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Features of Landscape Fires Occurrence (Based on the Example of Lviv Region of Ukraine)

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Abstract. The article is devoted to the investigation of peculiarities of landscape fires occurrence, namely: forest fires, peat fires, steppe fires and landfill fires. Publications related to the dynamics of these fires development, the conditions of their occurrence and the impact of these fires on the environment are analyzed in this paper. The analysis of fires, based on the example of Lviv region (Ukraine), revealed the following: the largest number of fires occurs at the beginning of the fire-dangerous period that coincides with the ascent of snow cover, as well as during harvesting. The frequency of fires in landfills closely depends on weather parameters (temperature and relative humidity); the frequency of steppe and forest fires occurrence is less dependent on these indicators. Constructing of a Voronoi Diagram for coordination of fires occurrence allows us to study the largest accumulation of fires and their impact on the environment during specific period, as well as to determine the locations of firefighting equipment for quick response to these fires.

Key words: Landscape fires, forest fires, peat fires, steppe fires, landfill fires, Voronoi Diagram.

Introduction

Currently there are tendencies in the world that the number and scale of fires in natural ecosystems are increasing; in particular, it concerns forest fires (DENNISON *et al.*, 2014; JAFARZADEH *et al.*, 2017). The research (ALBERS, 2012) shows disappointing statistics that every year in Europe 600 thousand hectares of forest are damaged and destroyed because of fires.

The problem of fires occurrence in ecosystems is global and is being researched by scientists around the world. In India fires happen in the area of 5 thousand hectares of forest every year. In particular, fires occur annually in 445 out of 647 districts of the country (DOGRA *et al.*, 2018). In the study (ULLAH *et al.*, 2013), the dynamics of forest fires was described in the Sanming forestry, Fujian Province, China, and within 2000 and 2009 on these territories there were 818 fires on an area of more than 8,500 hectares. The increasing frequency of fires in natural ecosystems in central Europe is also specified in research (MAJLINGOVÁ, 2015).

Statistics on forest fires and dry grass fires in Slovakia indicate their roughly equal numbers (an average of 2,000 per year). On the territory of the Czech Republic in the period from 1992 to 2004, there were about 15,985 fires on a total area of about 8 hectares (KULA & JANKOVSKÁ, 2013). The most shocking statistics on fires is in the United States. According to statistical data for 1992-2011 (REID *et al.*, 2016a; b), on average 80,000 fires have occurred in the United States and about 2 million hectares of forest were destroyed; and in 2006, there were about

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140,000 fires on an area of more than 4 million hectares. In addition, the study of dynamics over the past 5 years has been conducted in Portugal (MATEUS & FERNANDES, 2014), Canada (LE *et al.*, 2014), USA (MAUDLIN *et al.*, 2015; REID *et al.*, 2016a; b) and other countries of the world, where also the dynamics of growth is established.

Taking into consideration the above statistics, there is a need for a detailed analysis of the conditions and causes of landscape fires for a particular region, based on which it would be possible to develop and introduce preventive measures for their occurrence, spreading and negative impact on biota.

Many works were devoted to the dynamics of forest fires. In particular, the distribution of forest grassland and steppe fires was investigated in (BURASOV, 2016). It is established that the rate of fire distribution increases linearly with the wind speed increase, and decreases with an increase in the humidity of the combustible material. Due to stronger winds steppe fires spread faster because of the large inflow of oxygen into the combustion zone and a more powerful convective heat transfer by wind. It is established experimentally and theoretically (GRYSHYN, 2008) that the front of any natural (forest, peat, steppe) fire consists of a heating zone, drying and pyrolysis of natural (vegetative) combustible materials, as well as a flame burning zone of gaseous pyrolysis products. Using the information about the structure of the front, the authors managed to obtain analytical formulas for determining the distribution rate of forest and steppe fires.

Scientists (ADAB *et al.*, 2013; FILKOV, 2005) developed a geoinformation expert system for forecasting forest fires, which allows to determine the possibility, time and place of the fire, taking into consideration following factors: soil structure and the type of plant combustible material, precipitation, wind direction and radiation of the Sun, the dynamics of the drying of plant combustible material, anthropogenic loading, and lightnings. Moreover, the software for forecasting forest fires distribution was developed for the Mediterranean pine forests of Greece based on weather data and the state of plant combustible material (MITSOPOULOS *et al.*, 2016). The modelling of velocity of the highland coniferous forests spread was carried out in (CRUZ & ALEXANDER, 2017) using the Monte Carlo method.

What concerns the transition from downhill to highland fires, the most dangerous and complicated in terms of firefighting are the fires in highlands. Despite the fact that the percentage of upland forest fires is insignificant, the area they passed in comparison with the downhill fires is larger. Main reasons of this transition (HABIBULLIN, 2017) is an increase of superficial combustible materials mass on uncleansed areas of felling or the allocation of quarrying residues in heaps, low-down crowns of coniferous trees, as well as the development of coniferous growth and undergrowth. The transit process is described in (LAUTENSHLEGER, 2016). It is established that the downhill fire in this process consists in the heating, drying, pyrolysis and inflammation of pyrolysis products in the crowns of trees, as a result of the strong wind rapid spread of the fire front on the crowns of trees occurs.

In the paper (JAFARZADEH *et al.*, 2017) there were presented theoretical aspects of determining the risk of forest fires in the western Iran using the Apriori algorithm and the Fuzzy Clustering Algorithm (FCM). The risk of forest fires was estimated with the following factors: distance from settlements, population density, distance from the road, slope, dryness, temperature, soil cover and distance from agricultural land. The authors prove that the main cause of fires in natural ecosystems in 95% is human negligence (SYPHARD & KEELEY, 2015). The largest number of fires occurs in forests near the populated areas, in places where there is no entry ban, and also near agricultural lands of common ownership (CHAS-AMIL *et al.*, 2015). According to the study (KULA & JANKOVSKÁ, 2013), the increase in the number of fires is the result of an increase in the attendance of forest, and the main reasons become abandonment of the bonfire without supervision, smoking and disadvantages of forestry management. Another problem that directly affects the growth of fires in forests is the change in land use in recent decades (FERNANDES *et al.*, 2014).

It is necessary to indicate that forest behavior leads to the loss of life in this area, significant carbon emissions, deterioration of air quality and significant extinguishing costs (ABATZOGLOU & WILLIAMS, 2016). Even low-level low-intensity fires can destroy nests, eggs and kill young animals that cannot avoid the effect of fire (DOGRA *et al.*, 2018).

The hazard indicator is the concentration of fine particulate matter PM2.5 in air contaminated with fume of forest fires biomass. This particular matter includes carbon (soot and coal), organic carbon, sulfates, nitrates, potassium carbonate and silicon (LARSON & KOENIG, 1994). Authors of study (LE *et al.*, 2014) indicate that an increase in PM2.5 concentration due to forest fires can affect the health of elderly people thousands of kilometers away from these fires. In addition, combustion of plants, peat and especially solid household wastes accompanied with the formation of toxic combustion products remain in soil and water. Toxic combustion products are hazardous to human health, can cause respiratory diseases (LIU *et al.*, 2017), respiratory complications and children athma in children (HEHUA *et al.*, 2017), cardiovascular diseases, etc. (REID *et al.*, 2016a; b). The most dangerous are fires in forests located in the Exclusion Zone near Chornobyl (EVANGELIOU *et al.*, 2014), as well as in landfills, as they can cause cancer (WIWANITKIT, 2014). In their studies (O'DONNELL & BEHIE, 2015), scientists have found the impact of fires in ecosystems on the weight of male newborn children.

The effect of fires quantity and their intensity on the regeneration of tropical deciduous forests is not sufficiently studied (THEKAEKARA *et al.*, 2017). In the study of fires in the Nilgiri Biosphere Reserve, Western Ghats (India) (MONDAL & SUKUMAR, 2015), the survival rates of young tree species do not differ between the areas that were affected by fires and other areas. Fires in tropical deciduous forests have impact that is more negative. At the same time due to the fire, there is a smaller number of wood species and a lower density of plantings (KITTUR *et al.*, 2014). Instead, subtropical pine forests are more adapted to fires (DOGRA *et al.*, 2018). In the work (TROCHTA *et al.*, 2012) there was investigated the effect of fire on vegetation, in particular on defoliation of pine trees on the territory of the Bohemian Switzerland National Park, which was exposed to fire. A year after the fire that has happened in this area, pine plantings, which were in close proximity to the fire, were gradually defoliated. Forest fires, according to studies (KONSAM *et al.*, 2017), do not have effect on significant changes in vegetation regeneration compared to areas not exposed to fire. However, in (SEIFERT *et al.* 2017), a significant reduction in the growth of the radiant pine (*Pinus radiate*) was revealed after the lowland fire in the year when the fire occurred, as well as in the following year.

Fires in ecosystems lead to changes in the qualitative composition of soils. Thus, studies (HOLDEN & TRESEDER, 2013) show that the high temperature effects of the fire lead to a decrease in the large number of microbes, while fires with higher intensity deplete the soil, depriving it of nutrient organic substances, and exhaust the soil, depriving it of nutrient organic matter (CHANDRA & BHARDWAJ, 2015). Moreover, the drainage properties of forest soils are reduced, which lower their infiltration and increase erosion (VERMA & JAYAKUMA, 2012).

Also, forest fires make influence on the quality of underground and terrestrial water sources, lead to difficulties in supplying drinking water (BLADON *et al.*, 2014; BUSTAMANTE *et al.*, 2016), reduce soil fertility and pollute the air.

Dangerous impact on the environment is made by peat fires. In the study (DOGRA *et al.*,

2018) authors present the results of the mathematical modeling of peat fires, in particular, they describe the process of transition of grass forest fires into peat fires due to radiation and thermal heat transfer from the flame front of a lowland fire through the underlay of the forest. Theoretical and experimental studies (HUANG & REIN, 2015; HUANG *et al.*, 2016) confirm the theory of distribution of peat combustion considering its area and volume. It leads to long-lasted fires and continuous release of combustion products into the atmosphere. Therefore, the quality of air in the area is deteriorating, which leads to a human health deterioration, the sustainability of ecosystems and changes in the global carbon cycle (PAGE & HOOIJER, 2016). Smoldering of peat can continue in wet weather (TURETSKY *et al.*, 2015). Climate change leads to a decrease in water levels in peat bogs and, consequently, to an increase in the number of peat fires (TURETSKY *et al.*, 2015). The authors (PUTRA *et al.*, 2016) indicate that in order to reduce the risk of peat fires it is necessary to maintain groundwater level.

It should be noted that the fire hazard of landfills and the impact on the environment and human health have been investigated less. In particular, the concentration of landfill gas, microclimate and gas well temperature (MILOSEVIC *et al.*, 2018) have effect on the fire hazard of landfills. Research on the morphological composition of garbage in landfills (BUSTAMANTE *et al.*, 2016; WIWANITKIT, 2014) and the qualitative composition of combustion products released into the atmosphere have shown that smoke contains a number of carcinogenic compounds that increase the risk of human cancer (EVANGELIOU *et al.*, 2014; ROVIRA *et al.*, 2018).

Materials and Methods

Lviv Oblast is located in the west of Ukraine, located within the limits of 22°43'-25°24 'E and 48°45'- 50°46' N latitude. The total area of the region is 2.18 million hectares. The region is located in three zones: forest, steppe, foothills and mountainous areas of the Carpathians. Forests cover almost a one fourth of the total region area.

The climate is temperate continental, humid: winters are soft with thaws, wet springs, warm summers and warm autumns. The average January temperature is -5°C, July temperature is + 18°C in the central part of the region and + 12°C in the mountains. Annual precipitation varies from 600 mm on the plain to 1000 mm in the mountains.

Data on landscape fires from 2016 to 2018 has been provided by the State Emergency Service of Ukraine in Lviv Oblast. This information includes the place and time of the fire occurrence, their area, the causes of fires, consequences. The weather data, which includes the temperature and relative humidity of air, was obtained from the government web-resource of the Ukrainian Hydrometeorological Center at the station (49°48' N 23°56' E).

Statistics data are processed using mathematical statistical methods such as method of least squares to build trend lines, definition dependence between two quantities calculated using Pearson's correlation coefficient.

In order to study the largest accumulation of landscape fires on the territory of Lviv region, reasons of their occurrence, as well as the use of preventive measures, methods of mathematical statistics and Voronoi diagrams were used in the research. The Voronoi diagram is a special type of partition of the metric space, defined by the distances to a given discrete set of isolated points of this space, to the n-th number of convex polygons. In the simplest case, we have a plurality of points in the plane S, which are called vertices of the Voronoi diagram. Each vertex s belongs to the Voronoi cell, also known as the Dirichlet cell, $V(s)$, formed from all points closer to s than to any other vertex. The boundaries in the Voronoi diagram are all points in the plane, which are equidistant from the two nearest vertices. The Voronoi vertices (nodes) are the points equidistant to three (or more) sites. In Computational geometry, the Voronoi diagram is needed first of all to solve the problem of proximity of points (OKABE *et al.*, 2009).

Voronoi diagrams are used in various fields, in particular, in geolocation systems for different search and location analysis, in cartography to delineate the boundaries of the regions and further analyze on its basis. For instance, Voronoi diagram was used (KUZYK, 2014) to determine the area of proximity of trees in the forest, and behind it - the local forestry indicators of the trial area where the fire hazard was investigated.

Results and Discussion

Taking into consideration that the causes of the vast majority of landscape fires are carelessness and human negligence, the conditions that contribute to their occurrence and distribution are considered. The main conditions for the emergence and spread of landscaped fires on large areas are weather conditions such as temperature, relative humidity, rainfall, wind speed (ULLAH *et al.*, 2013). Therefore, it is necessary to analyze the influence of seasonality and weather parameters on the frequency of the occurrence of fires in ecosystems in Lviv region.

The distribution of forest, peat, steppe and fires in landfills monthly has been analyzed during 2016-2018. Fig. 1 shows graphical dependencies in changes in the number of fires in ecosystems for three years.

Exploring the occurrence of steppe fires throughout the year, it should be noted that most often they take place in February-April and August-September (Fig. 1a). In particular, in 2018 the peak of steppe fires was in April (more than 450 fires), for 2016-2017 years –in March (about 300). The second peak of fires was reached in August: in 2016 - 252 fires, in 2017 - 74, in 2018 - 26.

The dynamics of peat fires is somewhat different from the steppe ones (Fig. 1 b).

During 2016-2017, there was a gradual increase in the number of fires by exponential dependence from February to August-September. Within 2018 the peak of peat fires occurred in May. According to Fig. 1 c) and d) the conclusion can be made that there are no clear patterns of their occurrence during the year. These fires start to happen in March-April and ends in October.

The analysis of fires during the last 3 years has shown that there is no close correlation between the number of fires and the months of their occurrence. The highest number of fires in Lviv region is observed at the beginning of the fire-dangerous period when the snow cover melts, as well as during the harvest period.

The fire danger period is a part of the year when forest fires occur (from the moment the snow cover goes down to the onset of durable humid autumn weather or the formation of snow cover).

In China, the research of influence of weather conditions on increase of the forest fires has been conducted by the scientists (ULLAH *et al.*, 2013). They have analyzed the dependence of frequency of forest fire occurrence upon weather parameters (Fire weather index). The results showed that in 2000 - 2009 the number of forest fires and their area were larger when the average FWI value was greater than 50. With an average FWI of less than 27, very few forest fires occurred.

In order to determine the patterns of landscape fires occurrence in Lviv region, the weather parameters of this region and the frequency of these fires were analyzed. Statistical data on landscape fires in Lviv region during 2016-2018 (for each type of fires), as well as the average monthly weather parameters (relative humidity and air temperature) during this period were taken.

To study the influence of weather conditions on the occurrence and spread of fires, the dependence of the fire numbers on the average monthly temperature is considered.

Graphical dependencies in Fig. 2 show that as the average monthly temperature increases, the number of fires grows. This dependence is clearly visible in Fig. 1 b and d (for peat and landfill fires). The Pearson correlation coefficient between the amount of peat fires and the average monthly temperature is R = 0.533, and between the number of fires in landfills and the temperature is R = 0.525. It means that in this particular case a high correlation between the peat fires and the average monthly temperature exists, as well as landfill fires and temperature.

It is also established the mutual influence of the number of fires in natural ecosystems and the average monthly relative humidity of air.

According to Fig. 3, the greatest correlation is found between the average monthly relative humidity and fire numbers in landfills (R = 0.552). As the average monthly relative humidity increases, the amount of landfill fires decreases. Having compared the study results of the dependence between fire numbers and weather parameters, it was established that the frequency of fires in landfills closely depends on weather parameters (temperature and humidity). The frequency of occurrence of steppe and forest fires less depends on these parameters. Sufficiently significant influence of weather conditions exists on the occurrence of peat fires.

Fig. 4 shows the Voronoi diagrams in places where fires occur in natural ecosystems. The points show the places where fires have occurred most often during 2016-2018. For generating a Voronoi diagram from a set of points in a plane was used by Fortune's algorithm, an $O(n\log(n))$ algorithm.

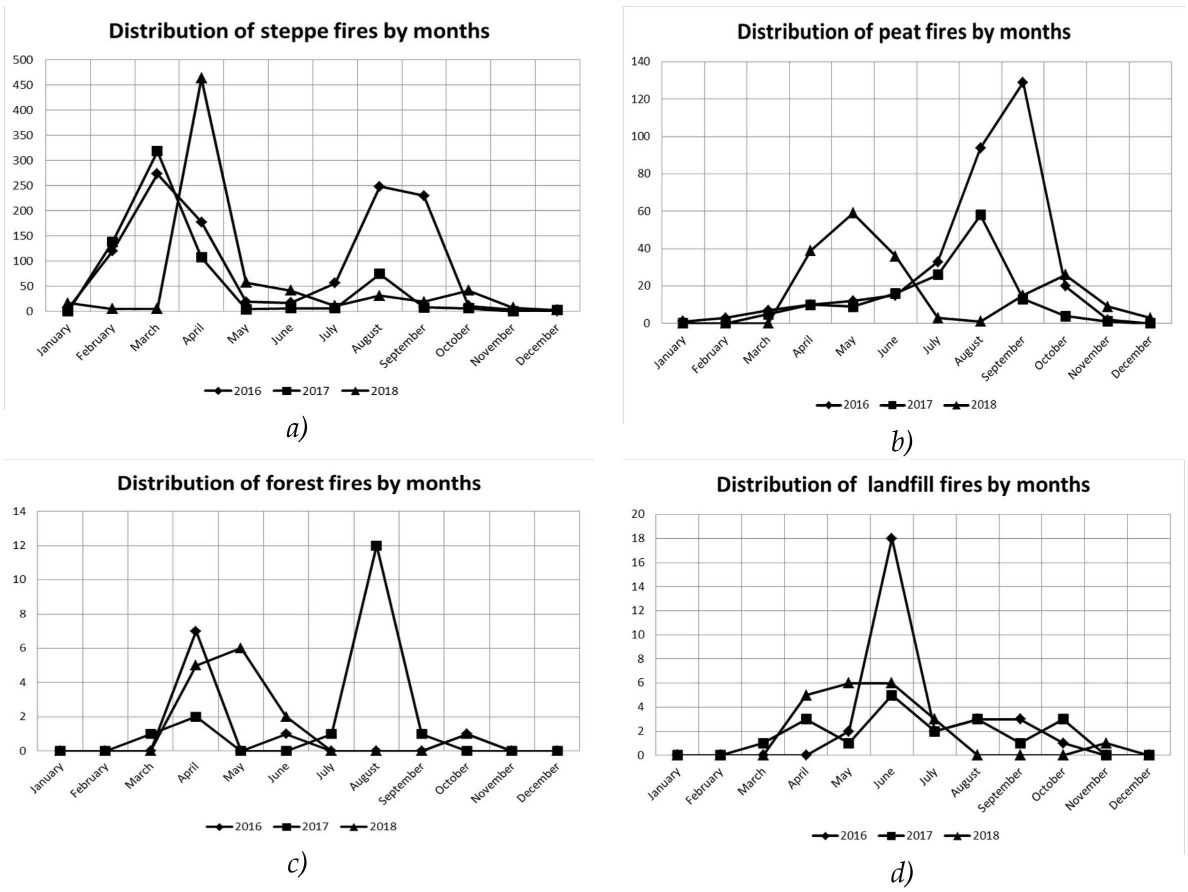

Fig. 1. Distribution of the number of fires in Lviv region:
a) steppe fires; b) peat fires; c) forest fires; d) landfill fires.

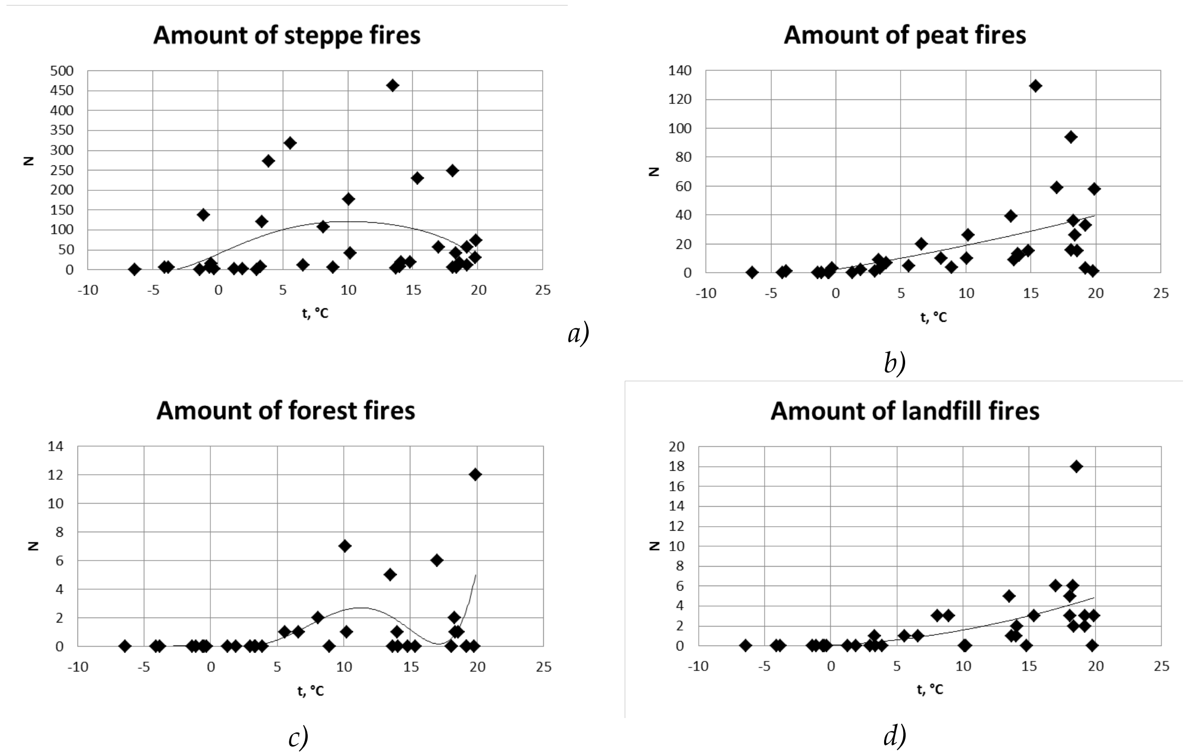

Fig. 2. Dependence between the amount of fires and the average monthly temperature in Lviv region: a) steppe fires; b) peat fires; c) forest fires; d) landfill fires.

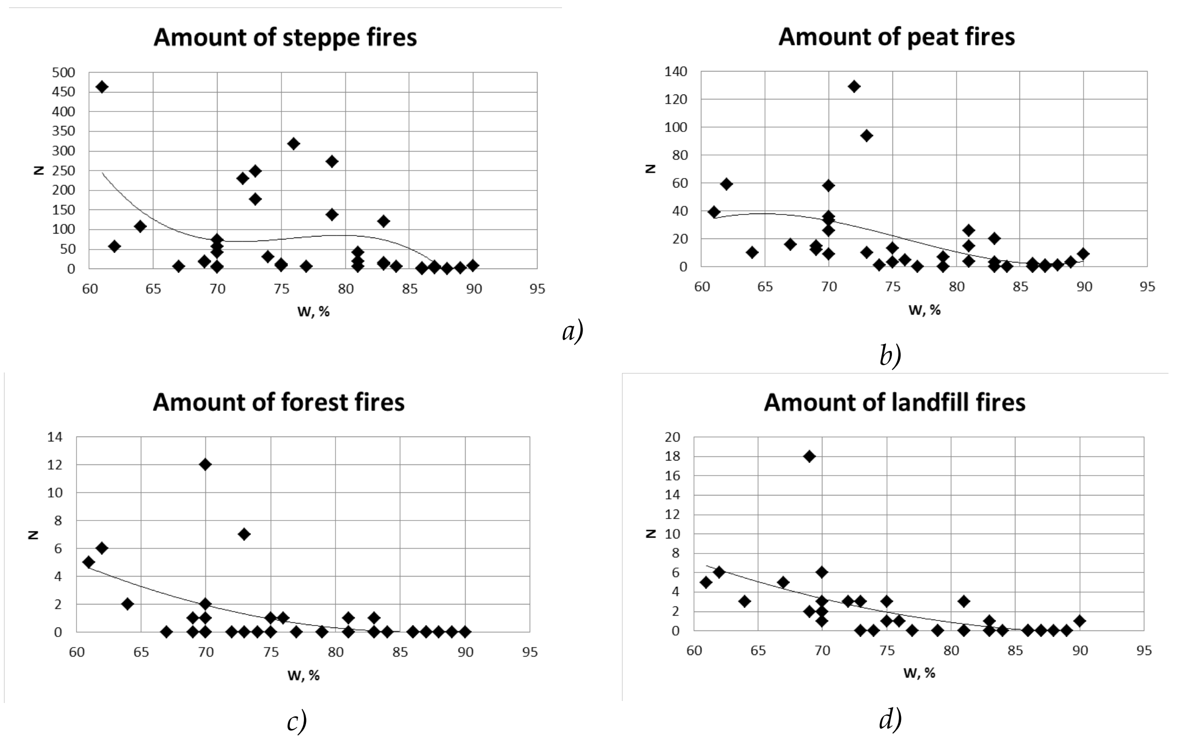

Fig. 3. Dependence between the amount of fires and the average monthly humidity in Lviv region: a) steppe fires; b) peat fires; c) forest fires; d) landfill fires.

According to Fig. 3, the greatest correlation is found between the average monthly relative humidity and fire numbers in landfills (R = 0.552). As the average monthly relative humidity increases, the amount of landfill fires decreases. Having compared the study results of the dependence between fire numbers and weather parameters, it was established that the frequency of fires in landfills closely depends on weather parameters (temperature and humidity). The frequency of occurrence of steppe and forest fires less depends on these parameters. Sufficiently significant influence of weather conditions exists on the occurrence of peat fires.

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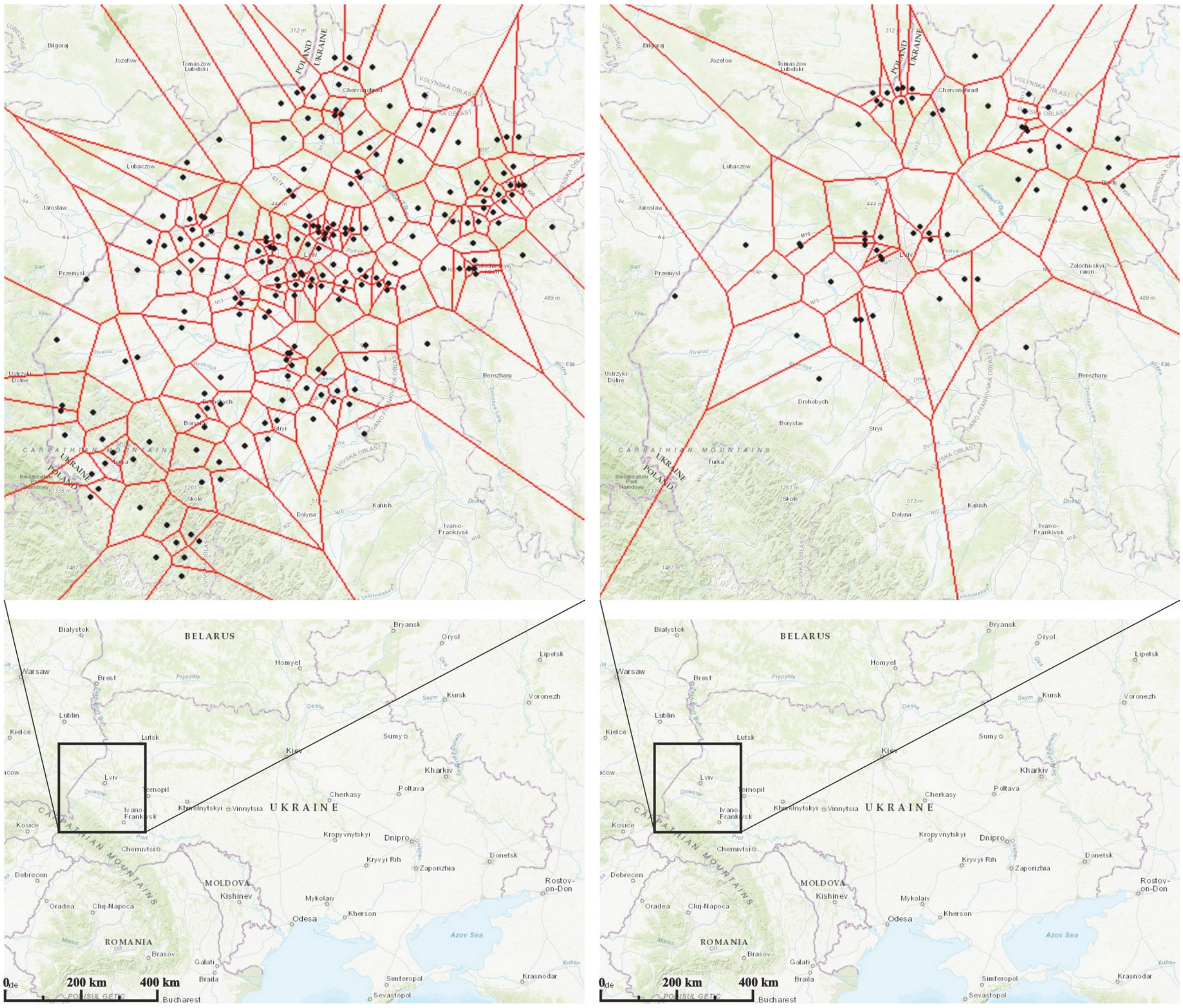
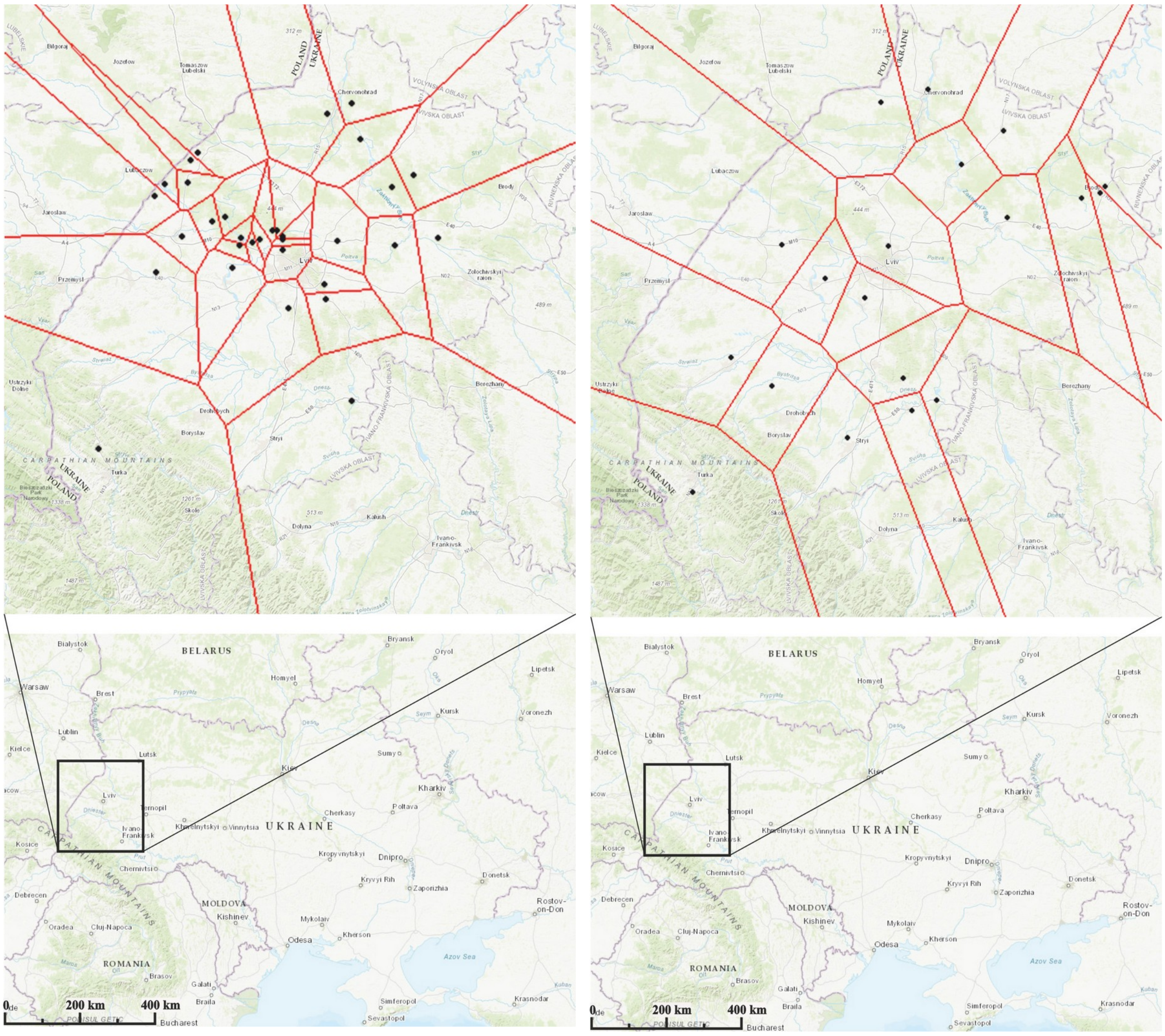
Because of the Voronoi diagrams, a plane is split and each region forms a set of points. It gives us an opportunity to study the biggest accumulation of fires and their environmental impact over a period. The vertices of cell rebars are points that are equidistant from 3 or more (depending on how many ribs intersect at this point) centers of fire origin.



a) b)



c) *d)*

Fig. 4. Voronoi diagrams: a) steppe fires; b) peat fires; c) forest fires; d) landfill fires.

It means that in areas of greatest concentration of fires it is necessary to place firefighting equipment in order to respond in a timely manner to a fire.

Conclusions

Having examined the connection between the occurrence of landscape fires and climatic parameters, we have a possibility to predict the peak periods of such fires and with developed preventive measures we can prevent its occurrence, as well as prepare state and voluntary fire brigades.

In order to respond in a timely manner to a fire, it is necessary to place firefighting equipment at fire safety points and forest fire stations in such a way that one checkpoint could service several populated areas where fires in ecosystems often occur. The optimal location of these points (taking into account the existing fire departments and community fire units) will be an intersection of the Voronoi chart cells rebars, provided that the distance from the most remote settlement to the point of reference will not exceed 3 km, as required by the State Construction Norms of Ukraine.

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