Ecological substantiation of formation of the large city planting system

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ABSTRACT: The subject of the research: the ecological justification of planting a large city in the context of the formation of conditions for its sustainable development. Objectives: to develop a methodology for determining priorities for planting to minimize the risks of damage to the environment and public health. Materials and methods: statistical and cartographic data, full-scale investigations of insolation regime and humidity characteristics, compositional city planning and technogenic nuances that cause the ecology of a million-industrial city (using an example of Volgograd). Research methods — statistical and cartograph-correlation analysis, geoinformation modeling, valuation technique for spread of pollution on the ground. Results: local and summary maps of atmospheric air pollution in Volgograd were built by industrial enterprises with the definition of the boundaries of pollution and the population under the influence; the zones of noise pollution and dispersion of carbon monoxide from motor vehicles (up to 180 m) were estimated, and as well as a higher content of heavy metals in soils near highways with a higher percentage of freight transport in the stream was detected; the oppressed state of the system of urban planting and below the normative provision of the population with plantations of common use were revealed. It has been established that sanitary protection zones do not have the proper density of green mass. Direct correlation between pollution levels and morbidity indicators, as well as inverse relationships between morbidity rates and the degree of planting are revealed. The author’s algorithm for calculating the requirement ratio for planting (KPO) is developed, which allows to assess the ecological picture of the analyzed territory, its potential for living / recreation of the citizens without the risk of causing direct harm or long-term health consequences, and the requirement for operational implementation environmental protection measures in the form of planting. Conclusions: 1) in Volgograd, foci of ecological disadvantage have clearly formed, under unfavorable weather conditions, at least 120,000 people will be exposed; 2) planting is in a depressed state, and the population’s supply of public green spaces is below the standard level by 2.5 times as a whole in the city and 3–4 times in some administrative districts; 3) the revealed correlation links testify to the negative impact of man-made impact factors and the compensation potential of the public access system of urban planting; 4) the developed author’s algorithm for calculating the requirement ratio for planting (KPO) allowed to carry out a comprehensive ecological zoning in Volgograd, to determine the priorities for environmental protection measures and from the ecological point of view to structure the concept of urban planting.

KEY WORDS: sustainable development of a large city, ecological role of green spaces, ecological bases of city planning, pollution levels and morbidity indicators, sanitary protection zones, ecological zoning.
INTRODUCTION

The formation of conditions for the successful development of the urban environment in the interests of future generations, the improvement and optimization of the qualitative indicators of the spheres of life activity of the population has always been a priority of city-planning policy and relevant scientific and practical research.

The search for answers to the multicomponent questions of safe, comfortable and progressive dynamics of urban-ecological structures is difficult in the absence of the scientific basis of decisions, clarification of the nuances of the functioning of the phenomenon/process of the urban organism as a whole or a separate urban planning unit in particular.

Unfavorable, and sometimes catastrophic for the natural environment, the experience of urbanization determines as a priority scientific and practical search for methods of protecting and improving the environment and public health in the conditions of functioning of the largest city. Significant impact is exerted by industrial enterprises and vehicles in the form of emissions of harmful substances, noise, vibration, soil contamination with heavy metals. Problems of the quality of living spaces, public areas, recreational areas require priority action and research, as high levels of ecological disadvantage of urban areas contribute to the decline in the health of the citizens.

The ecological basis and compensation potential of any city is formed mainly by greened areas [1, 2]. Grassy lawns, shrubs, tree species, a variety of flower beds create a certain ecological balance, acting as a counterbalance to the advancing aggressive urban environment (industrial zones, long roads, warehouse terminals, utilities and fuel and energy facilities, etc.). Along with the city’s clear life support systems (sewerage, water supply, electricity, etc.), green masses are the main environmental-forming component that forms quality indicators of the environment and public health [3, 4].

In urban structures with high anthropotechogenetic load, green masses are usually considered as an effective tool for protecting and improving the surrounding, their range of functions is diverse: filtration of pollutants, positive visual perception by citizens, air saturation with oxygen, improvement of temperature and humidity parameters, etc. [5, 6].

By means of practical observations, calculations and estimates by a number of authors, the absorption in one hour of about eight kilograms of carbon dioxide gas was estimated for vegetation planted on an area of one hectare, and the filtering potential of sulfuric pollutants reaches 3–3.5 times. Up to sixty tons of suspended particles per year settles on the leaf surfaces of tree-shrub plantings.

One of the means to restore eco-balance in the urban environment is the development/reconstruction of organized science-based green structures [7, 8]. At the present stage of the scientific and practical search, the composition and city-planning, natural and climatic, financial nuances of planting have been thoroughly studied, but the ecological justification for the development of the green systems of a large city is not enough, which is required in connection with the growth of urban transport, the increase in housing density, the functioning of industrial enterprises.

LITERATURE REVIEW

In scientific papers [9–11] the key aspects of urbanization and emerging economic, psycho-emotional, socio-cultural problems are described in detail, the negative dynamics of eco-structures are described. In this
regard, the most appropriate characteristics of the territories selected for construction, as well as target indicators of promising functional areas, facilities, processes are formulated.

Other sources [12–14] indicate the unacceptability of spontaneous development of various functional areas and deviations from the strategy of city-planning unity, and the importance of controlling the development of territories is shown.

The authors of the works [15–18] investigated promising city-ecological concepts of urbanization, based on eco-balance. There is a need for, and proposals to increase the effectiveness of existing urban green systems in the context of improving the city’s ecology [19].

Studies of many authors distinguish stable in time dust masses, emissions of industrial enterprises and vehicles as the leading causes of significant environmental and hygienic risks of populated areas [20–25]. Development of technical, technological, organizational, economic, legal solutions to minimize gas contamination and the corresponding consequences for public health is the subject of scientific research of scientists of different directions [26]. The functioning of the vast majority of urban facilities and infrastructure systems is accompanied by emissions of harmful substances into the air, and a significant number of urban residents are exposed to them [27, 28]. In this regard, the publications on the development and implementation of environmental protection measures, such as increasing the density of the green mass in the sanitary protection zones of stationary sources of emissions of chemical impurities, the device of filtration structures along busy highways, etc. are analyzed [29–31]. The number of sources is represented by a mathematical dependence of the efficiency of green designs from the geometric characteristics of the plantations, the configuration of the crown, roughness or hairiness of the leaves, the period of active life and development of plants.

The papers devoted to the assessment of the comfort of public facilities of the greening system of the largest cities are analyzed [32, 33].

A number of publications noted the rationality of the use of geoinformation technologies in the management of urban areas, including in the planning of projects to reduce harmful effects [34–36].

An important task in the development and implementation of environmental protection measures is to develop a methodology for determining the priorities for improving of the urban environment and public health, aimed at solving the most acute environmental problems of a large city and affecting the interests of the largest number of local population.

In the existing scientific and practical works in the field of city planning, the ecological problems of a large city are rarely analyzed, the combined mechanism of the action of various sources of harmful influence, there are no priorities in the implementation of priority urban environmental problems, and therefore the presented publication is relevant.

**MATERIALS AND METHODS**

Materials of the research were statistical and cartographic data, full-scale investigations of insolation regime and humidity characteristics, compositional-city planning and technogenic nuances that determine the ecological situation of a million industrial city (using an example of Volgograd).

The methods of research were statistical and cartographic-correlation analysis, geoinformation modeling, the evaluation technique for spread of pollution on the ground.

The relief of the city of Volgograd is cut by gully plantings. Industrial enterprises, communal and warehousing facilities are mainly located in the coastal lowlands, residential and public areas on the contrary are in the depths of the city up the terrain. This situation in combination with the highest percentage of wind recurrence (20 % east rhumb) forms a stable migration of pollutants to the zone of the settlement.

In Volgograd the leading stationary sources of air pollution are represented by oil refining, heat and power, metallurgical, chemical, metalworking, and machine-building industries. According to the data of field measurements of the Volgograd center for Hydro-meteorology and Environmental Monitoring in general over the last 5 years recorded 0.16…0.22 % of samples in excess of hygienic standards, and in general the air quality is characterized by an increased level of environmental pollution (APS = 5.4 on average over the past 5 years).

According to the form of the state statistical reporting of 2-TP-air and volumes of maximum permissible emissions (MPE) of the largest enterprises in Volgograd on the basis of the technique [37] dispersion of priority pollutants in the territory of Volgograd is simulated.

In researches of the impact of vehicles using the provisions [38], researches were conducted at 23 characteristic points on highways with the identification of the main characteristics of traffic steam and an assessment of the pollution zone with exhaust gases.

Urban vegetation of the model site is included in the regional environment-forming framework, structurally represented by plantations of microdistrict, district, urban importance, as well as suburban green areas. Their condition is considered by the controlling services and the scientific community as one of the key criteria of ecological well-being [39].

A survey of tree and shrub vegetation in Volgograd found its low quality. Chemical contamination, mechanical damage, lack of watering water in most cases led to a significant retreat of green mass from residential and public areas. Plantations of mainland territories are exposed to the influence of motor vehicles year-round, as
a result of which their ecological value is significantly reduced.

The level of oxygenation by means of urban planting does not meet the existing need, and therefore residents suffering from respiratory disorders, cardiovascular system, feel a serious malaise in a specific meteorological setting (5 % of the days in the annual cycle).

The distribution of urban vegetation in the administrative regions is uneven, represented mainly by narrow linear structures on city streets and boulevards. To a lesser extent, area green objects (parks, squares, sanitary protection zones) with high protective and health-improving potential are organized. The provision of residents with green common areas is only 10.8 m² per person at a rate of 25.

The sanitary gaps in large stationary sources of emissions, which are mainly in terms of distance to residential buildings but are totally unacceptable in terms of green mass, require close attention.

The screening analysis of morbidity of children aged 0–14 years as the most sensitive category of residents to the effects of environmental factors revealed a significant excess of morbidity in Volgograd over the indicators in the region and in the Russian Federation as a whole (table 1).

The analysis of conditions and features of formation of an ecological situation of Volgograd allows characterizing the city as the territory with high loading on environment, insufficient level of plantings by plantations of the general use, the increased level of morbidity of local population.

RESULTS OF THE RESEARCH

Based on the maps of the dispersion of priority pollutants of the MPE volumes of the largest enterprises, local and consolidated maps of atmospheric air pollution in Volgograd have been constructed with the definition of the boundaries of contaminated urban areas and the population under the influence. The results indicate a concentration of chemical air pollution in the southern and northern parts of the model site. Under adverse weather conditions, up to 120 thousand people can be exposed.

When assessing the role of road transport in the formation of the noise picture of Volgograd, the corresponding areas of distress are established - from 35 to 110 m from the highway border into the interior of the building. The negative impact of motor transport in the part of aerochemical pollution is estimated from 32 to 183 m from the main transport arteries.

Studies of the content in heavy metal soils have not revealed excess hygienic standards. However, higher concentrations of substances are noted in areas near highways with a higher percentage of freight traffic in the steam (fig. 1).

Analysis of planting of Volgograd was carried out on the basis of a specialized cartographic fund and a register of facilities of landscaping. The results of research papers and full-scale inspection of green spaces revealed a significant dispersion of vegetation formations in terms of the city.

Tree and shrub plantings, whose age is mostly fifty years old and characterized by clear signs of drying, are hardly capable of perceiving a wide range of urban influences, as well as resisting specific diseases and insect attacks. About twenty percent in the whole of the city is the share of plantings, characterized by extremely poor condition.

The forest vegetation of Volgograd is 4120 hectares, of which 29 % are needles, 45 % are hard-leaved species, 22 % are soft-leaved, 4 % are shrubs. The actual share of vegetation is less than the recommended value: on urban highways by 30 %, district value by 25 %, on residential streets by 48 %.

In order to confirm the negative impact of various kinds of pollution on the environment and public health, a correlation analysis was made between the levels of impact on urban areas, greenery and morbidity rates of the local population (table 2).

The table shows that there are significant direct correlations between the morbidity rates of the local population and the levels of urban environment, while the inverse correlation between the levels of morbidity and the degree of planting was revealed, which indicates the compensatory potential of planting systems in the issue of improving the urban environment and public health.

In order to substantiate the priorities in the implementation of planting works, the author’s algorithm for calculating the requirement ratio for planting is proposed:

\[
A = \sum_{i} (B_i \times C_i \times D_i),
\]

A — requirement ratio for planting; \(B\) — ratio characterizing the level of negative impact of the process / phenomenon; \(C\) — the value of the correlation between

| Territory          | Total (per 100 thousand children) child population (0–14 years) | Including diseases of the respiratory system |
|--------------------|---------------------------------------------------------------|--------------------------------------------|
|                    | 2014              | 2015            | 2016            | 2014            | 2015            | 2016            |
| Volgograd          | 233266.0          | 223057.5        | 192057.6        | 162969.2        | 164599.3        | 140971.6        |
| Volgograd region   | 166358.8          | 156139.7        | 155133.3        | 114169.8        | 109437.0        | 109208.1        |
| Russian Federation | 183499.4          | 177588.1        | 177438.1        | 117050.8        | 115757.8        | 117377          |
Table 2. Results of the correlation analysis between environmental factors and environmentally dependent diseases

| Environmental factor          | Cohorts of age groups | Affected organs and body systems                                      |
|------------------------------|-----------------------|-----------------------------------------------------------------------|
|                              | Total                 | Respiratory system | Asthma | Blood system | Neoplasms | Endocrine system | Circulatory system, incl. increased blood pressure | Digestion system | Skin diseases | Atopic dermatitis | Urinary system | Congenital malformation |
| Pollution by industrial emissions | Adults | 0.85 | 0.84 | 0.59 | 0.30 | 0.39 | 0.77 | 0.94 | 0.6 | 0.31 | 0.37 |
|                              | Children | 0.30 | 0.65 | 0.86 | 0.37 |
|                              | Teenagers | 0.37 |
| Planting                      | Adults | –0.33 | –0.57 | –0.72 | –0.30 | –0.57 | –0.58 | –0.60 |
|                              | Children | –0.34 |
|                              | Teenagers | 0.05 |
| Pollution by vehicle emissions | Adults | 0.65 | 0.54 | 0.42 | 0.53 |
|                              | Children | 0.90 | 0.42 |
|                              | Teenagers | 0.57 |
| Noise from vehicles           | Adults | 0.48 | 0.59 | 0.076 | 0.41 | 0.87 | 0.74 | 0.9 | 0.57 |
|                              | Children | 0.5 |
|                              | Teenagers | 0.5 |
| Zinc                          | Adults | 0.48 | 0.48 | 0.43 |
|                              | Children | 0.78 | 0.32 | 0.58 | 0.62 | 0.3 | 0.49 | 0.39 |
|                              | Teenagers | 0.38 | 0.49 | 0.51 | 0.61 | 0.65 | 0.65 |
| Copper                        | Adults | 0.64 | 0.34 | 0.49 | 0.47 | 0.38 | 0.38 |
|                              | Children | 0.43 | 0.43 | 0.41 | 0.47 | 0.41 |
|                              | Teenagers | 0.41 | 0.47 | 0.41 | 0.41 |
the process / phenomenon and the morbidity rate; \( D \) — number of population groups (children, adults, adolescents) with a correlation of more than 0.3; \( n \) — number of evaluated processes / phenomena.

* Note: ratio \( B \) is estimated in conventional units, depending on the ratio of the actual level of exposure to the normalized.

The requirement ratio for planting expresses the level of ecological well-being of the assessed territory and, accordingly, the requirement for the operational implementation of environmental protection measures in the form of planting. Classification of territories with different man-caused loads is as follows (table 3).

Approbation of the developed algorithm in the conditions of the model site made it possible to draw up a scheme for an integrated environmental assessment (fig. 2).

The greatest risk of harmful effects on human health arises from the emissions of industrial enterprises (the facts of exceeding standards in the residential district, 3 population groups under the influence, the correlation coefficient \( r_{\text{max}} = 0.86 \); in second place — emissions vehicles (the facts of exceeding standards, 2 population groups under the influence, \( r_{\text{max}} = 0.9 \)); in third place — the influence of heavy metals contained in the soil (2 population groups under the influence, correlation, medium, and strong forces, but not registered exceeding of hygienic standards in soil samples); in fourth place — noise pollution from vehicles (exceeding standards, one group of exposure to one type of disease, \( r_{\text{max}} = 0.5 \)).

The resulting ranking of influencing factor the urban environment of the model site (Volgograd) determines the following priorities in the improvement of the environment by means of planting:

- implementation of scientifically grounded planting projects for the sanitary protection zones of industrial enterprises, the formation of a system for protecting it (primarily from fires) and sustainable development (pest management, irrigation, etc.); first of all, the sanitary protection zones of the southern and northern industrial centers, which form the centers of aerochemical pollution in Krasnoarmeysk, Krasnooktyabrsky, and Tractorozavodsky districts, require sanitary measures;

- development of a system of landscaping of mainland territories that can significantly reduce the range

| Ranking of the requirement ratio for planting | Assessment of the environmental situation | Requirement for planting | Territory strategy |
|-----------------------------------------------|------------------------------------------|-------------------------|-------------------|
| 0.3…3 Low man-caused load                      | Low                                      | Low                     | it is recommended to develop without protective / health improvement projects |
| 3…6Average man-caused load                    | Average                                  | Average                 | It is allowed to develop during local protective / health improvement projects |
| 6…9 High man-caused load                      | High                                     | High                    | it is allowed to develop only during large-scale protective / health improvement projects |

Fig. 2. Map of the integrated environmental assessment of Volgograd

Table 3. Classification according to the requirement ratio for planting
of dispersion of harmful emissions within the urban development;
• the development of grassy planting in the city, aimed at containing the movement of dust particles and heavy metals near the soil cover in the period of high wind speeds, which in the annual cycle for the conditions of Volgograd constitute a significant amount of time;
• formation on the main sections where soundproof screens are not rational, the dense structure of green spaces is not rational in order to reduce noise near residential buildings and recreation areas of the population.

CONCLUSIONS

1. On the basis of full-scale measurements and geo-information modeling, we obtained the polluting maps of the contamination of the model site (Volgograd and its suburban zone), identified environmental outbreaks.

2. In order to confirm the negative impact of environmental factors, a correlation analysis between the levels of exposure and morbidity of the population with ecologically dependent diseases was carried out, connections of medium and strong strength were identified, and age contingents were identified that were more at risk of developing ecologically dependent diseases.

3. In order to confirm the positive effect of planting, a correlation analysis was made between the level of planting of urban areas and the morbidity rates of the population with ecologically dependent diseases, inverse correlations of medium and strong strength were identified, age contingents most sensitive from the point of view of health to this kind of land improvement.

4. In order to substantiate the priorities in the implementation of environmental protection works, the authors propose an algorithm for calculating the requirement ratio for planting, which expresses the level of ecological well-being of the assessed territory and, accordingly, the requirement for prompt implementation of measures in the form of planting.

5. Approbation of the developed algorithm in the conditions of the model site made it possible to draw up a scheme for an integrated environmental assessment.

6. From the ecological point of view, the main directions of development of the urban planting are substantiated.

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