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Original article

Influence of Climatic and Geographical Features of the Subjects of the Russian Federation on the Activities of Fire Departments

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Abstract

Introduction. When determining the number and technical equipment of fire departments, regulatory documents on fire safety do not take into account natural, climatic and geographical features of the subjects of the Russian Federation in an explicit form. At the same time, there is some information in scientific literature about the influence of certain natural and climatic factors on the effectiveness of fire protection actions in extinguishing fires. The aim of this study was to determine the influence of the system of natural, climatic and geographical characteristics of the subjects of the Russian Federation on the rapid response indicators of territorial fire departments. The results obtained are recommended for further use in rationing the number and technical equipment of fire departments.

Materials and Methods. A factor analysis of statistical data for 2020–2022 was carried out. The statistical data were obtained from the Federal State Information System "Federal Database "Fires", from the website of the Federal State Statistics Service of the Russian Federation and from other sources. For the analysis, the authors selected ten indicators characterizing natural, climatic and geographical features of the subjects of the Russian Federation, two indicators of the rapid response of territorial fire departments and four indicators of the fire situation.

Results. Five significant factors were identified, the change of which explained the change in the observed indicators. The first factor characterized the relationship of climatic conditions with fire situation indicators. The second factor connected the indicators of the rapid response of fire departments with the terrain features of the subjects of the Russian Federation. The third factor described the relationship between fire situation indicators and rapid response indicators with population density and forest cover of the territory. Other factors did not significantly contribute to the indicators of fire situation and rapid response.

Discussion and Conclusion. By means of mathematical analysis and factor modeling, the authors investigated the interdependence of natural, climatic and geographical features of the subjects of the Russian Federation, fire situation indicators and indicators of rapid response of fire departments. The most significant factors influencing these indicators were identified. They included the average air temperature, the area covered by forest, the presence of mountain ranges, and population density. These indicators should be taken into account when determining the number and technical equipment of fire departments to increase the efficiency of their functioning.

Keywords: fire protection, factor analysis, subject of the Russian Federation, death, injury, arrival time, climatic and geographical indicators

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Научная статья

Влияние природно-климатических и географических особенностей субъектов Российской Федерации на деятельность подразделений пожарной охраны

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Аннотация

Введение. Нормативными документами по пожарной безопасности при определении численности и технической оснащенности подразделений пожарной охраны в явном виде не учитываются природно-климатические и географические особенности субъектов Российской Федерации. При этом в научной литературе встречаются сведения о влиянии отдельных природно-климатических факторов на эффективность действий пожарной охраны при тушении пожаров. Целью настоящего исследования явилось определение влияния системы природно-климатических и географических характеристик субъектов Российской Федерации на показатели оперативного реагирования территориальных подразделений пожарной охраны. Полученные результаты рекомендованы для дальнейшего использования при нормировании численности и технической оснащенности подразделений пожарной охраны.

Методы и материалы. Проведен факторный анализ статистических данных за 2020–2022 гг. Статистические данные получены из федеральной государственной информационной системы «Федеральный банк данных «Пожары», с сайта Федеральной службы государственной статистики Российской Федерации и из других источников. Для анализа отобраны 10 показателей, характеризующих природно-климатические и географические особенности субъектов Российской Федерации, 2 показателя оперативного реагирования территориальных подразделений пожарной охраны и 4 показателя обстановки с пожарами.

Результаты исследования. Выделены пять значимых факторов, изменение которых объясняет изменение наблюдаемых показателей. Первый фактор характеризует связь климатических условий с показателями обстановки с пожарами. Второй фактор связывает показатели оперативного реагирования подразделений пожарной охраны с особенностями рельефа субъектов Российской Федерации. Третий фактор описывает взаимосвязь показателей обстановки с пожарами и показателей оперативного реагирования с плотностью населения и лесистостью территории. Остальные факторы в показатели обстановки с пожарами и оперативного реагирования существенного вклада не вносят.

Обсуждение и заключение. С помощью математического анализа и с использованием факторного моделирования авторами исследована взаимозависимость природно-климатических и географических особенностей субъектов Российской Федерации, показателей обстановки с пожарами и показателей оперативного реагирования подразделений пожарной охраны. Определены наиболее значимые факторы, влияющие на эти показатели. Среди них средняя температура воздуха, лесистость территории, наличие горных массивов, плотность населения. Данные показатели следует учитывать при определении численности и технической оснащенности подразделений пожарной охраны для повышения эффективности их функционирования.

Ключевые слова: пожарная охрана, факторный анализ, субъект Российской Федерации, гибель, травматизм, время прибытия, природно-климатические и географические показатели

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Introduction. When determining the number and technical equipment of territorial fire departments, a survey of the territory of the subject of the Russian Federation is carried out. This includes an analysis of the state of the existing fire safety system of the subject of the Russian Federation, operational and tactical features of the territory under

consideration, the frequency of fires, the risks of death and injury to people on them[1]. Among the factors influencing the state of fire safety in the subjects of the Russian Federation, climatic and geographical characteristics are of great importance. In this regard, in this work, using factor analysis, a study was conducted of the relationship between natural, climatic and geographical characteristics of the subjects of the Russian Federation, indicators of rapid response of territorial fire departments and fire situation indicators. Factor analysis is one of the most widely used methods aimed at isolating a small number of latent factors from a variety of heterogeneous indicators, the variation of which can explain the change in most of the observed indicators [1–5]. This allowed us to build a mathematical model in which the studied factors have a simple and visual structure [6]. Previously, the authors used factor analysis to study the rapid response of fire departments [7], the social consequences of fires [8], the situation with fires in rural settlements [9], and the readiness of fire departments [10].

Materials and Methods. The study included three stages. At the first stage, a matrix of initial indicators was created. For this purpose, the values of 16 indicators were determined in each subject of the Russian Federation, divided into three groups.

The first group included data characterizing the situation with fires (the designation of the indicator is indicated in parentheses):

– the number of fires per 1 thousand people of the population, units (Y_1);

– the average direct material damage from one fire, rubles (Y_2);

– the number of deaths from fires per 100 thousand people, people (Y_3);

– the number of people injured in fires per 100 thousand people, people (Y_4).

– The second group reflected the indicators of rapid response of fire departments:

– the average time it took for the first fire department to arrive, min. (Z_1);

– the average time spent on extinguishing a fire, min. (Z_2).

The third group consisted of indicators characterizing climatic, geographical and demographic characteristics of the subjects of the Russian Federation:

– the population density, people/km^2 (X_1);

– the percentage of water surface area in the territory of the region, % (X_2);

– the length of the sea coastline compared to the total length of the border of the subject, % (X_3);

– the share of forested areas in the territory of the subject, % (X_4);

– the average annual precipitation, mm per year (X_5);

– the average temperature in July, °C (X_6);

– the average temperature in January, °C (X_7);

– the seismic hazard (presence of settlements with the specified seismic intensity for the degree of seismic hazard), °C (X_8);

– the share of the territory occupied by mountains from the total area of the territory of the subject, % (X_9);

– the number of sunny days per year, (X_{10}).

Fire situation indicators and operational response indicators of fire departments were obtained from an electronic database of fires, which was maintained using an automated analytical support and management system by the control and supervisory authorities of the Ministry of Emergency Situations of Russia[2].

Information on population density and forest area in the subjects of the Russian Federation was taken from the data of the Federal State Statistics Service of the Russian Federation[3]. Climate characteristics of the subjects of the Russian Federation were obtained on the reference and information portal "Weather and Climate"[4]. When determining the seismic hazard in the subjects of the Russian Federation, the data from SP 14.13330.2014 were used[5].

The selected statistical indicators were characterized by a wide range, which was due to different sizes of the subjects of the Russian Federation (territory area and population), as well as differences in their natural, climatic and geographical conditions. In this regard, in order to make statistical data more uniform, a number of indicators have been normalized. This made it possible to transform many natural indicators into synthetic indicators. The normalization of

[1] *Ob utverzhdenii metodik rascheta chislennosti i tekhnicheskoi osnashchennosti podrazdelenii pozharnoi okhrany.* Order of the Ministry of Emergency Situations of Russia from 15.10.2021 No. 700. URL: https://base.garant.ru/403136953/ (accessed: 18.12.2023) (In Russ.).

[2] *Ob utverzhdenii Reglamenta raboty v informatsionnoi sisteme "Avtomatizirovannaya analiticheskaya sistema podderzhki i upravleniya kontrol'no-nadzornymi organami MChS Rossii".* Order of the Ministry of Emergency Situations of Russia No. 954 from 04.10.2022. URL: https://fireman.club/normative-documents/prikaz-mchs-rossii-954-ot-04-10-2022-ob-utverzhdenii-reglamenta-raboty-v-informaczionnoj-sisteme/ (accessed: 11.12.2023) (In Russ.).

[3] *Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli 2022.* Federal State Statistics Service of the Russian Federation. URL: https://rosstat.gov.ru/folder/210/document/13204 (accessed: 08.12.2023) (In Russ.).

[4] Spravochno-informatsionnyi portal "Pogoda i klimat".URL: http://www.pogodaiklimat.ru/ (accessed: 08.12.2023) (In Russ.).

[5] *Seismic building design code.* SP 14.13330.2018 from 25.11.2023. URL: https://docs.cntd.ru/document/550565571 (accessed: 08.12.2023) (In Russ.).

indicators was carried out for the area of the territory of the subjects (population density, the proportion of forests and water surface from the area of the territory of the subject) and for the population (number of fires, the number of deaths and injuries in fires).

Further modeling was carried out using the obtained matrix of synthetic indicators. Significant factors were identified using three of the most common methods: centroid, principal component, and maximum likelihood. All three methods gave similar results, which were consistent within statistical errors. Subsequently, the principal component method was used to perform factor analysis.

At the second stage, significant factors were obtained using the principal component method. To facilitate their interpretation, the rotation of the obtained factors was performed using the following methods:

– varimax (this method, by reducing the number of variables for each factor, allowed for a better separation of factors);

– quartimax (this method, by reducing the number of factors related to each variable, made it possible to identify the general factor and simplify interpretation);

– biquartimax;

– equimax.

Before performing the rotation, factor loads were normalized using the Kaiser method. This made it possible to exclude the influence of variables with great similarity on the result. In subsequent studies, the varimax rotation method was used, since the analysis of the results showed that factor loads did not significantly depend on the rotation method.

As a result of the factor analysis, five significant factors were obtained. The share of the total variance explained by these factors was distributed as follows: the first factor — 22.1%, the second factor — 15.4%, the third factor — 12.1%, the fourth factor — 9.7%, the fifth factor — 7.7%. These five significant factors explained 67.0% of the total variance.

Table 1 shows the values of factor loads for each of the five factors (significant indicators are highlighted in bold).

Table 1

Matrix of factor loads

Variable (indicator)	Factor				
	1	2	3	4	5
Y_1	0.019	-0.179	**0.681**	0.212	-0.308
Y_2	**0.692**	0.028	-0.241	0.027	0.123
Y_3	**0.692**	0.164	**0.484**	-0.123	0.021
Y_4	**0.821**	-0.095	0.229	0.046	-0.121
Z_1	-0.362	**0.587**	**0.417**	0.091	0.306
Z_2	0.009	0.218	**0.509**	-0.343	0.265
X_1	-0.093	0.069	**-0.587**	-0.086	-0.063
X_2	0.018	0.234	0.056	0.070	**-0.836**
X_3	0.000	-0.373	-0.155	-0.422	**-0.532**
X_4	0.236	-0.305	**0.536**	-0.357	0.002
X_5	-0.334	0.026	0.008	**-0.758**	0.016
X_6	**-0.636**	0.032	-0.062	**0.630**	0.200
X_7	**-0.646**	0.357	-0.343	-0.144	0.040
X_8	-0.073	**-0.833**	0.097	0.174	0.133
X_9	0.058	**-0.841**	0.180	-0.019	0.051
X_{10}	**-0.437**	-0.322	0.191	**0.630**	-0.081

At the third stage, a creative task was solved that went beyond the formal method. A meaningful interpretation of the obtained factors using subject terms was carried out.

Results. It was found that the following variables made the greatest contribution to the first significant factor:

– the average direct material damage from one fire, rub. (Y_2);

– the number of deaths from fires per 100 thousand people, people (Y_3);

– the number of injured people per 100 thousand people, people (Y_4);

– the average temperature in July, °C (X_6);

– the average temperature in January, °C (X_7);

– the number of sunny days per year (X_{10}).

Among fire situation indicators, the indicator "the number of injured people in fires per 100 thousand people of the population" made the greatest contribution to the first factor. This factor characterized the relationship of climatic

conditions with indicators of the situation with fires. In those regions of the Russian Federation where the climatic conditions were more severe (low temperatures, few sunny days), there were more severe consequences of fires (more dead and injured people, higher property damage).

This relationship is demonstrated in Figures 1 and 2, which show the dependence of the number of victims (dead and injured people) in fires per 100,000 people on the average temperature in January. It can be seen that with a decrease in the average temperature, the number of victims of fires increased.

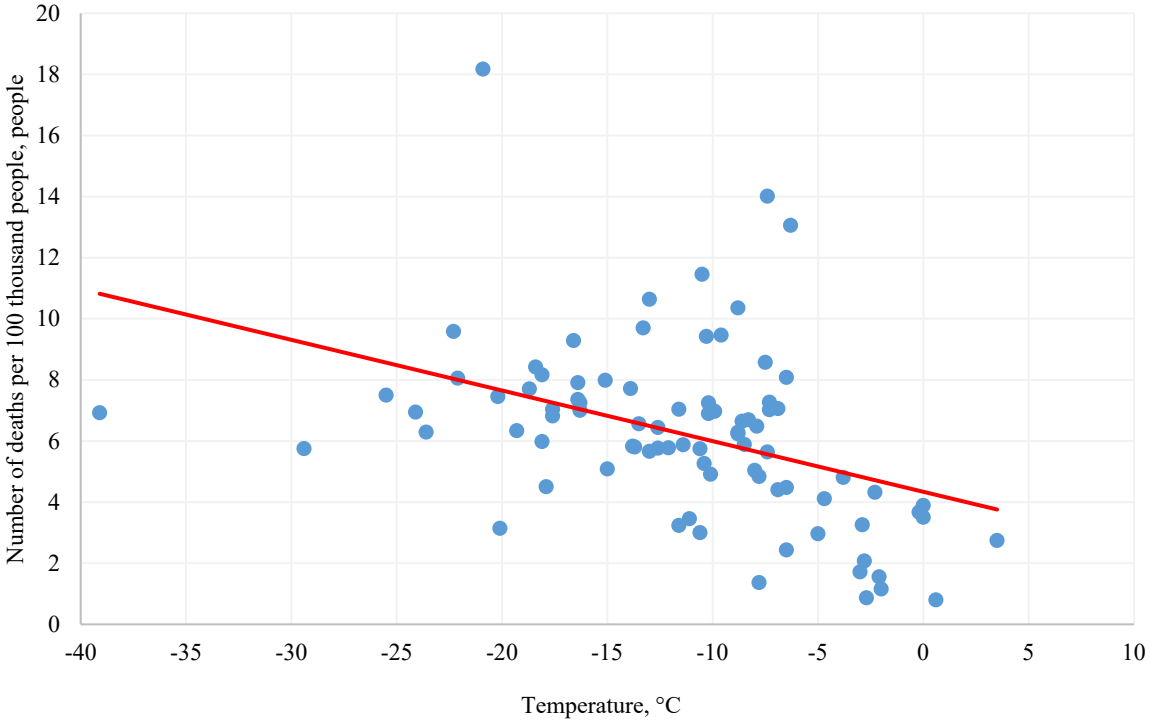

Fig. 1. Dependence of the number of deaths in fires per 100,000 people on the average temperature in January in the subjects of the Russian Federation. The straight line is the result of approximation by linear function $y = -0.166x + 4.338$

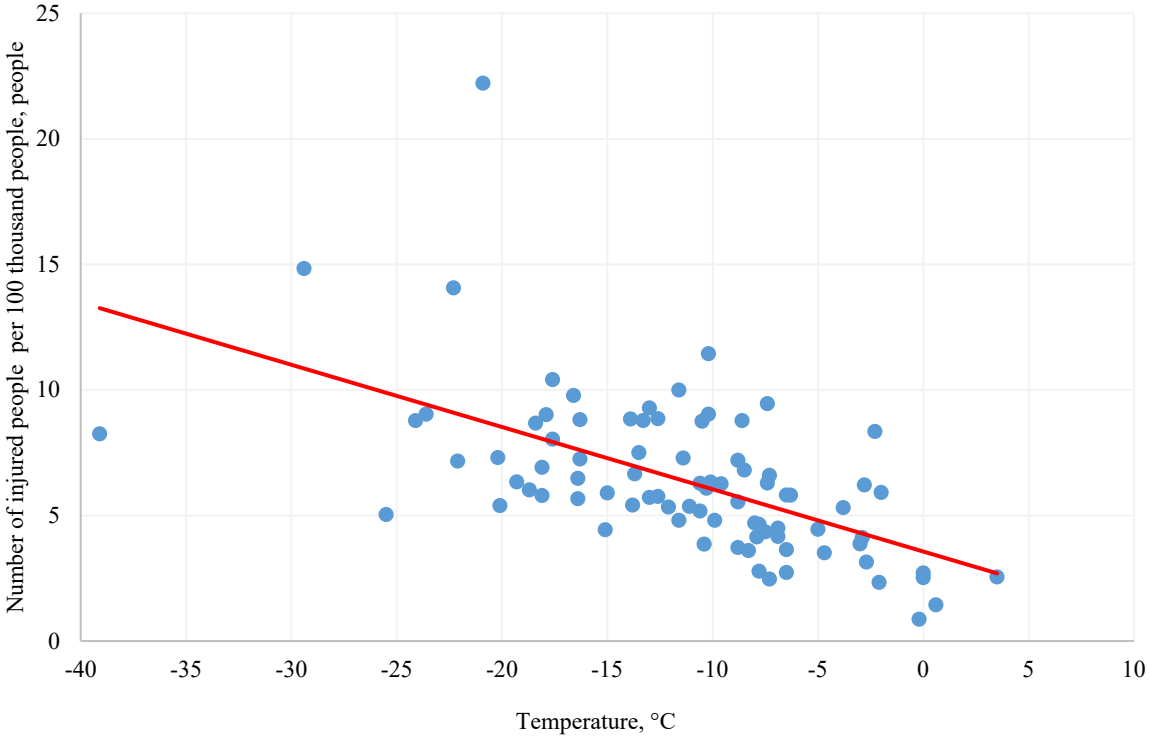

Fig. 2. Dependence of the number of injured people in fires per 100 thousand people on the average January temperature in the regions of the Russian Federation. The straight line is the result of approximation by linear function $y = -0.248x + 3.565$

For the second significant factor, the following variables were the most essential:

– average time it takes for the first fire department to arrive, min. (Z_1);

– seismic hazard (the presence of settlements with the specified seismic intensity for the degree of seismic hazard C) (X_8);

– percentage of the territory occupied by mountains from the total area of the territory of the subject, % (X_9).

The second factor characterized the relationship of the indicators of rapid response of fire departments with the geographical features of the subjects of the Russian Federation. There was an important dependence. The larger the territory of the subject was occupied by mountains, the shorter the average time for which the first fire department arrived at the place of the call was.

Figure 3 provides the distribution of factor loads for three groups of indicators in the plane of factors 1 and 2.

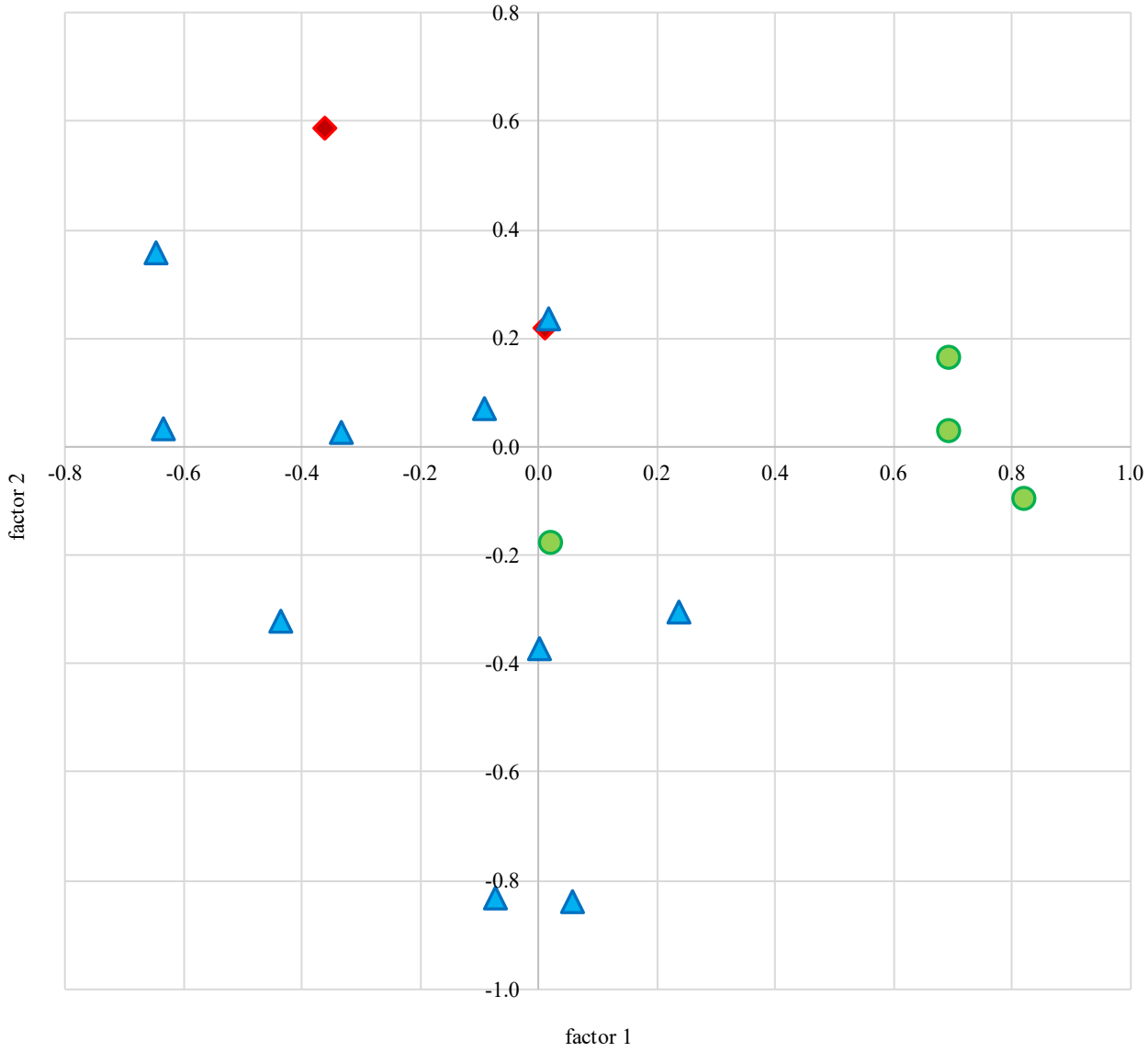

Fig. 3. Values of factor loads in the plane of factors 1 and 2. The indicators of the first group are indicated in green, the indicators of the second group are indicated in red, and the indicators of the third group are indicated in blue

The following variables made the greatest contribution to the third significant factor:

– the number of fires per 1,000 people, units (Y_1);

– the number of deaths in fires per 100,000 people, people (Y_3);

– the average time it takes the first fire department to arrive, min. (Z_1);

– the average time spent on extinguishing a fire, min. (Z_2);

– population density, people/km^2 (X_1);

– share of forests from the area of the territory of the subject, % (X_4).

The third factor describes the relationship between fire situation indicators and rapid response indicators with population density and forest cover of the territory. As previously conducted studies showed, with increasing density, the average area of the service area of one fire department decreased, resulting in a decrease in the arrival time of the first fire department. On the other hand, the lower the density, the larger the area of the territory where the same number of people lived, respectively, more fires occurred in a larger area. It is also interesting to note that with increasing population density, the number of fire victims per 100,000 people decreased.

The fire situation was also affected by the area of forests. With an increase in the share of the territory of the subject of the Russian Federation occupied by forests, the number of fires per 1,000 people increased.

The dependence of the number of fires per 1,000 people on population density was obtained. As it can be seen in Figure 4, the number of fires decreased with increasing population density. This dependence was described by an exponential function.

Figure 5 shows the distribution of factor loads for three groups of indicators in the plane of factors 1 and 3.

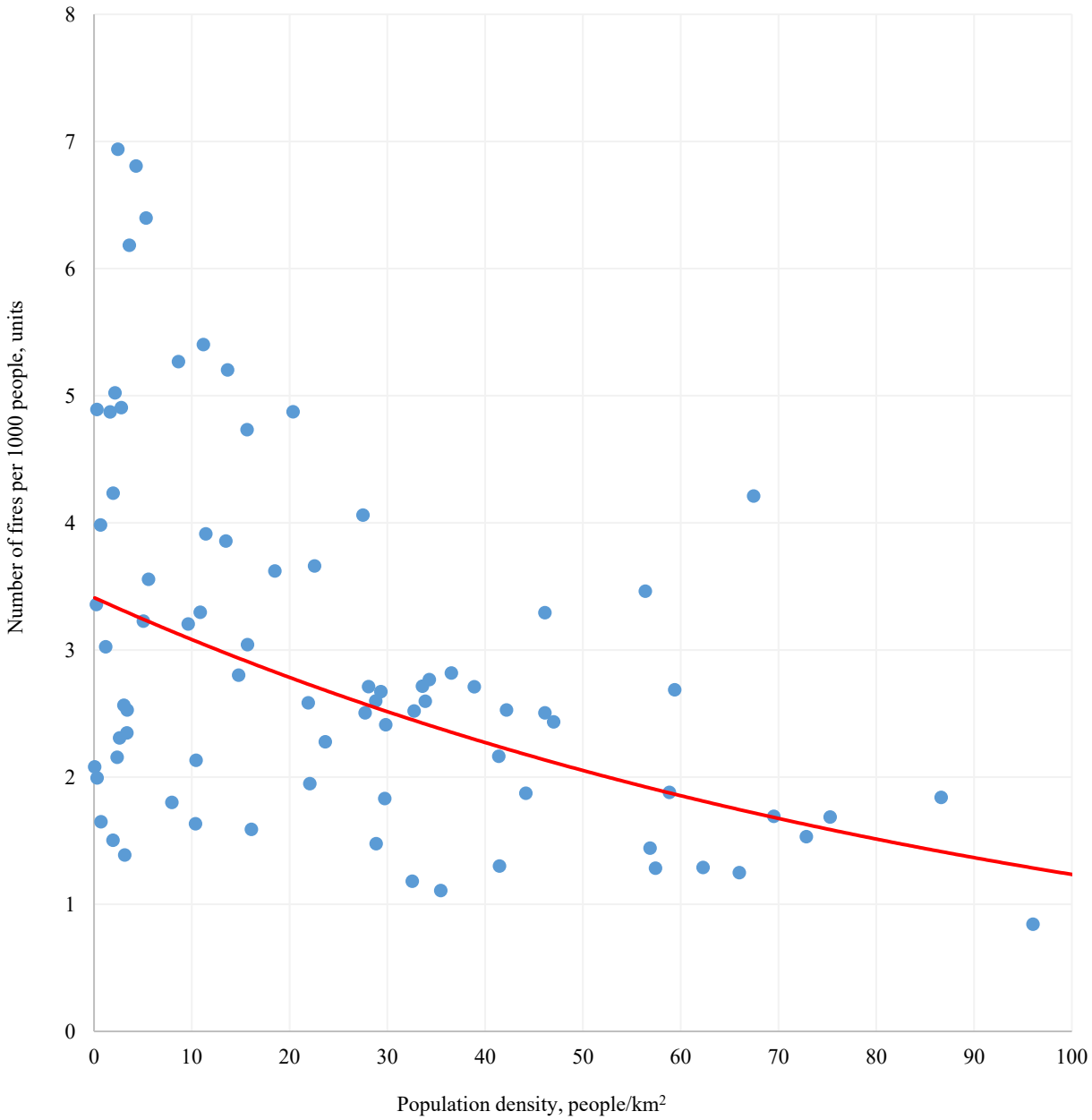

Fig. 4. Dependence of the number of fires per 1,000 people on population density. The curve is the result of approximation by exponential function $y = 3.412e^{-0,0102x}$

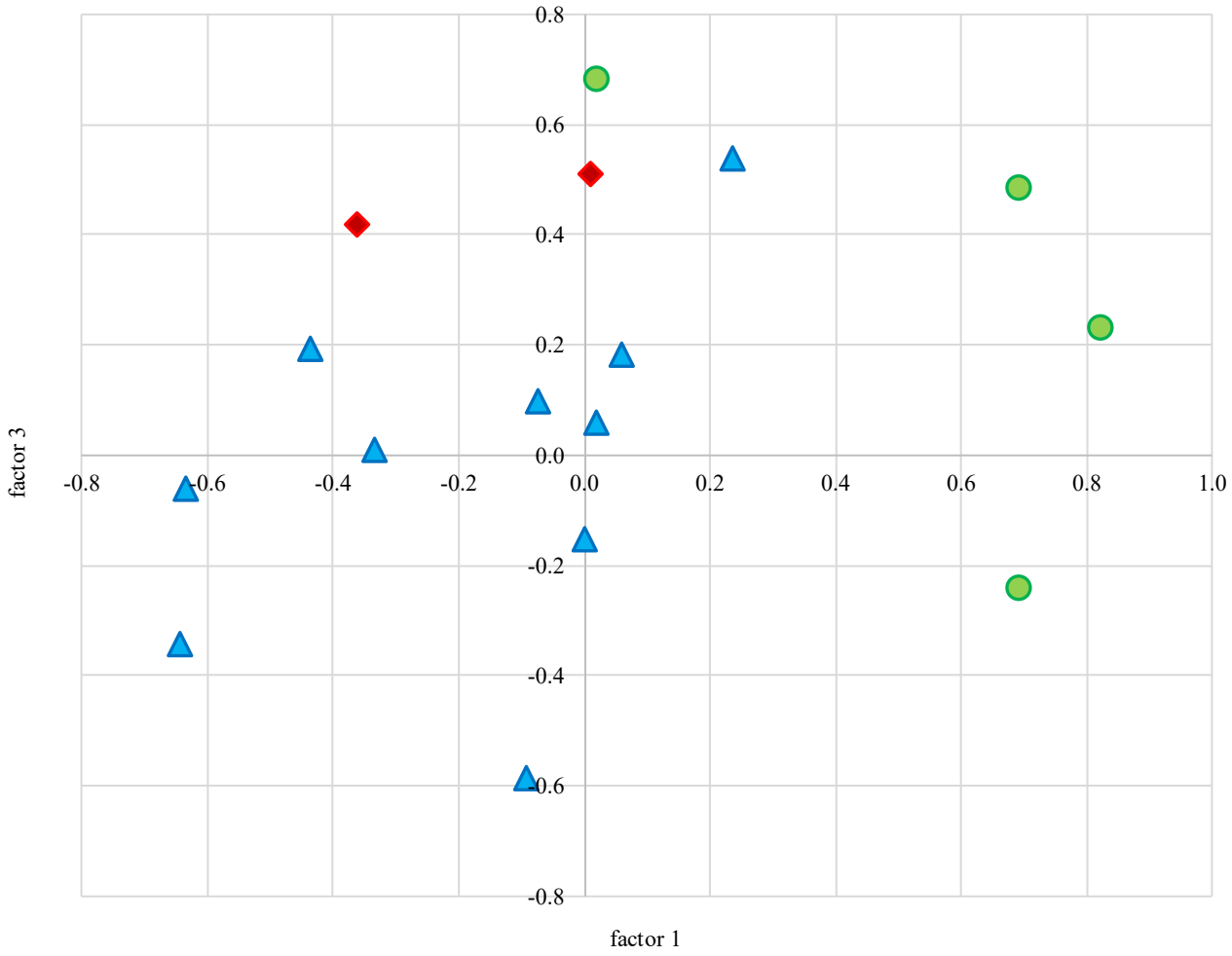

Fig. 5. Values of factor loads in the plane of factors 1 and 3. The indicators of the first group are marked in green, the indicators of the second group are marked in red, and the indicators of the third group are marked in blue

For the fourth significant factor, the following variables are the most important:

– average annual precipitation, mm per year (X_5);

– average July temperature, °C (X_6);

– number of sunny days per year (X_{10}).

This factor is related to climatic characteristics of the subjects of the Russian Federation. The indicators of the first and second groups did not make a significant contribution to this factor. It should be noted that the relationship between the climatic characteristics of the subjects and the indicators of the fire situation was well traced from the analysis of factor loads for the first factor (see above).

For the fifth significant factor, the following variables are decisive:

– the proportion of the water surface area of the territory of the subject, % (X_2);

– the length of the sea coastline of the total length of the border of the subject, % (X_3).

These hydrographic characteristics did not have a significant impact on the fire situation and on the operational response indicators of fire departments in the constituent entities of the Russian Federation.

Discussion and Conclusion. For the first time, using factor analysis, a study of the influence of natural, climatic and geographical features of the subjects of the Russian Federation on the level of fire safety was conducted. The analysis showed that the following climatic, geographical and demographic indicators most significantly affect the situation with fires and the activities of fire departments in the subjects of the Russian Federation: average temperature, forest cover of the territory, the presence of mountain ranges, population density. Thus, when determining the number and technical equipment of fire departments, it is necessary to take into account these features of the subjects of the Russian Federation.

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