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COMPREHENSIVE ENVIRONMENTAL ASSESSMENT OF THE STATE OF GREEN SPACES OF THE URBAN ENVIRONMENT OF THE CITY OF ATYRAU

The article presents a comprehensive ecological assessment of the urban green spaces in Atyrau, one of the major industrial centers of Kazakhstan. The study applied modern environmental monitoring methods, including tree and shrub inventory, evaluation of biological conditions, calculation of per capita green space availability, and determination of dust load levels. The survey revealed a total of 15587 trees and shrubs, of which 82% were classified as «healthy». The average integral biological assessment score was 4.8, corresponding to the category of a «healthy stand», while the vitality index calculated by Alekseev's methodology reached 92.3%, indicating stable functioning of urban greenery. However, the provision of green spaces per capita was only 0.59 m², which is significantly below the World Health Organization standard (9 m²/person) and Kazakhstan's national standards (6–12 m²/person). Furthermore, the average dust load index was recorded at 3080 mg/m²/day, exceeding the permissible limit by more than three times. These findings highlight a contradiction between the relatively high biological quality of green plantations and their extremely insufficient spatial availability. The authors emphasize the urgent need for large-scale expansion of green areas, introduction of plant species adapted to arid climates and industrial stress, implementation of innovative air purification technologies, and systematic integration of green infrastructure into urban planning. This study holds both scientific and practical significance as it establishes a foundation for strategies of sustainable urban development under conditions of intensive industrial impact.

Keywords: green spaces, urban environment, dust load, biological stability, Atyrau city, ecological state.

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Атырау қаласы қалалық ортасының жасыл желектерінің жағдайын кешенді экологиялық бағалау

Мақалада Қазақстанның ең ірі өнеркәсіптік орталықтарының бірі болып табылатын Атырау қаласының жасыл екпелерінің экологиялық жағдайына кешенді баға берілген. Зерттеу барысында экологиялық мониторингтің заманауи әдістері қолданылып, ағаштар мен бұталардың түгендеуі, олардың биологиялық жағдайын бағалау, жан басына шаққандағы көгалдандыру тығыздығын есептеу және шаң жүктемесінің деңгейін анықтау жүзеге асырылды. Нәтижесінде қала аумағында 15587 ағаш пен бұта тіркелді, олардың 82%-ы «сау» санатына жатады. Биологиялық бағалаудың интегралдық көрсеткіші 4,8 балды құрады, бұл «сау орман» деңгейіне сәйкес келеді. Алексеев әдістемесі бойынша жасыл екпелердің орташа өміршеңдік индексі 92,3% құрады. Дегенмен қала тұрғындарының жасыл аймақтармен қамтамасыз етілуі небәрі 0,59 м²/адам деңгейінде, бұл Дүниежүзілік денсаулық сақтау ұйымының (9 м²/адам) және Қазақстан ұлттық стандарттарының (6–12 м²/адам) нормаларынан айтарлықтай төмен. Сонымен қатар шаң жүктемесінің орташа көрсеткіші 3080 мг/м²/тәулікке жетіп, рұқсат етілген деңгейден үш еседен астам асып түсті. Осылайша зерттеу нәтижелері жасыл екпелердің биологиялық жағдайының жоғары деңгейі мен олардың кеңістікте жеткіліксіз қамтамасыз етілуі арасындағы қарама-қайшылықты айқындайды. Авторлар жасыл қорды кеңейту, құрғақ климатқа бейімделген өсімдіктерді енгізу, ауаны зу, ауаны тазартудың инновациялық технологияларын пайдалану және жасыл инфрақұрылымды қала құрылысы саясатына жүйелі түрде енгізу қажеттігін атап көрсетеді. Бұл жұмыс ғылыми тұрғыдан да, тәжірибелік тұрғыдан да маңызды, себебі қарқынды өнеркәсіптік әсер жағдайындағы урбанизацияланған аумақтардың орнықты дамуы үшін стратегиялық негіз қалайды.

Түйін сөздер: жасыл желектер, қалалық орта, шаң жүктемесі, биологиялық тұрақтылық, Атырау қаласы, экологиялық жағдай.

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Комплексная экологическая оценка состояния зеленых насаждений городской среды города Атырау

В статье представлена комплексная экологическая оценка состояния зелёных насаждений города Атырау, одного из крупнейших промышленных центров Казахстана. Исследование проведено с применением современных методов экологического мониторинга, включающих инвентаризацию деревьев и кустарников, оценку их биологического состояния, расчет плотности озеленения на душу населения и определение уровня пылевой нагрузки. По результатам обследования установлено, что общее количество исследованных зелёных насаждений составляет 15 587 экземпляров, из которых 82 % относятся к категории «здоровые». Средний интегральный показатель биологической оценки составил 4,8 балла, что соответствует категории «здоровый древостой», а индекс жизненного состояния по методике Алексеева достиг 92,3 %, что указывает на устойчивое функционирование насаждений. Вместе с тем обеспеченность населения зелёными зонами в городе составила всего 0,59 м² на человека, что значительно ниже нормативов Всемирной организации здравоохранения (9 м²/чел) и национальных стандартов Казахстана (6–12 м²/чел). Кроме того, индекс пылевой нагрузки превысил допустимые значения более чем в три раза и составил 3080 мг/м²/сутки. Таким образом, полученные результаты выявляют противоречие между высоким качеством биологического состояния зелёных насаждений и их крайне низкой пространственной обеспеченностью. Авторы подчёркивают необходимость масштабного расширения зелёного фонда города, использования адаптированных к засушливому климату и техногенным условиям видов растений, внедрения инновационных технологий очистки воздуха и системного включения зелёной инфраструктуры в процессы градостроительного планирования. Работа имеет как научное, так и практическое значение, так как формирует основу для разработки стратегий устойчивого развития урбанизированных территорий в условиях интенсивного промышленного воздействия.

Ключевые слова: зелёные насаждения, городская среда, пылевая нагрузка, биологическая устойчивость, город Атырау, экологическое состояние.

Introduction

The city of Atyrau is one of the largest industrial centers of Kazakhstan and is subjected to significant anthropogenic pressure, which is reflected in its green plantations. The intensive development of the oil and gas industry is accompanied by environmental problems, particularly within the urbanized environment. However, the combined effects of intensive industrial growth and climatic conditions (aridity, wind erosion) exert substantial pressure on the urban ecological system, particularly on green plantings. Green zones play a crucial role in improving the microclimate, reducing air pollution, providing noise insulation, and ensuring recreational functions. The reduction of green areas, the high levels of dust, gas emissions, and soil contamination lead to vegetation degradation.

Currently, the ecological assessment of green plantations in the urban environment of Atyrau requires a multidimensional analysis that considers biodiversity, ecosystem services (such as air and water purification), urban planning, and sustainable development goals. Urban green zones represent a diverse spectrum of vegetated areas embedded within the urban fabric and constitute essential components of the city’s ecological infrastructure. These green areas can be categorized into various types, such as parks, green belts, street tree corridors, gardens, urban forests, and blue–green zones that incorporate water bodies and vegetation. Each type possesses unique spatial and functional characteristics, contributing differently to ecological processes and human well-being. For instance, parks often serve multifunctional purposes, including recreation, habitat provision, and microclimate regulation, whereas green belts typically function as ecological buffers surrounding urban territories, limiting urban sprawl and maintaining biodiversity.

The spatial scales of these green plantations vary considerably, ranging from small parks and street vegetation to extensive urban forests and riparian corridors. This heterogeneity underscores the importance of understanding not only the quantity but also the quality and connectivity of green plantings for maintaining the ecological integrity of the city. As urban ecosystems, green plantations form vital nodes in the broader ecological matrix, providing ecosystem services such as habitat connectivity, nutrient cycling, and climate regulation. Their typological and spatial diversity affects their ecological functioning and the breadth of benefits they can offer both to urban residents and to wildlife [1].

The ecological assessment of urban green plantations is inherently complex due to the heterogeneity and multifunctionality of urban landscapes. Unlike natural ecosystems, urban green plantings constitute a mosaic of built and unbuilt elements, resulting in considerable variability in their ecological structure and functioning. This complexity complicates the development of standardized assessment systems that would effectively account for both the biophysical attributes and the social dimensions of green plantation quality. Moreover, green plantations often serve multiple and sometimes conflicting purposes, ranging from biodiversity conservation to recreation, which complicates their evaluation from a single ecological perspective.

One of the most essential services of urban green plantings is climate regulation, where green zones significantly contribute to mitigating the urban greenhouse effect through mechanisms such as evapotranspiration and shading provided by vegetation. Trees and green areas help regulate surface and air temperatures, thereby improving urban thermal comfort, reducing energy consumption for cooling, and enhancing overall livability.

Air purification represents another critical ecological function delivered by green plantations. Vegetation acts as a filter by absorbing gaseous pollutants (e.g., nitrogen dioxide, carbon dioxide) and particulate matter, improving urban air quality and thus benefitting the population. These purifying functions are strongly dependent on the type, density, and condition of vegetation within green plantations. Additionally, urban green plantations contribute to biodiversity conservation by providing habitats and resources essential for various species, including pollinators and wildlife. They serve as refuges, stepping stones, and ecological corridors that support ecological connectivity in highly fragmented urban landscapes.

Urban green zones, including parks, street trees, and landscaped areas, are vital for ecological stability, public health, and the resilience of cities in Kazakhstan. Such zones reduce air pollution, mitigate greenhouse effects, and maintain biodiversity. Green infrastructure is recognized as an integral component of ecological security and sustainable urban development at the national level, although cities in Kazakhstan still face serious challenges associated with air and soil quality, infrastructure, and overall environmental sustainability [2].

Contemporary models of ecological assessment of urban green plantations often rely on quantitative indices that predominantly reflect the amount of greenery rather than its quality or functionality. Such indices may fail to account for critical ecological characteristics, including habitat suitability, species diversity, and ecosystem processes, which limits their effectiveness in comprehensive evaluations [3]. Quantitative indicators of the structure of green plantings and landscape features play a decisive role in ecological assessments. Key indicators include green area per capita, proximity to green plantations, accessibility measures within walking distance (e.g., buffer zones of 300–500 meters), and the percentage of green cover within residential areas. These indicators assess spatial equity and the functional accessibility of green plantations for urban inhabitants [4].

Assessments of the resilience of major cities in Kazakhstan, including Atyrau, demonstrate that they possess only moderate resilience, with none of them achieving the highest resilience thresholds. This is largely due to the pressures associated with rapid industrial development, urbanization, and environmental management systems, which are still in the process of formation [5].

Green zones in the harsh climatic and industrial conditions of Atyrau typically require careful plant selection and continuous maintenance. Research conducted in the border regions of the area recommends incorporating plant species adapted to arid climates and environmental stressors, as these species are best suited for survival, stabilizing the microclimate, and sustaining ecosystem productivity [6].

Cities in Western Kazakhstan exhibit varying but often elevated levels of air pollution due to industrial activities. Urban vegetation, particularly dense and diverse plantations of trees and shrubs, has been shown to reduce air pollution by particulate matter, although empirical data for Atyrau remain lacking. Innovative approaches, such as the installation of moss-based biofilters, have demonstrated effectiveness in other Kazakhstani cities and could be implemented in Atyrau as a supplement to traditional green infrastructure [7].

The city of Atyrau is located in the European part of Kazakhstan and serves as the administrative center of the Atyrau Region. It is situated in the western part of the country, on the banks of the Ural River, and represents one of the largest cities of Western Kazakhstan. Atyrau is a major industrial, economic, and scientific-technical hub of the region.

The climate of the city is classified as semi-arid, characterized by hot, long, and dry summers and cold, short winters. The average temperature of the coldest month, January, is −6.4 °C, whereas the hottest month, July, averages +27.4 °C. The mean annual precipitation is approximately 190 mm [16].

As a large city in the oil-rich western region of Kazakhstan, Atyrau is currently exposed to intensive anthropogenic pressure. Oil and gas exploration, infrastructure expansion, and related industrial activities have exerted significant impacts on soil, water, and local ecosystems. These impacts include increased chemical contamination of soils, alterations of hydrological regimes, as well as the reduction of diversity and productivity of plant and animal populations [8]. Such factors directly threaten the quality and functioning of urban green areas in Atyrau, diminishing their capacity to provide essential ecosystem services.

Materials and methods

At the first stage of the research, an inventory of the number of green trees in the city of Atyrau was conducted, and the conditions of their habitat were assessed. In the spring–summer period of 2025, a total of 12,611 trees and shrubs were studied along Satpayev Avenue, within five parks (Victory Park, Nursaya, Dostyk, Zhastar, and Almagul), and along the Kurmangazy Alley.

The inventory work on the green plantations of Atyrau was carried out by the research team of the scientific project in three microdistricts of the city (Nursaya, Avangard, and Zhilgorodok) (Figure 1).

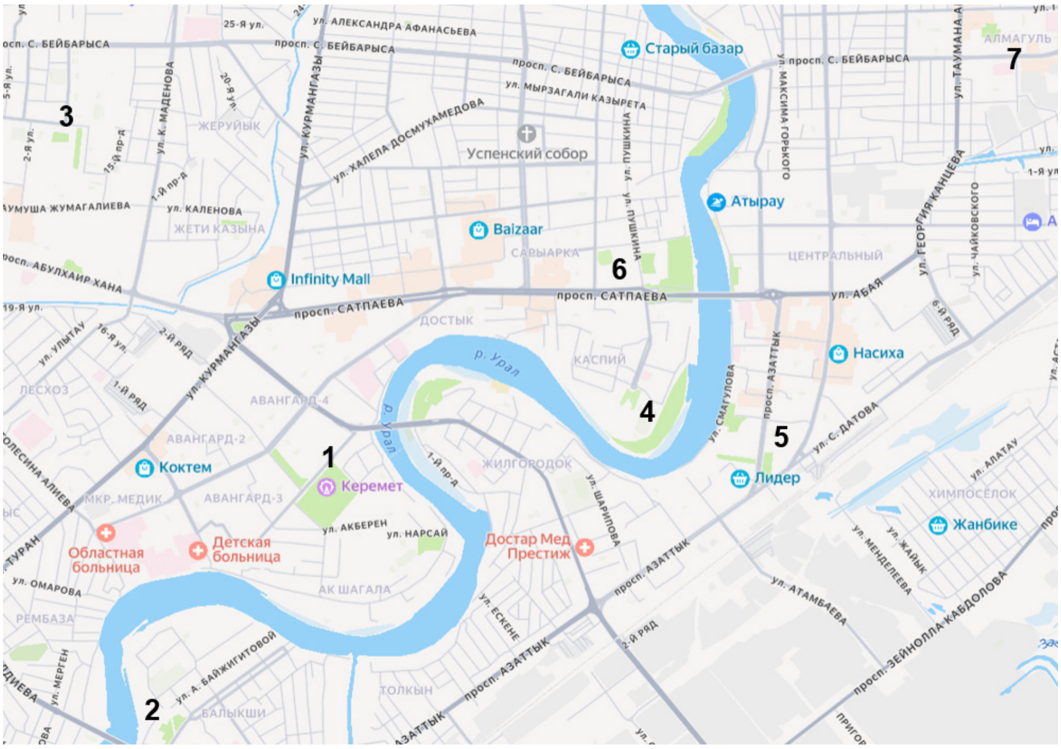

Figure 1 – Parks and Avenues of the City of Atyrau
1 – Zhenis Park, 2 – Dostyk Park, 3 – Nursaya Park, 4 – Zhastar Park,
5 – Kurmangazy Alley, 6 – Satpayev Avenue, 7 – Almagul Park

At the second stage, the study was conducted within the aforementioned green areas of Atyrau city in order to provide a comprehensive assessment of the state of the urban green infrastructure, its per capita density, the level of dust load, and the bioecological condition of tree plantations. The research employed widely accepted methods of environmental monitoring developed by foreign and domestic authors (SOST 17.5.3.01–83; Huili Xie et al., 2023; Yusupov, 2008; V.A. Alekseev, 2013).

The per capita density of green plantations (D, m²/person) was calculated using the formula proposed in the methodological guidelines for the ecological standardization of green areas and in several works of foreign researchers [9,10]:

$$D = \frac{S_{green}}{N} \quad (1)$$

where,

S_{green} – the total area of green plantations, m² (determined using remote sensing data, cartographic materials, and field surveys);

N – the population of the city of Atyrau, persons (statistical data for 2024). According to the Bureau of National Statistics of the Republic of Kazakhstan, the population of Atyrau in 2024 amounted to 324 682 inhabitants [11].

The calculation of the dust load index (P_n) was carried out according to formula (2), using filters for dust collection at exposure stations:

$$P_n = \frac{P_o}{S \times t} \quad (2)$$

where,

Po – the mass of dust deposited on the filter, mg (determined by the gravimetric analysis method);

S – the area of the filter (m²);

t – the duration of exposure, expressed as the number of days from the beginning to the sampling time.

In practice, the following gradation of average daily dust load is applied: less than 250 – low level of pollution; 251–450 – medium; 451–850 – high; more than 850 – very high [12].

The biological assessment of the green plantations in the parks and alleys of Atyrau was conducted according to formula (4), which is based on the plant vitality scale:

$$B = \frac{\sum (K_i \times D_i)}{A} \quad (4)$$

where,

B – the integral biological assessment of plantations (in points);

K_i – the number of trees according to the vitality assessment scale;

D_i – the vitality score of the trees;

A – the total number of surveyed trees.

The vitality assessment scale of trees was carried out by visual evaluation based on external features and was assessed according to the following criteria: 5 points – healthy trees, 4 points – weakened, 3 points – severely weakened, 2 points – declining trees, and 1 point – deadwood.

The indicator *B* for the biological assessment of green plantations was ranked according to Table 1.

Table 1 – Biological condition of green plantations

Value of *B*	Category of tree condition
< 4,5	Healthy stand
3,5-4,49	Weakened stand
2,5-3,49	Severely weakened plantations
1,5-2,49	Declining green plantations
0-1,49	Dead green plantations

To assess the vitality of tree plantations, the methodology of V.A. Alekseev [13] was applied:

$$L = \frac{100n_1 + 70n_2 + 40n_3 + 4n_4}{N}, \quad (3)$$

where,

L – the relative vitality of the stand, calculated by the number of trees;

n_1 – number of healthy trees;

n_2 – weakened trees;

n_3 – severely weakened trees;

n_4 – declining trees;

N – the number of trees within the sample plot [14, 15].

The obtained data were statistically processed using the computer software MS Excel 2020 and Statistica 8.0.

Results and discussions

The results of the study demonstrate a systemic ecological problem of insufficient urban greening. The low level of green space density per capita, combined with the high dust load, creates an unfavorable ecological situation, particularly in the central and industrial districts of the city.

In the course of the conducted research, a comprehensive assessment of the state of green plantations in the city of Atyrau was carried out using three key parameters: the density of green spaces per capita, the level of dust load, and the bioecological condition of trees according to the aforementioned methodologies.

As of today, according to our conducted research, the total volume of green areas in the investigated territories amounts to 193.0 thousand linear meters. According to the dendrological plan of the city of Atyrau, a total of 133 thousand trees have been recorded within the city (excluding the private sector).

Within the studied territories of Atyrau (parks, alleys, and avenues), 15587 trees and shrubs were found. All tree species growing in the investigated territory of the city belong to species resistant to air pollution (Table 2).

Table 2 – Condition of Trees in the Investigated Territories

Tree Condition Class					Total
Healthy	Weakened	Severely weakened	Dying back	Standing deadwood	
12780	2650	106	38	13	15587

According to the obtained data, the majority of tree plantations in the investigated territories of the city of Atyrau belong to the “healthy” condition class, comprising 12,780 trees (82%). The “weakened” category includes 2,650 trees, accounting for 17%. The remaining 1% consists of severely weakened trees (106), Dying back trees (38) and standing deadwood (13) (Figure 2).

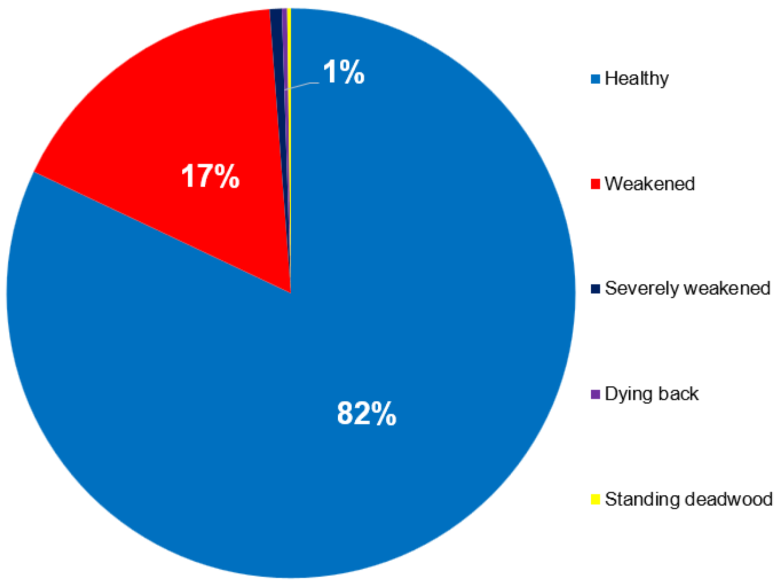

Figure 2 – Categories of Tree Vitality Status

Within the framework of the survey, a total of 15587 trees of various species (poplar, elm, maple, and others) were recorded. The visual assessments of the biological condition of the trees were distributed according to the evaluation scale as follows: 5 points (healthy) – 82% of trees, 4 points – 17%, 3 points (moderate condition) – 0.6%, 2 points – 0.3%, and 1 point (deadwood) – 0.1%.

The integral biological assessment index of green plantations (B), which represents the cumulative value of B and characterizes the ecological condition of trees, was calculated using formula (4). According to the performed calculations, the biological assessment index of green plantations in the city of Atyrau equals B = 4.8, which corresponds to the category of a “healthy stand.” Thus, more than 82%

of the trees are in a healthy condition, indicating a satisfactory state of the city's green plantations.

According to the results of the conducted analysis, the total area of the surveyed urban green territories amounted to 192183 m^2, while the population of Atyrau, according to the Bureau of National Statistics of the Republic of Kazakhstan, was 324682 people in 2024. The standard of green space area in cities established by the World Health Organization (WHO) is 50 m^2 of urban green plantations per inhabitant. Cities where vegetation covers less than 10% of the total area are considered poor in terms of greening, while those with 40–60% coverage are considered favorable. Accordingly, the availability of green spaces per capita in Atyrau amounts to D = 0.59 m^2/person. This value is significantly below the WHO minimum recommendation of 9 m^2/person, as well as the Kazakhstani standard of 6–12 m^2/person. This indicates an acute deficit of green spaces and highlights the necessity of intensified measures for the expansion of the city's green fund, particularly in areas with high residential density.

The calculation of the dust load index (P_n) was carried out according to formula (2) using filters for dust collection at control sites. At seven control sites (Satpaev, Azattyk, Elorda, Utemisov, Abai, and Auezov avenues, and Taumanov street), filters with an area of S = 0.01 m^2 were installed, with an exposure period of five days. The average mass of dust deposited on the filters was m = 154 mg. Accordingly, the average dust load index amounted to P_n = 3080 mg/m^2/day. This level of dust load is classified as high, particularly in the vicinity of heavily trafficked transport routes (Elorda, Azattyk avenues, and Taumanov street). The WHO standard for residential areas should not exceed 1000 mg/m^2/day. This confirms the necessity for the expansion of buffer green plantations and the introduction of dust-trapping systems, especially in areas with high traffic intensity.

For the assessment, the methodology of V.A. Alekseev, based on a point-scale system, was applied. The following categories of tree conditions were identified in the parks, alleys, and avenues of Atyrau (Table 3, Figure 3).

According to formula (3), calculations were performed to assess the ecological condition of trees in the parks, alleys, and avenues of the city of Atyrau (Table 4).

As a result of the conducted studies on the condition of green plantations in different zones of the city, the values of the vitality index (*L*) were obtained according to the methodology of V.A. Alekseev for seven sites: Dostyk Park, Zhenis Park, Nursaya Park, Zhasstar Park, Almagul Park, as well as the greened areas along Satpayev Avenue and the Kurmangazy Alley. The *L* values ranged from 89.0% to 95.9%, with an average value of 92.3%. According to Alekseev's classification, the range of 100–80% corresponds to the category of "healthy" or "good" condition of plantations, reflecting a high level of physiological activity, balanced growth processes, and the absence of pronounced signs of suppression.

Table 3 – Condition of Trees in the Parks, Alleys and Avenues of the City of Atyrau

Study sites	Healthy trees	Weakened trees	Severely weakened trees	Dying trees
Dostyk Park	852	344	19	2
Zhenis Park	5659	805	18	16
Nursaya Park	498	148	15	3
Zhasstar Park	3598	602	16	11
Almagul Park	538	262	11	5
Satpaev Avenue	1125	356	14	8
Kurmangazy Alley	510	133	13	6

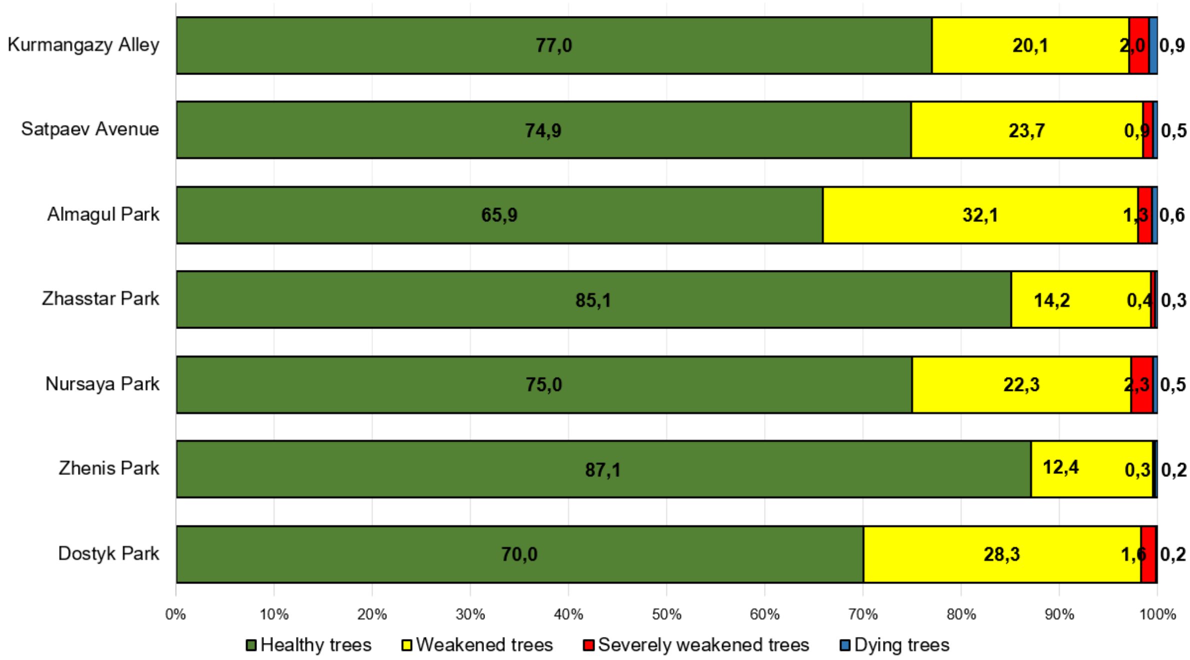

Figure 3 – Vital status of green plantations in the park areas of the city of Atyrau

Table 4 – Relative vital status of trees in the city of Atyrau

№	Study sites	Vital status, *L*
1	Dostyk Park	90,4
2	Zhenis Park	95,9
3	Nursaya Park	91,5
4	Zhasstar Park	95,3
5	Almagul Park	89,0
6	Satpaev Avenue	91,8
7	Kurmangazy Alley	91,9
-	Средний показатель	92,3

The analysis showed that all surveyed sites fall into the “healthy” category. The highest index values were recorded in Zhenis Park (95.9%) and Zhasstar Park (95.3%), which can be considered as an indication of an almost optimal state of tree stands. Slightly lower, but still high values were observed in Nursaya Park (91.5%), Dostyk Park (90.4%), along Satpayev Avenue (91.8%), and Kurmangazy Alley (91.9%). The minimum value was recorded in Almagul Park (89.0%); however, even this result significantly exceeds the threshold of transition into the “weakened” category, indicating the overall resilience of the plantations. The low range of variation (6.9%) and the small standard deviation (around 2.3%) indicate the uniformity of the condition of green plantations across all studied sites. A coefficient of variation of about 2.5% confirms that the differences between sites are minimal and local in nature.

From a physiological perspective, such values of the vitality index *L* indicate a high level of photosynthetic activity of the trees, sufficient accumulation of assimilates, and a balance in growth and development processes. The tree crowns, as reflected by the integral assessments, possess a significant assimilation surface, ensuring the full performance of ecological functions–from carbon dioxide absorption and oxygen release to dust filtration and the mitigation of the urban microclimate. The absence of sharp differences between sites suggests that during the study period, plantations were not significantly affected by mass infestations of phytopathogens or insect pests, prolonged periods of extreme weather conditions, or considerable anthropogenic impacts.

Thus, the obtained results make it possible to characterize the condition of green plantations in the surveyed sites as consistently good, without signs of systemic decline in vitality. This confirms that the ongoing maintenance measures–sanitary pruning, pest control, and regular irrigation–are generally effective and ensure the maintenance of high vitality indicators. At the same time, it is advisable to continue regular monitoring to timely detect possible negative changes, while for sites with a relatively lower index value (e.g., Almagul Park), a detailed survey is recommended to identify local factors that may influence the condition of the trees.

Overall, according to the methodology of V.A. Alekseev, the vitality status of plantations in the studied sites can be confidently classified as "healthy," which is a positive indicator of the stability of the urban ecosystem and testifies to its ability to effectively perform environmental, aesthetic, and recreational functions.

Conclusion

A comprehensive study of the condition of green plantations in the city of Atyrau has revealed both positive trends and serious environmental challenges requiring systemic solutions. Atyrau is a major industrial center of Kazakhstan, where the high concentration of oil and gas production facilities, in combination with unfavorable climatic conditions–aridity, wind erosion, and low water availability–creates a significant anthropogenic burden on the urban ecosystem. Under these conditions, green plantations play a crucial role in stabilizing the urban environment: they regulate the microclimate, purify the air from gaseous emissions and dust, reduce noise pollution, support biodiversity, and provide essential recreational functions. However, despite these advantages, the provision of green space per capita in Atyrau was found to be extremely low–only 0.59 m^2 per person, which is substantially below both the minimum standard recommended by the World Health Organization (9 m^2/person) and the national standard of Kazakhstan (6–12 m^2/person). This deficit of green areas objectively indicates an acute ecological imbalance and the necessity for large-scale expansion of the city's green fund.

At the same time, the conducted inventory demonstrated that the qualitative condition of the existing trees and shrubs can be assessed as satisfactory. More than 82% of all surveyed trees fall into the "healthy" category, while the integral biological assessment amounted to 4.8 points, corresponding to the state of a "healthy stand." According to Alekseev's methodology, the average index of tree vitality was 92.3%, which also indicates a high physiological resilience of trees and their ability to fully perform ecological functions. Particularly favorable conditions were observed in Zhenis and Zhasstar parks, where index values exceeded 95%, which may be interpreted as an almost optimal condition of tree stands. At the same time, in some zones, such as Almagul Park, the values were somewhat lower, which necessitates local diagnostics and additional care measures.

A serious threat to the city's ecosystem remains the elevated dust load, the average value of which amounted to 3080 mg/m^2/day, three times higher than the maximum permissible level established by the World Health Organization (1000 mg/m^2/day). The highest concentrations were recorded along busy traffic arteries, indicating the urgent need for the development of green buffer zones and the implementation of additional dust-capturing technologies. Such a load creates an unfavorable sanitary and hygienic background, increases health risks for the population, and accelerates the degradation of the urban environment.

Thus, the current condition of green plantations in Atyrau is contradictory: on the one hand, the existing trees demonstrate high vitality, confirming the effectiveness of ongoing maintenance measures (sanitary pruning, irrigation, pest protection); on the other hand, the catastrophically low density of green space and critically high dust load objectively undermine the ecological stability of the urban environment. The scientific and practical significance of this study lies in demonstrating the necessity of a comprehensive approach to the assessment of green infrastructure, which should take into account not only quantitative indicators of area but also qualitative indices of vitality and ecosystem services.

To improve the situation in the future, large-scale measures are required: the expansion of green areas through the establishment of new parks, boulevards, and green corridors; the introduction of tree and shrub species resistant to arid conditions and industrial stress, including xerophytes; the application of innovative biotechnologies for air purification, such as moss-based filters; systematic ecological monitoring of the condition of green zones and dust load levels using remote sensing and bioindication methods; and the integration of "green infrastructure" principles into the city's urban planning strategy.

Overall, the results obtained allow us to conclude that the green plantations of Atyrau are in a paradoxical state–biologically resilient yet spatially insufficient. This means that, with proper care, the existing trees continue to fulfill their functions, but the overall ecological security of the city cannot be ensured without an increase in green space and a reduction in technogenic pressure. Only the combination of traditional landscaping practices with modern ecotechnologies and a comprehensive urban policy can form a sustainable and environmentally balanced urban environment, ensuring the health and well-being of the population.

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