg	–0.02 ± 0.03	1.02	0.02	0.03
Relative humidity, %	–0.01 ± 0.001	1.01	0.01	0.03
K-index	0.02 ± 0.001	1.02	0.02	0.03

Note: *χ^2 = 13,3; p = 0,0001; OR — Odds ratio (range); E — Estimate; SE — Standard Error.*

When comparing the calculated results with the actual data on the presence of HC, a strong correlation was obtained: $\chi^2 = 9.8$; $p = 0.002$; OR = 4.25; 95 % CI — 1.6–11.2. The overall accuracy of the predictive model was 76.0 % (Table 2).

Table 2. Correspondence of the calculated results obtained using the logistic regression equation with the actual data on the risk of a hypertensive crisis in the subjects

Actual results		Calculated results: hypertensive crisis, positive (*n* = 286)	Calculated results: hypertensive crisis, negative (*n* = 18)
Hypertensive crisis	Negative (*n* = 229)	221 (14.5 %)	8 (33.7 %)
	Positive (*n* = 75)	65 (9.6 %)	10 (42.2 %)

Note: *$\chi^2 = 9.8$; $p = 0.002$.*

When the air temperature increment changes during the daytime from 1 (OR: 1.07, CI: –4.07–6.04) to 5 (OR: 1.35, CI: –3.65–6.35) degrees, the chances of a hypertensive crisis increase by 26.0 %. When the increment of atmospheric pressure increased from 1 (OR: 1.02, CI: 1.01–1.05) to 5 (OR: 1.10, CI: 1.07–1.13) mmHg, the chances of a HC increased by 55.0 %. Similarly, a change in the step of the K-index value from 3 (OR: 1.06 CI: 1.04–1.08) to 4 (OR: 1.08 CI: 1.06–1.10) points led to a 55.0 % increase in the chances of a HC.

Statistical analysis demostrated that during summer, up to 89.0 % of days in Gelendzhik had a climatotherapeutic effect due to a combination of high temperature, low humidity, and an optimal atmospheric pressure. Both cities, Novorossiysk and Gelendzhik, are located in the same climatic-landscape zone and have similar values of meteorological indicators.

In contrast to summer, winter (76.0 %) ($\chi^2 = 66.4$; $p = 0.0001$) and spring (59.0 %) ($\chi^2 = 46.4$; $p = 0.0001$) had a higher number of days with unfavorable climatic factors, primarily leading to sharp rises in blood pressure. In autumn, the number (77.0 %) of climatically favorable days decreased, with the majority of such days occurring in the first month of autumn (Figure 4).

The problem of cases of HC remained unresolved, when the calculation of the logit regression on magnetic quiet days and days with favorable weather gives low values of sensitivity, specificity, and model accuracy (about 50–55 %), which is unacceptable for reliable conclusions. Under the influence of a number of climatic and geomagnetic factors (K-index), the cardiovascular system responds, and these responses are often delayed in time from the moment of exposure.

By performing spectral Fourier analysis on the frequency of ambulance visits for HC, significant periodicities at weekly, three-week, half-year, and annual intervals were observed (Figure 5).

Following the guidelines for time series prediction (2012), the HC series was converted into a stationary form, and model identification was conducted. The autocorrelation and partial autocorrelation functions were used to calculate a prediction of the HC frequency. The autocorrelation displayed an exponential decrease, while the partial autocorrelation showed prominent values at lags 1 and 2.

The obtained model parameters were added into the ARIMA section's menu to generate a forecast using the exact maximum likelihood method. The resulting graph depicted the number of calls to ambulance teams for HC, along with a five-day forecast (Figure 6).

To verify the model's adequacy, several stages of analysis were conducted. First, the presence of autocorrelation was

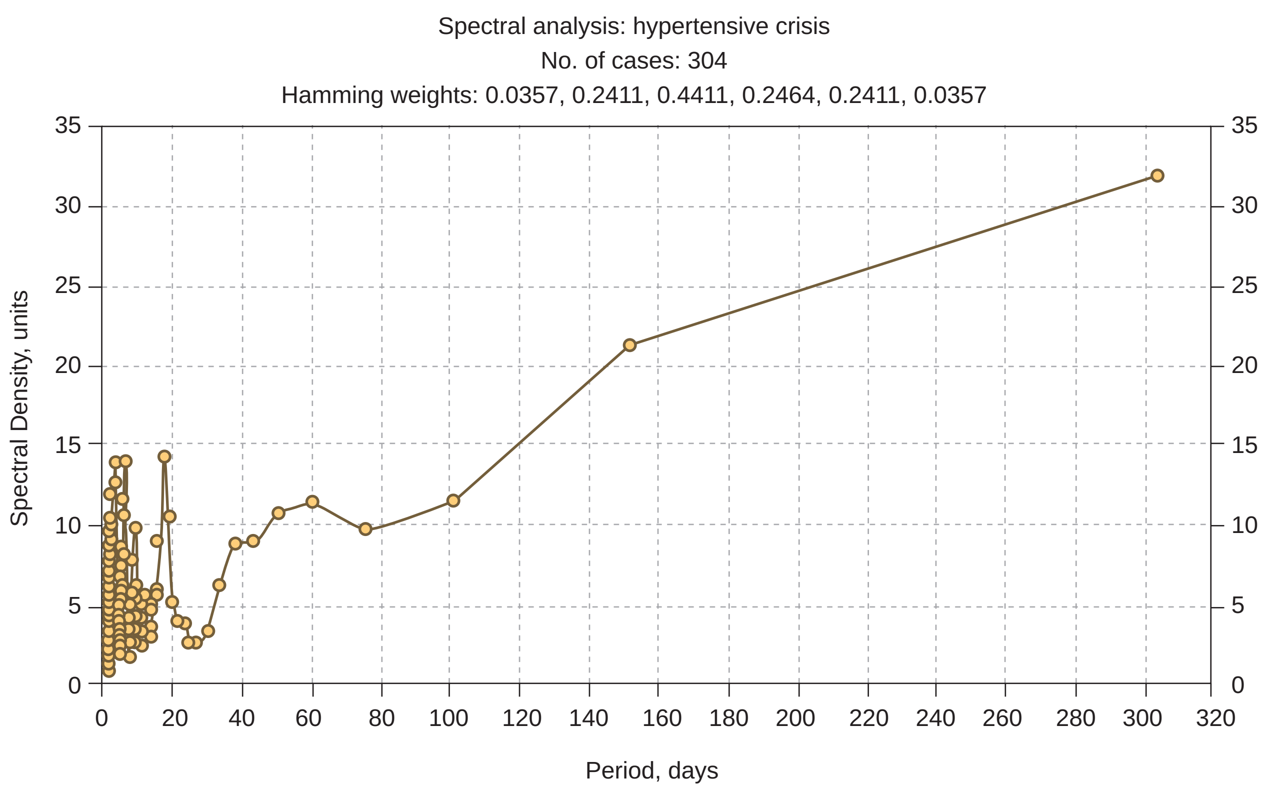

Fig. 5. Periodogram of the «hypertensive crisis» time series using Fourier spectral analysis

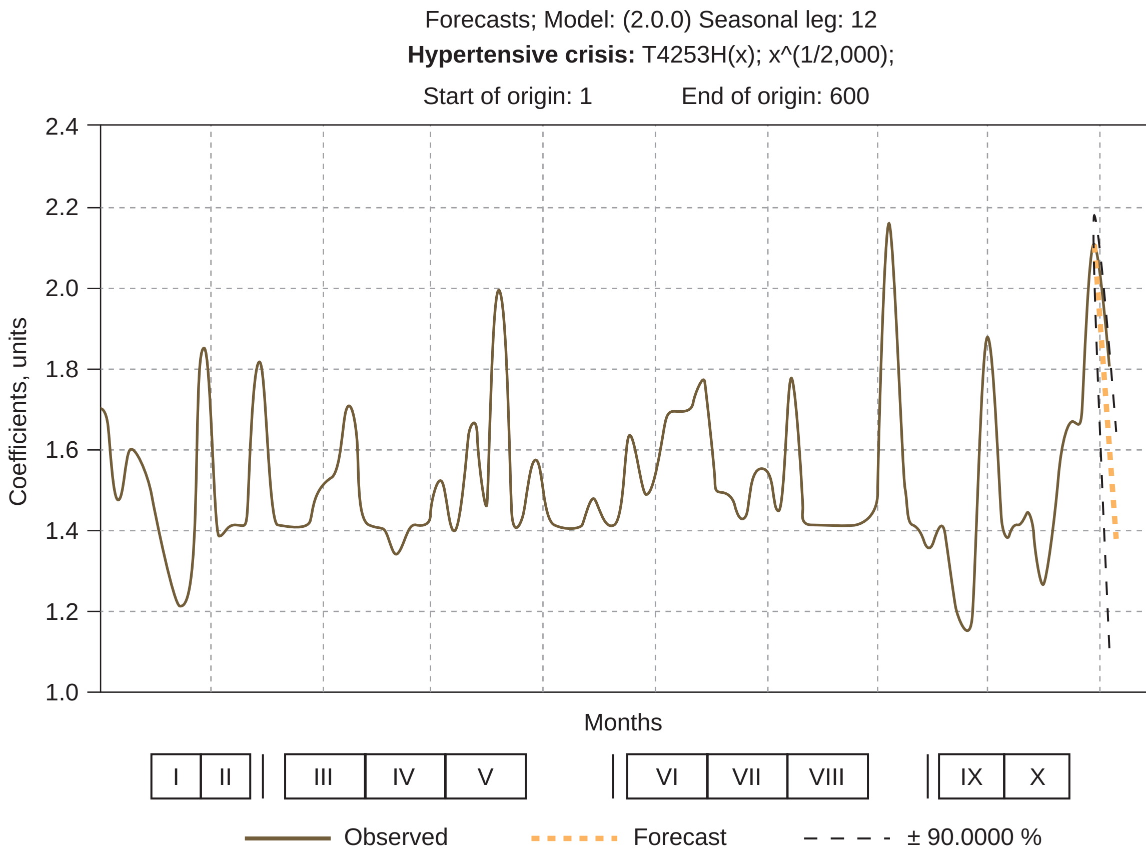

Fig. 6. ARIMA model: short-term forecast for 5 days of the frequency of ambulance calls for HC in Novorossiysk and Gelendzhik

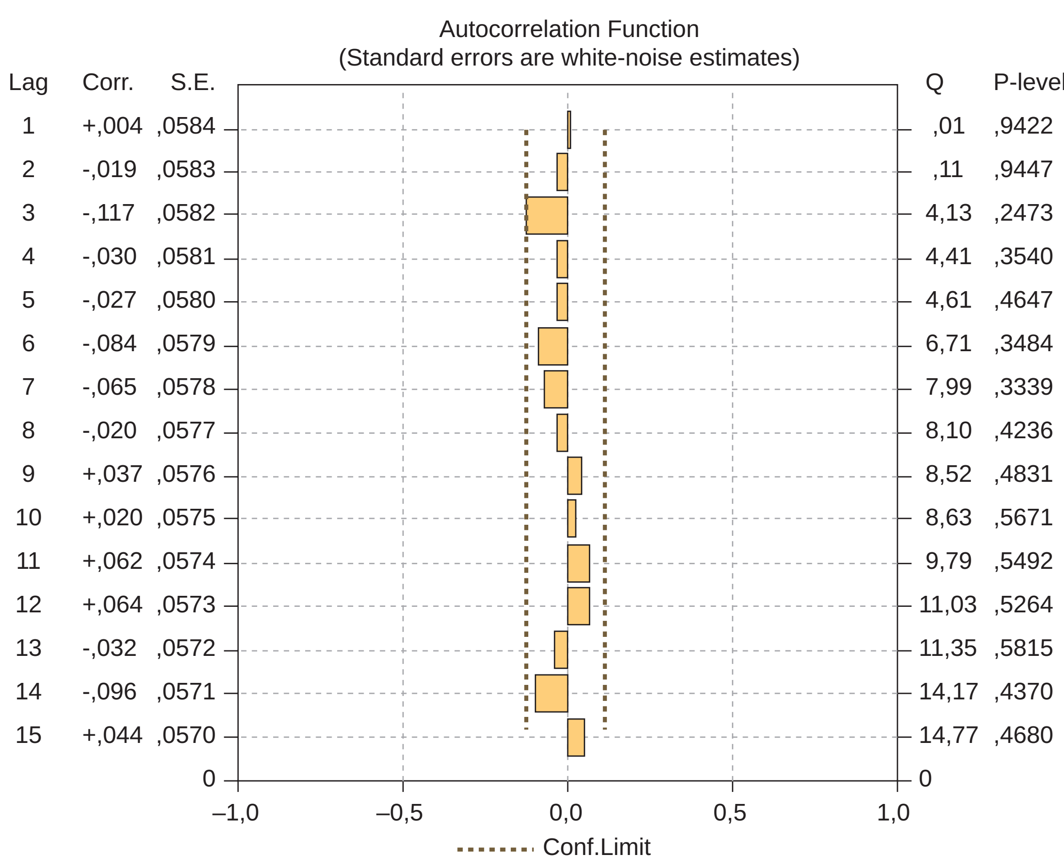

Fig. 7. Auto-correlation function values of the «hypertensive crisis» series after the transformation

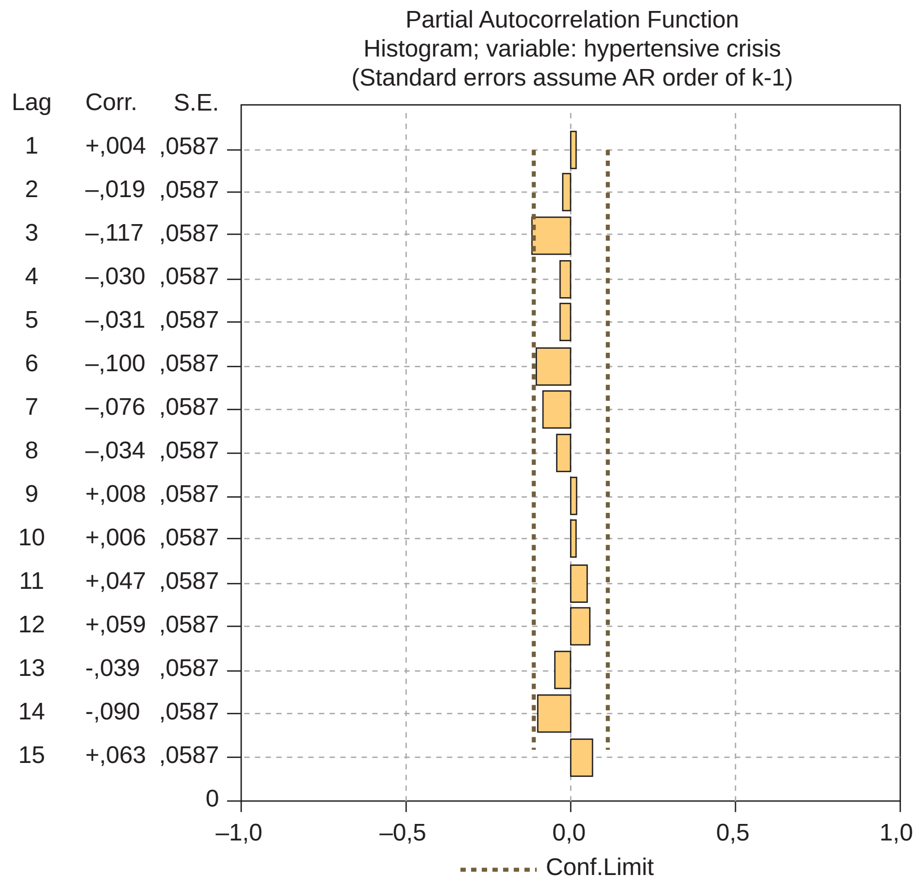

Fig. 8. Partial autocorrelation function values of the «hypertensive crisis» series after the transformation

checked (Figures 7, 8). The graphs indicated that the residuals were mostly uncorrelated, suggesting the model adequately described the time series.

Further examination of the distribution of the residuals proved their normal distribution, further supporting the adequacy of the model (Figure 2). In general, if the model is adequate, the residuals should be independently and equally distributed normal values, without a systematic component.

Subsequently, testing the distribution of the residuals showed that there were no outliers, which further confirms the adequacy of the model. The graph of the residuals is shown in Figure 3. The result of the developed model is shown in Table 3.

Table 3. Calculated predictive values of the frequency of calls for HC

Date	Predictive value of the frequency of calls for hypertensive crisis	–90,0 %	+90,0 %
01 Nov. 19	2,04	1,909198	2,168036
02 Nov. 19	1,99	1,637533	2,142359
03 Nov. 19	1,7	1,353871	2,073850
04 Nov. 19	1,5	1,101611	1,980411
05 Nov. 19	1,4	0,908533	1,883627

Additionally, an analysis was performed considering sex and age stratification, including subjects aged between 18 and 65 and those over 65, of both sexes. However, no significant differences were observed within these stratifications.

5. DISCUSSION

According to global studies, there has been a clear recent trend in global climate change, presumably related to the processes in the outer space, and possibly to anthropogenic (industrial and military) activity, which has tripled in the last 20 years [8, 26]. Global warming is not only accompanied by an increase in average surface temperatures, but also by an increase in the frequency, intensity and duration of extreme temperatures, with 19 of the 20 hottest years of this century occurring in the last 22 years. The national school of climatologists in the 60s-80s of the past century developed the basic methods of climatotherapy and climatic prophylaxis, which are still actively used today, built on the principles of compensation of the natural factor deficiency, relief from their excessive action or stimulation of vital functions, and also defined the seasons of the year, in which these factors influence most effectively in each of the particular resort areas [27, 28]. The current climate changes, however, compel us to rethink the experience accumulated by the previous generations of researchers and determine the need for further research.

When considering the impact of climate on human health, it is relevant to examine the consequences of exposure to non-optimal temperatures [7, 8, 29–31], relative humidity [7], atmospheric pressure [27], increased heliomagnetic activity [32] and to a lesser extent other meteorological and space factors [26], whose excessive impacts are associated with increased levels of both overall mortality and mortality/disease from certain causes [6, 33] or disease classes [26, 34, 35].

Large international and Russian studies covering a number of populations in different climatic zones have shown a link between weather conditions and morbidity and mortality from circulatory diseases (especially myocardial infarction and other forms of coronary heart disease) [36–39].

Commonly known mechanisms of weather factors affecting patients with cardiovascular diseases include changes in blood rheological parameters (such as increased thrombosis tendency), blood pressure levels, heart rate variability, and lipid peroxidation processes in the body (for example, with increased levels of ozone in inhaled air) [32, 40–42]. Additionally, weather factors can create barriers to implementing necessary lifestyle modifications [7, 26, 43].

Considering these findings, the study design was chosen. Gelendzhik and Novorossiysk were selected as the study sites due to their historical continuity and tradition as "All-Russian health resorts," favorable climatic and geographical conditions, and the high frequency of vacationers from various regions of the Russian Federation seeking spa treatment in these areas.

This study analyzed daily data on the frequency of ambulance visits for patients with hypertensive crisis in Gelendzhik and Novorossiysk, along with daily data on several climatic indicators (such as average temperature, humidity, wind speed, and geomagnetic activity) that exhibit cyclical patterns. Logistic nonlinear regression and ARIMA analysis with model building were used to determine days with low and high probabilities of a hypertensive crisis occurrence. This study is the first to conduct a daily analysis of these parameters and calculate the risk of HC patients with arterial hypertension.

Despite the fact that the factors of the patient's environment are not included in the main risk-metric scales that are currently used to assess the total cardiovascular risk, in recent decade there has been a surge of research interest to study them [36, 44, 45]. Large international studies covering a range of populations in different climatic zones, as well as those conducted by Russian researchers, have shown a link between weather conditions and morbidity and mortality from cardiovascular disease [36–39].

The analysis of time series data is traditionally used as the main statistical tool, both in Russian and international research papers [46–49]. In the course of mathematical calculations, time series of various physiological and geophysical data are analyzed to determine the degree of individual sensitivity of an organism to meteorological and geomagnetic factors [50]. In addition to our study, there are several academic papers that have analyzed the relationship between cardiovascular diseases, weather, and the frequency of ambulance calls using time series data analysis methods [50–52]. Furthermore, our results are consistent with other studies that have examined the impact of meteorological indicators on the occurrence of main symptoms in patients with arterial hypertension undergoing spa treatment in the Crimean Peninsula [53–55]. These studies have calculated the most favorable season and duration of the treatment season with a minimal HC. However, they did not employ ARIMA analysis, logistic nonlinear regression, or other types of models (such as FFLM, SFLM, or DLNM) based on different statistical analyses or primary data.

The strength of our study lies in the analysis of daily data on the frequency of emergency calls for patients with HC, which provides a higher level of accuracy compared to studies that use weekly data.

There are, however, several limitations to our study. Firstly, more precise assessments of the impact could be achieved by considering space-time factors and incorporating socio-demographic and economic characteristics of the region. Secondly, using average outdoor temperature, as is common in most time series studies, introduces systematic errors. Finally, individual tolerance thresholds for high or low temperatures should be taken into account, as every person may have different sensitivities.

6. CONCLUSION

To summarize, our study focused on developing a predictive logit model for HC based on weather factors. The predictive logit model achieved a sensitivity of 56.0 %, specificity of 77.3 %, and an overall accuracy of 76.0 %, indicating its moderate predictive capability. Our analysis provided insights into the seasonal variation of HC risk, with the winter season having no more than 75.0 % of low-risk days, followed by 59.0 % in spring, 89.0 % in summer, and 77.0 % in autumn. Furthermore, the developed model for predicting the onset of HC using the ARIMA time series analysis exhibits a high predictive accuracy (95 %), which was established when the model was validated using ambulance calls data in Novorossiysk and Gelendzhik.

These findings contribute to understanding the relationship between weather factors and HC occurrence, providing valuable insights for healthcare professionals and policymakers in mitigating the risk of HC. Further research incorporating additional socio-demographic and economic factors could enhance the precision of impact assessments in this area.

ADDITIONAL INFORMATION

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