MATHEMATICAL MODELING OF ECONOMIC LOSSES CAUSED BY FOREST FIRE IN UKRAINE

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Abstract. In this publication, the authors analysed the current state of economic and environmental damage caused by forest fires in Ukraine. Uncontrolled spread of fire not only causes significant economic damage, but also has dire consequences for the ecology. The burning of large areas of forest leads to a radical change in the ecosystems of the affected region, which can eventually lead to unpredictable results. Thus, the negative indicators of forestry are: quantity of forest fires, units; area of forest lands covered by fires; losses caused by forest fires; burned and damaged forest. It should be noted that the indicators of the consequences of forest fires do not mathematically correlate with the loss of wood cover in Ukraine, which are determined by the data remote sensing of the earth (Forest Global Watch). At the same time, a data set Global Forest Watch on the loss of wood cover concerted with a number of institutions, including the University of Maryland, Google, USGS i NASA, and this resource uses satellite imagery Landsat to display the loss of yearly tree cover with a resolution of 30 × 30 meters. Existing approaches to calculating economic losses are described. The authors' approach to the determination of losses from forest fires, which is based on statistical and mathematical methods (correlation analysis, mathematical modelling) of scientific research, is proposed. The proposed mathematical model makes it possible to estimate the amount of economic damage caused by forest fires in Ukraine.

Keywords: mathematical modelling, economic methods, economic damage, forest land, forest fire.

Introduction

Solution of any nature management problems, including forest lands, requires in-depth and comprehensive study. At the same time, any managerial, organizational decisions should be based on certain scientific forecasts on the consequences of nature management in the project, development of measures to prevent the impact of negative factors on the environment and improvement of approaches to economic planning taking into account the environmental factor. Also, the protection of forest lands requires a powerful material and technical base, taking into account modern advances in technology, in particular, Global Navigation Satellite System – technologies that allow you to record forests (areas) with high accuracy; large-scale introduction of technologies of waste-free (low-waste) production; increasing the volume of production of synthetic (artificial) substitutes for natural materials [1-3].

The issue of studying the losses due to forest fires is the subject of the publication H. Cai, Zl. Liu, G. Yang, X. Di. [1]. Scientists say that forest fire loss statistics is becoming a crucial tool in decision-making and in helping to reduce loss to life and property due to fires around the world. Estimating forest fire direct loss is important pieces of data when assessing fire at local and national levels. So far, the fire direct loss assessment work abroad has been greatly developed. And current forest fire direct loss assessment only stays in simple statistics and lacks the deep data intellectualized and analysis. Based on the current situation status of forest fire direct loss assessment, they divided the direct loss of forest fire into standing trees resource loss, commodity wood loss, fixed assets loss, current assets loss, forest by-product loss, agriculture and animal husbandry product loss, fire fighting expenses, personnel casualty loss, residents' property loss and made a quantitative and qualitative assessment of forest fire loss through the data of self-made forest fire case.

O. V. Akinola, J. Adegoke [4] emphasize that forest fire is one of the major disasters that distresses the terrestrial environment and causes economic disruptions for people and communities in areas prone to forest fire. Information on forest fire risk zones is therefore essential for effective and sound decision-making in forest management. Forest fire risk assessment is a critical part and the most important step in forest management because it enables us to know where the risk is higher in order to minimize threats to life, property and natural resources. This study used a hazard assessment model to assess forest fire risk in Missouri based on several measurable environmental parameters influencing forest fire risk vulnerability. Using the four ecological zones in Missouri as the basis of analysis, three forest risk zones were identified. These were high forest fire risk zones, moderate forest fire risk zone and low forest fire risk zone. Strategies for the mitigation of the hazard of forest fire in the state were also recommended.

In a scientific article by M. Zhong, W. Fan, T. Liu, P. Li [5] considered statistical data on forest fires in China are analyzed in order to reveal new features regarding the forest fire safety situation as the economy of China is growing. The causes of forest fires in China are also discussed. The classifications of forest fire hazard used to improve forest fire prevention and management in China are reviewed, and the current status of the fire researches in China is introduced.

However, the destruction of large forest areas that regulate climatic conditions and water regime of huge basins, as noted by H. I. Vorobiov, K. D. Mukhamedshyn, L. M. Deviatkin [6, p. 6], Tedim, F., Xanthopoulos, G., Leone, V. [7], Ubysz, B., Szczygiel, R. [8] violates the ecological balance established for millions of years, which in turn leads to constant devastating floods, mudslides, water erosion processes, dust storms, droughts or development of wetlands depending on the specific climatic conditions and the nature of woody vegetation.

At the same time, the problem of forest fires, the numerous environmental and economic losses they cause, in recent years has attracted special attention in the context of growing influence to global processes such as declining global forest resources, numerous biodiversity losses, global climate change and land use change. All this is due to the complexity and ambiguity of the impact of forest fires on forest lands, the environment and safe living conditions for the population in settlements (united territorial communities), which are located near forests [9; 10].

Materials and methods

In order to economically assess the loss of natural resources, scientists I. V. Voronin, A. A. Senkevych, V. A. Buhaiev developed a method for determining the total losses to forestry as a result of forest fires, which foresee the following indicators [11]:

- damages from fire damage to plantations;
- the cost of work to collect damaged trees;
- losses of harvested wood due to fire;
- the cost of burned or damaged buildings and structures;
- losses of crops, hay and more;
- fire extinguishing costs;
- losses from deterioration of protective, sanitary and hygienic properties of forest plantations as a result of fire;
- losses from side use, secondary use of the forest (collection of juice, fruits, berries, mushrooms, etc.);
- losses of the forest industry in the amount of investments for the destroyed timber stock.

Damage from damaging of plantations (V) is determined by formula (1):

$$V = B \times K - T \tag{1}$$

where B – cost of burned plantings at the age suitable for felling;
T – cost of wood damaged by forest fire;
K – coefficient that takes into account economic conditions of reforestation works after the fire.

At the same time, mathematical modelling allows to determine the total scope of economic losses from forest fires, based on dependent factors, determinants, which are pre-determined on the basis of correlation. In order to quickly assess the economic losses caused by forest fires, we proposed a regression model, the adequacy of which is confirmed by Fisher’s criterion – 107.659 and the coefficient of determination R^2 = 0.923 (formula 2) (Fig. 1) [12; 13].

$$Y = -4171.26 + 1.12 \times X_1 + 0.13 \times X_2 \tag{2}$$

where Y – losses caused by forest fires, thousand UAH;
X_1 – area of forest lands covered by fires, ha;
X_2 – quantity of forest that burned and was damaged on the stump, m^3.

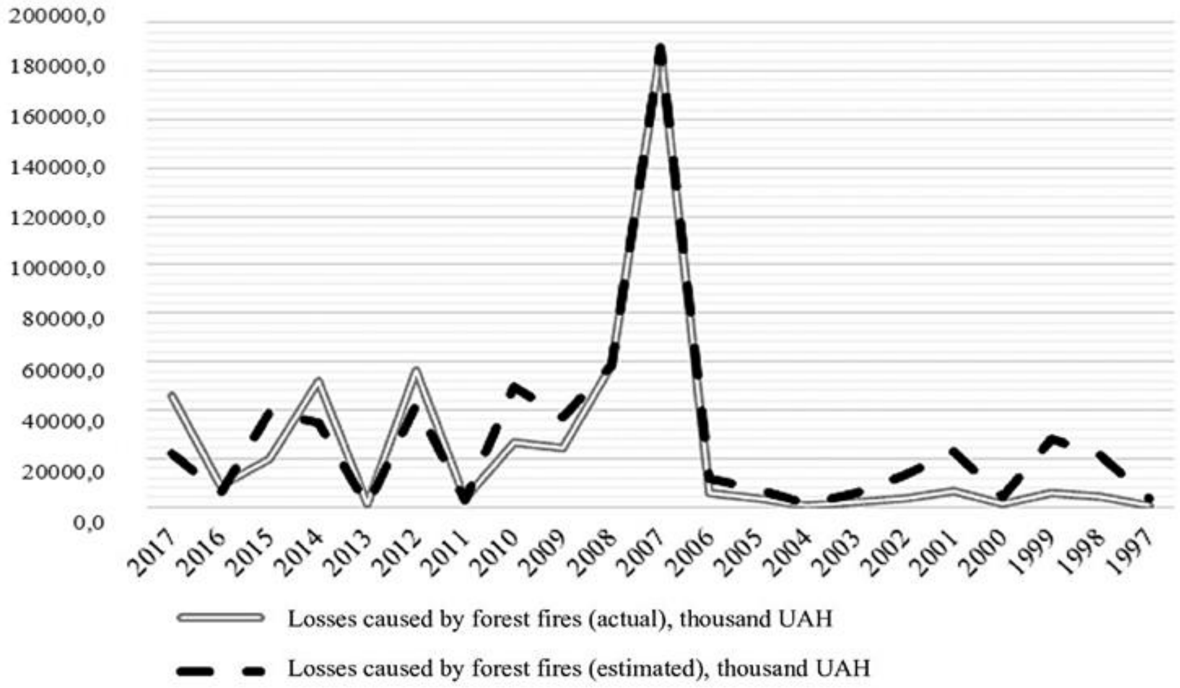


Fig. 1. **Image of the adequacy of the mathematical model developed on the basis of regression for determining the damage caused by forest fires, thousand UAH**

Results and discussion

Uncontrolled spread of fire not only causes significant economic damage, but also has dire consequences for ecology. The burning of large areas of forest leads to a radical change in the ecosystems of the affected region, which can eventually lead to unpredictable results. Thus, the negative indicators of forestry are (Table 1) [14; 15]:

- quantity of forest fires, units;
- area of forest lands covered by fires, ha;
- losses caused by forest fires, thousand UAH;
- burned and damaged forest, m^3 (Table 1).

Table 1

Indicators of the consequences of forest fires in Ukraine

Year	Consequences of forest fires			
	Quantity of forest fires, units	Area of forest lands covered by fires, ha	Burned and damaged forest, m^3	Losses caused by forest fires, thousand UAH
2017	3131	5939.0	149775.0	45877.6
2016	1249	1249.0	32559.0	8619.2
2015	3813	14691.0	170686.0	20164.5
2014	2003	13778.0	144694.0	51701.8
2013	1113	418.0	2496.0	1376.2
2012	2163	3479.0	289291.0	56062.7
2011	2526	1049.0	11804.0	3215.9
2010	3240	3668.0	343840.0	26728.4
2009	7036	6315.0	223764.0	24686.4
2008	4042	5529.0	395257.0	58750.3
2007	6100	13787.0	1304271.0	188412.2
2006	3842	4287.0	53119.0	5917.6
2005	4223	2325.0	32101.0	3535.0
2004	1876	595.0	1944.0	428.7
2003	4527	2817.0	19720.0	1817.5
2002	6383	4983.0	59206.0	3378.9
2001	3205	3772.0	139604.0	6204.3

Source: own calculations according to the State Statistics Service of Ukraine [16].

It should be noted that the indicators of the consequences of forest fires do not mathematically correlate with the loss of wood cover in Ukraine, which are determined by the data remote sensing of the earth (Forest Global Watch) (Table 2). Methodology for obtaining data on forest cover losses with the help of remote sensing of the earth Global Forest Watch is described by a team of scientists Hansen M. C., Potapov P. V., Moore R., Hancher M. et al. [17].

At the same time, the data set Global Forest Watch on the loss of wood cover concerted with a number of institutions, including the University of Maryland, Google, USGS i NASA, and this resource uses satellite imagery Landsat to display the loss of yearly tree cover with a resolution of 30 × 30 meters [13; 17] (Table 2).

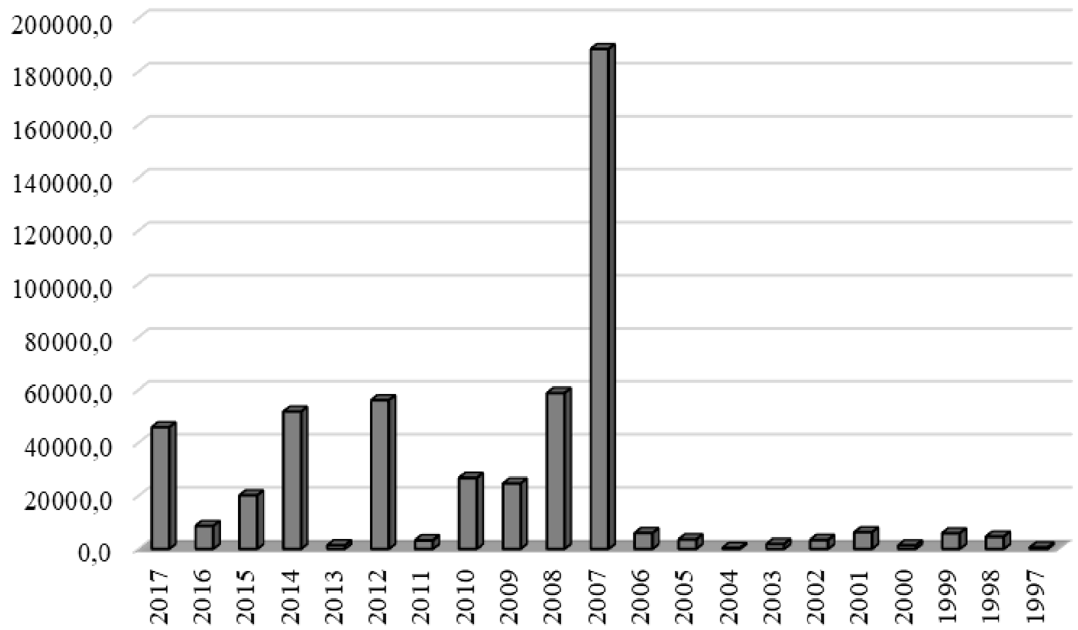
Table 2

Correlation of consequences of forest fires and loss of wood cover in Ukraine

R^2	**Loss of wood cover in Ukraine according to data remote sensing of the earth (Forest Global Watch), thousand ha**	**Indicators of the consequences of forest fires**
Correlation coefficients	-0.325	Quantity of forest fires, units
	-0.002	Area of forest lands covered by fires, ha
	0.162	Burned and damaged forest, m³
	0.259	Losses caused by forest fires, thousand UAH

According to the results of analytical calculations, the losses caused by forest fires, which during 2001-2017 amounted to UAH 506.877 million, mainly depend on the area of the forest land covered by fires (R = 0.632) and the quantity of burned and damaged forest on the stump (R = 0.956).

The diagram (Fig. 2) shows that 2007 was marked by the largest environmental "catastrophe" associated with forest fires, in particular, in the Kherson region. As a result, the forest fire was extinguished on an area of about 4 thousand hectares.



Source: own calculations according to the State Statistics Service of Ukraine.

Fig. 2. **Diagram of the dynamics of damage caused by forest fires, thousand UAH**

Given the current dynamics and cyclical nature of the negative consequences of forest fires, we predicted the area of forest land covered by forest fires, the quantity of burned (damaged) forest on the stump, and the damage caused by forest fires by 2030.

According to the calculations we have found that for the period 2019-2030 in Ukraine, the total projected area of forest land covered by fires will be 49.991 thousand hectares, the total quantity of burned and damaged forest on the stump – 4.086 million m³, losses caused by forest fires, – UAH 906.211 million or UAH 1.817 billion (taking into account the consumer price index for 2020).

Conclusions

Therefore, to reduce the amount of environmental and economic losses from the effects of forest fires in the future it is necessary to implement effective management, organizational measures to protect forest lands from such negative phenomena.

A forest fire monitoring system has been developed, in particular the European Forest Fire Information System (EFFIS), which supports forest fire protection services in the EU and provides services to the European Commission and the European Parliament. Updated and reliable information on fires in Europe allows the relevant services to respond quickly to protect forest lands from such negative phenomena. The system allows to determine the area of burned lands from forest fires and to compare these data with the indicators of previous years (average).

According to the results of the study, the forecast indicators of economic losses from forest fires were calculated, taking into account the existing dynamics of these negative phenomena. The proposed mathematical model will allow to calculate the economic losses from forest fires in order to compensate for them.

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Author contributions

The contribution of each author. Conceptualization, Ivan Openko; methodology, Ivan Openko and Ruslan Tykhenko; software, Oleksandr Shevchenko; validation, Anatoliy Rokochinskiy and Pavlo Volk; formal analysis, Oleksandr Shevchenko; investigation, Ivan Openko and Yanina Stepchuk; data curation, Ivan Openko, Yanina Stepchuk and Oleg Tsvyakh; writing original draft preparation, Ivan Openko and Yanina Stepchuk; writing – review and editing, Ivan Openko and Ruslan Tykhenko; visualization, Yanina Stepchuk; project administration, Ivan Openko; funding acquisition, Oleg Tsvyakh, Anatoliy Rokochinskiy and Pavlo Volk. All authors have read and agreed to the published version of the manuscript.

References

[1] Cai H. -y., Liu Z. -l., Yang G., Di, X. -y. Study on forest fire direct loss assessment. World Automation Congress 2012, pp. 1-4.

[2] Gensiruk S. A. Ratsional’noye prirodopol’zovaniye, Moskow: Lesnaia promyshlennost’, 1979. (In Russan).

[3] Vorob′ev H. Y., Mukhamedshyn K. D., Devyatkyn L. M. Lesnoe khozyaystvo myra, Moskow: Lesnaia promyshlennost’, 1984. (In Russian).

[4] Akinola O. V., Adegoke J. Assessment of forest fire vulnerability zones in Missouri, United States of America, International Journal of Sustainable Development & World Ecology, 26:3, 2019, pp. 251-257. DOI: 10.1080/13504509.2018.1551815

[5] Zhong M., Fan W., Liu T., Li P. Statistical analysis on current status of China forest fire safety. Fire Safety Journal. Volume 38. Issue 3. 2003, pp. 257-269.

[6] Zibtsev S. V., Borsuk O. A. Protection of lisiv vid pozhezh u sviti that in ukraine - wiki of the 21st century and prospect of development. Lisove i sadovo-parkove hospodarstvo, vol. 1. 2012. [online][02.03.2021] Available at: http://journals.nubip.edu.ua/index.php/ Lis/article/download/9630/8613

[7] Tedim F., Xanthopoulos G., Leone V. Chapter 5 – ForestFires in Europe: Facts and Challenges. Wildfire Hazards,Risks and Disasters, 2015, pp. 77-99.

[8] Ubysz B., Szczygiel R. Fire Situation in Poland. International Forest Fire News, 27, 2002, pp. 38-64.
[9] Voronin I. V., Senkevich A. A., Bugaev V. A. Ekonomicheskaya effektivnost' v lesokhozyaystvennom i lesomeliorativnom proizvodstvakh, Moskow: Lesnaia promyshlennost', 1975. (In Russian).
[10] Sirin A., Maslov A., Makarov D., Gulbe Y., and Hans Joosten. Assessing Wood and Soil Carbon Losses from a Forest-Peat Fire in the Boreo-Nemoral Zone. Forests. 12, no. 7, 2021, 880 p. DOI: 10.3390/f12070880
[11] State Statistics Service of Ukraine. Main indicators of forestry activity (1990-2017). 2018. [online][02.03.2021] Available at: http://www.ukrstat.gov.ua/operativ/operativ2014/sg/lis/lis_u/lgd2016_u.htm (In Ukrainian).
[12] Strand J. Modeling the Marginal Value of Rainforest Losses : A Dynamic Value Function Approach. Policy Research Working Paper No. 7445. World Bank, Washington, DC, 2015.
[13] Shevchenko O., Openko I., Tykhenko R., Tsvyakh O., Zhuk O., Kryvoviaz E., Tykhenko O., Bavrovska N., Stepchuk Ya., Rokochinskiy A., Volk P. Assessment of economic losses caused by degradation processes of agricultural land use. Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. 2021, pp. 102-109.
[14] Martyn A., Openko I., Ievsiukov T., Shevchenko O., Ripenko A. Accuracy of geodetic surveys in cadastral registration of real estate: value of land as determining factor. 18th International Scientific Conference. Engineering for Rural Development, 22-24.05.2019 Jelgava, Latvia, 2019, pp. 1818-1825.
[15] Hall J.V., Zibtsev S.V., Giglio L., Skakun S., Myroniuk V., Zhuravel O., Goldammer J. G., Kussul N. Environmentaland political implications of underestimated croplandburning in Ukraine. Environmental Research Letters, 16:064019, 2021.
[16] Hansen M. C., Potapov P. V., Moore R., Hancher M. et al. High-Resolution Global Maps of 21st-Century Forest Cover Change. American Association for the Advancement of Science, 342, 6160, 2013, pp. 850-853. DOI: https://doi.org/10.1126/science.1244693
[17] Global Forest Watch. Tree Cover Loss in (selected area name), 2018. [online][02.03.2021] Available at: www.globalforestwatch.org.