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Mathematical Modeling of Human Activity on Forested Areas from Point Objects of Railway Infrastructure in a Two-Dimensional Statement

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Abstract – *Human activity causes a large quantity of wildfires in areas close to the location of different industrial or transport infrastructure. All the infrastructure facilities of JSC Russian Railways may be classified into linear, point and area sources of human activity. This work purpose is to suggest an approach for predicting, assessing, and monitoring the human activity on forested areas based on a deterministic mathematical model. Partial differential equations have been solved using the finite difference method. The program realization is executed in the RAD Studio software. Expressions like the heat conduction equation are used to describe the propagation of human activity around railway facilities. Different railway objects have produced different distribution of the virtual (possible) number of forest fires (VNF) caused by the different level of human activity. Different sizes of the railway facilities have also showed that a highest VNF is predicted for large one. The proposed mathematical model is applicable to predict wildfires due to human activity. This paper discusses the possibility of predicting forest fire dangers near point infrastructure facilities of JSC Russian Railways. The results obtained are part of a large project aimed to develop methods for predicting, assessing, and monitoring forest fire danger near infrastructure facilities of Russian Railways.* ***Copyright © 2022 The Authors.***

Keywords: *Human Activity, Mathematical Model, Point Source, Virtual Number of Forest Fires, Forest Fire Danger, Railway*

Nomenclature

A	Coefficient that characterizes the propagation speed of ignition sources [m^2/s]
α_1	First left running coefficient
β_1	Second left running coefficient
CWFIS	Canadian Wildland Fire Information System
EFFIS	European Forest Fire Information System
φ	Angular coordinate, [angular degree]
FWI	Fire Weather Index
h	Spatial step [m]
ISDM-Rosleskhoz	Information System for Distant Monitoring of forest fires
N^*	Virtual number of forest fires
N	Number of nodes in x-direction
M	Number of nodes in φ-direction
OJSC	Open Joint Stock Company
RAD Studio	Rapid Application Development Studio
r	Radial coordinate [m]
t	Time [s]
T_i	Temperature of the forest fuel in the point of the i-th layer [K]
WFAS	Wildland Fire Assessment System

I. Introduction

Human activity leads to the initiation of a large quantity of wildfires in areas close to the location of different industrial or transport infrastructure [1], [2]. For example, the anthropogenic impact of the railway infrastructure leads to the initiation of wildfires within adjacent forested areas [3], [4]. All the infrastructure facilities of JSC Russian Railways can be classified into linear, point and area sources of human activity [5]. As a point source, there can be railway stations, substations, and wayside stops located in forested areas. Usually human activity is considered as a stochastic process [6].

However, this work proposes an approach for assessing the human activity on forested areas based on a deterministic mathematical model. By considering all the variety of mathematical models, it is proposed to formulate a deterministic mathematical model of the human activity, taking into account the similarity of the spread of human activity and the heat transfer process [7]-[9]. Such a mathematical model is applicable to estimate the VNF within forested areas, caused by human activity from the railway facilities. The VNF

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characterizes the predicted or the expected number of wildfires in the nodes of the computational grid covering controlled forested area [10]. It should be noted that this number would correspond only at certain points according to the actually recorded number of wildfires [11]. Therefore, the VNF does not show the real quantity of wildfires, but this number shows the human activity grade. The greater the VNF is, the higher the level of human activity is. Human activity describes the influence of the population movement across the forested area in the context of forest fire initiation. The presence of humans in forested area corresponds to the presence of fire sources in this forested area. Actually, human activity refers to human-caused wildfires. VNF is the virtual number of fires. Mathematically, VNF is an analogue of temperature in heat transfer problems. The averaged value of VNF within forest site or/and quarter will correspond to the real predicted number of fires for this forest site or/and quarter.

The rest of the article is organized as follows: II. Background, III. Materials and Methods, IV. Results and Discussion, V. Conclusion. The current published results on forest fires and anthropogenic load are described in the Background section. The study area and the mathematical method and procedure are described in the Materials and Methods section. The key findings and the obtained dependences are described in the Results and Discussion section accompanied with some considerations and discussions. The summary of the research and further developments are described in the Conclusion section.

II. Background

Because of wildfires, environmental, societal, and economic damages occur [12]. Preventing wildfires is impossible without predicting their occurrence [13]-[15].

In Canada, forest fire predicting is carried out through the Canadian Forest Fire Information System (CWFIS) [16]-[20]. This system is also used in some regions of the United States. The American system (WFAS) [21], [22] makes it possible to predict forest fire danger due to lightning and human activity [23]. The forest fire danger characteristics are expressed in dimensionless quantities. Dimensionless indicators use scales of various fractionalities (hundredths, twelve-, five-point). Some subsystems use partial scale range, less than 80%. The European Forest Fire Information System (EFFIS) has been originally built on a complex of South European Indices [24], [25]. Later, the Canadian Wildfire Weather Index System has been incorporated to predict the occurrence of wildfires in Europe. The information system for remote monitoring of forest fires (ISDM-Rosleskhoz) [26] was developed in 2003 (Podolskaya et al., 2011) [27]. Earlier, probabilistic criteria have been developed for predicting the probability of wildfires caused by lightning and human activity [28]-[30].

Urbanization and recreational pressure are the main causes that lead to forest change [31], [32]. The authors of [32] have analyzed the socio-psychological reasons for visiting forests and the occurrence of fires. It has been found out that with an increase in the distance from the settlement, the population impact decreases [33], [34] corresponding to Rayleigh and Poisson dependences [35]. Among the factors under consideration for the occurrence of wildfires there are, e.g., the density of roads and railways, the distance to an urbanized area, the distance to the city, population density, etc. [36].

Accordingly, in forests with a higher population density, roads, and railways, the fire danger is also higher. The influx of vacationers and hunters increases the summer maximum of fires associated with the distance from settlements and transport infrastructure [33], [37], [38]. It has been found out that the distribution of wildfires, depending on the distance from the transport infrastructure, is often described by an exponential function [35]. The frequency of wildfires in Catalonia (Spain) was estimated from 1975 to 1998 [39]. Remote sensing data have identified forest fires with an area of more than 30 hectares, ensuring the determination of the parameters of the wildfires distribution over forested areas in Catalonia. In order to analyze data for the interval under consideration, various models of the frequency of wildfires have been used: the period of natural fire succession (NFR), the Poisson Process Model (PPM), and the average interval of fires (MFI). The simplest of them, NFR, allows determining how many years it will take to cover by fire the forested area comparable to the investigated one. In some areas of the forest, repeated fires have been recorded. In [40], a model for estimating fire danger has been considered within the country of Daiu, China. A genetic algorithm has been used to assess forest fire danger [41]. The work has been carried out through the following steps: a) determination of the location of forest fires; b) selection and classification of parameters using the natural partitioning method [42], multicollinearity analysis [43], weighted estimation of individual classes of parameters using the confidence factor method, creation of data for training and normalization of parameters; c) the use of a genetic algorithm; d) Application of Random Forests [44] and Support Vector Machine [45] methods, visualization of forest fire danger data, and verification of the proposed methodology. Such parameters, such as the use of the territory, the distance to the road network, the distance to the river network are taken into account. Remote sensing data from Aster and Landsat satellites have been used as one of the data sources. In [46], an analysis of the influence of human activity on the initiation of wildfires in the Mississippi region (USA) has been presented. The dataset on temporal, spatial, social, and economic characteristics in the initiation of 52,532 wildfires as a result of human activity have been analyzed. The period of occurrence of forest fires from 1991 to 2005 was analyzed. Ignitions from equipment, children, and burning particles are more frequently than fires near roads and railways as reported in statistics.

Eleven parameters are selected to calculate the probability of seven types of wildfires caused by human activity. The time of the year and the weekends have been considered as temporary variables. Spatial variables have been analyzed using a geographic information system in order to estimate distances to roads, railways, and settlements. Population density has been also considered as a parameter. Socio-economic characteristics like income, poverty, and unemployment have been also considered. The transport network has been linked to forest fires driven by human activity. For example, it has been found out that increasing the distance from the road network by 1 km reduces the probability of wildfires. In [47], the initiation of wildfires in Spain has been analyzed from the point of view of the relationship between climatic and anthropogenic variables. The following climatic parameters have been considered: mean monthly temperature and precipitation [48], [49]. These characteristics have been presented with a spatial resolution of 10 × 10 km. This data has been obtained using the Spanish Meteorological Network from 1951 to 2010. The following data have been used as parameters of human activity: land use, population, and human factor index. The principal component analysis has been used to process these data [50] in combination with the Varimax procedure [51]. In addition, regression analysis methods have been used. Data processing has showed that most of the fires occur in summer, regardless of the study region. It has been found out that the human pressure index is an important indicator of the wildfires initiation. In [52], the leading factors of the wildfire initiation due to lightning and human activity within the region of the Great Xin'an Mountains (China) have been considered. The data for the period from 1967 to 2006 have been analyzed. Statistical data have included information on the reason of wildfires, the place, and the date of wildfires, the area of the fire and the date of its suppression, and the type of vegetation. Two groups of forest fires have been considered. In one group, forest fires have been considered as a result of lightning activity, and in the other one, as a result of the human factor. The meteorological data have been also analyzed. According to [53], [54], the population of this region increased from 30,000 to 116,000 between 1964 and 1968. From 1969 to 1986, 787,000 people arrived and 599,000 left the region. In the period from 1987 to 1997, the number of inhabitants remained relatively stable with an annual growth rate of 2%. From 1998 to 2011, the annual population growth was 0.04%, resulting in a population of 516,000 by the beginning of 2011. The regression analysis has showed that the maximum temperature in the fire season has a significant effect. In [38], the spatial aspects of fires caused by human activity in the Yunnan province (China) have been analyzed. The following parameters have been analyzed: distance from roads and railways, population density, tourist sites and farms [55]-[57]. The road network of the region has been divided into two groups: a) main roads; b) minor roads.

The main roads have been national roads, highways, provincial roads, and railways. The second group has consisted of village roads and paths. These have been linear objects. Point sources of human activity have been also presented: urban-type settlements (city, village, township) and villages. In addition, the consideration has included water bodies, including hydroelectric power plants and tourist centers. For data analysis, the basic principles of the theory of probability have been used [58]. Wildfire mapping has been done in ArcGIS software. The final risk has been assessed in four categories: low, medium, high, very high predictable risk. It has been revealed that the maximum human activity is observed within 5 km from roads and settlements. The greatest risks are associated with roads, water bodies, and farms. As a result, a probabilistic model has been developed to predict the occurrence of forest fires. The purpose of the article is mathematical modeling of the human activity from a railway station applicable to forest fire danger predicting.

III. Materials and Methods

For the Republic of Buryatia, the problem of forest fires becomes urgent every year. Many researchers pay attention to the study of the features of the occurrence and spread of fires in Buryatia, and also study the sources of their occurrence [59]-[68]. The fire dangerous season in Buryatia begins from the moment the snow cover in the forest melts and it goes on until the onset of stable rainy autumn weather. The most fire dangerous months in the Republic are the second part of May, June and the first part of August, and during the autumn period [69].

The Republic of Buryatia occupies a large part of the Baikal region. Forests in Buryatia occupy an area of 29.6 million hectares or 84.4% of the region's area. Most of the forests (about 75%) belong to the most fire dangerous forests (I – III classes), and to the I class - almost one third. The class of a forest is defined in the Russian Frderation according to Melekhov scale and Nesterov Index. The plots of the forests of classes IV and V can be exposed to fires during periods of prolonged droughts [70]. Among natural emergencies, forest fires in the Republic account for more than 90% of the damage in the form of a reduction in forestry resources [60]. In 2015, 16% of fire cases in the Republic of Buryatia were caused by dry thunderstorms (in July - 36%, in August - 62% of the whole number of wildfires). In 2016, the release of the southern cyclone was observed on July 9-10 with heavy rains in places, thunderstorms, and a decline in heat. The first thunderstorm of 2019 was noted on April 26 in Tsakir, Zakamensky district, in May - 5 cases. On average, in the Republic of Buryatia, 118.3 thousand hectares of forests are destroyed every year, which is 0.6% [60]. The length of communication lines in the Republic of Buryatia (at the end of the year; kilometers) is 1227 km. The ratio of public railways, (km of tracks per 10,000 sq. km of territory) is 35 km [71].

The railways of the Republic of Buryatia are represented by a network of public railways (East Siberian Railway - a branch of the Russian Railways

OJSC) and industrial railway transport. The Trans-Siberian Railway runs from west to east; its length within the Republic of Buryatia is 1293 km. From it, in the southern direction, there is a branch to the border with Mongolia in the area of Naushki station. The section of the Ulan-Ude - Naushki railway has a length of 256 km, departing from the Trans-Siberian Railway after the station. Zaudinskaya, within the city of Ulan-Ude, was built in 1939 and it has not been electrified yet. The station is one of the leading railway crossings for the transport of goods to the People's Republic of China and Mongolia. The territories of the northern regions are crossed by the Baikal-Amur Mainline, whose Buryat section is currently part of the East Siberian Railway, a branch of the JSC Russian Railways. The length of the section is 1856 km. The construction of the railway was completed in December 2003 with the opening of the Severomuisky tunnel, which made it possible to organize through traffic along the Baikal-Amur Mainline. There are 49 railway stations and stations in the Republic of Buryatia. The level of wear on public railway tracks is 60% [72]. Dynamics of fires on locomotives are presented in Figure 1. Such fires can produce some quantity of wildfires [73]. The program realization is implemented in the RAD Studio software (computational procedure is presented in Fig. 2). Expressions like heat conduction equation are used to describe spread of human activity over controlled forested area around railway station. Partial differential equations have been solved using the finite difference method. The main idea of this method is that instead of partial derivatives in the equation, their finite-difference approximations should be used. Therefore, the study region is represented as a set of nodes (finite-difference mesh). A finite difference representation of the boundary conditions also is used.

As a result, the closed system of the linear algebraic equations is solved by numerical methods using a computer. When realizing this method, implicit four-point difference pattern has been used. According to this pattern, it is necessary to take into account three points on the new temporal layer of scheme and one point from the previous temporal layer.

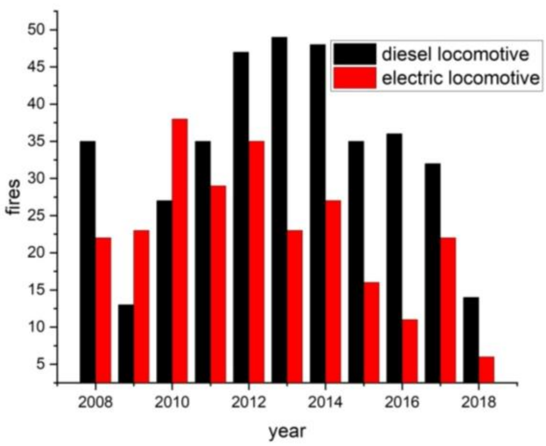


Fig. 1. Dynamics of fires on locomotives within Republic of Buryatia (Russian Federation) [73]

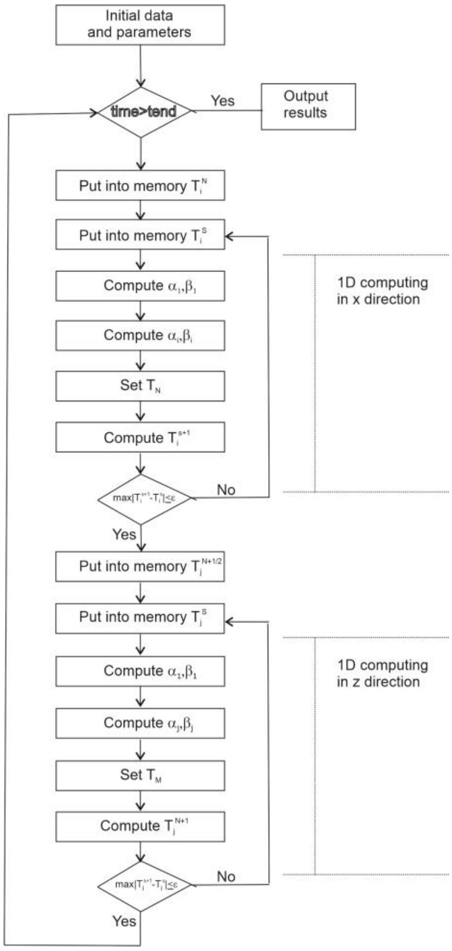


Fig. 2. Computational procedure [77]

In this scheme, the temperature field is presented in implicit form. This scheme is used quite frequently, because of its stability [74]-[76]. A short description of the procedure for computing is done as follows.

Computational procedure is implemented using RAD Studio high-level programming language Delphi. The first step is a setting-up of parameters and initial conditions. For these purposes, computing software uses constants and variables with fixed values. During this step, spatial and temporal mesh is also constructed using uniform discretization for spatial and temporal coordinates. 100 nodes have been used for each direction. In order to determine this parameter, computation on condensing mesh sequence has been conducted. The next step is used to organize computational circle within definite period consisting of two sub-circles in order to calculate VNF in r and φ directions at the condition when another spatial coordinate is fixed. Computational circle with pre-condition is used. The following condition has been used: current time variable value is equal or greater than the ending time of calculations. In fact, the first and the second sub-circles are calculated VNF using a group of one-dimensional tasks of mathematical physics in r and φ directions. Each sub-circle is a circle with parameterization (Delphi uses Object Pascal language constructions). By following the algorithm, each one-dimensional task should be presented as a systematic procedure consisting of forward and backward run using marching method. Forward run is started using initialization of first running coefficients according to corresponding boundary conditions. During the next step, other running coefficients are computed using variables of finite-difference analogue of partial differential equation. At the end, corresponding boundary condition should be used to set up last value of VNF in forward run. Backward run is presented by circle with downward parameterization. In order to take into account possible non-linearity of partial differential equations, simple iteration method is used at the each temporal step. In order to organize the iteration circle, computational circle with parameterization is used. After computing the parameters of the task, the obtained array of VNF is written in the data file (for example, text formatted data file), that can be analyzed and visualized in Origin Pro software. A model forest-covered, typical for the forests of the Republic of Buryatia (Russian Federation) area, is considered. A part of the Trans-Siberian railway runs through the Republic of Buryatia, which is operated by JSC Russian Railways [78]. As mentioned earlier, the infrastructure facilities of JSC Russian Railways are sources of human activity on controlled areas. For example, linear and point sources of human activity can be identified. An example of a linear source of human activity is a railway track running in a forest. An example of a point source of human activity is a railway station, a substation, or a wayside stop. As a rule, woodlands are located around such a station, through which forest roads and trails pass. These transport and pedestrian canals are the main route of the anthropogenic pressure spreading around the railway station. In addition, a person can move directly through the forest. This is especially true for mushroom pickers, berry pickers, and hunters.

Because of the movement of people from the railway station deep into the forest, the human activity is distributed over the adjacent territory and forest fires are possible for various anthropogenic reasons. As already noted, the bulk of the works is devoted to the assessment of anthropogenic fires as a stochastic process [6].

However, in [32], it has been found out that when visiting a forest area, people are characterized by the same patterns in decision-making. This fact makes it possible to question the stochastic nature of the human activity on forested areas. This paper proposes a deterministic mathematical model of the human activity spread based on the similarity of the spread of human activity and heat transfer processes. Such a similarity is considered an axiom within the framework of a new approach being developed to predict the spread of human activity. Mathematically, the process of propagation of human activity can be described by a partial differential equation of mathematical physics with the corresponding initial and boundary conditions. Moreover, a non-stationary equation is considered, which makes it possible to take into account the change in human activity in time and space. As a quantitative characteristic of human activity, the concept of the VNF is introduced.

This parameter shows the predicted, expected number of wildfires. The level of human activity is increased with the growth of the VNF. Mathematically, the suggested similarity of heat transfer and human activity spread is used. VNF is mathematical analogue of temperature in heat conduction problems. The definitions of the derivatives are the same as in heat conduction problems. The decision area is shown in Figure 3. The equation of human activity spread is:

$$\frac{\partial N^*}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(rA\frac{\partial N^*}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \phi}\left(A\frac{\partial N^*}{\partial \phi}\right) \qquad (1)$$

The boundary conditions are:

$$r = 0, \quad N^* = N^*_{r_0} \qquad (2)$$

$$r = R, \quad A\frac{\partial N^*}{\partial r} = 0 \qquad (3)$$

The periodic boundary conditions along the φ coordinate can be used, or in a symmetrical setting:

$$\phi = 0, \quad A\frac{\partial N^*}{\partial \phi} = 0 \qquad (4)$$

$$\phi = \pi, \quad A\frac{\partial N^*}{\partial \phi} = 0 \qquad (5)$$

The initial conditions are:

$$N^*(r,\phi)\big|_{t=0} = N^*_0(r,\phi) \qquad (6)$$

In this study, a GIS-system based on proprietary programming code and the Origin Pro software has been used to visualize computed VNF [79]. Delphi high level programming language is applicable to create specific program unit for computing anthropogenic pressure level using RAD Studio by Embarcadero [80].

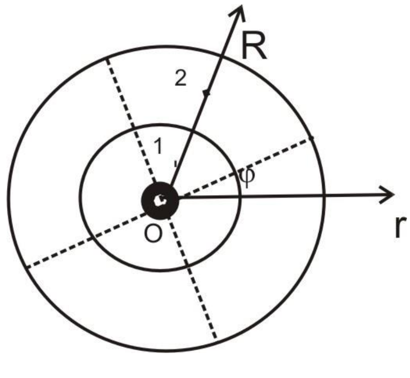


Fig. 3. Decision area [10]

This unit is the console application working in dialog mode. Origin Pro software can provide more cheaper decision in order to visualize and analyze the predicted data on VNF in comparison with other systems to construct GIS. This software package also provides advanced possibilities to analyze and process predicted data using suggested GIS-system. The use of Origin Pro is a good idea because local forestry maps are not geo-referenced and Origin Pro is compatible with MS Excel.

Moreover, Origin Pro software is applicable for statistical data analysis and approximation accompanied with data visualization of wildfires and forest fire danger and human activity parameters. This system uses deterministic mathematical simulation instead of ones based on rules or knowledge with artificial intelligence [81], [82]. Moreover, high performance computing is applicable to faster processes of predicting, monitoring, and assessing forest fire danger using deterministic approach rather then stochastic methods. GIS systems underlie geoinformatics, which studies natural and socio-economic geosystems taking into account various hierarchical levels through computer processing of the created databases and knowledge bases [83]. GIS-systems simulate the processes occurring in the studied geosystem [84],[85]. It should be noted that information processing could be carried out using existing software products, or using original techniques and computer programs. The general definition of GIS is as follows: a geographic information system is an interactive information system that provides collection, storage, access, display of spatially organized data and that is focused on the possibility of making scientifically grounded management decisions [83]. According to the territorial level, GIS refers to local ones with the following coverage of the territory - 102 - 103 km^2 [83].

GIS includes generation of new information based on the synthesis of existing data, display of spatiotemporal connections of objects, support for decision making, ability to promptly update databases due to newly received information.

IV. Results and Discussion

In order to analyze the processes of the human activity from a point source, it is proposed to use scenario modeling [86]. First, it is necessary to highlight the various sources of human activity based on the analysis of data on the railway infrastructure in the Russian Federation.

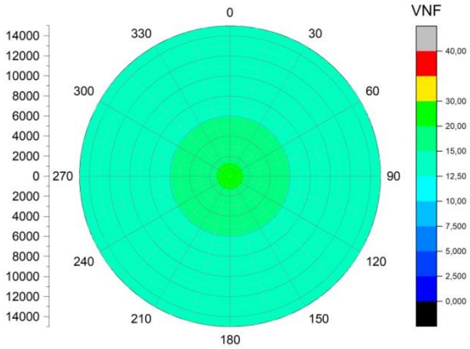
The following point sources of human activity can be identified: railway stations, substations, and wayside stops. The level of human activity should be maximum for a railway station and minimum for a wayside stop.

Secondly, two options for the impact of a point source on the forested area should be considered, namely, the impact in a circle of 360° and a semicircle of 180°. The first option is typical for a railway facility located in a forested area. In such a situation, people can move in all the directions relative to a point object. The second option is characterized by the location on one side of a point source of a natural barrier for the spread of human activity or the absence of forests. For example, on one side of a point source there is a large body of water or a mountain range. The third group of scenarios is due to the different periods of the spread of human activity. It is believed that the highest anthropogenic pressure is observed at noon and later. Therefore, the period of local time from 6 am to 4 pm is considered. Thus, the estimated exposure time of a point source will vary from 0 to 10 hours. Tables A1-A3 provide descriptions of model scenarios for a railway station, a substation, and a wayside stop, respectively. Parameter A, represented in Tables A1-A3, indicates the propagation of human activity through the controlled area. This parameter applicable for characterizing the properties of forest within decision area like thermal diffusivity is responsible to the characteristics of material during heat conduction [87], [88]. Different types of point sources, namely, railway station, substation and wayside stop have been marked out taking into account characteristic object sizes (small, medium and large) using definite VNF in the boundary conditions in the centre of circle represented decision area. The VNF for different sizes of railway station produced human activity during 10 hours around 360° is shown in Figures 4. The VNF for different sizes of railway substation produced human activity during 10 hours around 360° is shown in Figures 5. The VNF for different sizes of railway wayside stop produced human activity during 10 hours around 360° is shown in Figures 6. The VNF for different sizes of railway station (a), substation (b) and wayside stop (c) produced human activity during 10 hours around 180° is shown in Figures 7. As a result of the analysis, different railway objects have produced different distribution of the VNF caused by the different level of human activity. Namely, railway station situated in the forest leads to highest level of anthropogenic pressure. Substation has produced a moderate level of anthropogenic pressure while wayside stop leads to low level of human activity according to the predicted VNF. Different sizes of the railway object have also showed that a highest VNF is predicted for large one.

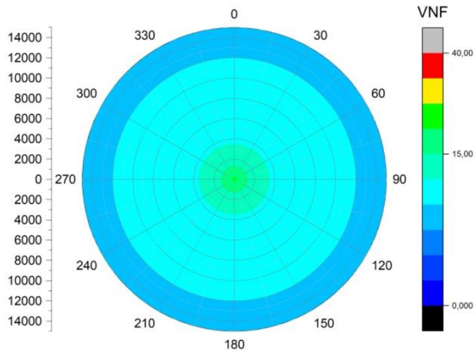
Medium and small sized railway objects cause moderate and lower grade of anthropogenic pressure. Parameter A has been fixed during computational experiments.

This means that the forested territory with the same characteristics has been considered for more corrective scenario simulation. It should be postulated that further computational scenarios should be devoted to study of decision areas with different characteristics.

Predicting the VNF around railway object is highly significant task for firefighter services. Wildfires near the railway objects can be detected within short time interval while wildfires detection in the remote areas is a more difficult task. This reason may lead to hard suppression of wildfires in this case [89]. 2nd type boundary conditions have been used in this study.



(a)



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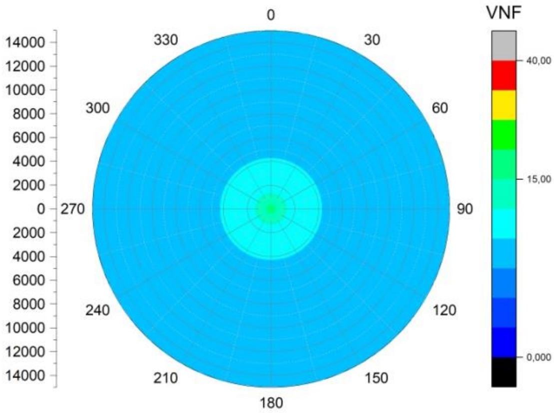
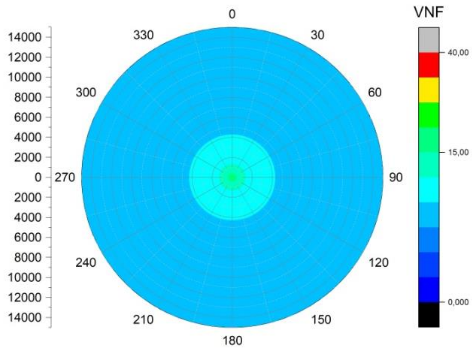
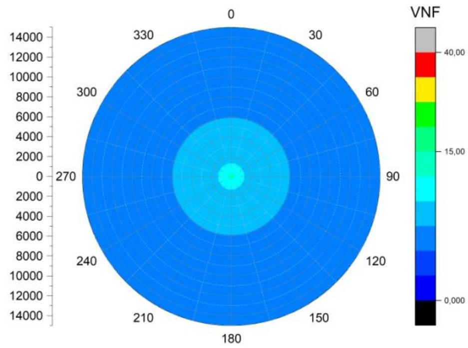


(c)

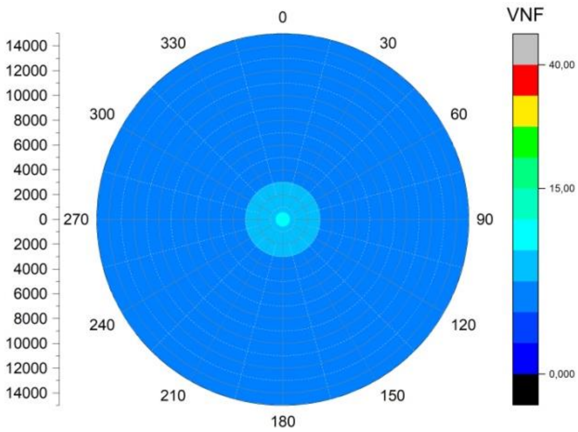
Figs. 4. The VNF for a railway station: (a) large; (b) medium; (c) small



(a)

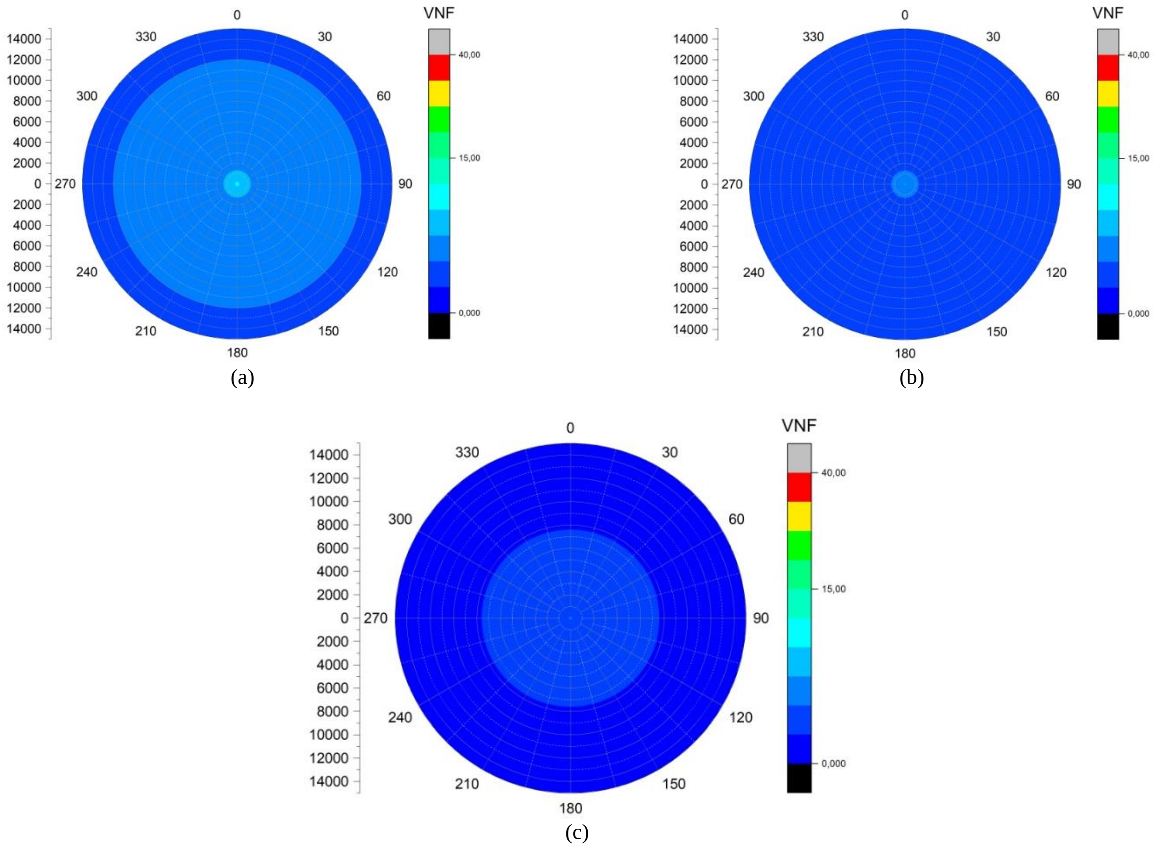


(b)

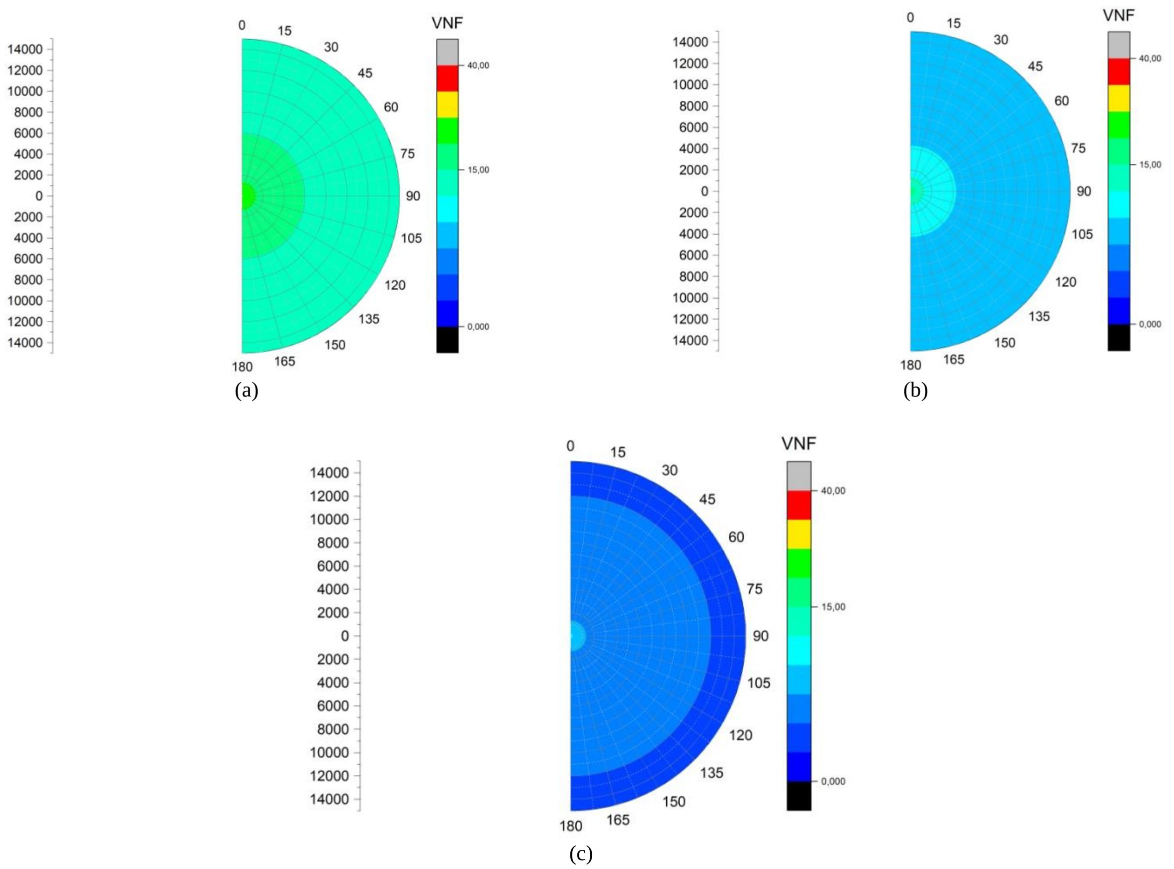


(c)

Figs. 5. The VNF for a railway substation: (a) large; (b) medium; (c) small



Figs. 6. The VNF for a railway wayside stop: (a) large; (b) medium; (c) small



Figs. 7. The VNF for a large railway station, substation and wayside stop

Further developments of the mathematical model should be aimed to analysis of influence of different boundary conditions on the predicted VNF in context of recorded number of wildfires within considered forested territory. Moreover, non-uniform two-dimensional dependences of the VNF should be subjected to analysis in further research. In addition, changeable parameter A can lead to different results obtained. At present time, boundary conditions of first type in the inner boundary of study area have been used. Therefore, VNF is equal to the constant value at this boundary. This means unchangeable boundary value of VNF at this boundary r=0. Further developments also will consider boundary conditions of second and third types and its physical interpretations. At present time, this new approach is in the initial stage. At the outer boundary r=R boundary condition of second type with zero flux has been used to simulate impermeability at this boundary for human activity. This means analogues with thermal insulation conditions. The periodic boundary on angular coordinate has been used for circle of 360 degrees within study area. In order to resolve these boundary conditions, the cyclic marching method suggested by Samarskiy A.A. has been used. Equations (4) and (5) have been used to simulate 180 degrees study area. There are many examples of using correctly these boundary conditions in the heat and mass transfer problems, e.g. devoted to tree ignition by the cloud-to-ground lightning discharge published, for example, in the book [10]. Thus, this paper presents a theoretical study of a mathematical approach to predict human activity in forested areas in the context of forest fires initiation. A two-dimensional deterministic mathematical model is proposed to determine the VNF as a result of human activity. Mathematically, the spread of human activity is described by a non-stationary partial differential equation of parabolic type with appropriate initial and boundary conditions. The work has been carried out on the example of a point source of human activity, which can be represented by railway objects.

Subsequent studies will consider the impact of the heterogeneity of the forested area on the spread of human activity from a point source. Varying the coefficient A will provide an opportunity to model inhomogeneous areas around a point source by applying a geometric decomposition of the solution domain and boundary conditions of the fourth kind at the boundaries of the territory with different coefficients A. As a result of such modeling, two-dimensional non-uniform distributions of the VNF in the controlled forest-covered area can be obtained. Another problem that should be solved in subsequent studies is the development of a physical justification for boundary conditions of the second and third kind in relation to the problem of modeling the spread of human activity. In addition, a theoretical study of the influence of the boundary conditions of the second and third kind on the obtained distributions of the VNF is necessary. It should be separately specified that it is also necessary to develop mathematical models of the spread of human activity for a linear and area source of human activity. It is proposed to simulate a linear source by setting the parameters of its influence on the boundary of the computational domain, represented in Cartesian coordinates, by means of boundary conditions of various types. Initially, it is planned to consider a symmetrical setting, when human activity is to the left and to the right of the linear source of human activity. The study area can also be represented taking into account structural heterogeneities caused by different values of the coefficient A. An area source can be represented by a sufficiently large object of human activity, which can no longer be displayed on an electronic map as a point and it is necessary to take into account the actual size of this source of human activity. Geometrically, an area source can be represented by a sub-domain of finite dimensions in the solution area with a given value of the VNF within this area. In the software implementation of the mathematical model for the area source, it will use the assignment of the values of the VNF within the area of the area source, ensuring that its effect on the adjacent territory is taken into account by means of boundary conditions of the fourth kind. It is important to note that this paper deals with a single source of human activity. In a real situation, the geometry of the solution area can be represented by a set of inclusions, which also represent various combinations of sources of human activity. For example, all the three sources of human activity, point, linear and area, can be simultaneously present in the study area. A typical example of such an area would be a large settlement, from which a railway with periodically located railway stations leaves. In this case, a large settlement will represent an area source of human activity, while a railway station and a railway will represent point and linear sources, respectively.

Geometrically, the area of investigation can be split into different subareas to use polar or Cartesian coordinates. In this case, it is necessary to ensure the stitching of solutions for sub-domains with different coordinate systems. Ultimately, the distribution of the VNF over the research area will be determined by the superposition of various sources of human activity.

V. Conclusion

Thus, as a result of this study, a new deterministic mathematical model to simulate human activity spread on forested areas has been developed using similarity of heat transfer and human activity. A mathematical formulation is formulated using a non-stationary partial differential equation of mathematical physics with corresponding initial-boundary conditions. Fully ready mathematical model for spatial and temporal modeling of human activity is suggested. Non-uniform 2-dimensional field of VNF will be used in further scenarios and real statistical data (another paper will be devoted to analysis of wildfires in real study area and some proofing of suggested model). In addition, different boundary conditions should be investigated theoretically before proofing the model with real data on wildfires. Scenario modeling has been carried out for various point sources of human activity, namely, a railway station, a substation, and wayside stop. Moreover, modeling has been carried out for scenarios of large, medium and small sizes of a specific point source. As a result of modeling, it has been found out that the highest VNF is typical for a railway station. The lowest VNF is typical for the wayside stop. In turn, the substation is characterized by moderate VNF. The impact of a natural barrier in modeling the human activity on forested areas was also demonstrated. The proposed mathematical model is applicable to predict wildfires due to anthropogenic pressure. This paper discusses the possibility of predicting forest fire dangers near point infrastructure facilities of JSC Russian Railways. The results obtained are part of a large project to develop methods for predicting forest fire dangers near infrastructure facilities of Russian Railways.

Appendix

TABLE A1
MODEL CHARACTERISTICS FOR THE RAILWAY STATION

N scenario	Source	VNF_L	A	t_{end}	Type
1	Station	40	10 000	2	360
2	Station	40	10 000	4	360
3	Station	40	10 000	6	360
4	Station	40	10 000	8	360
5	Station	40	10 000	10	360
6	Station	30	10 000	2	360
7	Station	30	10 000	4	360
8	Station	30	10 000	6	360
9	Station	30	10 000	8	360
10	Station	30	10 000	10	360
11	Station	25	10 000	2	360
12	Station	25	10 000	4	360
13	Station	25	10 000	6	360
14	Station	25	10 000	8	360
15	Station	25	10 000	10	360
N scenario	Source	VNF_L	A	t_{end}	Type
1	Station	40	10 000	2	180
2	Station	40	10 000	4	180
3	Station	40	10 000	6	180
4	Station	40	10 000	8	180
5	Station	40	10 000	10	180
6	Station	30	10 000	2	180
7	Station	30	10 000	4	180
8	Station	30	10 000	6	180
9	Station	30	10 000	8	180
10	Station	30	10 000	10	180
11	Station	25	10 000	2	180
12	Station	25	10 000	4	180
13	Station	25	10 000	6	180
14	Station	25	10 000	8	180
15	Station	25	10 000	10	180

TABLE A2
MODEL CHARACTERISTICS FOR THE SUBSTATION

N scenario	Source	VNF_L	A	t_{end}	Type
1	Substation	25	10 000	2	360
2	Substation	25	10 000	4	360
3	Substation	25	10 000	6	360
4	Substation	25	10 000	8	360
5	Substation	25	10 000	10	360
6	Substation	20	10 000	2	360
7	Substation	20	10 000	4	360
8	Substation	20	10 000	6	360
9	Substation	20	10 000	8	360
10	Substation	20	10 000	10	360
11	Substation	17.5	10 000	2	360
12	Substation	17.5	10 000	4	360
13	Substation	17.5	10 000	6	360
14	Substation	17.5	10 000	8	360
15	Substation	17.5	10 000	10	360
N scenario	Source	VNF_L	A	t_{end}	Type
1	Substation	25	10 000	2	180
2	Substation	25	10 000	4	180
3	Substation	25	10 000	6	180
4	Substation	25	10 000	8	180

N scenario	Source	VNF_L	A	t_{end}	Type
5	Substation	25	10 000	10	180
6	Substation	20	10 000	2	180
7	Substation	20	10 000	4	180
8	Substation	20	10 000	6	180
9	Substation	20	10 000	8	180
10	Substation	20	10 000	10	180
11	Substation	17.5	10 000	2	180
12	Substation	17.5	10 000	4	180
13	Substation	17.5	10 000	6	180
14	Substation	17.5	10 000	8	180
15	Substation	17.5	10 000	10	180

TABLE A3
MODEL CHARACTERISTICS FOR THE WAYSIDE STOP

N scenario	Source	VNF_L	A	t_{end}	Type
1	Wayside stop	15	10 000	2	360
2	Wayside stop	15	10 000	4	360
3	Wayside stop	15	10 000	6	360
4	Wayside stop	15	10 000	8	360
5	Wayside stop	15	10 000	10	360
6	Wayside stop	10	10 000	2	360
7	Wayside stop	10	10 000	4	360
8	Wayside stop	10	10 000	6	360
9	Wayside stop	10	10 000	8	360
10	Wayside stop	10	10 000	10	360
11	Wayside stop	7	10 000	2	360
12	Wayside stop	7	10 000	4	360
13	Wayside stop	7	10 000	6	360
14	Wayside stop	7	10 000	8	360
15	Wayside stop	7	10 000	10	360
N scenario	Source	VNF_L	A	t_{end}	Type
1	Wayside stop	15	10 000	2	180
2	Wayside stop	15	10 000	4	180
3	Wayside stop	15	10 000	6	180
4	Wayside stop	15	10 000	8	180
5	Wayside stop	15	10 000	10	180
6	Wayside stop	10	10 000	2	180
7	Wayside stop	10	10 000	4	180
8	Wayside stop	10	10 000	6	180
9	Wayside stop	10	10 000	8	180
10	Wayside stop	10	10 000	10	180
11	Wayside stop	7	10 000	2	180
12	Wayside stop	7	10 000	4	180
13	Wayside stop	7	10 000	6	180
14	Wayside stop	7	10 000	8	180
15	Wayside stop	7	10 000	10	180

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References

[1] Ruffault J., Mouillot F.(2017). Contribution of human and biophysical factors to the spatial distribution of forest fire ignitions and large wildfires in a French Mediterranean region. *International Journal of Wildland Fire*, 26, 498–508.

[2] Pew K. L., Larsen C. P. S. GIS analysis of spatial and temporal patterns of human-caused wildfires in the temperate rain forest of Vancouver Island, Canada // *Forest Ecology and Management*. 2001. V. 140, N 1. P. 1—18.

[3] Komarov K.L., Kachinsky V.A. Modeling of emergency response processes in railway transport // *Transport of the Urals*. 2011. No. 2 (29). P. 25-30. (In Russian)

[4] Ilyavin M.V., Katin V.D. On the problem of ensuring fire safety during the reform of the Transsib // In the collection: Transsib: at the forefront of reforms. materials of the international scientific and practical conference. *Irkutsk State University of Railways; Transbaikal Institute of Railway Transport*. 2016. P. 254-259. (In Russian)

[5] Baranovskiy N.V. Testing the system of assimilation of data on the level of human activity for a linear source of human activity / Environmental safety management system: a collection of proceedings of the correspondence international scientific and practical conference. *Yekaterinburg, Russian Federation: USTU - UPI*. 2007. P. 319 - 322. (In Russian).

[6] Baranovskiy N., Kritski O. Probabilistic simulation of non-uniform human activity in the context of forest fires // *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*, 2019, 19 (2.1), pp. 525-530.

[7] Baranovskiy N.V. Mathematical simulation of human activity from a linear source using partial differential equations in the context of the forest fires occurrence // *Advances in Differential Equations and Control Processes*. 2018. Vol. 19. P. 237-262. doi: 10.17654/DE019030237

[8] Samarskii A.A., Vabishchevich P.N. *Computational Heat Transfer*, Vol. 1. Mathematical Modelling, Wiley, Chichester, 1995, 418 p.

[9] Samarskii A.A., Vabishchevich P.N. *Computational Heat Transfer*, Vol. 2. The Finite Difference Method, Wiley, Chichester, 1995, 432 p.

[10] Baranovskiy N.V. (Ed.). (2021). Forest Fire Danger Prediction Using Deterministic-Probabilistic Approach. *IGI Global*. doi: http://doi:10.4018/978-1-7998-7250-4

[11] Baranovskiy N.V. (2020). Predicting Forest Fire Numbers Using Deterministic-Probabilistic Approach. In Baranovskiy, N. V. (Eds.), *Predicting, Monitoring, and Assessing Forest Fire Dangers and Risks* (pp. 89-100). IGI Global. doi: http://doi:10.4018/978-1-7998-1867-0.ch004

[12] Grishin A.M. (1997) *Mathematical modeling of forest fire and new methods of fighting them*. Publishing House of the Tomsk State University: Tomsk, Russian Federation.

[13] Grishin A.M., Filkov A.I. (2011) A deterministic-probabilistic system for predicting forest fire danger. *Fire Safety Journal*, Vol. 46, pp. 56-62. doi: 10.1016/j.firesaf.2010.09.002

[14] Al Janabi S., Al Shourbaji I., Salman M.A. (2017) Assessing the suitability of soft computing approaches for forest fires prediction. *Applied Computing and Informatics*. doi: https://doi.org/10.1016/j.aci.2017.09.006

[15] Read N., Duff T.J., Taylor P.G. (2018) A lightning-induced wildfire ignition predicting model for operational use. *Agricultural and Forest Meteorology*, Vol. 253-254, pp. 233-246. doi: 10.1016/j.agrformet.2018.01.037

[16] Canadian Wildland Fire Information System. Official site. (Accessed 03 March 2021). Access: http://cwfis.cfs.nrcan.gc.ca/home

[17] Wotton B.M. (2009) Interpreting and using outputs from the Canadian Forest Fire Danger Rating System in research applications. *Environmental and Ecological Statistics*, Vol. 16, pp. 107-131. doi: 10.1007/s10651-007-0084-2

[18] Gould J.S., Patriquin M.N., Wang S., McFarlane B.L., Wotton B.M. (2013) Economic evaluation of research to improve the Canadian forest fire danger rating system. *Forestry*, Vol. 86, pp. 317-329. doi: 10.1093/forestry/cps082

[19] Lee B.S., Alexander M.E., Hawkes B.C., Lynham T.J., Stocks B.J., Englefield P. (2002) Information systems in support of wildland fire management decision-making in Canada. *Computers and Electronics in Agriculture*, Vol. 37, pp. 185-198. doi: 10.1016/S0168-1699(02)00120-5

[20] Martell D.L. (2000) A Markov Chain Model of Day to Day Changes in the Canadian Forest Fire Weather Index. *International Journal of Wildland Fire*, Vol. 9, pp. 265-273

[21] WFAS Wildland Fire Assessment System. Official site. (Accessed 03 March 2021). Access: http://www.wfas.net

[22] Deeming J.E., Lancaster J.W., Fosberg M.A., Furman W.R., Schroeder M.J. (1974) The National Fire Danger Rating System. United States Department of Agriculture, Forest Service, *Research Paper RM-84, Rocky Mountain Forest and Range Experiment Station*, Fort Collins, Colorado. 165 P.

[23] Deeming J.E., Burgan R.E., Cohen J.D. (1977) The National Fire Danger Rating System - 1978. *United States Department of Agriculture, Forest Service, General Technical Report INT-39, Intermountain Forest and Range Experiment Station*, Odgen, Utah. 66 P.

[24] European Forest Fire Information System. Official site. (Accessed 03 March 2021). Access: http://effis.jrc.ec.europa.eu

[25] Viegas D.X., Bovio G., Ferreira A., Nosenzo A., Sol, B. (2000) Comparative study of various methods of fire danger evaluation in Southern Europe. *International Journal of Wildland Fire*, Vol. 10, pp. 235-246.

[26] Information system for remote monitoring of forest fires ISDM-Rosleskhoz. Official site. (Accessed 03 March 2021). Access: https://nffc.aviales.ru/main_pages/index.shtml

[27] Podolskaya A.S., Ershov D.V., Shulyak P.P. (2011) Application of the method for assessing the probability of occurrence of forest fires in ISDM-Rosleskhoz. *Modern problems of remote sensing of the Earth from space*, Vol. 8, pp. 118 - 126. (In Russian).

[28] Baranovskiy N.V. (2015) Project of the eurasian segment of the new system of the forest fire risk prediction based on information and computer technologies. *Journal of Automation and Information Sciences*, Vol. 47, pp. 40-56. doi: 10.1615/JAutomatInfScien.v47.i3.40

[29] Baranovskiy, N., Forest Fire Danger Assessment Using SPMD-Model of Computation for Massive Parallel System, (2017) *International Review on Modelling and Simulations (IREMOS)*, 10 (3), pp. 193-201. doi: https://doi.org/10.15866/iremos.v10i3.10570

[30] Baranovskiy N., Zharikova M. (2014) A web-oriented geoinformation system application for forest fire danger in the typical forests of the Ukraine. L*ecture Notes in Geoinformation and Cartography*, article 199669, pp. 13-22. doi: 10.1007/978-3-319-08180-9_2

[31] Melekhov I.S. (1947) *Nature of forest and forest fires*. Nauka: Arkhangelsk, USSR (In Russian)

[32] Andreev Y.A., Larchenko G.F. (1987) Socio-psychological aspects of recreational forest visits and the emergence of fires. Forest fires and the fight against them. VNIILM: Moscow, USSR. (In Russian).

[33] Kurbatskiy N.P. (1964) *The problem of forest fires. The emergence of forest fires*. Nauka: Moscow, USSR. (In Russian).

[34] Melluma A.Zh., Rungule R.H., Emsis I.V. (1982) *Recreation on nature as a nature protection problem*. Zinatne: Riga, USSR. (In Russian).

[35] Telitsin G.P. (1984) Study of the connection between forest attendance and the occurrence of fire. *Lesovedenie*. pp. 59-63. (In Russian).

[36] Cardille J.A., Ventura S.J., Turner M.G. (2001) Environmental and Social Factors of Influencing Wildfires in the Upper Midwest, United States. *Ecological Applications*, Vol. 11, pp. 111-127. doi: 10.1890/1051-0761(2001)011[0111:EASFIW]2.0.CO;2

[37] Ganteaume A., Guerra F. (2018) Explaining the spatio-seasonal variation of fires by their causes: The case of southeastern France. *Applied Geography*, Vol. 90, pp. 69-81. doi: 10.1016/j.apgeog.2017.11.012

[38] Ye J., Wu M., Deng Z., Xu S., Zhou R., Clarke K.C. (2017) Modeling the spatial patterns of human wildfire ignition in Yunnan province, China. *Applied Geography*, Vol. 89, pp. 150-162. doi: 10.1016/j.apgeog.2017.09.012

[39] Diez-Delgado R., Lloret F., Pons X. (2004) Statistical analysis of fire-frequency models for Catalonia (NE Spain, 1975-1998) based on fire scar maps from Landsat MSS data. *International Journal of Wildland Fire*, Vol. 13, pp. 89-99. doi: 10.1071/WF02051

[40] Hong H., Tsangaratos P., Ilia I., Liu J., Zhu A.-X., Xu C. (2018) Applying genetic algorithms to set the optimal combination of forest fire related variables and model forest fire susceptibility based on data mining models. The case of Dayu Country, China. *Science of the Total Environment*, Vol. 630. pp. 1044 – 1056. doi: 10.1016/j.scitotenv.2018.02.278

[41] Haupt L.R., Haupt S.E. (2004) *Practical genetic algorithms*, 2nd edition. John Wiley & Sons Inc.

[42] Chen W., Xie X., Wang J., Pradhan B., Hong H., Tien Bui D., Duan Z., Ma J. (2017) A comparative study of logistic model tree, random forest and classification and regression tree models for spatial prediction of landslide susceptibility. *Catena*, Vol. 151, pp. 147 – 160. doi: 10.1016/j.catena.2016.11.032

[43] Dormann C.F., Elith J., Bacher S., Bushmann C., Carl G., Carre G., Marquez J.R.G., Gruber B., Lafourcade B., Leitao P.J., Munkemuller T., McClean C., Osborne P.E., Reineking B., Schroder B., Skidmore A.K., Zurell D., Lautenbach S. (2013) Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, Vol. 36, pp. 27 – 46. doi: 10.1111/j.1600-0587.2012.07348.x

[44] Ghimire B., Rogan J., Galiano V.R., Panday P., Neeti N. (2012) An evaluation of bagging, boosting and random forests for land-cover classification in CapeCod, Massachusetts, USA. *GIScience and Remote Sensing*, Vol. 49, pp. 623 – 643. doi: 10.2747/1548-1603.49.5.623

[45] Duan K., Keerthi S., Poo A. (2001) *Evaluation of simple performance measures for tuning SVM hyperparameters*

(Technical report). National University of Singapore. Department of Mechanical Engineering, Singapore.

[46] Grala K., Grala R.K., Hussain A., Cooke W.H. (2017) Impact of human factors on wildfire occurrence in Mississippi, USA. *Forest Policy and Economics*, Vol. 81, pp. 38 – 47. doi: 10.1016/j.forpol.2017.04.011

[47] Jimenez-Ruano A., Rodrigues Mimbrero M., de la Riva Fernandez J. (2017) Understanding wildfires in mainland Spain. A comprehensive analysis of fire regime features in a climate-human context. *Applied Geography*, Vol. 89, pp. 100 – 111. doi: 10.1016/j.apgeog.2017.10.007

[48] Gonzalez-Hidalgo J.C., Brunetti M., de Luis M. (2011) A new tool for monthly precipitation analysis in Spain: MOPREDAS database (monthly precipitation trends December 1945 – November 2005). *International Journal of Climatology*, Vol. 31, pp. 715 – 731. doi: 10.1002/joc.2115

[49] Gonzalez-Hidalgo J.C., Pena-Angulo D., Brunetti M., Cortesi N. (2015) MOTEDAS: A new monthly temperature database for mainland Spain and the trends in temperature (1951 – 2010). *International Journal of Climatology*, Vol. 35, pp. 4444 – 4463. doi: 10.1002/joc.4298

[50] Flury B.N. (1984) Common principal components in K groups. *Journal of the American Statistical Association*, Vol. 79, pp. 892 – 898.

[51] Kaiser H.F. (1958) The varimax criterion for analytic rotation in factor analysis. *Psychometrika*, Vol. 28, pp. 187 – 200.

[52] Hu T., Zhou G. (2014) Drivers of lightning- and human-caused fire regimes in the Great Xing'an Mountains. *Forest Ecology and Management*, Vol. 329, pp. 49 – 58. doi: 10.1016/j.foreco.2014.05.047

[53] Liu Q., Gao P., Wang Z. (2012) Great Xing'an Mountains: the relationship between population growth and economic development. *Statist Consult*, Vol. 6, pp. 17 – 19.

[54] Liu Z.H., Yang J., Chang Y., Weisberg P.J., He H.S. (2012) Spatial patterns and drivers of fire occurrence and its future trend under climate change in a boreal forest of Northeast China. *Global Change Biology*, Vol. 18, pp. 2041 – 2056. doi: 10.1111/j.1365-2486.2012.02649.x

[55] Curt T., Frejaville T., Lahaye S. (2016) Modelling the spatial patterns of ignition causes and fire regime features in southern France: Implications for the prevention policy. *International Journal of Wildland Fire*, Vol. 25, pp. 785 – 796. doi: 10.1071/WF15205

[56] Fusco E.J., Abatzoglou J.T., Balch J.K., Finn J.T., Bradley B.A. (2016) Quantifying the human influence on fire ignition across the western USA. *Ecological Applications*, Vol. 26, pp. 2390 – 4201. doi: 10.1002/eap.1395

[57] Zhang Y., Lim S., Sharples J.J. (2016) Modelling spatial patterns of wildfire occurrence in South-Eastern Australia. *Geomatics, Natural Dangers and Risk*, Vol. 7, pp. 1800 – 1815. doi: 10.1080/19475705.2016.1155501

[58] Agterberg F.P., Cheng Q. (2002) Conditional independence test for weight-of-evidence modeling. *Natural Resources Research*, Vol. 11, pp. 249 – 255. doi: 10.1023/A:1021193827501

[59] Imetkhenov A.B. Forest fires of Buryatia: analysis of the current state and some recommendations for preventive maintenance // *Coll. mat-lov scientific-practical. conf.* - Ulan-Ude, 2016. P. 68–73. (In Russian).

[60] Borisova T.A. Forest fires in Buryatia: causes and effects // *Vestnik VSU, series: geography, geoecology*, 2017. No. 2. P. 78-84. (In Russian).

[61] Chebotaeva D.O., Alymbaeva Zh.B. Geoecological aspects of forest fires in the Republic of Buryatia // *Proceedings of the V International scientific conference dedicated to the 130th anniversary of the Herbarium named after P.N. Krylov and the 135th anniversary of the Siberian Botanical Garden of Tomsk State University "Problems of studying the vegetation cover of Siberia."* Tomsk. Publishing house: TSU. 2015. P. 150-153. (In Russian).

[62] Sidorov A.A., Khankhunov Yu.M. On problems with forest fires in the Republic of Buryatia // *Coll. mat-lov scientific-practical. conf. with int. participation.* - Ulan-Ude, 2015.P. 84–89. (In Russian).

[63] Sofronova T.M., Volokitina A.V., Sofronov M.A. Improving the assessment of fire danger by weather conditions in the mountain forests of the Southern Baikal region. *Krasnoyarsk*, 2007. 236 p. (In Russian).

[64] Belyakin A.A., Volokitina A.V. Pyrological characteristics of forest types in the southern Baikal region // *Bulletin of KrasGAU. Ecology*. 2010. No. 7. P. 91–96. (In Russian).

[65] Evdokimenko M.D. Geography and causes of fires in the Baikal forests // News of higher educational institutions. *Forest Journal*. 2013. N 4.P. 30 - 39. (In Russian).

[66] Evdokimenko M. D. On long-term predicting of high fire danger of forests in the Baikal region // *Forestry*. 2000. No. 1. P. 47–50. (In Russian).

[67] Ukraintsev A. V., Plyusnin A. M. Forest fires in the Zaigraevsky district of the Republic of Buryatia in 2010–2012: causes of fire and damage // *Geography and natural resources*. 2015. No. 2. P. 60–65. (In Russian).

[68] Makarenko EL Forest fires and their consequences in the Central ecological zone of the Baikal natural territory // *Interactive science*, 2016. No. 5. P. 9–12. (In Russian).

[69] Imetkhenov A.B. Forest fires in Buryatia: analysis of the current state and some recommendations for preventive maintenance // *Materials of the VIII All-Russian scientific-practical conference "Actual issues of technosphere safety"*. Ulan-Ude. 2015. P. 75-79. (In Russian).

[70] Dorzhiev Ts. Z., Yuukhai Bao, Badmaeva E. N., Batsaykhan V., Urbazaev Ch. B., Yushan Forest fires in the Republic of Buryatia in 2002-2016. // *The Nature of Inner Asia*, No. 3 (4), 2017, pp. 22-37. (In Russian).

[71] Territorial body of the Federal State Statistics Service for the Republic of Buryatia. (Accessed 04 April 2021). Access mode: https://burstat.gks.ru/transport_communications

[72] Resolution of the Government of the Republic of Buryatia "On the strategy of socio-economic development of the Republic of Buryatia until 2025" dated December 15, 2007 No. 410. (Accessed 04 April 2021). Access mode: http://docs.cntd.ru/document/446260821

[73] Aslamova V.S., Frolova E.Yu. System analysis of the causes of fires on locomotives of JSC "Russian Railways" // *Modern technologies. System analysis. Modeling*, 2018, vol. 60, no. 4. P. 63-70. (In Russian).

[74] Samarskii A.A. *The theory of difference schemes*. New York – Basel. Marcel Dekker, Inc, 2001, 761 P.

[75] Samarskii A.A., Vabishchevich P.N. *Computational Heat Transfer, Vol. 1. Mathematical Modelling*, Chichester: Wiley. 1995.

[76] Samarskii A.A., Vabishchevich P.N. *Computational Heat Transfer, Vol. 2. The Finite Difference Method*, Chichester: Wiley. 1995.

[77] Baranovskiy, N., Kirienko, V., Mathematical Simulation of Forest Fuel Element at the Crown Forest Fire Impact Taking Into Account Multiphase Reactive Media Mechanics Fundamentals, (2020) *International Review of Mechanical Engineering (IREME)*, 14 (8), pp. 504-515. doi: https://doi.org/10.15866/ireme.v14i8.19655

[78] JSC Russian Railways. (Accessed April 02, 2021). Access mode: http://rzd-company.ru/

[79] Origin Lab Official (Accessed: 2019-05-25). Web-site: https://www.originlab.com/

[80] RAD Studio Accessed: (2019-05-25). https://www.embarcadero.com/ru/products/rad-studio

[81] Jarratano J., Riley G. *Expert systems: design principles and programming*. Translation from English. Moscow: Williams Publishing House. 2007. 1152 p. (In Russian).

[82] Russell S., Norvig P. A*rtificial intelligence: a modern approach*. Translation from English. Moscow: Williams Publishing House. 2007. 1408 P. (In Russian).

[83] Trifonova T.A., Mishchenko N.V., Krasnoshchekov A.N. *Geographic information systems and remote sensing in environmental research*. Moscow: Academic Project, 2005. 352 p. (In Russian).

[84] Garliz I.V. et al. *Geoinformation technologies: Principles,*

international experience, development prospects. Moscow: 1989. (In Russian).
[85] Shaytura S.V. *Geographic information systems and methods of their creation*. Kaluga: N. Bochkareva Publishing House. 1998. 252 p. (In Russian).
[86] Baranovskiy N.V. *Mathematical modeling of the most probable scenarios and conditions for the occurrence of forest fires*. PhD Thesis. Tomsk: Tomsk State University. 2007. 153 P. (In Russian).
[87] Kunkel S., Teumer T., Dörnhofer P., Schlachter K., Weldeslasie Y., Kühr M., Rädle M. , Repke J.-U. Determination of heat transfer coefficients in direct contact latent heat storage systems // *Applied Thermal Engineering* 145 (2018) 71–79.
[88] Li F., Bai B. A model of heat transfer coefficient for supercritical water considering the effect of heat transfer deterioration // *International Journal of Heat and Mass Transfer*. 2019. Vol. 133, P. 316-329.
[89] Larjavaara M., Kuuluvainen T., Rita H. Spatial distribution of lightning-ignited fires in Finland // *Forest Ecology and Management*. 2005. V. 208, N 1—3. P. 177-188.

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