ATLANTIS PRESS
Advances in Engineering Research, volume 191
IV International Scientific and Practical Conference 'Anthropogenic Transformation of Geospace: Nature, Economy, Society' (ATG 2019)

Fire Regime of Landscapes in the Volgograd Region According to Remote Sensing Data

Stanislav Shinkarenko
Federal Scientific Center of Agroecology, Complex Meliorations and Agroforestry RAS, Volgograd State University, Institute of Natural Sciences, Chair of Geography and Cartography
Volgograd, Russia
shinkarenko@volsu.ru,
https://orcid.org/0000-0002-9269-4489

Valeriya Doroshenko
Volgograd State University, Institute of Natural Sciences, Chair of Geography and Cartography
Volgograd, Russia
dor.valerya@yandex.ru
https://orcid.org/0000-0003-3253-1132

Asel Berdengalieva
Volgograd State University, Institute of Natural Sciences, Chair of Geography and Cartography
Volgograd, Russia
berdengalieva@mail.ru
https://orcid.org/0000-0002-5252-7133

Abstract **– The article is devoted to the analysis of fire regime of the Volgograd region's landscapes. The problem of wildfires became especially urgent at the beginning of the 21st century, when climate change and reduced agricultural load created conditions for landscape fires break-out and spread. Research material includes the archive of active fire foci (thermal spots) over the period of 2001-2018 years. Corpora of thermal spots in the context of seasonal, perennial, and landscape features of the region are formed on the basis of spatial analysis and attributive data samples. Landscape, seasonal and spatial regularities of the fire regime of the Volgograd region are revealed. The second decade of the 21st century was marked by a threefold decrease in the total number of active fire foci in the region mainly due to fires in typical steppe and dry-steppe landscapes. The research results provide an opportunity to analyze the implemented and planned fire prevention measures and to propose the ways of improving their efficiency.**

Keywords: landscape fire, GIS, remote sensing, satellite imagery, Landsat, Sentinel

I. Introduction

Over the last two decades we observe intensification of landscape fires in Russia and neighboring countries. Both the scale and the frequency of fires is rapidly increasing. The problem of forest fires is sufficiently covered [1], while the fires in steppe, semi-desert and desert landscapes have been understudied [2, 3]. Pyrogenic factor is one of the most important ones affecting vegetation [4]. According to some researchers, steppe fires may improve the state of pastures, while others, on the contrary, note the destructive impact of steppe fires on natural phytocenoses. Fires also cause death of arthropods and rodents, and contribute to erosion development [5-7]. Thus, the study of the fire regime should be an important part in complex landscape studies. First of all, it is necessary to determine burned areas, the frequency of fires and periods of the greatest fire danger.

The present research is aimed at studying landscape fires in the Volgograd region located in the steppe zone. The Northern, Western and Central parts of the territory under study refer to the steppe type of landscapes. The Trans-Volga region and the South of the Volgograd region are represented with semi-desert types of landscape. Intrazonal forest-steppe landscapes are located along the river valleys and up to the Northern part of the region. The region's vegetation is of a steppe type with sod grasses, such as *Agropyron*, *Stipa*, *Festuca*, *Poa*, etc. being the dominant plant cultures. Precipitation varies from 448 mm in the North-West (the town of Uryupinsk) to 380 mm in Volgograd. Average annual temperatures in these locations are 7.1 °C and 8.8 °C, respectively. Fire regime of the region's landscapes changes depending on the natural conditions.

Such climate change as increase in the temperature and precipitation caused by the reduced pasture loads and arable lands at the turn of the 20th and 21st centuries contributed to development of herbaceous vegetation and accumulation of dead grass, which led to increased number of fires. The use of remote sensing data and geoinformation modeling methods seems to be the best tool for analyzing the fire regime of landscapes.

II. Materials and Methods (The Model)

The research is based on the archive of active fire foci (thermal spots, thermal anomalies), FIRMS (Fire Information for Resource Management System), MODIS 500 m-resolution spectroradiometer data over the period of 2001-2018 years [8]. The data are provided free of charge in the WGS84 (EPSG 4326) system. Geoinformation processing has been carried out in the QGIS program of versions 2.18 and 3.2. Open Street Map of administrative borders and municipal districts of the Volgograd region is used as a base map. Determining the period with the biggest number of active fire foci has been carried out on the basis of tools of the QGIS attribute table field calculator. The FIRMS source data contain the attribute – date of fire (in the format YYYY-MM-DD), which allows determining numbers of the week (function "week") and month (function "month") of fires. The methods of spatial analysis let determine the number of thermal spots in 2000-2018 per 1 km^2 in the cells of a regular grid of 10x10 km. After that, a pseudo-isolinear map has been built on the basis of interpolation algorithm by the universal kriging method.

Grant of the President of the Russian Federation MK-321.2019.5

Maps are presented in UTM projection (zone 38), coordinate system WGS84 (EPSG 32638).

The Global Land Cover (GLC30) and USGS Land Cover Classification System underlying surface data have a resolution of 30 and 400 m, respectively, and are provided in UTM and geographic projections with the WGS84 coordinate system [9]. The data were reprojected and converted into vector thematic GIS layers. The methods of spatial analysis have been applied to calculate active fire foci in the polygons of different categories of the underlying surface and different types of landscapes with identification of month and year attributes as classification fields. The data on burnt areas in zonal landscapes are given according to the previous research works [10].

III. Results and Discussion

The intensity of landscape fires in the Volgograd region is reflected in the maps in Figure 1. The lowest density of fire foci is on the pasture lands of the Trans-Volga region. However, the largest areas in the region are burned here annually. This imbalance is caused by the high dynamism of grass fires, particularly high speed of spreading and cooling. Due to this fact, thermal spots cover only the fire front at the time of satellite imagery.

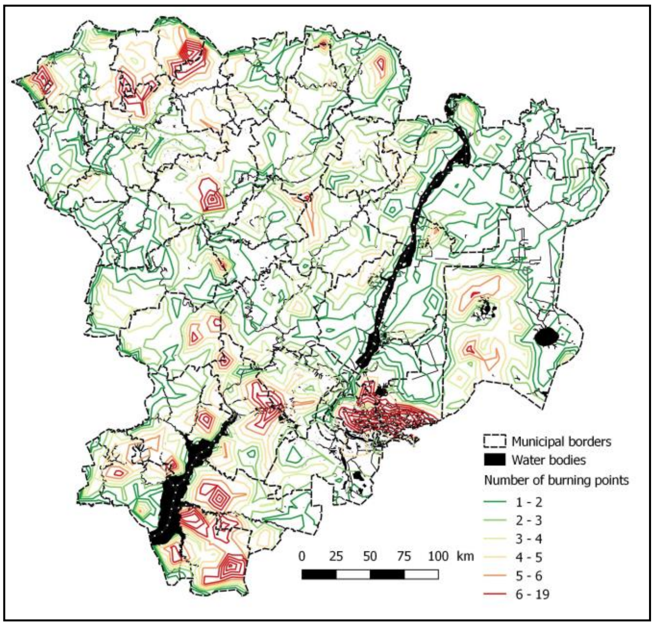

Fig. 1. Pseudoisolinear map of active fire foci in grid cells of 10x10 km.

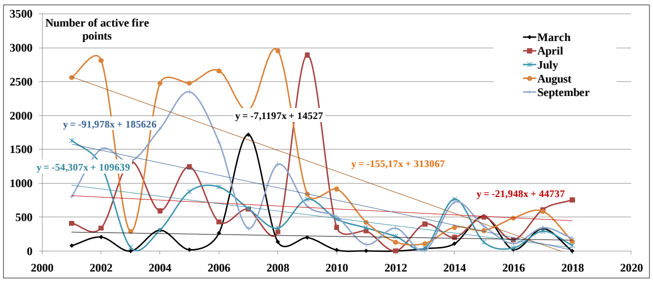

Fig. 2. Trends of change in the number of thermal spots for the most fire-hazardous months.

High density and a large number of thermal spots per year are typical for the Volga-Akhtuba floodplain (the Leninsky district and the Sredneakhtubinsky district) and the areas with large arable lands: the Kotelnikovsky, Oktyabrsky, Kalachevsky, Mikhaylovsky, Kikvidzensky and Novonikolaevsky districts.

Figure 2 shows changes in the number of active fire foci by months during the period under study. August and September are characterized by the largest decrease: 156 and 92 thermal spots per year, respectively. The number of fire foci during these months over the period of 2010-2018 had reduced by 5.6 and 4.4 times, respectively, as compared to the period of 2001-2009.

With regard to the second decade of the 21st century, we can point to a decrease in the number of fire foci by 3.3 times as compared to the first decade. This means that the intensity of landscape fires has significantly decreased, mainly during the late summer-autumn period. We will show the regularities of the fire regime of the Volgograd region depending on the types of underlying surface and landscape conditions.

The long-term dynamics of the number of fire foci in the region in terms of landscapes subtypes is shown in Figure 3. Since 2009, the largest decline in the number of fire foci (4.9 times) is peculiar of typical steppe landscapes, followed by dry steppe (3.2 times), forest-steppes (2.4 times) and semi-deserts (1.9 times). Until 2010, typical steppe and dry steppe landscapes accounted for about 40% of all fire foci. Later on, this figure plummeted to 27%, while in semi-desert the number of fire foci increased from 17% to 30%. In the dry steppes the situation did not change.

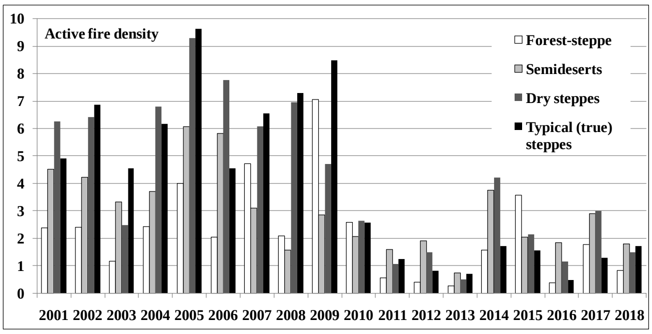

Fig. 3. Density of fire foci by landscape subtypes (number of foci per 100 km^2).

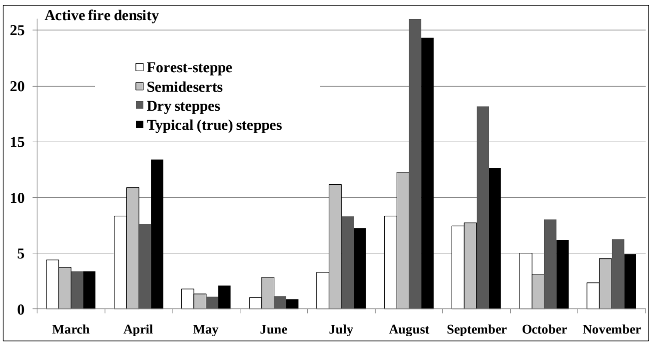

Fig. 4. Seasonal distribution of fire foci by landscape subtypes (number of foci per 100 km^2).

The highest density of thermal spots for the entire period of research was observed in semi-desert and dry-steppe landscapes: up to 9 foci per 100 km^2 annually. In absolute terms, the largest share (15%) in the first decade fell for typical steppe glacial accumulative landscapes; since 2010 – in semi-desert marine accumulative landscapes of the Trans-Volga region (21%).

Figure 4 shows seasonal patterns of fire regime of the region's landscapes. The highest density of thermal spots during the period under study was observed in August and September in dry-steppe and typical steppe landscapes. The density of fire foci is also high in March, April in semi-arid saline and deltaic-accumulative and typical steppe of the loessic accumulative-denudation landscapes. The lowest density of fires is typical of May and June – the period of active vegetation of the steppe zone. Due to the high humidity of the above-ground parts of plants, there is no high fire hazard during this period. In the Volga-Akhtuba floodplain, the burning of reeds is prevented by high water, and agricultural fires in late spring are very rare. In the second decade of the 21st century as compared to the first one, the highest decrease in the number of fire foci was observed in March in typical steppe landscapes of river valleys, mixed dry steppe landscapes; in June – in the dry deluvial-proluvial, dry steppe landscapes of river valleys and in the typical steppe loessic accumulative landscapes; in July – in the dry steppe and typical steppe landscapes of river valleys; in August – in typical steppe glacial accumulative, loessic accumulative and river valley landscapes; in September – in the dry accumulative landscapes and river valleys (Figure 5).

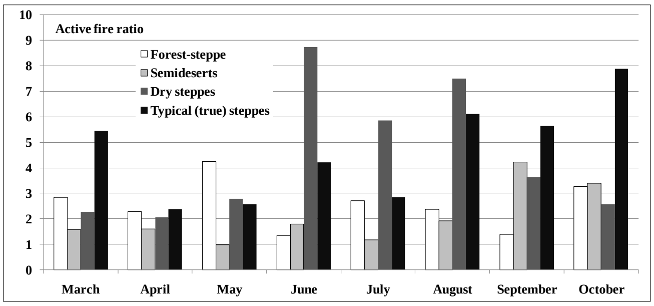

Fig. 5. Ratio of the number of fire foci by month over the period of 2001-2009 to that of the period of 2010-2018 by landscape subtypes.

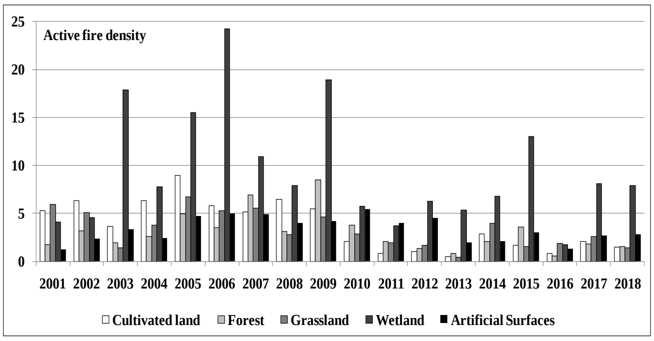

Fig. 6. Density of fire foci by the type of Global Land Cover underlying surface (number of foci per 100 km^2).

The analysis of the fire regime of the region's landscapes in the context of underlying surface types is of undoubt scientific interest (Figures 6-8). Throughout most of the period under study the highest density of active fire foci was observed in the wetlands. This primarily concerns the Volga-Akhtuba floodplain. Until 2010, a high density of thermal spots was also observed on cultivated lands. All subtypes of landscapes, as well as different types of underlying surface, are characterized by a decrease in the number of thermal spots in the second decade of the 21st century as compared to the first decade. Particularly strong (by 4 times) decrease in the number of thermal spots occurred on cultivated lands. The number of fire foci decreased twofold in forests, steppes and wetlands, and remained almost unchanged in urban areas.

Figure 7 shows the seasonal distribution of fire foci by the types of underlying surface during the whole period under study. The highest density of thermal spots was observed in March and April in the wetlands. In forests and steppes, most fires occur in the second half of summer and early autumn. In almost all months, the number of fire foci in all types of underlying surface decreased in 2010-2018 on cultivated lands as compared to the first decade (Figure 8): by 8.8 times – in August, by 4.9 times – in September, by 1.6 times – in October and May, by 2.6 times – in April, by 3.5 times – in March. The number of thermal spots in forests decreased by 3.3 times in March, by 2.3 - 2.5 times in April, July and October, and by 1.6-1.7 times in May and October. The number of fire foci on artificial underlying surfaces remained practically unchanged: decreased by 1.8-1.9 times in March, April and October, but increased by 1.1-1.3 times in other months.

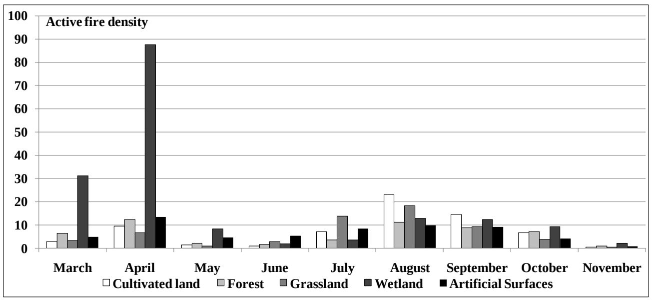

Fig. 7. Seasonal distribution of fire foci by Global Land Cover underlying surface (number of foci per 100 km^2).

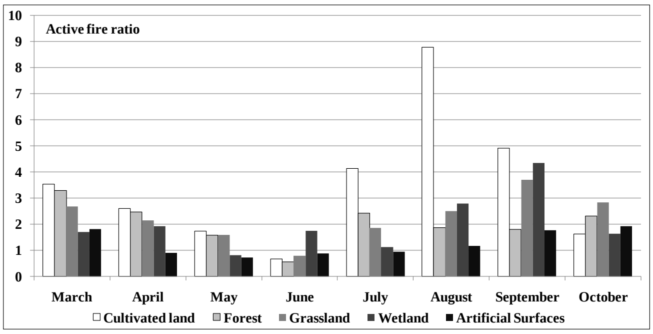

Fig. 8. Ratio of the number of fire foci by month over the period of 2001-2009 to that over the period of 2010-2018 by the types of underlying surface.

Correlation analysis has been carried out to identify the link between the areas of fires (Table 1) and different climatic indicators (precipitation and average temperatures in the current and previous years, warm and cold half-year periods, fire-hazardous period). In the Southern part of the region (Volgograd weather station), a significant correlation coefficient (r=0.51) is observed only between the areas of fires and the amount of precipitation for the previous years. In the North-West (Uryupinsk weather station), the largest correlation is observed between the dynamics of fire areas and the average temperature for the fire-hazardous period. In the Central part of the region (Frolovo weather station), the correlation coefficients between the areas of fires and the amounts of precipitation for the previous year and the fire-hazardous period are 0.28 and -0.26, respectively. The strongest link between the areas of fires and the amount of precipitation for the previous year was noted in the Trans-Volga region (Elton weather station) (r=0.62). Such differences are conditioned by the difference in natural conditions and the system of nature management in different areas. In the steppe North-West and in the Central part of the region, pasture loads on natural zonal landscapes are insignificant, and moisture is sufficient for the accumulation of mortmass [11].

At the same time, due to the high plowing, natural landscapes were preserved only on large beams, where the vegetation is of the meadow type. Therefore, the current year conditions are much more important: the summer period should be quite long, hot and dry. In some areas of the region's Southern part, the share of natural pastures is higher and the climate aridity is more strongly marked than in the Northern regions. Therefore, the hydrothermal conditions of previous years are important here. In the semi-desert Trans-Volga region, productivity of natural vegetation is even lower, that is why some wet years cause its rapid development largely due to ephemera. Therefore, all years characterized by large fire areas were preceded by one- or two-year periods with precipitation level above the annual average one. There is no reliable interdependence between the number of fires and their total area. The correlation coefficient is equal to 0.68. Two-thirds of the fire area (67%) account for a small number (1.2% of all fires) of very large fire sites with an area of more than 100 km^2. Each of the other scale classes accounts for no more than 10% of the area.

TABLE I. AREAS AND THE NUMBER OF STEPPE FIRES [11]:

Year	The area of fires, km^2	The area of fires, number
2001	281	6390.1
2002	406	4395.0
2003	51	231.1
2004	212	3331.6
2005	759	5698.9
2006	493	4948.9
2007	347	2847.0
2008	357	2240.0
2009	92	2103.1
2010	261	4099.2
2011	29	1024.5
2012	36	2812.9
2013	10	21.3
2014	113	3953.0
2015	94	485.2
2016	43	3236.2
2017	105	2642.6
2018	44	508.6

The largest number of fires (38.2%) have an area of up to 1 km^2 with a total area of 1.2% of all fire sites. They are followed by fires of 2-6 km^2 (23.8%) and 1-2 km^2 (17%). Since 2010, there was a significant decrease in the number of fires in zonal natural landscapes (by about 4 times), while the fire area decreased only by 1.7 times. This means that in some years there are few large-scale fires. For example, in each of the years 2012, 2016 and 2017, more than 2.5 thousand km^2 burned.

IV. Conclusion

The analysis of the fire regime of the Volgograd region's landscapes let reveal the trend of reduction in the number of active fire foci in the second decade of the 21st century as compared to the first decade. This decrease is typical of all subtypes of landscapes and the types of underlying surface. The largest decrease in the density of thermal spots occurred on cultivated lands. This may be connected with the use of lands that were not used in 2001-2009, as well as with rarer burning of stubble residues.

The highest frequency of fires was noted in the Trans-Volga region (the Pallasovsky district) – 12.3% of all fire sites were burned from eight to thirteen times. In the right-bank part of the Volga river, the Don bend (The Ilovlinsky and Kalachevsky districts) is the focus of steppe fires.

Fire foci are tied to the territories, which are the least subjected to agricultural development and are remote from settlements. The index of the nearest neighbors of the fire site centers indicates significant clustering of their spatial distribution.

Acknowledgment

The research has been funded by the grant of the President of the Russian Federation for support of young scientists, candidates of sciences No. MK-321.2019.5.

References

[1] S.A. Bartalev, V.A. Egorov, V.Yu. Efremov, E.A. Loupian, F.V. Stytsenko, and E.V. Flitman, “Integrated burnt area assesment based on combine use of multi-resolution MODIS and Landsat-TM/ETM+ satellite data),” in Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa, vol. 9, no. 2, pp. 9-26, 2012.

[2] V.M. Pavleichik, “The conditions for the spread of grass fires and the periodicity of their occurrence in the Trans-Volga-Ural region”, in Geography and natural resources, no. 2, pp. 65-56, 2017. DOI: 10.21782/GIPR0206-1619-2017-2(56-65).

[3] M.Yu. Dubinin, A.A. Lushchekina, and F.K. Radelof, “Assessment of modern burning dynamics in arid ecosystems using remote sensing data (case study of Chernye zemli)”, in Aridnye ekosistemy, vol. 6, no. 3, pp. 5-16, 2010.

[4] M.L. Oparin, and O.S. Oparina, “Influence of fires on dynamics of steppe vegetation”, in Povolzhskiy ekologicheskiy zhurnal, no. 2, pp. 158-171, 2003.

[5] CEC. “Analysis of the Effects of Fire, Grazing, and the Distance to Wetlands on Grassland Bird Abundance“, Montreal, Canada, Commission for Environmental Cooperation, 2003, 189 p.

[6] P. Cheney, and A. Sullivan, “Grassfires: Fuel, Weather and Fire Behavior", CSIRO Publishing, 2008, 150 p. DOI: 10.1071/9780643096493.

[7] N.O. Ryabinina, S.N. Kanishchev, and S.S. Shinkarenko, “The current state and dynamics of geosystems in the South-East of the Russian plain (exemplified by the natural parks of the Volgograd

region)", in Yug Rossii: ekologiya i razvitie, no. 1, pp. 116-127, 2018. DOI: 10.18470/1992-1098-2018-1-116-127

[8] L. Giglio, W. Schroeder, and C.O. Justice, "The collection 6 MODIS active fire detection algorithm and fire products", in Remote Sensing of Environment, vol. 178, pp. 31-41, 2016. DOI: 10.1016/j.rse.2016.02.054

[9] J. Chen, Y. Ban, and S. Li, "China: Open access to Earth land-cover map", in Nature, vol. 514 (7523), p. 434, 2014. DOI: 10.1038/514434c

[10] S.S. Shinkarenko, "Fire regime of North Caspian landscapes according to the data of active burning centers", in Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa, vol. 16, no. 1, pp. 121-133, 2019. DOI: 10.21046/2070-7401-2019-16-1-121-133

[11] S.S. Shinkarenko, and A.N. Berdengalieva, "Analysis of steppe fires long-term dynamics in the Volgograd Region", in Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa, vol. 16, no 2, pp. 98-110, 2019. DOI: 10.21046/2070-7401-2019-16-2-98-110