VOL. 17, NO. 12, JUNE 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

THE IMPACT OF CLIMATE CHANGE ON THE SPREAD OF FOREST FIRES

Inna Pivovarova and Alexander V. Matveev
Department of Applied Mathematics and Information Technology, Saint Petersburg University of State Fire Service of Emercom of Russia St. Petersburg, Russia
E-Mail: I_Pivovarova@mail.ru

ABSTRACT

The article proposes a spatio-temporal analysis of the relationship between the distribution of forest fires and climatic factors. With the help of GIS technologies, data on the number of forest fires over thirty years in the European territory of Russia were processed and visualized. Statistically significant trends in the long-term variability in the number of forest fires and their regional distribution have been identified. The paper identifies and analyzes the general climatic trends for the study area. The correlation between the interannual variability of fires and climatic characteristics is clearly shown. The results of the work on determining the degree of influence of the main fire-hazardous factors in specific territories will make it possible to further identify areas of potential fire danger and make decisions on fire prevention strategies.

Keywords: forest fires, geoinformation systems, analysis, climate, spatial distribution, effective management.

INTRODUCTION

Forest fires are a global phenomenon. Over the past decades, both the number of fires and the area of burnt areas have increased significantly throughout the world (Turco, 2018). The largest fires provoked not only serious economic and environmental damage, but also human casualties. Forest fires are raging in the USA, Australia, on the European continent. The largest part of the burnt forests in Europe falls on the Mediterranean regions. In the summer of 2021, the Mediterranean countries coped with the fires with great difficulty, when for several months new pockets of flames appeared, despite the efforts of firefighters and volunteers (Pausas, 2014).

The number of fires in Russia has also increased. For example, in 2020, the forest fire season began earlier than usual: due to the warm winter, the first forests caught fire in January. By July, the fire had spread over 1.2 million hectares of land, and the total number of fires reached 9 thousand, one of which for the first time in history occurred beyond the Arctic Circle. However, these are much more reassuring figures than in 2021, when the fire area in Siberia covered 5 million hectares and the fires themselves became one of the most destructive since the early 2000s.

The results of a natural fire or fire-related processes affect the energy and water exchange between the land surface and the atmosphere. Fires can lead to a decrease in surface albedo and an increase in the amount of solar radiation reaching the soil layer on a local and regional scale. These surface changes, in turn, increase the amount of energy absorbed by the incoming solar radiation and generally increase the temperature of the earth. These changes in ground temperature affect a wide range of processes, including nutrient and water availability, and microbial respiration. The consequences of forest fires for the northern Russian territories, along with the global ones, also have a specific, very important feature. Fires hasten the disappearance of permafrost as the fire destroys the organic layer of soil that protects it from melting. As recent studies have shown, after a fire, permafrost retains abnormally high temperatures for 20 years, and the soil layer that melts in summer becomes 30-50% deeper (Kostarev, 2020).

Today, there is no doubt that a further increase in the average air temperature will lead to a decrease in the recurrence interval of natural fires, and intensification of fires in boreal forests and tundra ecosystems. This increase in fires, in turn, can lead to a significant reduction in carbon stocks in these ecosystems with a comparable increase in carbon in the atmosphere. In fairness, it should be noted that not all forest fires are bad, and some may even be beneficial for forest ecosystems. For example, fire clears away dead and dying undergrowth, which, in some cases, can help restore ecosystem health (Sivrikaya, 2022). Thus, each natural fire is a one-time and unique event, which is a very inconvenient object for study and influence. However, the long-term spatial distribution allows you to see the main trends and make a forecast for the future.

The aim of the work was to systematically (spatio-temporally) analyze the long-term values of the number of fires in the European territory of Russia, identifying areas of potential fire danger and determining the factors provoking this danger.

MATERIALS AND METHODS

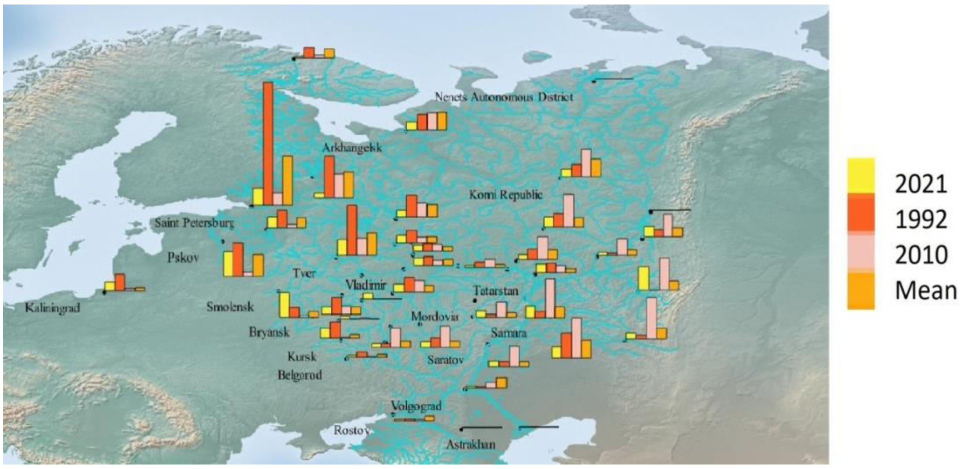
Forest fire management begins with its assessment. The Food and Agriculture Organization of the United Nations (FAO) defines a forest fire as uncontrolled human burning and spread of fire in a forest area (Yanets, 2019). This is a natural phenomenon that is difficult to extinguish and can take on catastrophic proportions (Dali, 2021).

The risk of a fire depends on the combination of fire hazard and ignition factors. In this paper, we will talk about the long-term variability in the number of forest fires and their regional distribution. Those at the first

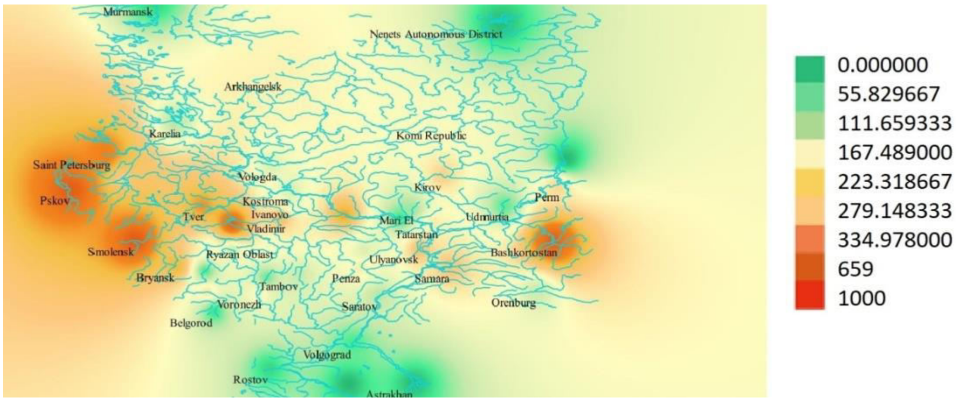
ARPN Journal of Engineering and Applied Sciences

stage, we answer the question of what is the trend in the number of fires and their territorial connection over the past decades; at the second stage, we analyze to what extent the interannual variability of fires depends on climatic factors. The aim of the study is not to make an accurate climate analysis for the study area, but rather to highlight general climate trends at the same regional scale as the fire information and analyze the variability of these data.

The paper collected and summarized data on the number of forest fires from 1992 to 2021 for all administrative districts of the European territory of Russia (Figure-1).



(a)



(b)

Figure-1. Long-term distribution of fires in the European territory of Russia (a) comparative diagram of the distribution of the number of fires in 1992, 2010, 2021 and the average value for the study period; (b) GIS model of the surface distribution of fires across the European territory of Russia for 2021.

The following data were used as initial material: data of the Ministry of Emergency Situations of Russia; EMISS (state statistics); Information system for remote monitoring of the Federal Forestry Agency; reports of the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet).

Geoinformation technologies (GIS) served as a tool for visualization and analysis, which made it possible to combine a large amount of heterogeneous information and identify certain patterns in the distribution of fires in the European part of the Russian Federation.

Geoinformation modeling in our project was carried out step by step. Initially, various types of data were collected: raster, vector files, quantitative and qualitative indicators, which were then entered into the geodatabase of the geographic information system. The next step was the processing, classification of data and the creation of a model for the distribution of the studied characteristics.

From a mathematical point of view, the construction of a continuous data distribution surface can be considered as an interpolation problem. In the classical approach, the unknown function is approximated by a parametric function, whose shape is specified in advance explicitly (polynomial) or implicitly (minimum curvature condition). The parameters are chosen so as to optimize some criterion of the best approximation of the values at the points, which can be statistical (least squares) or deterministic (exact match at the measurement points). Most of the existing interpolation methods are built into

VOL. 17, NO. 12, JUNE 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

modern GIS packages. The main ones are: IDW - inverse distance weightings method (weighted average values of neighboring points for a given number of neighbors or within a specified radius); Kriging (multi-stage selection of a mathematical function for a given number of points or for points within a given radius to spread dependencies to all points); Natural Neighbor (finds the closest subset of input samples to the requested point and applies weighted values to them based on proportional areas to interpolate the value); Bilinear (bilinear interpolation, where the value of a point in the new image is calculated using linear interpolation between the values of the four nearest points); TIN (a method when all the original points are connected by triangles, resulting in an irregular triangulation network) (Makhovikov and Pivovarova, 2015, Kuzmin *et al*, 2018).

In our case, the inverse distance weightings (IDW) method was chosen as the interpolation method. In the IDW method, evaluation points are determined by averaging the values of applicate points located in a certain neighborhood (http://gisgeography.com/qgis-arcgis-differences). The averaging process takes place taking into account the weight coefficients, and some inverse function of the distance from the reference point to the center of the raster cell is determined. Several parameters affect the result, such as the search range, the number of points involved in the analysis, and the weighting factor (Merem, 2010). The IDW interpolation process can be described in points:

a) Search for control points that satisfy the neighborhood criterion (number or distance).

b) Assign a weighting factor to each entered point. The larger it is, the more influence these points will have on the result.

c) Calculation of values.

$$\mathrm{ww}_{\mathrm{nn}} = [(\mathrm{x}_{\mathrm{n}} - \mathrm{x}_0)^2 + (\mathrm{y}_{\mathrm{n}} - \mathrm{y}_0)^2]^{(-\frac{\mathrm{p}}{2})}$$
$$zz = \sum(ww_{nn} * zz_{nn} / \sum ww_{nn})$$

where:
w_n - weight of points used for interpolation
z_n - value of the point used in the interpolation,
x_o, y_o - calculated point coordinates
p - weight coefficient,
z - value of the calculated point.

The method well processed a large initial amount of data and showed the result in a form convenient for perception.

RESULTS AND DISCUSSIONS

Thus, fire data and climate data were analyzed for the same region over the same time period (30 years). For comparative analysis, 1992 (the initial period of the study), 2010 (the year with the maximum values of fires), 2021 (the final stage of data processing) were selected. A GIS-project was made according to the values interpolated for the entire period of the study.

As a comparative analysis of distribution maps in 1992 and 2010 (the year with maximum summer temperatures over the period under consideration) shows, there is a clear tendency to shift the zones of the highest concentration of fires from west to east (Figure-2). We see a decrease in extremes in the North-West region and an increase in the number of fires in the Central region and the upper Volga region. In 2021, in general, there is a decrease in the number of fires in the European territory of Russia and a shift in the centers of high value to the Asian part of the country.

ARPN Journal of Engineering and Applied Sciences

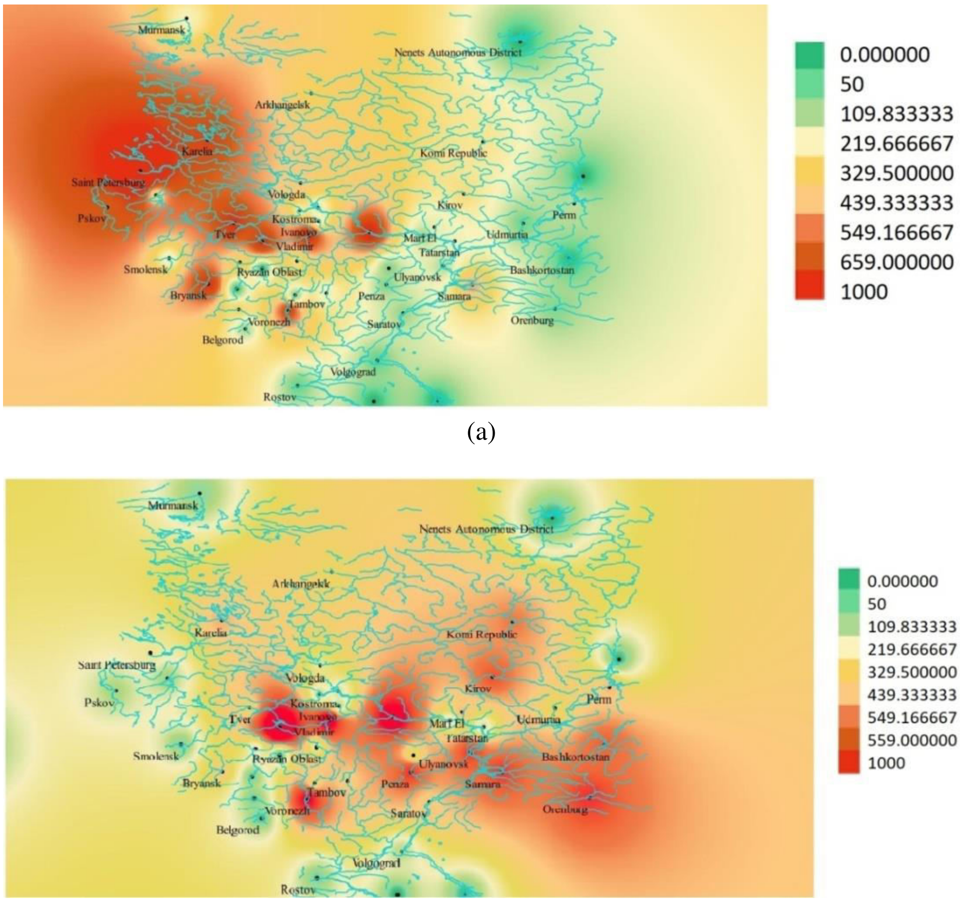


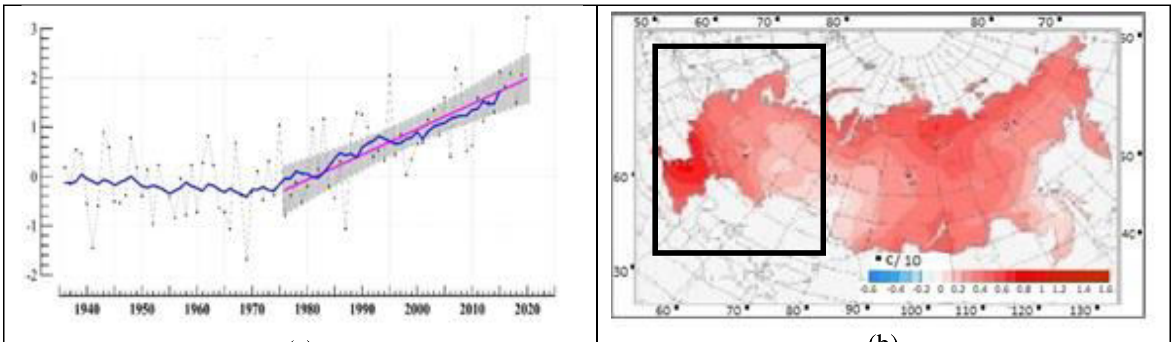
Figure-2. Distribution of the number of fires a) 1992 and b) 2010.

The fire distribution map for 2010 is especially indicative. In the summer of 2010, Russia experienced an abnormal heat wave, smog and the most severe forest fires. These cataclysms were caused by the abnormally long stay of the anticyclone in the European part of the country - from June 21 to August 19. For two months, the central part of Russia remained without precipitation; anomalously high temperatures were recorded on it, which had never been observed during the entire period of instrumental observations. During this period, the most fire hazardous days were from the end of July to mid-August, when up to 300 fires occurred per day, and on some days up to 400. On these days, over 5 thousand hotbeds of natural fires operated on the territory of the Central and Volga Federal Districts of the European territory of Russia (ETR) on a total over 300 thousand hectares. Thus, it is absolutely obvious that air temperature and precipitation are the main factors provoking a serious fire hazard.

If we analyze the maps of the distribution of average temperatures over the territory of Russia over a long period, we will see a clear correlation with fires. With an increase in solar radiation, conditions for ignition become more favorable and the number of fires increases. In general, in Russia, the air temperature is increasing (Figure-3(a)), however, in different regions, the average annual and seasonal growth is not the same. (Figure-3(b)).

VOL. 17, NO. 12, JUNE 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

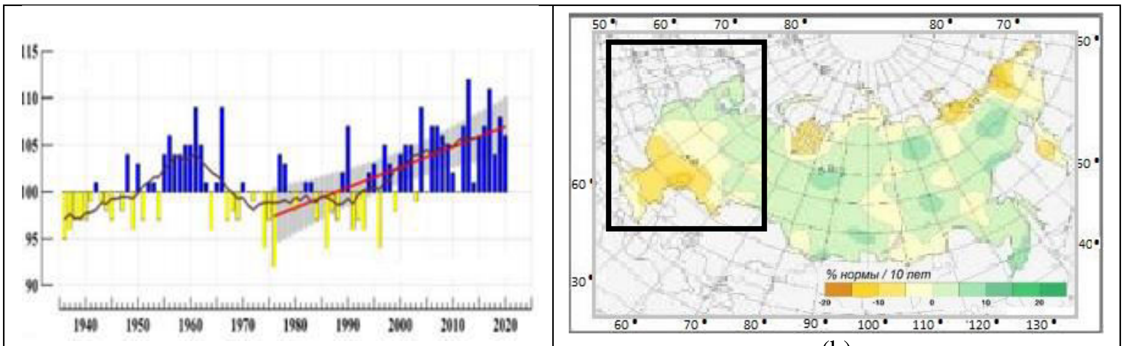
www.arpnjournals.com



(a) (b)

Figure-3. Temperature distribution (a) average annual surface air temperature anomalies, averaged over the territory of Russia, 1936-2020 Anomalies are calculated as deviations from the average for 1961-1990. (b) coefficient of the linear trend of seasonal values of surface air temperature on the territory of Russia for the period 1976-2020.

According to Roshydromet data, the growth rate of the mean annual temperature averaged over Russia (linear trend) was +0.51/10 years (55% contribution to the total variability). The fastest growth is observed for spring temperatures (0.66°C/10 years), but against the background of interannual fluctuations, the trend stands out most in summer (0.39°C/10 years: describes 64% of the total variance). The maximum summer warming is observed in the south of the European territory of Russia: (0.72°C / 10 years). Moreover, the rate of warming in ETR increases from north to south (http://meteorf.ru/upload/pdf_download/doklad_klimat2020.pdf). The second main climatic factor influencing the number of fires is precipitation. Here, unlike temperature, there is an inverse relationship, with an increase in precipitation, the risk of a fire decreases. According to the same report from Roshydromet, the trend towards an increase in annual precipitation prevails in Russia: the trend is 2.2% of the norm / 10 years, the contribution to the dispersion is 39% (the trend is statistically significant at the level of 1%). Figure-4 shows that a pronounced increase in annual precipitation has been observed since the second half of the 1980s (http://global-climate-change.ru/index.php/ru/bul-izmenenie-klimata/archive-of-bullet). However, the regional distribution is different. In the Central, Volga, Southern regions, the amount of precipitation decreases. In the North - West - increases faster than in Russia as a whole.



(a) (b)

Figure-4. Distribution of precipitation (a) Average annual precipitation anomalies (mm/month) averaged over the territory of Russia, 1936-2020. Anomalies are calculated as deviations from the average for 1961-1990. (b). Spatial distributions of local coefficients of the linear trend of seasonal precipitation sums for 1976-2020 on the territory of Russia (% / 10 years).

Thus, we can safely conclude that the northern regions of the European part of Russia are becoming warmer and rainier, which contributes to the non-proliferation of fires. In continental, drier areas, air temperatures and fires increase.

CONCLUSIONS

An analysis of a large amount of data for a statistically significant period of research allows us to make an unambiguous conclusion about the relationship between the regional coverage and the number of fires and climatic factors. That is, it may seem that, in general, the mechanism of the impact of meteorological factors on the risk of fires is quite simple: warmer and drier summers lead to larger fires. However, the relationship between weather conditions and fires is, of course, more complex. It is necessary to answer a number of questions on regional patterns. For example, where is the relationship between climatic features and fires most pronounced, in the northern or southern regions? It may be more prominent in northern (generally wetter and more productive) regions because in southern (drier) regions vegetation is better adapted to water scarcity. It is also very important to analyze the time intervals (for example, the duration of high temperatures and the absence of precipitation) that precede the occurrence of fires. This information could be of great help in making decisions on strategies for preventing and managing fires more effectively.

However, the spatio-temporal analysis carried out suggests that the main relationships reflecting the physical features of the meteorological conditionality of the occurrence and spread of fire in the forest, all other things being equal, were obtained. The results of the work are useful in terms of identifying suspected active fire hazards. In addition, the study shows the potential of GIS simulation as an effective tool for assessing when and where wildfires are most likely to occur and what preventive measures can be taken.

REFERENCES

Arkhiv byulleteney «Izmeneniye klimata» za 2009-2021 gg. Access mode: http://global-climate-change.ru/index.php/ru/bul-izmenenie-klimata/archive-of-bullet.

Dali F. A. 2021. Teoriticheskie osnovy postroenija risk-orientirovannyh modelej upravlenija pozharoopasnymi sobytijami. Inzhenernyj vestnik Dona. 9. Access mode: http://ivdon.ru/uploads/article/pdf/IVD_33__7_Dali_F.A..pdf_eceebc6f7c.pdf.

Doklad ob osobennostyakh klimata na territorii Rossiyskoy Federatsii za 2020 god. 2021. Federal′naya sluzhba po gidrometeorologii i monitoringu okruzhayushchey sredy: ofitsial′nyy sayt. 104 p. Access mode: http://meteorf.ru/upload/pdf_download/doklad_klimat2020.pdf.

Kostarev S. 2020. Klimaticheskiy krizis 2020 v Rossii: tayushchaya zemlya i lesnyye pozhary. Access mode: http://nangs.org/news/ecology/klimaticheskiy-krizis-2020-v-rossii-tayushtaya-zemlya-i-lesnye-pozhary.

Kuzmin V. et al. 2019. Method of prediction of the stream flows in poorly gauged and ungauged basins. Journal of Ecological Engineering. 20(1): 180-187.

Makhovikov A. B., Pivovarova I. I. 2015. Free data use for designing GIS-projects in the ecology students training course. Journal of Engineering and Applied Sciences. 10(8): 257-265.

Merem E, Robinson B, Wesley J. M, Yerramilli S., Twumasi Y. A. 2010. Using GIS in Ecological Management: Green Assessment of the Impacts of Petroleum Activities in the State of Texas. Int. J Environ Res Public Health. 7(5): 2101-2130.

Pausas J. 2014. Changes in Fire and Climate in the Eastern Iberian Peninsula (Mediterranean Basin) Climatic Change. 63(3): 337-350.

Sivrikaya F. and Küçük Ö. 2022. Modeling forest fire risk based on GIS-based analytical hierarchy process and statistical analysis in Mediterranean region. Ecological Informatics. 68 Access mode: https://doi.org/10.1016/j.ecoinf.2021.101537.

The Differences between QGIS and ArcGIS.2017. GIS Geography. Access mode: http://gisgeography.com/qgis-arcgis-differences.

Turco M. et al. 2018. On the key role of droughts in the dynamics of summer fires in Mediterranean Europe. Scientific Reports. 7: 81-95. Access mode: https://doi.org/10.1038/s41598-017-00116-9.

Yanets P. K., Gadal S. ZH., Ivanova S. A. 2019. Modelirovaniye riska lesnykh pozharov v Respublike Sakha (Yakutiya) metodami GIS. Uspekhi sovremennogo yestestvoznaniya. 11:37-42. Access mode: https:// natural-sciences.ru/ru/article/view?id=37237.