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Methods of Computer and Mathematical Modeling in Estimating Impact of Leninsky Prospekt Highway

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***Abstract*—The article deals with methods of computer and mathematical modeling for estimating the impact of the Leninsky Prospekt highway on the phytocoenoses in the campus of RUDN. The computer model of the spread of pollutants from the Leninsky Prospekt highway has been constructed. Margalef, Menhinick and McIntosh diversity indices of the phytocoenoses of the RUDN campus have been used. Moreover, the composite fluctuating asymmetry index of leaves of these phytocoenoses has been calculated. As a result, the factor values of the pollutants spreading from the Leninsky Prospekt highway and the composite fluctuating asymmetry index of leaves have been determined.**

Keywords—computer modeling; mathematics analysis; phytocoenoses; impact of environment; highway; spread of pollutants; biodiversity indices; fluctuatimg asymmetry index

I. Introduction

Currently, RUDN is one of the top Universities in Russia, participating in many international environmental and educational programs, among which are the UI Green Metric Universities ranking, the Russian Academic Excellence Project (Project 5-100), etc. In this field, RUDN develops policies on the green campus and improves a lot of educational environmental programs. One of them is environmental monitoring, particularly monitoring of plant communities of the RUDN campus located near the Leninsky Prospekt highway.

In the beginning of 1901, K. Pearson expressed the need to apply methods of mathematical statistics and computer data processing to assess the state and behavior of living things [1]. Prominent researchers used these methods and supplemented them with computer programs [2-5]. Therefore, to estimate the

impact of the Leninsky Prospekt highway on the plant communities growing near the RUDN campus, we use computer and mathematical methods.

The object of our study is phytocenoses of the RUDN campus near the Leninsky Prospekt highway.

The main objectives are:

- - to construct the computer model of the spread of pollutants from the Leninsky Prospekt highway;
- - to identify species of trees growing in three sampling areas near the Leninsky Prospekt highway;
- - to calculate Margalef, Menhinick, McIntosh biodiversity indices, determine the morphological parameters of leaves, the fluctuating asymmetry indices of leaves of each morphological parameter and the composite indices of fluctuating asymmetry of leaves;
- - using factor analysis to determine factor values of the pollutants spreading from the Leninsky Prospekt highway and the composite fluctuating asymmetry indices of leaves.

II. Methods

Our study was conducted in May 2017 and included field testing and laboratory analysis (Fig. 1).

It should be noted that for identification of sampling sites, the geographical coordinates, the terrain, the distance between the RUDN campus and the Leninsky Prospekt highway were taken into account [6].

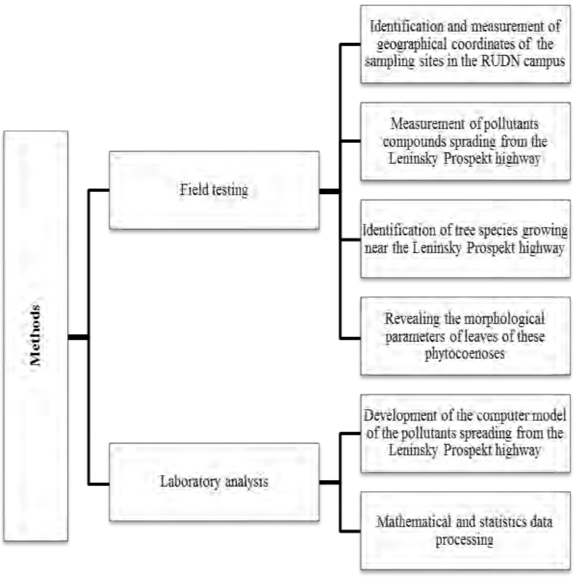


Fig. 1. The scheme of the used methods

To study the spread of pollutants from the Leninsky Prospekt highway, we identified 33 sampling sites where we carried out 1122 measurements of geographical coordinates (latitude and longitude) and the concentration of carbon monoxide (CO), nitrogen dioxide (NO_2), hydrogen sulfide (H_2S), soot and benzene (C_6H_6) in the atmosphere (Fig. 2). GIS technology and the gas analyzer GANK-4 were used (RD 52.04.186-89). We also constructed a computer model of the spread of pollutants from the Leninsky Prospekt highway using the computer program Surfer version 12.0.

According to the results, we divided the territory of the RUDN campus into three sampling areas (Fig. 2).

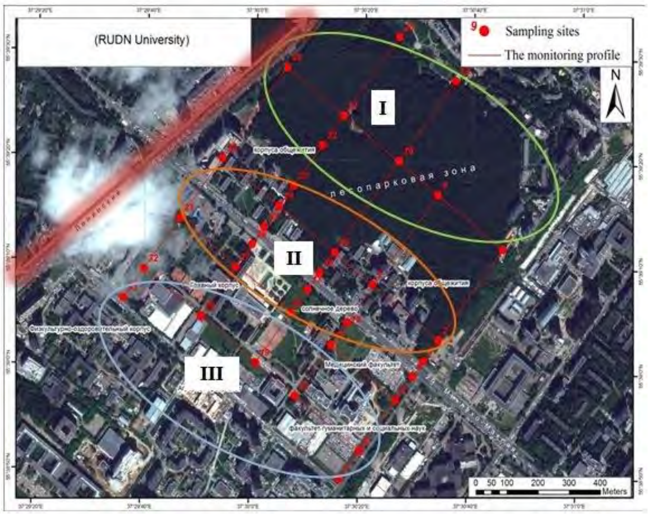


Fig. 2. The map of the sampling sites in the RUDN campus

The first one (Fig. 2, I) is the recreation area, which covers the distance of 1000 m from the Leninsky Prospekt highway and is situated in the northern part of the campus. The second one (Fig. 2, II) is the residential area located in the middle of the campus more than 1000 m away from the highway. The third one (Fig. 2, III) is the territory of RUDN departments in the south of the campus over 1100 m away from the highway.

In these areas we selected three sampling sites (1000 m^2 each), identified tree species growing there, determined biodiversity indices and morphological parameters of leaves. We identified tree species according to S. Cherepanov [7]. Margalef Index *(Ma)*, Menhinick index *(Me)* and McIntosh *(Mc)* diversity index were used to calculate biodiversity indices [8]. Morphological parameters of leaves include length *(cm)*, width *(cm)*, thickness *(μm),* weight *(g)* and area *(cm^2)* of a leaf as well as the length between the first and the second vein of a leaf *(cm)*, the length between the tip of a leaf and the end of the fourth vein of a leaf *(cm),* the distance between the second vein of a leaf and the blade of a leaf *(cm)*, the width between the midrib and the margin of a leaf *(cm)*, the distance between the first and the second blade of a leaf *(cm)*, the angle between the midrib and the second vein of a leaf *(˚)* [8-9]. In these terms we examined 5 leaves from each tree species. In total, we collected 75 leaves from the trees. To compare all these parameters on the right and on the left side of the leaf, we calculated the fluctuating asymmetry index of each parameter *($As_{1,2…5}$)* and determined the composite index of fluctuating asymmetry of leaves *(As_{total})* [8-9].

To represent the results concerning the composite fluctuating asymmetry index of leaves *(As_{total})*, the computer program Grapher version 8 was used.

Mathematical data processing includes calculation of Margalef *(Ma)*, Menhinick *(Me)* and McIntosh *(Mc)* biodiversity indices [10] and the composite index of fluctuating asymmetry *(As_{total})* [8-9].

Using statistical data processing, particularly by factor analysis, we determined the influence of the spread of pollutants from the Leninsky Prospekt highway on the composite fluctuating asymmetry index of leaves. The calculation of the factor value was based on the principal component analysis.

III. Results

The results of measuring concentration of polluting compounds spreading in the air of the RUDN campus are presented in Table I.

As shown in Table I, the concentration of nitrogen dioxide (NO2), hydrogen sulfide (H_2S), and benzene (C_6H_6) in the atmosphere in the recreation, residential and RUDN department areas is higher than MAC taking into consideration the average and maximum values. Thus, due to the spread of pollutants a new anthropogenic area is created wherein plants and animals are under pressure from the environmental point of view. Meanwhile, the concentration of carbon monoxide (CO) and soot is constantly lower than MAC. Although according to Table I, the highest concentration of pollutants is in the nearby recreation area in the north-western part of the campus near the Leninsky Prospekt highway.

TABLE I. CONCENTRATION OF POLLUTANTS IN THE ATMOSPHERE

Pollutants	Area	Min	Average	Max	MAC[a]
CO	Recreation	0,0500	0,8000	1,9000	5,0000
	Residential	0,0430	0,3100	0,8400	
	RUDN department	0,3860	0,9230	1,4800	
NO_2	Recreation	0,0410	0,2450	0,5720	0,2000
	Residential	0,0040	0,3970	0,4930	
	RUDN department	0,0120	0,1960	0,4120	
H_2S	Recreation	0,1260	0,2130	0,3620	0,0080
	Residential	0,1130	0,2410	0,3440	
	RUDN department	0,1080	0,2030	0,3410	
Soot	Recreation	0,0030	0,0280	0,0420	0,5500
	Residential	0,0110	0,0460	0,0480	
	RUDN department	0,0010	0,0490	0,2410	
C_6H_6	Recreation	0,0001	0,6120	1,7580	0,6000
	Residential	0,0001	0,0092	0,2290	
	RUDN department	0,0001	0,0501	0,108	

[a]MAC – maximum allowable concentration.

The computer model of the spread of pollutants from the Leninsky Prospekt highway is shown in Fig. 3.

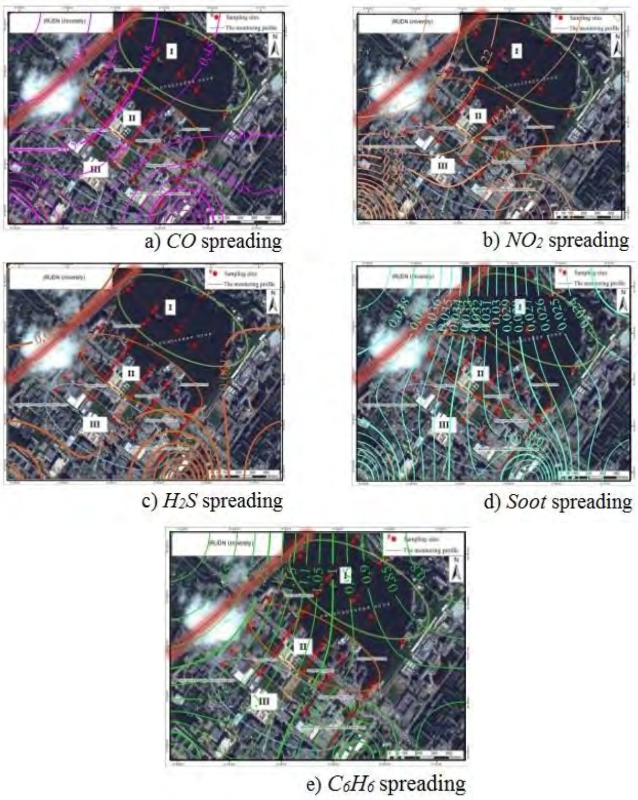


Fig. 3. The computer model of the spread of pollutants in the RUDN campus

As we can see in Fig. 3, the primary source of the anthropogenic impact on the RUDN campus is the Leninsky Prospekt highway. The mass concentrations of CO, NO_2, H_2S, soot and C_6H_6 enter the atmosphere near the Leninsky Prospekt highway, cross the residential area and migrate to the area of RUDN departments. It could be related to the north-west wind direction on the date of the study. The pollutants are generated due to combustion in vehicle engines and are released into the atmosphere. An important method for determining the atmospheric quality is the bioindication method, particularly the fluctuating asymmetry of plant leaves [10-12].

First of all, we identified tree species and calculated Margalef (*Ma*), Menhinick (*Me*) and McIntosh (*Mc*) biodiversity indices in the recreation, residential and RUDN department areas.

In the recreation area we marked *Tilia cordata*, *Betula pendula* and *Quercus robur*, in the residential area – *Tilia platyphyllos*, and *Tilia cordata* and in the area of RUDN departments – *Tilia cordata* and *Castanea sativa*. It should be noted that in the recreation and residential areas all the tree species were in an equal proportion, whereas in the RUDN department area the species *Tilia cordata* predominated. Besides, in all the areas the most common family is *Malvaceae*.

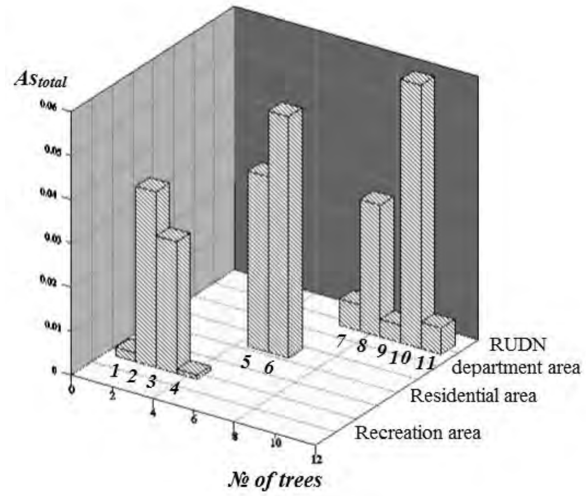
The result of the calculation of Margalef (*Ma*), Menhinick (*Me*) and McIntosh (*Mc*) biodiversity indices is presented in Table II.

TABLE II. BIODIVERSITY INDICES OF THE SAMPLING AREAS

Area	***Ma* index**	***Me* index**	***Mc* index**
Recreation	1,45	1,50	3,10
Residential	1,44	1,40	0,34
RUDN department	0,62	0,90	0,31

Table II shows that the maximum biodiversity indices were determined in the recreation area *(Ma=1,45;Me=1,5; Mc=3,10)*. According to Table I and Table II, we can say that most tree species in the RUDN campus are growing in conditions of the mass concentration of pollutants spreading from the Leninsky Prospekt highway. The negative impact of spreading pollutants on plant tissue could lead to changes in the morphological parameters of leaves [12-13]. One popular method which could help to compare the morphological parameters of leaves growing in an anthropogenic area is the fluctuating asymmetry method [12,14]. The results concerning the fluctuating asymmetry of leaves in the RUDN campus are shown in Fig. 4.

In Fig. 4 we can see that the maximum values of the composite fluctuating asymmetry index (As_{total}) were determined in the residential (As_{total} = 0,055) and the RUDN department areas (As_{total} = 0,06). Although the figure shows that Quercus robur, Betula pendula are in the recreation area, *Tilia platyphyllos, Tilia cordata* are in the residential area, *Tilia cordata* is in the area of the university departments, there are high values of the composite index of fluctuating asymmetry. It means that these tree species are more sensitive to environmental changes in the RUDN campus.



Explanation: 1 – *Tilia cordata*; 2 – *Quercus robur*; 3 – *Betula pendula*; 4 – *Quercus robur;* 5 – *Tilia platyphyllos*; 6 – *Tilia cordata*; 7 – *Tilia cordata;* 8 – *Tilia cordata;* 9 – *Tilia cordata; 10 – Tilia cordata; 11 – Castanea sativa*

Fig. 4. The 3D diagram indicating the values of the composite index of fluctuating asymmetry of leaves *(As_{total})* in the sampling areas

For the detailed study of the influence of pollutants spreading from the Leninsky Prospekt highway on the composite index of fluctuating asymmetry of leaves factor analysis was carried out (Table III).

TABLE III. THE RESULTS OF THE FACTOR ANALYSIS OF THE EFFECT OF POLLUTANTS SPREADING FROM THE LENINSKY PROSPEKT HIGHWAY ON THE COMPOSITE INDEX OF FLUCTUATING ASYMMETRY OF LEAVES

Parameter	Factor 1 (value)	Factor 2 (value)
CO	0,103	0,687
NO_2	0,933	0,102
H_2S	0,487	0,682
Soot	0,613	0,550
C_6H_6	0,648	0,025
As_{total}	0,047	0,587
Total loading, (%)	32,13	26,37

Factor analysis, particularly the principal component analysis allowed us to identify two factors. Factor 1 combines NO_2 (0.933), Soot (0.613), C_6H_6 (0.648) and has a factor loading of 32.13 %, whereas Factor 2 includes CO (0.687), H_2S (0.682), Soot (0.550), the fluctuating asymmetry index (As_{total}) and has a factor loading of 26.37 %. So, as the concentration of CO, H_2S and soot increases the index of fluctuating asymmetry (As_{total}) rises. Also the total loading of two factors is 58.5 %. It means that there are some other factors which could affect the fluctuating asymmetry of leaves such as climatic and soil condition, the type of soil and others. Despite this, we noticed a high correlation (>0.5) between the pollutants spreading from the Leninsky Prospekt highway and the index of fluctuating asymmetry (As_{total}).

IV. CONCLUSION

When measuring concentration of pollutants in the atmosphere in the recreation, residential and RUDN department areas, we can say that the concentration of nitrogen dioxide (NO_2), hydrogen sulfide (H_2S), and benzene (C_6H_6) was 1,5-2 times higher than MAC taking into consideration the average and maximum values. These pollutants generated due to combustion in vehicle engines on the Leninsky Prospekt highway are released into the atmosphere and migrate to the recreation, residential and RUDN department areas. As a result, all the tree species in the RUDN campus such as *Tilia cordata*, *Betula pendula, Quercus robur*, *Tilia platyphyllos* and *Castanea sativa* are growing in the conditions of the mass concentration of spreading pollutants. The negative impact of such pollution could lead to changes in the morphological parameters of leaves of each plant, particularly could change the index of fluctuating asymmetry of leaves. As it has been mentioned above, *Quercus robur, Betula pendula* in the recreation area, *Tilia platyphyllos, Tilia cordata* in the residential area, *Tilia cordata* in the RUDN department area had high values of the composite index of fluctuating asymmetry of leaves. It means that these tree species are more sensitive to environmental changes in the RUDN campus. Moreover, the influence of the pollutants spreading from the Leninsky Prospekt highway on the composite index of fluctuating asymmetry of leaves is confirmed by factor analysis where Factor 2 including CO, H_2S, Soot, the fluctuating asymmetry index (As_{total}) has a high factor value (>0,5). It means that with the increase in the concentration of CO, H_2S and soot, the index of fluctuating asymmetry (As_{total}) rises. Thus, to conserve the phytocenosis in the RUDN campus, we need to urgently extend the territory of the campus up to over 1000 m from the Leninsky Prospekt highway and develop the project for greening the new extended RUDN campus area.

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