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Assylbekova G.E.

**USE OF PHYTOINDICATION IN ENVIRONMENTAL
ASSESSMENT**

Monograph

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The monograph examines the ecological and geochemical evaluations of the extent to which the plant component of the natural environment in the city of Pavlodar and the Pavlodar region in Kazakhstan has been transformed due to extensive human activity.

This study introduces a methodology and technique that enable the evaluation of urban environment quality through an integrated approach, combining bioindication and biogeochemical methods. The feasibility of employing bioindication techniques to monitor and predict the potential changes in the natural environment of Pavlodar city has been showcased. The study focused on examining certain vegetation species, namely the leaves of *Populus nigra* L., *Betula pendula* Roth., and the pollen of *Taraxacum officinale* sl.

This monograph will be valuable to scientists and professionals in the subject of ecology and sustainable development, environmental conservation, biology, geochemistry, geoecology, botany, and other relevant fields. This work can serve as an educational tool for university and college students, as well as for schoolchildren and anybody with an interest in environmental issues.

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Abstract

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INTRODUCTION

The purpose of this monograph was to choose a group of bioindication indicators for the purpose of regulating toxic substances and dividing urban ecosystems into ecological zones. Additionally, the aim was to establish a database of biogeochemical data on the elemental composition of plant communities in areas affected by human activities, in order to determine the specific ways in which toxic substances accumulate, considering both natural and human-induced factors.

Pavlodar is a multifaceted industrial hub situated in the northeastern region of Kazakhstan, on the eastern bank of the Irtysh River. The total area of the region is 326,882 hectares, which is equivalent to 0.3 thousand square kilometres. The population of the region is 300.0 thousand people. Throughout the designated study period, a total of 87 industrial enterprises were officially registered inside the city. In Pavlodar, there are multiple sources of pollution that collectively impact biological entities.

The fundamental premise of the work was a comprehensive investigation into the ecological condition of a major industrial hub in Kazakhstan, employing plant specimens as indicators.

The initial section of the book explores the utilisation of bioindication as a means to evaluate the ecological condition of the environment.

The subsequent section of the book provides a concise analysis of the geoecological attributes of the Pavlodar region's area. The area under investigation is characterised by its administrative-geographical features and environmental challenges.

The book's third section delves into materials and research methodologies.

The fourth section of the monograph outlines techniques for doing complicated bioindication examination. These approaches include examining the sterility of *Taraxacum officinale* pollen, studying the changing asymmetry of *Betula pendula* leaves, and assessing the vitality of common tree species.

Chapter five presents an examination of biogeochemical data using instrumental neutron activation analysis (INAA) to determine the composition of ash from *Populus nigra* leaves. This study describes the regional variation in the chemical makeup of the leaves of *Populus nigra L.* Additionally, the study area is divided into different zones based on biogeochemical data.

The book offers pragmatic suggestions for carrying out such study.

The monograph includes relevant graphic imagery and tabular statistics to support all sections.

1. Use of bioindication to assess the ecological state of the environment.

All living systems, whether they are individual species, groups, or ecosystems, have undergone adaptations to a combination of external conditions during their existence. They have occupied a specific ecological niche in the biosphere, where they enjoy favourable conditions for survival, feeding, and reproduction (Schubert, 1984).

Bioindication involves monitoring alterations in the parameters of biological entities and systems in response to different situations and changes in the organisms' habitats. Simultaneously, bioindication primarily emphasises the biological responses (consequences) that occur in reaction to environmental stimuli.

Indicator plants effectively and accurately indicate the condition of the ecosystem. By utilising their assistance, you may discern the extent of air and soil contamination, pinpoint the origins of pollution, ascertain their areas of influence, and identify the specific pollutants involved. Indicator plants must fulfil specific criteria, including having a broad geographic range, a significant population size, and well-documented physiological and environmental traits.

There exist two categories of indicators - sensitive and accumulative, or toxic tolerant. Poplar leaves, known for their resistance to dust and acid gases, are commonly employed as an indicator for the second type. These tools are utilised to examine the overall contamination and movement of trace elements in the environment when subjected to industrial influence on the land. Toxicants accumulate in the organs of both plants and animals. (Dubinin, 1978; Panin, 1999; Alloway BJ, 2012, Singh N., 2019; Kumari B., 2012, Singh N., 2019)

Bioindication is conducted across multiple levels of biological organisation, including macromolecules, cells, organs, organisms, populations, and biocenoses. Every group of species, when used as a biological indicator, possesses distinct strengths and weaknesses that dictate the extent of its applicability in addressing bioindication issues (Evseeva A.A., 2002.).

Ancient scientists, who were the first to recognise the correlation between the appearance of plants and their environmental conditions, made the initial observations in the field of bioindication. Resided during the years 327-287 BC. Theophrastus authored a renowned publication titled "The Nature of Plants," which offers extensive guidance on assessing the characteristics of lands based on the vegetation there. Theophrastus documented his observations and reflections on the botanical realm. He provided a comprehensive account of several plant species, including their

anatomical structure, growth patterns, reproductive traits, and their applications in medicine and other domains of human existence. It exerted a substantial influence on the advancement of botanical science and continues to be a crucial resource for comprehending the plant realm in ancient eras. Comparable material can be discovered in the writings of the Romans Cato and Pliny the Elder. Columella stated that a diligent owner should possess the ability to accurately assess the characteristics of the soil based on the appearance of trees, herbs, or fully grown fruits, and determine what can thrive in it. A.P. is regarded as the pioneer among Soviet scientists in utilising plants to analyse the features of soils and underlying rocks, based on the characteristics of plant growth and the composition of the vegetation cover. Karpinsky.

Bioindicators, such as indicator plants, enable the assessment of the presence and extent of compounds in water or soil, as well as the level of pollution. The impact of the mineral content of bedrock ores on plants was seen in the distant past. In 1550 G. Agricola observed that the vegetation atop the mineral deposits had distinct differences compared to the surrounding plants. The vegetation in this area is characterised by stunted growth and poor condition. The examination of this geobotanical characteristic enabled the assessment of the composition of various elements in the rocks based on the growth and development of specific plants found on them. The geobotanical method of prospecting for mineral reserves originated in this manner. Geobotanical study in Siberia began in 1938 and was conducted by S.M. Tkalich and N.G. Nesvetailova. In 1970, they compiled the findings of their geobotanical research in the book "Searching for Ore in Plants." In parallel with the geobotanical method, the biogeochemical method of prospecting was also created. This method involves identifying areas of mineralization by analysing the increased concentration of elements in plants that grow above these areas. The theoretical underpinnings of this approach are established in the writings of V.I. Vernadsky, who coined the term "biogeochemistry," and A.P. Vinogradsky (Alekseenko, 2006, p. 8).

The study of geobotanical alterations in plants, particularly their potential use in practical activities, has intermittently sparked interest throughout the centuries. Originally, this was attributed to the potential of utilising plants for the purpose of locating mineral reserves. Based on several publications, it can be inferred that geobotanical approaches were extensively employed in the 16th century for the purpose of prospecting ore deposits. In Kazakhstan, several copper, gold, polymetal, and mercury deposits such as Sayak, Naydorf, Sarnakoy, Salkinbel, Tuyuk, etc. include remnants of historic mining activities known as "Chud". Their age is roughly

considered to be around 2000 years. The discovery of deposits at this time is likely to be attributed to the use of "dowsing" and geobotanical approaches (Alekseenko, 2006, pp. 113-121).

Instances of employing biogeochemical indicator have been documented since the 17th century. Miners discovered that they could find zinc ore deposits by observing the presence of specific plant species, such as the Helme violet (*Viola calaminaris*) and the Galme violet (*Thlaspi calaminaris*), in the surrounding areas. This information is documented in the works of Malyuga (1963), Petrunina (1974), and Ermakov and Tyutikov (2008).

An elevated concentration of metal salts in natural substances is widely recognised to cause significant disruptions in the clinical, morphological, and biochemical condition of the organism (Yamamoto Akiko, 2002; Bigaliev, 1976, 1986).

Various plant species exhibit distinct responses to alterations in the geochemical environment (Kabata-Pendias, 1989). The species specificity of the accumulation of heavy metals (HMs) in plants, even when present in identical amounts in the soil, can be attributed to biological traits such as the selectivity of absorption by root systems and metabolic activities in tissues. The membranes surrounding the protoplast, vacuole, and cellular organelles control the selectivity. These membranes have varying permeability during passive ion transport. Additionally, electrogenic proton and non-electrogenic pumps located in these membranes play a role in selectivity. These pumps operate using metabolic energy (Pshenichnov et al., 1990).

The proliferation of a specific plant species in an area with high levels of particular microelements in the soil led to the emergence of biological and biogeochemical techniques for mineral exploration. Biological methods can be categorised as geobotanical and microbiological approaches (Polikarpochkin, Polikarpochkina, 1964; Letunova, 1978, etc.).

The early geobotanical approaches relied on observing changes in the external morphological aspects of plants, such as teratological changes, which refer to alterations in the external appearance, growth, and development of plants (Tklich, 1960; Levinson, 1976; Kovalsky, 1974, etc.). A number of scientists, including N.K. Vysotsky, S.M. Tkachenko, L. Tyulina, and others, have conducted research on the correlation between flora and specific types of rocks. A comprehensive investigation in this field provided the foundation for the recognition of several types of floras, such as calcium and halophilic floras (Vinogradov, 1938; 1954; Tklich, 1960, etc.). The application of the microbiological technique is demonstrated in the research conducted by S.V. Letunova, V.V. Kowalski (1978), and other scholars.

An assemblage of urban vegetation is a rather delicate ecological community that can be utilised to evaluate the condition of the natural urban environment in the face of prolonged human-induced disturbances. Pollutants have been observed to induce alterations in the size, shape, quantity of organs, orientation of shoot growth, and fertility of perennial plants. The condition of the plant component in an urban ecosystem is a crucial indicator of the influence of natural or human-related causes and environmental circumstances. It can be utilised to evaluate and analyse these elements.

The phytocenosis, or biological system, reacts to the impact of the environment as a complete entity. The range of variations in physiological tolerance is adjusted by the internal condition of the system, including factors such as nutritional conditions, age, and genetically determined resistance. Urban vegetation can serve as a bioindicator in areas with chronic human-made pollution. Even minor impacts might have an effect because to the cumulative nature of the pollution. Reactions may occur when specific critical levels of pollution accumulate over time (Ermokhin, 2004; Bokova, 2004, 2005; Panina, 2006). The plant component of the research region reveals the locations and routes where harmful substances accumulate, providing insight into the extent of environmental pollution.

The condition of vegetation, which reflects its response to external environmental factors, can be seen as a cumulative bioindicative indicator. This is because perennial vegetation gradually accumulates anthropogenic impact, which greatly exceeds natural levels, without any visible changes.

Since 2001, a thorough investigation has been conducted to evaluate the risk and predict the future environmental conditions of Pavlodar's plant component in the face of long-term technogenic pollution. This study includes an inventory and phytopathological examination of the green fund (Kadenova A.B. et al., 2001; Kadenova et al., 2002; Shaimardanova, 2002). A survey of the green areas in the city of Pavlodar was conducted to determine the species composition, number, and age of trees. The survey followed the procedures developed by Professor Yu.V. Sinadsky and academician B.A. Bykov (Sinadsky, 1977; Bykov, 1978. P. 287).

The prevailing bioindication approaches employed in practical applications involve the assessment of morphological alterations in higher plants, in conjunction with the mapping of cryptogams. The primary benefit of this strategy is the minimal labour expenses associated with watching and evaluating the observed events. Measurements can typically be conducted without the need for specialised laboratories or experienced staff. Several morphological markers have been evaluated and selectively chosen to assess stress factors. These signs can provide indications of short- or long-term

effects at both low and high levels of exposure. Contemporary research is centred around the standardisation of the test material and the settings under which it is employed.

Morphological markers are utilised in the national monitoring system of several countries. The use of bioindication methods that rely on plant morphology resulted in the acquisition of the majority of maps depicting the impact of human activity on the area. Morphological indication approaches are employed for selecting resistant lines of forest, fruit, and ornamental plants. Leaf colour changes are typically a generic reaction to different stimuli. Chlorosis refers to the condition where leaves appear pale between the veins. This can occur in plants growing in places contaminated with heavy metals from mining activities or in pine needles exposed to toxic gases. In some cases, this discoloration can be reversed in young leaves. The affected leaves may also exhibit yellowing along the edges or in specific areas. Necrosis, which refers to the localised death of tissue, is a significant indication of damage and can sometimes be highly specific. It is important to differentiate between several types of necrosis, including point and spot necrosis, interveinal necrosis, marginal necrosis, apical necrosis, and pericarp necrosis (Schubert, 1988).

In the context of bioindication, an effect can serve as an indicator only if the associated system parameter promptly and sensitively reacts to variations in any environmental factor, adhering to the main principles of bioindication. Physiological, biochemical, and enzymatic assays typically involve intricate procedures and necessitate specialised measurement instruments (Rabe and Kreeb 1979). It is not always possible to make a clear comparison between the observed reaction and the anthropogenic stressor being evaluated (Werner 1977). Therefore, air pollution is only identified when its impacts significantly surpass the influence of all other environmental elements (Benqart 1981). Conversely, it is imperative to implement bioindication at the first stage to facilitate early detection in regions with a low to moderate level of pollution, where evident harm to test organisms is not yet apparent (Rabe, Kreeb 1979).

An ecological evaluation of biosphere taxa is conducted by analysing the composition and abundance of organisms in ecosystems and their dispersal throughout space. The chemical elemental composition of ash from organs and tissues of organisms can provide specific information on how the composition of the environment influences them.

The evaluation of the influence of human-caused environmental pollution on biological systems relies on the dose-effect relationship. This relationship allows biological systems to directly or indirectly manifest the nature and extent of the impact caused by human activities, making them

indicators of this impact (Environmental Chemistry / Ed. . I. Borkhis. –1982; Krivosheint 2001).

The response of a living organism enables the evaluation of the human-caused influence on the environment using biologically relevant criteria, typically applicable to humans as well. The environment can be significantly altered by physical variables or chemical compounds, which are influenced by both living and non-living components. However, accurately predicting their overall effects can be challenging. Bioindicators offer a precise and comprehensive representation that considers any overlooked pollution discharges, as observed by the environmental control service during periodic assessments of environmental parameters.

A reduction in the viability and fertility of plant pollen is a reliable indicator of the condition of the natural environment and the effects of pollution (Geraskin et al., 2005). Seed productivity is a crucial measure that describes the significance of a species within a plant community. The value of seed productivity represents how well a plant is able to adapt to its surrounding environmental conditions (Severyukhina, 2004). The response of pollen to the influence of physical and chemical variables might vary. Several researchers (Doroshenko, 1928; Vlasyuk, 1969; Shchapova A.I., Potapova T.A. 1989) have found that microelements and UV light have a stimulating effect on development processes at low concentrations, but inhibit them at large ones (Bezel, 2006).

The population density is one of the elements that determines the level of plant reproduction in a given population. Individuals exhibit variations in their size, height, and number of peduncles when they undergo alterations. Simultaneously, certain reproductive mechanisms of organisms exhibit low responsiveness to population density, while others demonstrate a great degree of adaptability (Zimmerman and Weis, 1984; Watkinson, 1986; Zlobin, 1989, 1993). The reproductive process is also influenced by the age distribution of the population (Nosova, 1970, 1979). The decline in the reproductive activity of plants caused by industrial pollutants is a result of the direct harm inflicted on their reproductive organs by toxic substances (Influence of industrial..., 1990; Lyanguzova, Bezel, 2006).

There has been a significant decline or total lack of natural regrowth of coenopopulations, such as Scots pine, Siberian larch (Karaseva, 1998), silver birch and downy birch (Vasfilov, Makhnev, 1990), dandelion (Zhuikova, Severyukhina, 2001; Severyukhina, Zhuikova 2002; Bezel, 2006). Within the area of highest pollution, the detrimental effects on reproductive processes can lead to a deficiency in the natural rejuvenation of the environment (Stavrova, 1990).

It is important to consider the utilisation of morphometric properties of organisms. Fluctuating asymmetry (FA) is a method employed to analyse plants, amphibians, fish, and rodents. (Ermakov and Tyutikov, 2008).

A recent method has been employed to evaluate the condition of living organisms in the presence of toxic environmental pollution. This method involves assessing the asymmetry of bilateral characteristics, which is based on the inherent features of living organisms - specifically, the symmetry of dimensional or quantitative characteristics. It is essential that the minimum degree of physical activity only takes place in ideal developmental circumstances. When experiencing stress, this signal rises, indicating abnormalities in the process of ontogenesis. It is considered that there is a known genetic standard for development, and any divergence from symmetry in a trait indicates a deviation from this standard. The conventional method for evaluating fluctuating asymmetry (FA) in a population sample involves determining the mean value or frequency of asymmetric features (Zakharov et al., 2000, 2001; Gelashvili et al., 2004; Ilyinskikh N.N. 2005, Bezel 2006).

In 2000, V.M. Zakharov and colleagues introduced a scoring method that enables the evaluation of the environmental condition by considering the stability of development of indicator species' functional attributes. It is important to highlight that variations in the stability of organism growth are not specific to any particular unfavourable environmental circumstances. E.G. Shadrina et al. (2003) observed high levels of FA (fluorine accumulation) in small animals such as voles and shrews, as well as in different types of vegetation, in Yakutia. These high levels were found in areas heavily affected by mining companies, including dumps and drainage sites. This information was also mentioned by Bezel (2006). The morphogenetic approach, which has become increasingly popular, focuses on evaluating the variation within individuals of morphological structures, specifically known as fluctuating asymmetry. The minor, non-directional disparities between the right and left sides of the leaf blade arise from deviations that occur throughout the individual ontogeny of the organism. The amount of asymmetry grows with the growing technogenic effect (Kryazheva et al. 1996; Zakharov et al., 2000; Soldatova, 2007). The method of analysing leaf asymmetry in biological monitoring allows for the evaluation of the environmental condition and the correlation between the morphophysiological traits of plants and the ecological situation. The distribution of chemical elements in environmental objects is a crucial indication of natural global and regional biogeochemical cycles. Plants, as primary producers, have the ability to selectively absorb and "pump" macro- and microelements from the soil into the biological cycle, according to V.M. Goldshmidt's concept of a geochemical pump (1938) and Vinogradov's

research (2006, p. 280). Populations of creatures, including plants, demonstrate the distribution of chemical components throughout trophic levels. They play a role in stabilising the ecosystem by acting as biogeochemical barriers and accumulating these elements in food chains. There is a phenomenon known as "geochemical selection" (Dobrovolsky, 1983), which is influenced by the varying biological availability of different chemical compounds in soils, the specific characteristics of vegetation in different zones, and the selective absorption of chemical elements and compounds by plants and animals. The chemical composition of plants and animals can be used to create a biogeochemical profile of natural and man-made ecosystems, which reflects their unique biogeochemical characteristics (Lebedeva, 1999).

Contrary to the primary chemical constituents of living creatures, the levels of trace elements in organisms fluctuate in response to variations in external environment. The phenomenon described here, which rapidly demonstrates the distinctiveness of different landscapes and the extent of human impact, can be utilised to assess the condition of natural ecosystems (Vtorova, Markert, 1995; Lebedeva, 1999; Bezel, 2006). The human-induced alteration of the natural environment, including the introduction of chemical pollutants, unavoidably results in the distortion of metabolic processes. This is primarily caused by the selective accumulation of chemical elements by different components of ecosystems and the subsequent changes in their productivity (Bezel et al., 2008, pp. 5-10). Living organisms, being the most active and responsive part of the environment, consistently react to any alteration in it, even if there are no apparent disruptions in other elements. The introduction of elevated levels of chemicals into the environment has an impact on the elemental makeup of vegetation.

Advancements in the field of analysing the microelement composition of natural settings have enabled the research and examination of a diverse array of chemical elements (Baranovskaya, 2003). An example of such a method is the neutron activation analysis (INAA), which utilises thermal neutron irradiation and is known for its high sensitivity in the field of nuclear physics. INAA has several advantages in comparison to alternative approaches. This method does not include any chemical preparation of the sample, hence eliminating errors that may arise from the introduction or removal of elements together with reagents (Rikhvanov et al., 2006, pp. 35-37).

The chemical influence of human activities on the biosphere is presently widespread, encompassing local, regional, and global pollution with several highly concentrated dangerous compounds, such as heavy metals. Consequently, these issues have gained significant importance. The escalating "metal pressure" on the biosphere is an ongoing environmental element that continues to exert its influence. Over the past few decades,

human activities have significantly contributed to the movement of heavy metals in the natural environment. The quantity of chemical components introduced into the environment by technogenesis, in certain instances, surpasses the normal intake level of these elements (Panin, Geldymamedova, 2006; Yakovleva N.A., 2008).

The presence of various ways of entry of heavy metals into plants suggests the existence of two leading factors in the formation of the elemental chemical composition of plants: genetic and environmental. Each person's share varies depending on changes in environmental conditions. When the geochemical situation of phytocenoses corresponds to the trophic requirements of plants, their elemental composition mainly reflects the work of genetic control. Under such conditions, selective and characteristic absorption of metal ions by plant tissues is maintained (Ilyin, 1985). The environmental factor prevents this in cases where the habitat is enriched with mobile forms of heavy metals (Ilyin, 1991; Kurinskaya, 2006).

The impact of heavy metals on living organisms is highly varied. The reasons for this can be attributed to three factors: the chemical properties of metals, the response of organisms towards them, and the prevailing environmental conditions (Cadmium: Environmental Aspects, 1994; Chemistry of Heavy Metals... 1985, Kenneth G. 1993).

Elevated levels of heavy metals in plants and the human body have an adverse impact. The impact of higher levels of heavy metals on living organisms has been studied by various researchers, including Kabata-Pendias, Pendias (1989), Rautse, Kirstea (1986), Kovalsky (1974 Methodological recommendations for carrying out..., 1982), Avtsyn, Zhavoronkov et al. (1991), Kalnitsky (1985), Pokatilov (1993), Makarov (2002), and Shaimardanova B.Kh. (2010). Therefore, the elevated concentration of lead (Pb) in plants hampers respiration and hinders the process of photosynthesis. It also leads to an accumulation of cadmium and a reduction in the availability of zinc, calcium, phosphorus, and sulphur. Consequently, this results in decreased crop yield and a decline in the quality of agricultural products. Visible indications include the presence of dark green foliage, the curling of mature leaves, and the limited growth of foliage. High concentrations of lead in living organisms, including humans and animals, result in increased mortality from cardiovascular diseases, elevated overall morbidity, alterations in children's lung function, harm to hematopoietic organs, nervous and cardiovascular systems, liver, and kidneys. It also leads to complications in pregnancy, childbirth, and the menstrual cycle, as well as stillbirth and congenital deformities. Furthermore, it inhibits the activity of numerous enzymes and disrupts metabolic processes.

Enzyme activity disruption, transpiration and CO₂ fixation process disturbance, photosynthesis inhibition, biological reduction of NO₂ to NO

inhibition, and impaired nutrition delivery and metabolism in plants. Visible indications include stunted growth, impaired root system, and yellowing of leaves. These responses occur when there are higher amounts of cadmium (Cd) in plants. The presence of cadmium in the human body leads to impaired kidney function, suppression of DNA, protein, and nucleic acid synthesis, reduced enzyme activity, and delayed absorption and metabolism of other essential microelements (such as zinc, copper, selenium, and iron), potentially resulting in their deficit in the body.

Elevated concentrations of zinc (Zn) in plants result in the yellowing of newly formed leaves, a condition known as chlorosis. At high concentrations of zinc, characteristic abnormalities in the human body include alterations in the morphological makeup of the blood, the development of malignant tumours, and radiation sickness. In animals, excessive zinc levels lead to reduced weight gain, behavioural depression, and an increased risk of abortion.

Plants exhibit negative effects when exposed to higher levels of chromium (Cr), including impaired growth and development, wilting of above-ground parts, root system damage, yellowing of young leaves, significant reduction in essential macro- and microelement content (such as K, P, Fe, Mn, Cu, B, etc.) in plants. In addition, chromium exposure can lead to altered immune response and hinder cell repair processes in humans and animals, as well as enzyme inhibition and liver damage.

When metal concentrations reach a certain level, the barrier function might be disrupted, causing the accumulation coefficient (AC) to stabilise. As metal concentrations in soils grow, there is a corresponding increase in the accumulation of metals by plant roots (Bezel, 2006).

Studying the process of how some biogeochemical endemics arise enables us to conduct comprehensive investigations of the interconnected relationship between rocks, soils, waterways, plants, animals, and humans (Baraboshkina, 2001; Baranovskaya, 2003). The biogeochemical food chain illustrates the movement of chemical elements and nutrients across the food chain (Fig. 1).

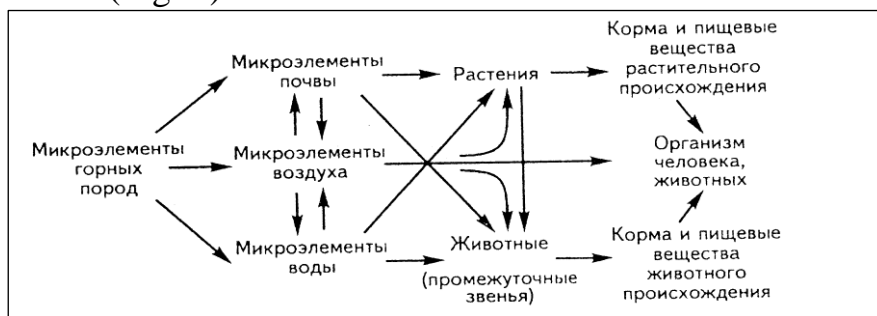


Fig.1.1. Migration of chemical elements and nutrients along the trophic chain (according to V.V. Kovalsky, 1970)

The degree of microelement (ME) absorption by the organism is contingent upon numerous circumstances. The body maintains a system of homeostasis for microelements, which is sustained via mechanisms developed through evolution. In their study, A.P. Avtsyn et al. (1991) identify many key factors: the specificity of absorption of the substance in question by the metabolic system, the specificity of its concentration in particular organs, tissues, and certain cellular organelles, and the specificity of its removal from the metabolic system. Nevertheless, in certain areas, the variations in the levels of elements in natural surroundings are so significant that the ensuing surplus in the body cannot be counteracted by the suggested processes (Stukes, 1997). The result of this is several cases of microelement deficiencies (MTOS) (Avtsyn et al., 1983, 1991). Biogeochemical approaches involve the analysis of the chemical makeup of living organisms such as plants and animals. Among these strategies, the phytochemical approach is the most commonly employed. For instance, galme violet grown on galme soils in regions with zinc deposits had a significant concentration of zinc. Similarly, plants growing on soils with barite showed a high content of barium, while plants from locations abundant in tourmaline shown a notable presence of beryllium. These findings were reported by Fersman in 1934 and by Vinogradov in 1954, 1957, and subsequent years.

Conversely, it has been discovered that plants of a specific type have an inherent tendency to selectively accumulate certain chemical elements, irrespective of their growth location. Increased concentrations of elements do not necessarily result in the development of specific morphological variability, thanks to the resistance of certain plants to chemical environmental variables and the presence of adaptive forms (Kovalsky, 1974, etc.). As a result, biogeochemical research approaches that involve analysing the chemical composition of plants and studying the chemical composition of soils at the same time have been extensively developed. The development of these methodologies has revealed numerous mechanisms of accumulation of various macro- and microelements in vegetation, which complement the complex of research conducted during the search for mineral deposits.

By the start of the 20th century, a substantial amount of geobotanical and chemical data had been collected. This data revealed a strong correlation between the plant and its surrounding environment. The potential of employing biogeochemistry for the exploration of nickel, cobalt, copper, chromium, lead, molybdenum, selenium, and other elements was highlighted in the studies conducted by A.E. Fersman (1939), D.P. Malyugi (1963), A.N. Perelman (1955), E.T. Shakhova (1958), Kh.L. Cannon (1957), and numerous other researchers.

The biogeochemical prospecting method has its origins in the works of S.M. Tkalich, A.P. Vinogradova, V.V. Polikarpochkina, A.L. Kovalevsky, and other researchers. Authors of the publication "Abroad" include S. Palmkvist, N. Brundina, G.V. Warren, H.L. Cannon, R.R. Brooks, and others. A substantial body of evidence supporting its efficacy has been gathered (Kovalevsky, 1984; Ivashov, 1998; Talipov, 1988, etc.). The application of the biogeochemical technique facilitated the identification of several deposits. In British Columbia, Canada, the Endako molybdenum deposit and the Bethlehem copper-molybdenum deposit were discovered by analysing pine needles and tree branches. Similarly, in the southeastern United States, a group of small uranium deposits was discovered by analysing astragalus ash, tree branches, and shrubs. Comparable findings were also documented in the old USSR, such as the identification of molybdenum reserves in Buryatia, among others. Dobrovolsky reported this information in 1983.

Through biogeochemical investigations, it was discovered that in locations with nickel silicate deposits, the ratio of cobalt (Co), nickel (Ni), and copper (Cu) in both soil and plant life is 1:15:3 (Malyuga, 1963). Warren and Delaveau (1954) demonstrated that it is possible to forecast the occurrence of copper and zinc deposits by analysing the ratio of copper to zinc in plant ash. The materials of L.I. also need significant attention. Grabovskoy, E.D., in his study conducted in Astrakhan in 1963, examined the accumulation of rare elements, including cesium, rubidium, tantalum, and others, by plants.

These and other works have shown that certain plants selectively accumulate chemical elements, and the level of their accumulation in different organs can differ significantly. The selective nature of uranium accumulation by plants was established, expressed in a decreasing order: grapes>mistletoe>apples>dill as 2800: 6.78: 5.06: 0.956 mg/kg ash (Hoffman, 1943). Beryllium and zirconium accumulate preferentially in the roots in comparison with the stems and leaves 80:69 and 80:44, respectively (Grabovskoy L.I. et al., 1963).

Moreover, in different landscape and climatic conditions in the same plants, chemical elements accumulate in different ways. This is a certain limitation in using the biogeochemistry method for widespread use in exploratory geochemistry ("Instructions", 1983).

The following indicators reflect the accumulation of heavy metals by plants: concentrations of elements, intensity of their biological absorption, accumulation series. These indicators are determined, in turn, by physiological factors: the growing season, the plant organ being studied, as

well as the systematic position - family, genus, plant species (Geldymamedova E.A., 2007).

The majority of chemical analysis techniques are primarily concerned with quantitatively determining the amounts of specific elements and their compounds. This requires prior knowledge of the composition of contaminants present in the environment. An alternative method involves examining the reactions of animals, plants, or microbes that are exposed to their natural environment. The bioindication approach encompasses methods that allow for the direct assessment of the potential harm to living organisms from a comprehensive range of factors, even those that are not monitored by environmental pollution control services (Geraskin et al., 2005).

The distinctiveness of biogeochemical cycles in different places is evident when comparing the baseline levels of chemical elements and living creatures (Bezel, 2006, P.37). Timely detection of ecosystem deterioration caused by human-induced stresses is imperative to prevent excessive changes in vital parameters of the human environment. Humans, being a part of the food chain in the ecosystem, respond to changes in the environment with distinct reactions.

The present condition of urban green spaces is a direct result of the significant influence of adverse human-caused elements that are inherent in urban environments. These causes inevitably result in the deterioration of woody vegetation, early ageing, susceptibility to diseases and pests, and the mortality of plantings. Urban landscapes face an urgent environmental concern regarding the contamination of soil and groundwater with hazardous elements and compounds, as well as the response of woody plants to these contaminants. The collection and organisation of information on the extent of this pollution is crucial (Kurinskaya, 2006).

An urgent concern in contemporary phytocenology is the examination of variables and processes related to human-induced changes in plant cover within specific areas of disruption (Sultanova, 2000, p.31). Plants enable the evaluation of the human-caused influence on their environment and offer a precise and comprehensive representation that encompasses all pollution elements.

Examining the effects of human-caused stresses on biological systems provides us with a unique perspective to assess the biological consequences of environmental changes, which cannot be achieved through methodologies focused on physical or chemical alterations in nature. Simultaneously, it is feasible to determine enduring patterns and the ability of biological systems to withstand and counteract many and concurrent disruptive influences (Schubert, 1988).

Migration processes are influenced by anthropogenic pollutants, which are harmful substances that have a detrimental effect on the living

organisms in the natural environment (Panin, 2002; Bokova, 2005). Pollution from human activities is one of the most important causes affecting the ecosystem. The extent to which pollutants affect the environment is mostly determined by the way chemical elements are present, which influences the toxicity, bioavailability, and capacity of their compounds to move about (Moskvitina, 2000).

The potential of bioindication is also linked to the correlation between an escalation in technogenic burden and its impact on human health. Multiple instances have demonstrated that scientific approaches formulated in biogeochemical investigations can effectively be employed in the examination of the environment and its influence on human health (Revich, 1990, Saet et al., 1990, Rikhvanov et al., 2006).

Utilising living organisms as an indicator provides the most accurate representation of the level of effect and expedites the implementation of measures to decrease it. Currently, the investigation of the features of indicators and regional geochemical characteristics of living organisms is also important in relation to the exploration of novel criteria for environmental regulation of the area. Bioindication, when combined with ecotoxicology, provides a diagnostic foundation for analysing human-induced alterations in ecosystems. It involves studying how biological systems respond to stresses (Vorobeichik et al., 1994).

Ecodiagnosics provides the fundamental basis for multiple areas of applied ecology, such as the development of environmental benchmarks. For more than two decades, the scientific community has been engaged in discussions on the difficulties of standardising the impact of loads on ecosystems. Nevertheless, none of the current conceptions can comprehensively tackle all the practical inquiries that emerge. This topic has been investigated in multiple research (Fedorov, 1976; Goncharuk, Sidorenko, 1986; Krivolutsky, 1988; Israel et al., 1991; Stepanov, 1988; Terytse, Pokarzhevsky, 1991). The prevailing belief is that the assessment of an ecosystem's standard can only be done by a person, however this perspective is not widely embraced. The reason for this is that, according to the system's viewpoint, all of its states can be regarded as "normal" (Vorobeichik et al., 1994). The approach to resolving this problem was developed in the study done by T.D. Alexandrova (1988) and D.A. Krivolutsky et al. (1984, 1986).

The correlation between the condition of population health and the biogeochemical composition of the land enables us to discuss the potential and importance of establishing environmental regulation parameters by examining this composition in both natural landscapes and human-altered areas. In order to determine the extent of ecosystem changes caused by firms

with varying technological cycles, it is necessary to first have a comprehensive grasp of the geochemical characteristics of the natural and biological environments in local territories and regions. Given that changes in biogeochemical cycles occur both spatially and temporally, it is important to establish a connection between the parameters of environmental regulation and the geochemical properties of natural settings. Furthermore, these parameters should be adjusted to account for any human-induced alterations to these environments ("Biogeochemical foundations", 1993).

Therefore, the assessment of ecosystem pollution caused by industrial production can be effectively conducted in biogeochemical ecology and environmental regulation of territories by utilising bioindication methods that analyse the microelement composition and morphological indicators of biosubstrates affected by technogenic flows of mineral matter resulting from anthropogenic activities.

The P.V. Ivashov method (1998), which utilises biogeochemical examination, is particularly significant at the local level in the current era. This is because the activities of local industrial facilities lead to a significant alteration in the geochemical conditions within relatively small areas, resulting in the formation of local technogenic anomalies.

As stated by V.V. Dobrovolsky (1983), the dispersion of metals caused by human activities mostly impacts specific regions rather than contributing significantly to overall planetary pollution. The presence of local pollution significantly impacts the biota, leading to hazardous conditions for the inhabitants. Considering the geochemical patterns of trace elements is essential for predicting and mitigating adverse outcomes. In expansive natural biogeochemical regions, it is possible for natural-technogenic biogeochemical zones to develop, including radiogeochemical zones. These zones can be found in places where nuclear fuel cycle companies are in operation (Rikhvanov, 1999, 2006). Investigating these specific local formations is a crucial undertaking, and employing highly responsive live organisms and their microelement composition as markers shows great potential.

2. Geoecological characteristics of the territory of Pavlodar.

2.1. Administrative and geographical characteristics of the study area.

The Pavlodar area was established in January 1938. The Pavlodar region currently has an area of 124.7 thousand square kilometres, which is equivalent to 4.5% of the total territory of Kazakhstan. The population of the region is 792.4 thousand people, with 875.7 thousand people in 1999, including 502.7 thousand residing in urban areas (Ekol.byul., 2008). The Pavlodar region is situated in the northeastern region of the Republic of Kazakhstan, encompassing the forest-steppe, steppe, and semi-desert zones along the middle sections of the river Irtysh. The majority of the land is situated in the southern region of the West Siberian Plain, also known as the Irtysh Plain, at elevations ranging from 110 to 200 metres.

With the exception of the floodplain of the Irtysh River and tiny parts in the Bayanaul and Maykaragay regions, the territory of the region is predominantly characterised by steppe terrain. The considerable expanse of land in the meridian direction is seen in the arrangement of families - ranging from arid grassland on sandy brown soils in the southern part, to grassland on fertile black soils in the northernmost area of the region. Its fragmented soil covering and, consequently, its vegetation distinguish the dry steppe family, which is contingent upon the terrain and underlying substrate.

The region's surface is separated into two portions, specifically the northeastern and southwestern areas, based on its origin and condition. The northeastern region is characterised by a typical flat terrain, while the southwestern section is occupied by the Kazakh minor hills, specifically the Bayanaul and Kyzyltau mountains.

The predominant characteristic of the region's climate is pronounced continentality, characterised by extended and frigid winters lasting for around 5-5.5 months, and brief but scorching summers lasting for around 3 months.

The mean annual precipitation varies from 200 mm in the southern region to 300-500 mm in the northern area, namely in the Bayanaul Mountains. The climate exhibits a dryness and irregular moisture levels throughout the years. The Pavlodar region is classified into three agroclimatic zones: moderately arid, arid, and dry.

The mean temperature in January ranges from -17^o to -19^o, while in July it ranges from +19^o to +22^o. In the northern part of the region, the average annual air temperature is 0.7°C, whereas in the southern part it is 3.2°C. The main maximum air temperature ranges from 35 to 40 degrees

Celsius, with an absolute amplitude of temperature swings of 90 degrees Celsius (Karchevsky, report).

The area is distinguished by a dry environment and fluctuating humidity over the years. Based on long-term data, the annual precipitation in the northern part of the region averages around 300 mm, while in the southern part it is around 200 mm. In the Bayanaul Mountains, the precipitation ranges from 300 to 500 mm per year.

The average annual precipitation in the eastern part of the Pavlodar region is 180 mm, while in the northern and southwestern areas it ranges from 240 to 250 mm. In the Ekibastuz zone, the average precipitation is 140-150 mm, with 70-80% occurring during the summer. However, these rainfall amounts are mostly used to wet the dry soil and are subsequently lost through evaporation. The average snow cover height in the northeast is 28 cm, on the open steppe it is 15 cm, in the Ekibastuz region it is 8 cm, in Bayanaul it is 22 cm, and in sheltered areas it can reach up to 44 cm. The average duration of snow cover in the northern region is 160 days, while in areas with minimal precipitation it is 136 days. The cumulative sum of positive temperatures is 27000.

The dominant wind patterns are from the southwest and west (Fig. 1). The mean annual wind velocity in the Pavlodar region is 5.6 metres per second. The mean wind velocity during July is 4.6 m/s, whereas in January it is 5.8 m/s.

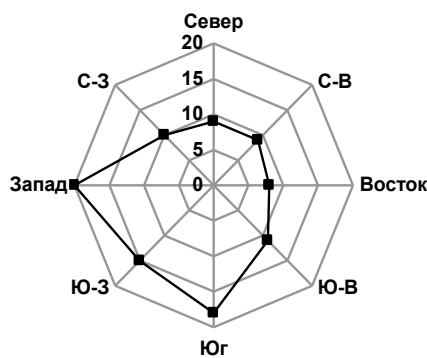


Figure 2.1.

Average frequency of wind direction (%) according to the Pavlodar Hydrometeorology Center for the period 1996-2000. (Pavlodar)

The Irtysh River is the primary watercourse in the Pavlodar region, flowing into the basin of the Arctic Ocean. Spanning a distance of 720 kilometres, the Irtysh river serves as a natural boundary, effectively dividing the region into two distinct portions. Notably, the river does not receive any tributaries within its bounds. Consequently, the entire territory of the region falls under the closed flow area, where surface waters accumulate in lakes and depressions without any outlets. The width of the Irtysh floodplain

ranges from 15 to 18 kilometres. The catchment area spans 260,000 square kilometres and represents the annual volume of river flow. The Irtysh River, which accounts for 95% of the water supply in the region, has a flow rate of 25.63 thousand cubic kilometres per year. The region contains approximately 130 rivers and temporary watercourses that are longer than 10 km, excluding the channels inside the river valley. The word "Irtysh." The rivers originate from adjacent regions and are effectively controlled there. These rivers become obscured in the steppe and desiccate throughout the summer or persist as a handful of eddies, situated in the southwestern part of the region and inside the area where the small hills merge with the plain. The right bank of the Irtysh and the neighbouring flat strip of the left bank are devoid of any watercourses.

The region contains a total of 1208 lakes, each covering an area greater than 2 km². Approximately one-third of these lakes are freshwater, whereas the largest lakes in the region are saline. Bayanaul is home to pristine lakes situated in low-lying areas. Small floodplain lakes and oxbow lakes can be found along the Irtysh River. In the steppe grasslands and forest-steppe regions, several tiny lakes can be found in low-lying areas. Heading south, the quantity of salt lakes grows. The largest brackish lakes, Kyzylkak, Zhalauly, and Silety, are located in the extreme northwest. Located to the south of their current position are naturally formed lakes consisting of sediment from the Ekibastuz group. Located in the central section of the right bank are the most extensive salt lakes, including B. Azhbulat (110 km²) and Maraldy (80 km²). The self-deposited salt lakes in the Irtysh region, including Bolshoy and Maly Kalkaman, Koryakovka, and Bolshoy and Maly Tavolzhnan, hold significant importance.

The soils in the region are characterised by the subzone of southern chernozems, which transition into the chestnut zone. The majority of the region is located in the subzone characterised by dark chestnut soils, which are accompanied by fescue-feather grass and mixed-grass feather grass steppes. In the northern part of the region, there are large areas of chernozem soils, which are poor in humus and have a high salt content. These soils are accompanied by diverse herbaceous steppes with red-feathered plants, along with groves of birch trees. Pine forests on sandy terrain in the southern region have been conserved. The floodplain of the Irtysh River contains floodplain meadows and floodplain woods. A substantial portion of the region's territory is characterised by an abundance of light soils, specifically sandy and light loamy soils. This soil composition plays a crucial role in determining the implementation of soil-protective crop rotations. The significance of soil salinity is particularly important. Both solonchic soils

and conventional solonchaks are prevalent throughout the region, exhibiting varied degrees of occurrence.

The primary mineral resources are primarily located in the southwestern region, specifically in two coal basins known as Ekibastuz and Maikuben. The Pavlodar region boasts rich reserves of copper ores (such as Bozshakol), gold (such Maikain), polymetallic ores, and rare metal ores. Significant reserves of brown iron ore have been found in the lower sections of the Shiderta River, with strata that extend all the way to the surface.

The region's land fund has a total area of 12,846.9 thousand hectares, with agricultural land accounting for 28.4%, land for settlements accounting for 14.2%, and forest land accounting for 3.5%. The total area of disturbed lands in the cities and districts of the region was 12,146 hectares, as reported in the Ecological Bulletin of 2008.

State of biological resources. Vegetation cover.

The Pavlodar region is situated in a dry steppe zone characterised by wormwood and feather grass-fescue vegetation. The extreme northeastern region of the area is characterised by a fairly arid steppe ecosystem, consisting of vegetation such as forbs, feather grass, and fescue. On the higher regions of the plain and the summits of the hills, the vegetation is very scarce, with the fescue-wormwood complex being the dominant plant community. The floodplains of rivers and valleys of temporary watercourses exhibit a significantly higher level of flora diversity, with the presence of meadow grasses in certain areas.

The southern portion of the right bank of the Irtysh River is predominantly characterised by a dense pine forest, interspersed with birch and aspen trees. The area has a woodland cover of 2.2%. The total area of land in the state forest fund is 31.5 thousand hectares, with 11.9 thousand hectares consisting of forested areas. On the northern side of the right bank, there are "kolki" - separate clusters of deciduous woodland. Their combined area measures approximately 900 square km. The valley of the Irtysh River contains dense clusters of trees and shrubs. Shelterbelts divide the entire region. Plants serve as the primary markers of soil quality. The species composition of plants is determined by the interaction of environmental components such as soil, water, and climate. This composition reflects the unique characteristics of biocenoses and ecosystems.

The soils and vegetation cover in the Pavlodar region are arranged in latitudinal zones, which transition from north to south. Located in the northern region is a forest-steppe area that features chernozem soils and meadow-forb steppes, which are typical of the West Siberian Lowland. Southward lies a tussock-grass steppe characterised by chestnut soils.

Further south, there is a semi-desert region where patches of tussock-grass vegetation alternate with abundant wormwood and saltwort clusters. This area transitions into a desert dominated by scattered thickets of wormwood and saltwort. The ploughing of 3.4 million hectares of steppes has led to the prevalence of the dry steppe zone, characterised by wormwood and feather grass-fescue vegetation (Solomatin, Shaimardanov, 2005). The alteration of ecosystems caused by human activity presents a more significant threat than the direct eradication of individual plant and animal species. This is because the destruction of natural habitats can result in the widespread extinction of numerous representatives of both plant and animal life (Atakova, 1998).

There is significant evidence of substantial transformations in the natural environment of the Pavlodar Irtysh region. Specifically, between 10% and 50% of the land in the area has been converted into salt marshes, often known as salt deserts. In the northern regions of Kazakhstan, the rapid development of vegetation leads to the coexistence of different animal species from both the northern and southern regions.

The Pavlodar region is situated inside the dry southern steppe zone. This region experiences low levels of moisture, with a humidity coefficient ranging from 0.2 to 0.6. While landscape resources are available, they necessitate reclamation and incur costs for reproduction. This involves ensuring the preservation of natural soil and vegetation cover, as well as seeding grass to secure any dusty and blown surfaces. Approximately 40% of the steppe zone near Pavlodar underwent ploughing as part of the process of cultivating previously uncultivated and unused lands. The foundation of the grass cover on untilled areas primarily consists of narrow-leaved turf grasses. The herbaceous vegetation consists of a mixture of wormwood, forb, and grass, which is rather sparse in certain areas but typically has a healthy turf. The primary species present is the red feather grass, along with other species such as hairweed, Marshall's wormwood, stemless cinquefoil, Marshall's knapweed, and snowflake. The sandy alluvium is primarily characterised by the prevalence of forb-feather grass communities, consisting of John's feather grass, sandy caraway, and Segier's milkweed. Hydromorphic solonetz-meadow-steppe complexes are developed within the second floodplain terrace, even on alluvium consisting of sandy and sandy loam.

The meadows on the alluvial soils of the floodplain terraces of the Irtysh River are particularly significant among the introzonal forms of vegetation. Their vegetative cover consists of important fodder grains, including brome wheatgrass, reed grass, burnet, and sedge. Weeds such as yellow sow thistle, purple sow thistle, field bindweed and wild oats are commonly found everywhere. Several plant species found on the

floodplain are categorised as endangered, including rose hips, bird cherry, hawthorn, blackberries, and drupes. The region is home to 40 species of medicinal plants, three of which are included in the Red Book: Shrank's tulip, steppe peony, and Pavlov's rose hips.

The primary component of the forest reserve comprises floodplain woods, while the remaining portion encompasses sections of the Omsk-Semipalatinsk forest belt and forest plantations surrounding the city of Pavlodar. Floodplain woods are found across the entire course of the Irtysh River, specifically on the first and second terraces of the floodplain as well as on the islands. The prominent species found in this area are black sedge, white poplar, white willow, and medium-sized trees and shrubs such as viburnum, bird cherry, buckthorn, different willows, rosehip, and angustifolia. Forests are included as part of the first category. The primary objectives of these measures are to safeguard water resources, preserve soil integrity, ensure sanitary and hygienic conditions, enhance aesthetic appeal, and provide recreational opportunities. The forest fund primarily consists of sedge grass, willow grass, and willow grass, which account for 83% of the wooded area. Poplar trees make up 2% of the forest, while the remaining 15% is occupied by artificially made plantings of pine, maple, elm, and oleaster in the green ring and forest belt.

The region is home to over 20 species of game animals and over 60 kinds of birds. The Red Book includes a total of 25 avian species and 2 non-avian species. The total area of the principal hunting grounds in the region is 10.5 million hectares. Out of this, 5.1 million hectares are allocated to game users, while the remaining 5.4 million hectares are part of the reserve fund as stated in the General Plan of 2005 and the Ecological Bulletin of 2008.

The avifauna in the area is primarily composed of birds that inhabit specific ecological niches, including those found in trees and shrubs, open spaces, meadows, and aquatic or semi-aquatic environments. The skylark, white-winged lark, and skylark are among the most often encountered species. The yellow wagtail and black-headed chakan build their nests in the fields. Feeding patterns are widespread among rooks, common kestrels, and during post-nesting migrations, buzzards and steppe eagles also engage in feeding activities.

As a result of extensive land ploughing, pesticide usage, and excessive hunting, several bird species including the Dalmatian pelican, black stork, bustard, demoiselle crane, lapwing, mute swan, white-tailed eagle, white-headed duck, Siberian crane, little bustard, and osprey, as well as the mammal species known as bandaging, have become scarce and are now classified as endangered in the Red Book. Yellow and white wagtails, stonechat, quail, white-winged and black terns, reed harrier, and short-eared

owls are frequently seen in the floodplain of the Irtysh River. The meadows, characterised by dense thickets of plants and scattered trees, are home to several bird species including the bluethroat, grey warbler, dunnock, warbler, crow, magpie, common kestrel, and grey partridge. The tree sparrow, starling, oriole, kite, falcon, and long-eared owl inhabit regions characterised by dense willow-poplar thickets. The sandbanks are distinguished by the presence of the little plover. The floodplain is expected to provide as a habitat for breeding and the occurrence of highly uncommon avian species, namely the white-tailed eagle and osprey. The steppe and meadow harriers, the common wheatear, and the dancer nest in the valleys and lakefront steppe meadow-solonetz complexes. Additionally, the demoiselle crane is conserved in certain areas.

The most common representatives of the animal kingdom include hares, foxes, wolves, marmots, ground squirrels, jerboas, hamsters, mice, corsac foxes, and light polecats. Roe deer and wild boars can be found in birch groves along the river valley and island forests. In the river. The Irtysh River is home to several species of fish, including bream, pike perch, carp, pike, and perch. Non-commercial fish species include ruffe, gudgeon, dace, roach, ide, spined loach, common loach, and others (Genplan., 2005).

Pavlodar is situated on the eastern bank of the Irtysh River, within the Irtysh depression, which marks the southeastern boundary of the West Siberian Lowland. Pavlodar is situated in a region characterised by chestnut soils, which have developed in an arid climate with dry-steppe flora and are predominantly found in uniform areas. The soil constituents are non-saline, old alluvial sandy loams. Groundwater is primarily composed of fresh water, but it may occasionally contain a small amount of minerals. It is located at a depth ranging from 2.72 to 8.12 metres and does not have any impact on the process of soil formation.

The region is characterised by the prevalence of chestnut deep-boiling soils. The physicochemical features of the soils under study are defined by the following characteristics: humus content ranging from 1.26% to 1.97%, CO₂ content ranging from 1.34% to 4.66%, silt content ranging from 7.02% to 12.24%, and physical clay content ranging from 2.10% to 5.66% (expressed as a proportion relative to completely dry soil). The pH value is 6.57. The soils in the city can be categorised as having a low buffering capacity, with a range of 11-20 points. This classification takes into consideration the acceptable levels of heavy metal buildup, which fall within the range of 4-7 background contents (Ilyin, Syso, 2001).

The city's climate is classified as highly continental. Throughout the winter season, the climate is icy for a total of 200 days, with temperatures dropping below -25°C and winds measuring less than 5 m/s. Temperatures

plummeted to -49°C in certain years. Summer is characterised by high temperatures, with an average monthly temperature in July ranging from 20 to 22°C . During the daytime, temperatures can reach as high as 26 to 28°C . Additionally, there is typically a wind speed of over 6 m/s. The mean annual precipitation ranges from 200 to 300 mm, occasionally reaching up to 350 mm. The majority of the rainfall occurs during the summer, primarily in the form of heavy downpour. The duration of a stable snow cover is said to be between 135 and 145 days, according to Geldymamedova (2007).

The vegetation cover consists of feather grass-fescue associations, accompanied by sandy staghorn, steppe timothy, and cold wormwood. The effectiveness of intracity landscaping in Pavlodar can be enhanced by increasing the amount of plant soil by $25-50\%$, and in certain instances, by completely replacing the existing soil. When used with water surfaces and humidifying equipment, it helps to generate favourable weather conditions in the city (General Plan, 2005).

2.2. Environmental problems of Pavlodar and the surrounding area

The Pavlodar region is a highly developed economic zone in the Republic of Kazakhstan, with significant strategic importance for the entire country (Fig. 2.2.1). The Pavlodar region in the Republic of Kazakhstan accounts for 20% of all emissions of pollutants into the atmosphere, totaling 598.5 thousand tonnes. The environmental situation in this region is described as both stressful and steady. The region has significant technogenic pollution due to its primary economic sectors, which include mining, oil refining, chemical industries, ferrous and non-ferrous metallurgy, and energy production (Ekol.byul., 2008).

The Semipalatinsk Nuclear Test Site (STS) was in operation on the region's territory from 1949 until 1990 . Approximately 39% of the site is situated within the Maysky district of the Pavlodar region. During the duration of the SIP, around 480 nuclear and thermonuclear detonations were conducted, resulting in significant radioactive contamination across vast regions of Kazakhstan. The primary elements contributing to the human-induced alteration of SIP vegetation include radiation, military-technical activities, residential development, mining operations, agricultural practices, communication infrastructure, and pyrogenic events. According to Sultanova (2000), the radiation element of human-induced changes to SIP vegetation is the most significant aspect in terms of the extent of disturbance, depth of impact, scale, duration of restoration, and long-term implications. Research has demonstrated that exposure to radiation leads to alterations in the physical structure, development, and reproductive system of

fish. It also causes significant disruptions in the genetic makeup of amphibians, reptiles, and the steppe biome as a whole (Kraynyuk, 1998).



Figure 2.2.1. Pavlodar region

The Pavlodar-Ekibastuz territorial-industrial complex has been established in the central part of the region. Its main components include a series of thermal power plants (which account for 60% of the installed capacity in the republic), coal mines, aluminium and ferroalloy plants, and oil refineries. These industrial facilities are the primary sources of pollution in the environment. The majority of pollutant emissions in the region are contributed by firms situated in the cities of Ekibastuz (43%), Aksu (30%), and Pavlodar (25%). The emissions of pollutants into the atmosphere for the cities of Ekibastuz, Pavlodar, and Aksu in 2007 were 277.4 thousand tonnes, 152.2 thousand tonnes, and 150.5 thousand tonnes, respectively. The annual increase in emissions by an average of 3% can be attributed to the rise in production volumes and the establishment of new firms such as the Kazakhstan Electrolysis Plant and the pipe rolling production of KSP-Steel LLP.

Analysis of all pollutants revealed a substantial rise in atmospheric emissions over the last decade. Between 1998 and 2007, the emissions of harmful

substances into the atmosphere from stationary sources grew from 446.3 to 598.5 thousand tonnes. This includes solid pollutants, which increased from 203.8 to 270.4 thousand tonnes, and liquid and gaseous pollutants, which increased from 242.5 to 328.1 thousand tonnes (Table 2.2.1).

Table 2.2.1. Emissions of pollutants into the atmosphere in 1998-2007,

pollutants, thousand tons	Years									
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total	446.3	408.3	461.5	471.0	461.9	521.1	567.6	575.6	592.8	598.5
Incl. hard	203.8	181.5	205.1	209.4	211.9	235.5	256.5	260.1	267.9	270.4
Liquid and gaseous	241.5	226.8	256.4	261.6	250.0	285.6	311.1	315.5	324.9	328.1

Air pollution is the primary environmental issue in the Pavlodar region. Thermal power stations that utilise the combustion of high-ash Ekibastuz coal in their boiler units are the primary contributors to pollution. Additionally, there is an elevated release of ash from the chimneys. Over 7,000 emission sources release pollutants into the atmosphere of the region. The combined emissions from power, metallurgy, and coal mining industries amount to 563.814 thousand tonnes, which represents about 94.4% of the overall volume of pollutant emissions in the Pavlodar region (Ekol.byul., 2008).

The industrial enterprises that have the greatest impact on air pollution in the city, in terms of the volume of emitted substances, are Aluminium of Kazakhstan JSC (including an aluminium smelter and CHPP-1), Pavlodar Oil Refinery JSC (POR), a chemical plant (PA "Khimprom"), JSC "Pavlodar-energo" (Thermal power plant-2 and Thermal power plant -3, Ekibastuz Heating Central Plant), JSC "EEC" (Aksu State District Power Plant, coal mine "Vostochny"), AFP branch of JSC TNK "Kazchrome", LLP "AES-Ekibastuz" (State district power station-1), JSC "Station Ekibastuz State district power station -2", LLP "BAK" Coal mines "Severny", "Bogatyr".

Major corporations that utilise natural resources release emissions into the atmosphere from a total of 3,880 emission sources. In 2007, the combined pollution emissions from these firms into the atmosphere totaled 563,814.3904 tonnes. The highest emissions were from Aksu GRES and Ekibastuz GRES-1,2, with 128,452.0271 tonnes, 139,897.534 tonnes, and 105,207.714 tonnes per year, respectively.

The city of Pavlodar is home to several major industrial companies that contribute to pollution. These include machine-building, cardboard and roofing felt production, shipbuilding and ship repair, tool manufacturing, tractor production, rubber factories, a plant that produces metal structures, and a factory that produces electrical installation goods (Fig. 2.2.2).

Furthermore, the city is home to three thermal power plants, over twenty boiler houses, and 5,751 privately owned housing units. Collectively, these entities consume over 3.5 million tonnes of coal annually. An additional 13.1 thousand tonnes are introduced from vehicle exhaust emissions, totaling 42,231 units.

Pavlodar, established in 1861, serves as the administrative hub of the Pavlodar area (since 1938) and is a multifaceted industrial centre situated in the northeastern part of the country, on the right bank of the Irtysh River. The entire area of the region is 326,882 hectares, which is equivalent to 0.3 thousand square kilometres. The population of the region is 300,000 people. Throughout the designated period, a total of 87 industrial firms were officially documented and registered inside the city. The primary industries in the Northern industrial zone of Pavlodar are major sources of pollution. TPP-2 and TPP-3, which have a production hazard class of 1, are designed to produce and distribute electrical and thermal energy to industrial users and residential areas in Pavlodar. The primary contributors to the release of noxious compounds into the air are steam boilers, which primarily utilise Ekibastuz coal as their major fuel source. Additionally, M-100 fuel oil is used as the initial fuel, accounting for 0.3% of the overall fuel quantity. During the operation, several pollutants are released into the environment, including coal and fuel oil ash, coal dust, nitrogen oxides, sulphur, carbon, hydrocarbons, chromium compounds, nickel compounds, silicon compounds, manganese compounds, wood dust, abrasive dust, welding aerosol, and hydrogen fluoride.

Pavlodar Oil Refinery is a fuel-oriented enterprise known as KOP-2. The plant refines sulphurous West Siberian oil, which is transported through the Omsk-Pavlodar oil pipeline. During this process, the plant releases saturated and unsaturated hydrocarbons, fuel oil ash, benz(a)pyrene, vanadium pentoxide, methane, hydrogen sulphide, benzene, toluene, xylene, phenol, carbon oxides, nitrogen, sulphur, and other substances into the atmosphere.

Pavlodar Chemical Plant (PCP OJSC), KOP-4, specialises in the maintenance and production of spare parts for equipment. The operational production facilities include of mechanical repair and nitrogen-oxygen shops. Aerosols generated during welding release various compounds such as manganese oxides, chromium, iron, carbon, and hydrogen fluoride into the environment. OJSC "Kaustik", KOP-4, is a company that focuses on producing liquid chlorine.

As a result of its production processes, it releases various pollutants into the atmosphere, including chlorine, caustic soda, acetone, toluene, oxides of manganese, chromium, titanium, carbon, hydrogen fluoride, and

others. OJSC "Kazenergokabel", KOP-4, specialises in manufacturing cable and wire products. It has a total of 9 organised and 5 unorganised sources that emit pollutants into the atmosphere. The factory premises are heated with boilers and an open coal warehouse. Maikuben coal serves as a source of fuel.

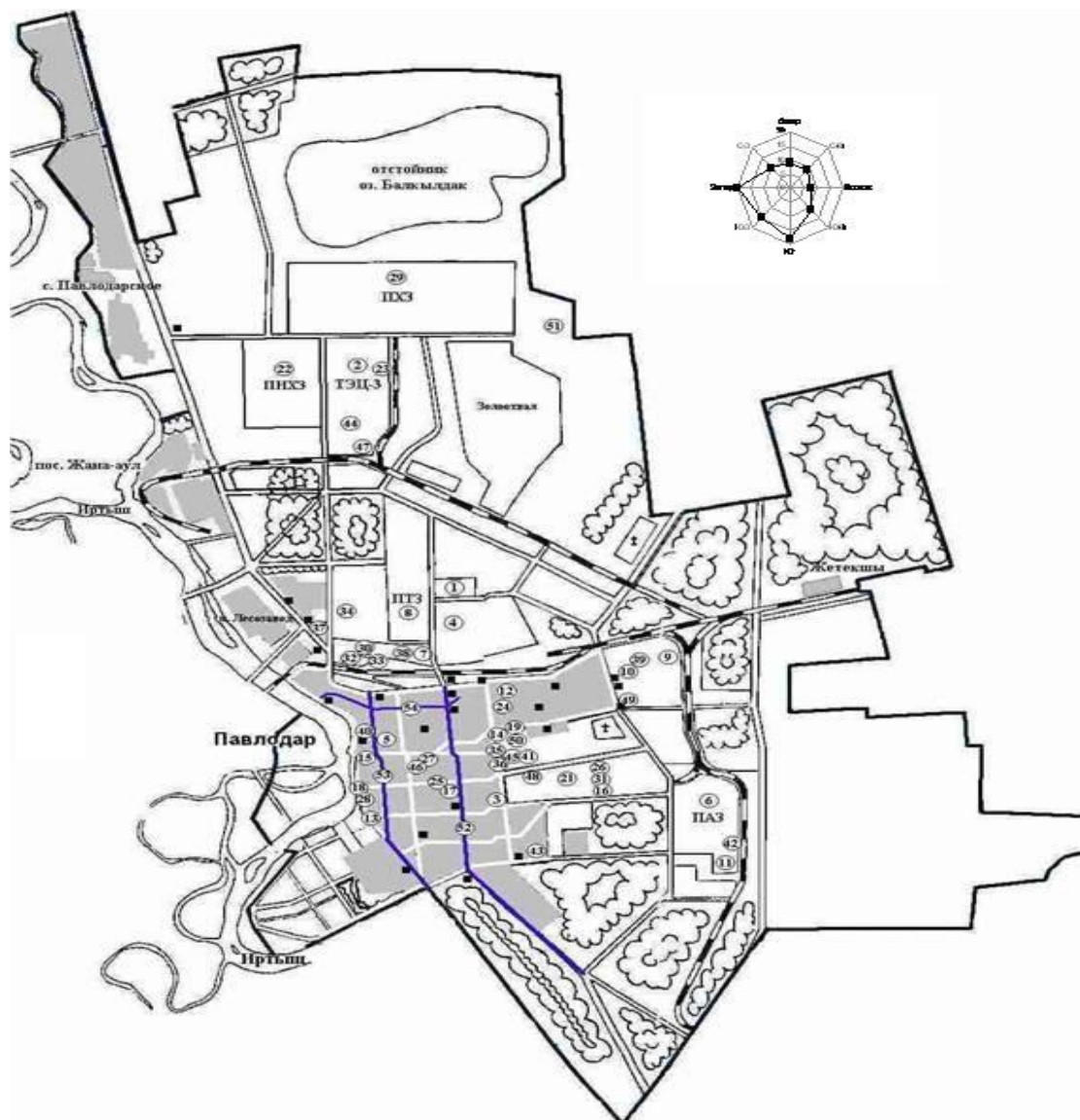
PF LLP "Casting" is a company that focuses on remelting steel scrap and producing various types of rolled products. However, it releases a range of pollutants into the atmosphere, including manganese oxides, tin oxides, iron oxides, calcium oxides, ammonia, petrol, butane, propane, saturated hydrocarbons, formaldehyde, metal dust, inorganic dust, coal dust, abrasive dust, rubber dust, nitrogen oxides, carbon oxides and sulphur dioxide.

Litmaskomplekt LLP engages in the manufacturing of steel-iron castings, which is categorised as hazard class II.

The limited liability partnership "Company of Industrial Materials", KOP-4, specialises in the process of impregnating railway sleepers with an antiseptic substance and manufacturing reinforced concrete products. The primary contributors to air pollution are the outdoor environment throughout summer and the manufacturing facility during winter, specifically used for treating sleepers, together with the chimney of a heating boiler. Various pollutants, including as cement dust, crushed stone dust, welding aerosol, phenol, naphthalene, benzene, toluene, xylene, acenaphthene, anthracene, hydrogen fluoride, manganese oxide, sulphur dioxide, nitrogen dioxide, carbon monoxide, and others, are released into the air.

OJSC "PKRZ" (Pavlodar Cardboard and Ruberoid Plant), KOP-4, is specifically intended for the manufacturing of roofing felt, cardboard, toilet paper, and other related products.

The primary raw materials utilised in the production process are waste paper and wood pulp. Various particulate matter such as paper dust, wood dust, abrasive dust, asbestos dust, ash, vanadium pentoxide, manganese oxides, and harmful gases including hydrogen fluoride, welding aerosol, carbon monoxide, xylene, toluene, phenol, and other compounds are emitted into the air.



Note: 1 – TPP-1; 2 – TPP –3; 3 – JSC Pavlodar Heating Networks; 4 – JSC Sevkazenergomont; 5 – JSC Pavlodar Electric Distribution Company; 6 – JSC Aluminum of Kazakhstan; 7 – Tram management; 8 – JSC Pavlodartractor; 9 – PZAO Vtorchermet; 10 – Pavlodarshina; 11 – TPP-1; 12 – Railway Department; 13 – JSC Sudostroitel; 14 – JSC Pavlodar Pinskadrov; 15 – PF LLP Casting; 16 – Pavlodar Machine-Building Plant OJSC; 17 – Vostokgas cleaning; 18 – Waterways Enterprise; 19 – FC Romat LLP; 20 – JSC ZhBI-1; 21 – ZhBI-3; 22 – JSC PNZ CCL; 23 – JSC Cardboard and Ruberoid Plant; 24 – Radio-television transmitting center; 25 – Garment factory March 8; 26 – Argo LLP; 27 – JSC Sut; 28 – JSC Pavlodarsol; 29 – Pavlodar Chemical Plant OJSC; 30 – JSC Pavlodarmoloko; 31 – Kvarts LLP; 32 – JSC Rosa; 33 – Bakery plant; 34 – JSC Medpolymer; 35 – Plastfarm LLP; 36 – Agrozintekhnika LLP; 37 – JSC Kamkor; 38 – JSC Irtysh-Lada; 39 – Pavlodarrezintekhnika; 40 – JSC Energostroy; 41 – JSC OT Avtobaza special vehicles; 42 – JSC Stroymontazh; 43 – KRG Gorvodokanal; 44 – JSC Neftekhimremont; 45 – Pavlodargaz JSC; 46 – Pavlodar canned milk plant; 47 – JSC Tyazhekskavatsia-22; 48 – JSC Promtekhmontazh; 49 – KP Mekhkolonna-59; 50 – JSC Gordorstroy; 51 – JSC Kazenergokabel. Central highways of the city: 52 – st. Kutuzova; 53 – st. Dzerzhinsky; 54 – st. Toraigyrov. - Gas station.

Figure 2.2.2. Scheme of location of enterprises on the territory of Pavlodar.

Eastern industrial zone

OJSC Aluminium of Kazakhstan, which comprises the aluminium factory PAZ and CHPP-1, operates KOP-1 to extract aluminium from low-grade bauxite found in mines in Central Kazakhstan. During the manufacturing of alumina, gallium, and aluminium sulphate, several dangerous compounds are emitted into the environment. These include inorganic dust, NaOH alkali, nitrogen oxides, carbon oxide, sulphur dioxide, fuel oil ash, vapours of hydrochloric and nitric acids, sulfuric acid aerosol, and aluminium sulphate dust, among others. CHP - 1 is designed to generate both electrical and thermal energy to meet the demands of an aluminium smelter, other industrial facilities, and the residential area of the city. The primary fuel used is high-ash coal. When combusted in boiler furnaces, this coal produces ash, together with ash from fuel oil, as well as different nitrogen, sulphur, and carbon oxides. Pollutants are introduced into the atmosphere via a pair of chimneys.

Almet-Center LLP, KOP-4, specialises in the processing of non-ferrous metals. Coloured melts are generated within a plasma furnace powered by liquid fuel. The atmospheric emissions include, of aluminium oxide, sulphur and nitrogen dioxides, saturated hydrocarbons, carbon monoxide, welding aerosol, and soot.

The eastern and northern industrial zones exhibit a significant amount of particulate matter (more than 146.3 kg/km²*day) and receive a natural input of chemical components through air dust (Panin et al., 2002). Studies have confirmed that the snow cover in Pavlodar city is contaminated with dust containing 21 different chemical components. The primary contaminants found in the snow cover of the city include mercury, cadmium, lead, strontium, beryllium, vanadium, molybdenum, and nickel (Panin et al., 2002). The majority of pollutants exist in a form that can dissolve in water. When snow melts, these pollutants are carried away by the runoff and into open bodies of water. Alternatively, they can seep through the soil and contaminate the water within the soil, so raising its pollution levels.

State of water resources

The Irtysh River, spanning 720 km in length, serves as the primary source of drinking, domestic, and industrial water supply in the Pavlodar area. It has a surface flow volume of 28 690,0 million m³/year.

The environmental agency has determined that the situation on the Irtysh River is stable. In 2007, water quality monitoring determined that the water pollution index (WPI) of the Irtysh River in the area was 1.13, falling within the range of 1.0 to 2.5. This indicates that the river is classified as a class 3 water body, meaning it is moderately contaminated. In the period of

2006-2007, the levels of pollutants for the components listed below surpassed the maximum allowable concentrations (MAC): copper - 1.9-3.7 MPC, zinc - 1.7 MAC, total iron - 3.7 MAC, nitrate nitrogen - 2.1 MAC, and ammonium nitrogen - 3.9 MAC.

The primary source of heat exchange water discharge into the Irtysh River is the Aksu power station of EEC JSC. In 2007, this facility discharged 1,566,030 cubic metres of water, contributing to thermal pollution. Pavlodar - Vodokanal LLP is responsible for discharging 2.1% of the total volume of pollutants (98.0 thousand m³/day) into the Irtysh River via wastewater. Overall, the quantity of wastewater generated by municipal treatment facilities (MTF) in the regional centre in 2007 was 35,911 thousand m³.

One of the primary challenges is the treatment of storm and drainage waters from the towns of Pavlodar and Aksu, which are released into the river. Currently, Pavlodar has a storm sewage system that spans around 10 km in length. Out of the four pumping stations, three are operational. The networks have been operational since the 1970s, and no significant maintenance has been performed on them during this period. As a result, their state is bad. Storm and drainage runoff discharges transport oil products, copper, zinc, nitrogen pollution, phosphates, and manganese into the Irtysh River, including all substances that are carried away from the city's surface soils.

The area manages three extensive complexes of treatment facilities to handle urban wastewater from the cities of Pavlodar, Ekibastuz, and Aksu. Additionally, there are eight departmental local treatment facilities for industrial and mixed wastewater at industrial companies in the territory. The purification efficiency of petroleum products at the main complex of Pavlodar-Vodokanal LLP is 99.9%, while the purification efficiency of the urban treatment facilities (UTF) in the Pavlodar area of Pavlodar-Vodokanal LLP ranges from 97.7% to 98.5%.

The technical state of the municipal wastewater treatment facilities in Ekibastuz is inadequate, specifically the sand traps, sedimentation tanks, and aeration tanks. There are frequent failures in the gravity collector that transports treated wastewater from the Ekibastuz State Enterprise to the Atygay storage tank. This has resulted in flooding of nearby lands and poses a significant risk of an environmental disaster.

The Pavlodar City Treatment Plant (PST) releases treated wastewater into the Irtysh River, which serves as a fishery reservoir. Despite meeting the treatment standards, wastewater may still have a detrimental effect on the Irtysh River, posing a risk of contaminating the river water with secondary pollutants. There is a lack of infrastructure for the fermentation of untreated sludge on sludge beds to facilitate the drying process. Insufficient

precautions have been taken to reach PDS criteria, since exceeding the maximum allowable concentration may have a detrimental impact on the quality of river water, which is then utilised for drinking purposes downstream. The storage tanks in the cities of Ekibastuz and Aksu (Atygay and Uzynbulak) are experiencing elevated levels of BOD_{total}, sulphates, phosphates, petroleum products, and chlorides. Additionally, the urban wastewater being released has not undergone adequate filtration. Illegal fishing takes place in stagnant bodies of water, leading to the spread of contagious illnesses.

Groundwater pollution occurs via the evaporation storage tanks of industrial wastewater, as well as the dumping of sludge, ash, and solid waste from industrial businesses. The city of Pavlodar has situated its industrial wastewater storage tanks and evaporators in three local lake depressions: Bylkyldak, which is associated with a chemical plant, Sarymsak, which is linked to an oil refinery, and Karabidaik, which is connected to an aluminium factory and CHPP-1 (General Plan, 2005).

Thus, Bylkyldak, located 1 km from the northern industrial zone of Pavlodar on the right bank 6 km from the bed of the Irtysh River, was originally supposed to be a place for unloading the ground flow, after the construction of the evaporator and the discharge of wastewater into it, the level in it rose, as a result of which, Bylkyldak moved from the area of groundwater discharge to the area of its supply. Water pollution with mercury occurred as a result of imperfect technology for the production of chromium and caustic soda at the Khimprom production association. After demercurization work was completed at the Khimprom Production Association, sources of mercury contamination were localized.

The firm BAK LLP (Bogatyr Access Komir) includes the lakes Akbidaik and Tuz, which are characterised by their bitter and salty properties. The surplus capacity of the Elemes reservoir, together with mine water from open-pit mines and residential water from the Bogatyr and Vostochny open-pit mines, is released into the Akbidaik reservoir, situated 14 km southeast of Ekibastuz city. Groundwater in this location has elevated levels of sulphides, chlorides, total BOD, enhanced mineralization, strontium, barium, manganese, titanium, aluminium, and fluorine, which likely result from natural processes. Simultaneously, there is an observed rise in the mineral content of groundwater. The contamination of aquifers in the vicinity of Lake Tuz has been confirmed as a result of limited water circulation and significant evaporation rates.

The Pavlodar Petrochemical Plant CJSC releases treated wastewater comprising suspended solids, hydrocarbons, surfactants, phenols, sulphides, nitrates, nitrites, and phosphates into the Sarymsak evaporator storage tank,

which is situated 14 km away from the plant. Instances of oil-contaminated substances (such as foam and silt) infiltrating the main channel of the storage tank have been documented.

Overall, the amount of wastewater being released into storage tanks in the area saw a rise in 2007 when compared to 2006. The increase in volume by 3,326.04 thousand/m³ is attributed to the rapid growth of the industry, including the activation of the first phase of the Kazakhstan Electrolysis Plant. Instances of illicit discharge of wastewater onto the land from several agro-industrial complexes, breaches in the functioning of filtration fields at the Pavlodar poultry farm, and failure to properly track the amount of wastewater discharged onto these fields, as well as non-compliance with regulations for environmental and sanitary upkeep of the banks of the Irtysh River, were detected. Furthermore, some municipal parking areas lack asphalt covering, and car washing facilities operate without an overpass equipped with a drainage system and local treatment facilities. This poses a risk of contaminating groundwater with oil spills.

Comparison of the provision of tap water to the inhabitants in the area in 2007 and 2006. The indicator had a consistent growth trend in the period 2003-2007, rising from 75.6% to 77.6%. The area has seen a general trend of stabilising and enhancing the quality of drinking water, as reported in the Ecological Bulletin of 2008 (pp. 36-45).

The production of industrial trash has consistently stayed at a high level since the year 2000. In 2008, the area had accumulated a total of 5,754,044.8 thousand tonnes of garbage, with municipal solid waste (MSW) accounting for 3,477.7 thousand tonnes. Coal mines are the primary source (90-93%) of their creation, followed by thermal power plants (4-5%). The area has amassed a total of 5,381,073.2 thousand tonnes of overburden, 259,415.3 thousand tonnes of ash and slag, and 113,522.4 thousand tonnes of sludge and slag. The recycling and waste utilisation rate is between 10.6% and 15.4%. Additionally, the petrochemical plant processes 100% of the oil sludge, while the Aksu Ferroalloy Plant processes more than 100% of the "stale" slag created annually. The region has a total of 307 well planned waste storage facilities, with the majority located in urban areas. Pavlodar, Ekibastuz, and Aksu.

The city's solid waste dump, spanning an area of 100.8 hectares, is situated in the northeastern part of Pavlodar's residential zone, about 3 km away. This landfill stores around 60 thousand tonnes of garbage per year, with a total accumulation of 1,833.5 thousand tonnes. 50 hectares of the landfill have been completely filled and restored, while the rest of the area is still actively being used.

The Ekibastuz city landfill, located on the Zapadny rock dump, covers an area of 96 hectares and is positioned 4 kilometres from the city. It gets an annual influx of 30 thousand tonnes of solid waste. The Aksu landfill is situated on the western side of the filtration fields and covers an area of 4.0 hectares. It has a capacity to hold 12 thousand tonnes of rubbish annually. Smouldering, an inherent process, takes place continuously throughout the year in all landfills, sometimes resulting in the burning of rubbish. The journal *Ecol. Bulletin* (2008) has recorded cases when the prescribed limits for carbon monoxide, formaldehyde, and nitrogen oxides have been surpassed.

The laboratory and analytical service section of the POTUEP monitors the environmental conditions, including the status of the atmosphere, groundwater, surface water, and soil.

Between 2006 and 2007, the quality of the atmospheric air deteriorated as a result of a surge in vehicle numbers, as well as unregulated sources of emissions from businesses. The concentrations of carbon monoxide, nitrogen, hydrocarbons, and suspended particles have seen a substantial rise, as shown by the recurring occurrence of "smog" (*Ecol. Bull.*, 2008). In the Pavlodar region, there were measurements indicating elevated levels of nitrogen dioxide (1.14 times the maximum permissible concentration), formaldehyde (1.31 times the maximum permissible concentration), dust (4.1 times the maximum permissible concentration), and carbon monoxide (1.56 times the maximum permissible concentration) in the air. In the cities of Aksu and Ekibastuz, there were observed excessive levels of dust content, reaching up to 2 times the Maximum Permissible Concentration (MPC), and formaldehyde levels of 1.2 times the MPC. The quality of groundwater is significantly affected by the economic activities of businesses, as well as their emissions, which dissolve and seep into groundwater through the influence of atmospheric precipitation.

Several wells owned by Khimprom JSC have elevated levels of mercury, exceeding 10 times the Maximum Permissible Concentration (MPC). PNHZ JSC has wells with oil products exceeding 5 times the MPC. TNK Kazchrome JSC has manganese concentrations up to 10 times the MPC. Aluminium of Kazakhstan JSC has wells with alkalis and fluorine levels up to 2 times the MPC (*Ekol.byul.*, 2008).

The 2007 monitoring of the Irtysh River revealed that the primary contamination is concentrated outside the boundaries of the Pavlodar district. In the samples taken on the border with the East Kazakhstan Region (EKR), there was an excess of BOD and petroleum products in all samples. Additionally, 80% of the selected samples had copper content that exceeded the MPC standard, ranging from 1.8-2.0 MPC. The oil products exceeded

the MPC standard by 2.2 times, and the BOD exceeded the MAC standard by 1.3 times. Some individual samples also showed an excess of zinc content, reaching up to 1.5 times the MAC standard (Ecol. Bull., 2008).

The Irtysh River is a transboundary river that flows through three countries: China, Kazakhstan, and Russia. The series of Irtysh reservoirs effectively controls the river's water flow within the borders of Kazakhstan. The Irtysh floodplain is now the focal point of the intricate convergence of commercial and environmental concerns. There are elevated levels of copper, zinc, iron, cadmium, manganese, phenols, and petroleum products in several parts of the river. These concentrations exceed the legal limits, with copper ranging from 2 to 2.3 times the Maximum legal Concentration (MPC), zinc ranging from 1.5 to 2 times the MPC, iron ranging from 1.2 to 1.5 times the MPC, cadmium being 4.4 times the MPC, manganese ranging from 1.1 to 1.5 times the MPC, phenols ranging from 0.4 to 4 times the MPC, and petroleum products ranging from 1.5 to 7.6 times the MPC. Pollution is the most significant human-caused element that has a greater effect on the biological components of rivers compared to other negative factors such as spontaneous introduction, poaching, floodplain fires, etc. (Ubaskin et al., 2006).

Soil contamination arises from the release of dust particles by industries, the escape of pollutants into the air, the disposal of waste in landfills, and the economic operations of businesses. Excessive levels of chromium, manganese, titanium, and arsenic were found on the border of the sanitary protection zone of Aksu city. These substances are present in the dust emissions from the Aksu Ferroalloy Plant (TNK Kazchrome JSC and EEC JSC).

Elevated concentrations of copper, zinc, and lead were detected in the soils around the perimeter of the sanitary protection zone of JSC Maikain-Zoloto. Similarly, heightened levels of titanium, manganese, copper, and zinc were observed on the boundary of the sanitary protection zone of JSC Kasting. The western side of PCP JSC exhibits historical mercury contamination, with levels reaching 4.5 MPC, as reported in the Ecological bulletin of 2008.

In 2007, the environmental register of the Pavlodar region documented several issues that require solutions at both the national and local levels. These issues include the development of a feasibility study for a comprehensive plan to establish a recreational zone in the Bayanaul National Natural Park, along with the construction of local wastewater treatment plants. Additionally, there is a shortage of air pollution monitoring posts in the cities of Pavlodar, Ekibastuz, and Aksu. It is necessary to establish a paleontological natural monument called "Goose Flight" in Pavlodar.

Furthermore, there is a lack of gauging stations to monitor the Irtysh River within the Pavlodar region, both at its entrance and exit. The development of a detailed design for a solid waste landfill in Pavlodar is also required. Lastly, there is a need to properly dispose of sources of ionising radiation at Pavlodar Chemical Plant JSC.

Local environmental issues in the area include the following: implementation of a project to construct storm sewers with treatment facilities; absence of specialised facilities for the disposal of medical waste; accumulation of sediment in the Irtysh river near the cities of Pavlodar and Aksu; deteriorating condition of the Ekibastuz sewerage treatment facilities and the pressure sewer collector used to discharge treated water into the Atygay reservoir; absence of filtration fields in the regional centres of the region; need for monitoring mercury pollution in the Northern industrial zone of Pavlodar where demercurization work is taking place; development of design documentation for the cleaning of Lake Sabyndykol within the territory of the BNNP; and implementation of projects for the construction of water protection zones and strips.

Therefore, based on the aforementioned materials, it is evident that there are several sources of polluted chemicals inside the Pavlodar region, which together impact living entities.

3. Materials and research methods

Sampling and sample preparation

In accordance with the goals and objectives set in the work, research objects and methods were selected (Table 3.1).

Table 3.1 Materials and research methods

N o.	Object	Organ or tissue	Number of samples	Type of analysis (research method)	Sampling location
1	Silver birch <i>Betula pendula</i> <i>Roth.</i>	Leaf blade	over 4000 leaves from 400 trees	Fluctuating asymmetry	Pavlodar and Bayanaul village, Aktogay village
2	Black poplar <i>Populus nigra L.</i>	leaf blade	61 samples	Instrumental Neutron Activation Analysis (INAA)	Pavlodar Zhelezinka village, Bayanaul village, Aktogay village
3	Dandelion <i>Taraxum</i> <i>officinale s. L.</i>	pollen	about 200 thousand pollen. Zeren from 44 points	Sterility Analysis pollen cells	G. Pavlodar Zhelezinka village Bayanaul village
4	Common tree species: silver birch <i>Betula pendula</i> <i>Roth.</i> , black poplar <i>Populis nigra L.</i> , Scots pine <i>Pinus</i> <i>silvestris L.</i> , pinnate elm <i>Ulmus pinnato-</i> <i>ramosa Dieck.</i> , ash- leaved maple <i>Acer</i> <i>negundo L.</i>	External manifestatio n and general appearance of the tree stand	About 73 thousand trees	Assessing the vital condition of trees	Pavlodar

In the Pavlodar region, six areas were identified based on their proximity to the main sources of pollution: the northern industrial zone consisting of Pavlodar Petrochemical Plant CJSC, Pavlodar Chemical Plant OJSC, PTETs-2 LLP, and PTETS-3 LLP, and the eastern industrial zone consisting of Aluminium of Kazakhstan JSC (PAZ) and TPP-1 (Figure 3.1).

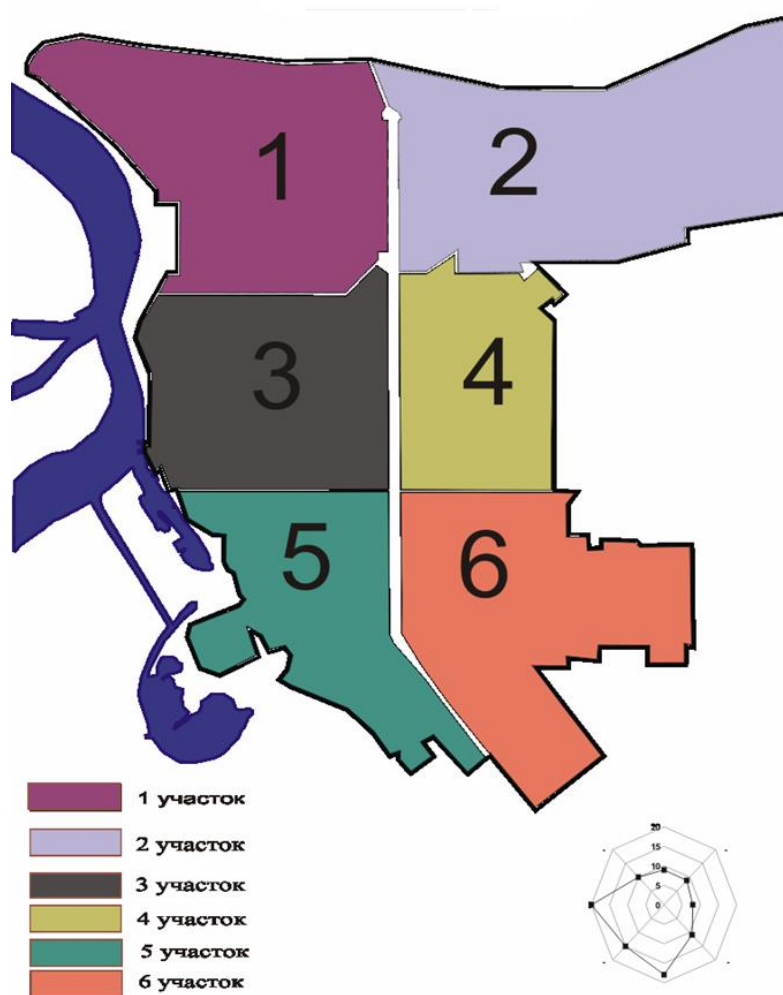


Figure 3.1. Layout of plots on the territory of Pavlodar

The backdrop locations that were taken into account are Bayanaul National Park, situated 185 km southwest; Aktogay village in the Aktogay district, located 105 km northwest; and Zhelezinka hamlet in the Zhelezinsky district, which is 180 km north of Pavlodar (Fig. 2.2.1).

Collection of material.

The research using the fluctuating asymmetry approach only gathered leaves from middle-aged trees of the *B. droopy* species. A total of 100 leaves were collected from 10 closely spaced trees, with 10 leaves taken from each tree at a single collecting site. Leaves are harvested from the lower portion of the crown, at the height of a raised hand, from as many branches as possible in various directions (north, south, west, and east). Every sample is accompanied with a label that includes information such as the date, time, location of collection, and the person who gathered the material. To ensure long-term preservation, use a fixative consisting of alcohol mixed with glycerin or water in a 1:3 ratio. Concurrently with the process of sampling,

a visual evaluation of the plants' state is conducted, and any indications of phytotoxic effects are seen and recorded.

When gathering the leaves of *T. black* were subjected to chemical analysis using a standardised approach. The leaves were randomly sampled by cutting them with a knife at a distance of one's arm length. Multiple leaves were taken from various sides of the tree. The sample is encased in plastic wrap and affixed with a label that specifies the tree species, date, and location of collection. The sampling points for studying the sterility of dandelion pollen (*Taraxum officinale s. L.*), analysing the fluctuating asymmetry of silver birch (*Betula pendula Roth.*) leaves, and conducting biogeochemical studies of black poplar (*Populus nigra L.*) leaf ash will be determined within the city's territory. The city of Pavlodar is seen in Figures 3.2 to 3.4.

Methods of research.

This study employed a comprehensive methodology that involved the use of bioindication methods, such as analysing the sterility of *Taraxum officinale* pollen, assessing the fluctuating asymmetry of *Betula pendula* leaves, and evaluating the vitality of five common tree species. Additionally, the composition of *Populus nigra* leaf ash was analysed using the method of biogeochemical analysis known as instrumental neutron activation analysis (INAA).

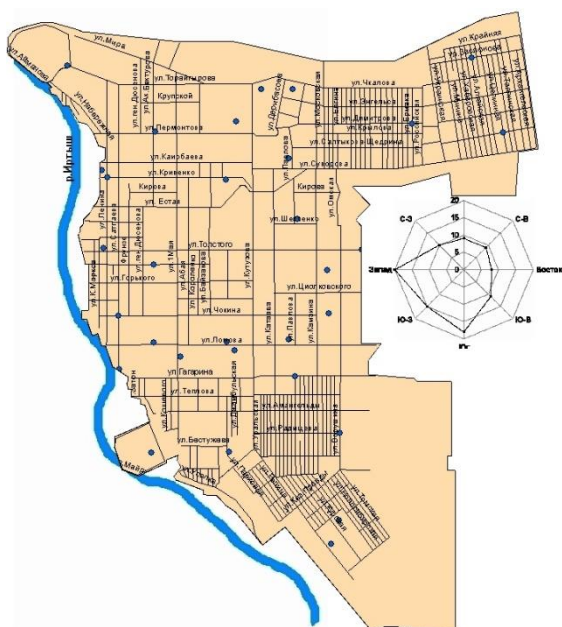


Figure 3.2. Sampling points for the analysis of fluctuating asymmetry of leaves of silver birch (*Betula pendula Roth.*) on the territory of Pavlodar

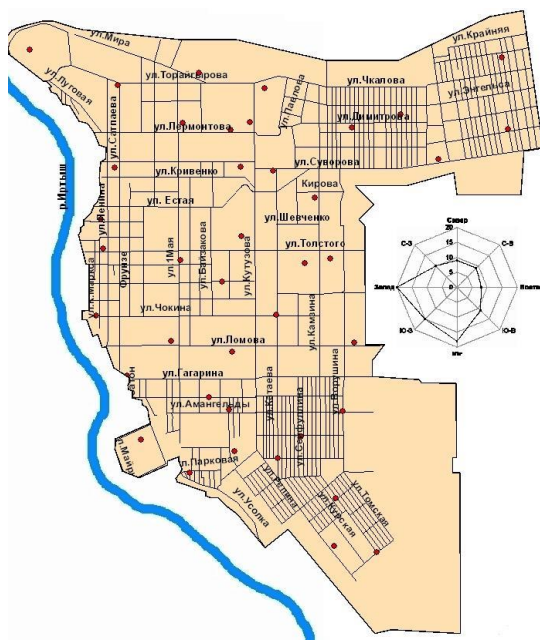


Figure 3.3. – Sampling points for analyzing the sterility of dandelion pollen (*Taraxum officinale s. L.*) on the territory of Pavlodar

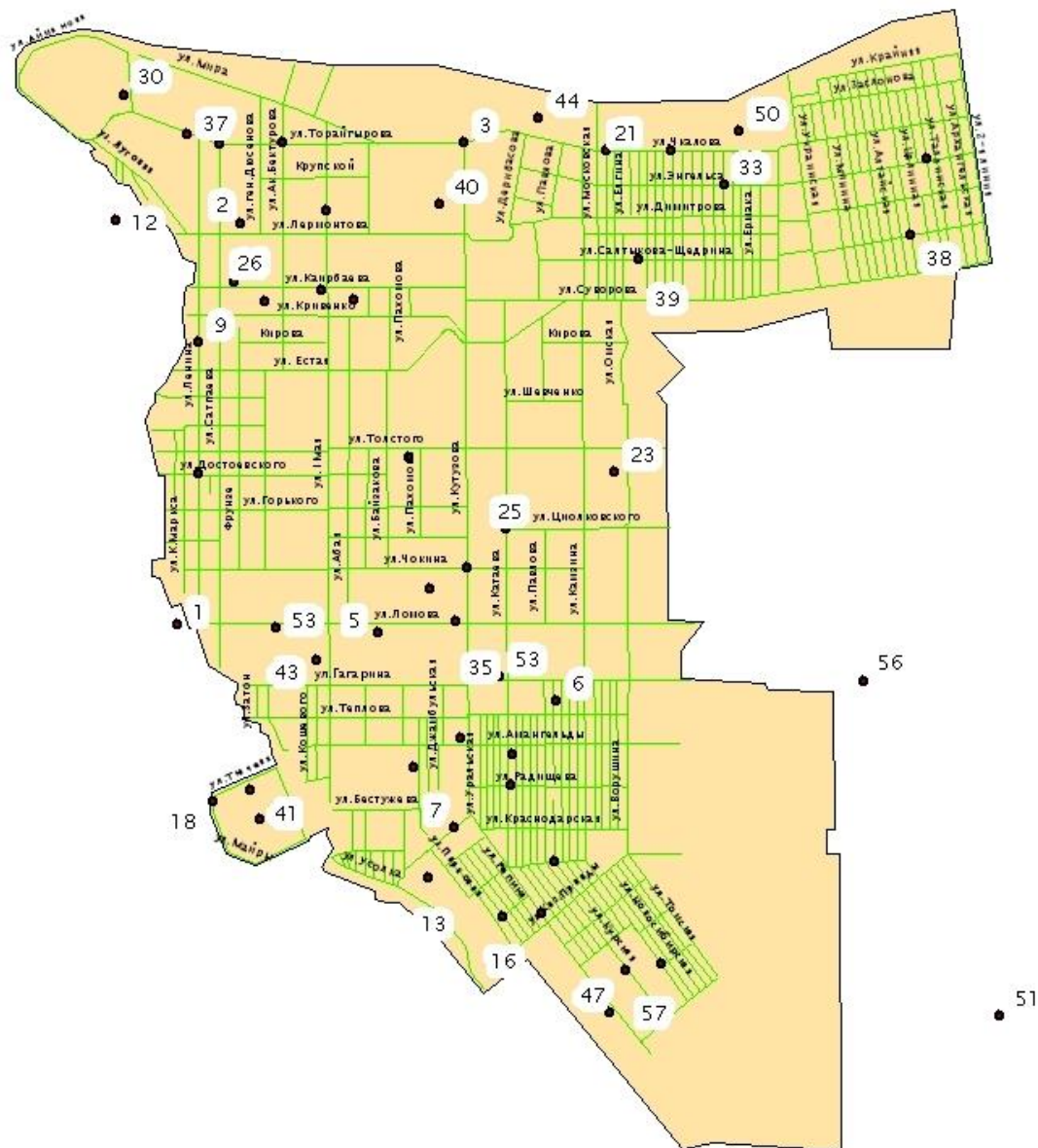


Figure 3.4 Sampling points of black poplar (*Populus nigra* L.) leaves for geochemical analysis

Bioindication methods make it possible to study the reaction of biota to technogenic pollution.

The cytogenetic method of fertility/sterility analysis is generally recognized as a promising bioindication method in the analysis of environmental conditions. For bioindication of a complex of unfavorable factors leading to disruptions in the process of pollen maturation, populations of herbaceous plants living in natural conditions are used.

Studies have been carried out on the reproductive characteristics of plants growing in a gradient of toxic load. The fertility of freshly collected

pollen was determined using the standard acetocarmine method (Jensen, 1965; Abramova and Karlinsky, 1968; Pausheva, 1974).

The meristem, as well as the generative organs formed from it, in particular the male generative sphere, are most sensitive to the toxic effects of industrial pollutants (Eiges, 1982; Shchapova, Potapova 1989; Shevchenko, 1983; Bessonova, 1992; Shumny et al., 1993; Tretyakova, Noskova, 2001, 2004; Ervandyan, Nebish et al. 2005). When studying the response of the male gametophyte to the influence of external factors, it is customary to distinguish between fertilizing ability (fertility) and pollen viability. Fertility involves the ability of the male gametophyte to cause complete fertilization. The viability of pollen is considered as its ability to grow on the corresponding tissues of the pistil (Severyukhina, Zhuikova, 2004; Bezel, 2006).

Analysis of leaf asymmetry of silver birch *Betula pendula* Roth. carried out using the FA method. (Zakharova V.M., Clark D.M. 1993; Streltsova A.V., Loginov A.A., Lykov I.N., Korotkikh N.V. 2000; Ilyinskikh N.N. 2005;).

To process the collected material, we used: a ruler, a measuring compass, and a protractor. From one sheet, indicators are taken for 5 parameters on the left and right sides of the sheet (Fig. 3.5 according to Ilyinsky, 2005).

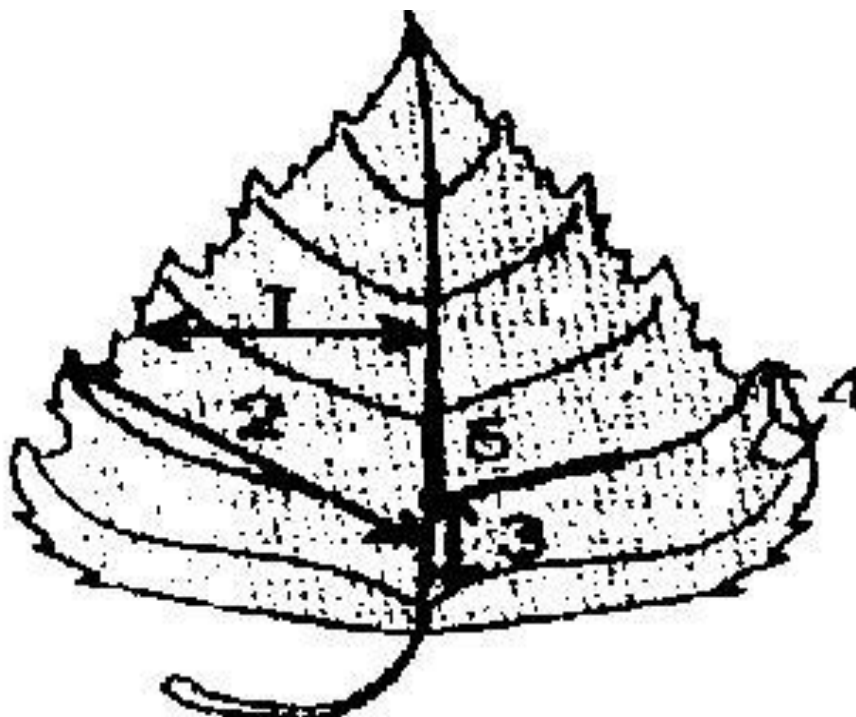


Figure 3.5 - Birch leaf parameters

- 1.- width of half sheet. To measure, fold the sheet in half, placing the top of the leaf against the base, then unbending it and taking measurements along the resulting fold.
- 2.- length of the second vein of the second order from the base of the leaf.
3. - the distance between the bases of the first and second veins of the second order.
- 4.- the distance between the ends of these veins.
- 5.- the angle between the main vein and the second vein of the second order from the base.

The first four parameters are measured with a measuring compass, the angle between the veins is measured with a protractor. When measuring an angle, the protractor is positioned so that the center of the base of the protractor window is at the location of the branch of the second vein of the second order. Since the veins are not straight, but tortuous, the angle is measured as follows: the section of the central vein, located within the protractor window, is combined with the center of the protractor, which is equal to 900, and the section of the second-order vein is extended to the degree values of the protractor using a ruler.

The measurement data is entered into the table “Measurement values” (Table 3.2; 3.3.).

Table 3.2. – Measurement values

Gathering place:	Performers:									
Sheet No.	1 sign		2 sign		3 sign		4 sign		5 sign	
	1	P	1	P	1	P	1	P	1	P

To input data onto a computer for storage and mathematical calculations, use the Microsoft Excel software. A metric quantifying the extent of asymmetry is computed for the aggregate number of leaves gathered at a single sample location.

Table 3.3. – Auxiliary table for calculating characteristics

Sheet No.	1 sign	2 sign	3 sign	4 sign	5 sign	Average relative difference per trait
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To enter data onto a computer for the purpose of storing and doing mathematical computations, use the Microsoft Excel programme. A metric is calculated to measure the degree of asymmetry in the total number of leaves collected at a certain sampling site.

Table 3.4. – Score values of the asymmetry indicator

Point	The value of the asymmetry indicator
1	up to 0.055
2	0.055-0.060
3	0.060-0.065
4	0.065-0.070
5	more than 0.070

The analysis of the health and diseases of common tree species in urban plantings is conducted using data provided by the teachers of the Pavlodar State Pedagogical Institute. The data was collected between 2001 and 2005 in the Pavlodar study area. Since 2001, a survey of green areas in Pavlodar has been conducted to determine the species composition, number, and age of trees and bushes. The survey has used the methodologies developed by Professor Yu.V. Sinadsky in 1977 and academician B.A. Bykova in 1978 and 1988.

The species composition of green spaces was determined using various publications, including "Flora of Kazakhstan" (1956-1966), "Illustrated Guide to Plants of Kazakhstan" (1969, 1972), and works by S.A. Arystangalieva, E.R. Ramazanov "Plants of Kazakhstan" (1977), Novikov V.S. (1985), Kirpichnikova M.E., Zabinkova N.N. "Russian-Latin Dictionary for Botanists" (1977), and others.

The plant population size was established by enumerating the individuals of each species. The plantings were categorised into two groups: even-aged and uneven-aged. If the age of coniferous trees varied within a single age category (10-20 years), the planting was classified as being of the same age. However, if these variations exceeded the stipulated limitations, it was classified as being of various ages. The life stage of trees was analysed using Cheremesinov's (1973) conventional categorization, which identifies six kinds of states (Table 3.5).

Based on this classification, 3 groups were identified:

Group 1 - satisfactory (includes 1.2 vital conditions),

Group 2 – unsatisfactory (includes 3.4 vital conditions),

Group 3 – critical (includes 5.6 vital conditions)

Table 3.5 Diagnostics of the vital state of trees

Category state of life	General crown configuration	State of second order branches	Linear growth of shoots	Condition of needles or leaves
1	2	3	4	5
1. Conditionally healthy trees	Dense, normally developed crown, loss of needles and leaves up to 10%.	There are no dry branches of the second order.	The length of shoots and annual growth are normal.	Pine needles last up to 4 years. Needles and foliage are of normal color and size.
2. Lightly damaged trees	The tree crown is sparse, the loss of needles and leaves is up to 11-25%. The crown length is reduced by 10%.	The share of dry branches of the second order is no more than 20%.	The linear growth of shoots is reduced by 20-25%. Sometimes the tops of the shoots are bunch-shaped (damage to pine beetles).	Anomalies in the size of leaves and needles.
3. Moderately damaged trees	The crowns are noticeably sparse, the loss of needles and leaves is 26-60%	The share of dry branches of the second order is 21-50%. Trees begin to dry out	Lin. growth decreases by 26-75%, curvature of shoots appears	A significant proportion of leaves or needles have abnormal symptoms
4. Heavily damaged trees	Clearly translucent crowns, loss of foliage or needles is 60%. Dry top, crown length is reduced by 40%.	More than 50% dry branches. Abundance of phytophages.	Annual shoots are shortened (resemble rosettes). The curvature of the shoots is clearly expressed.	The needles last 1-2 years. The leaves are small and turn yellow quickly.
5. Fresh dead wood	Trees without greenery. The general outlines of the crown can still be guessed	All branches are dry	Preserving Fine-Order Branches	Fallen needles, however, may remain.
6. Old dead wood	Died several years ago, the general outline of the crown is no longer discernible.	The thickest branches are preserved.	There are no small shoots	None

In order to ascertain the elemental composition of T. black leaves, a very sensitive technique called instrumental neutron activation analysis (INAA) was used. INAA is particularly successful in identifying rare, rare earth, and radioactive elements in living organisms, and relies on a research nuclear reactor for its operation. The benefits of using it for biological entities were acknowledged by several writers (Kist, 1964, 1969; Boyarkina et al., 1980;

Dubinskaya et al., 1980; Kist et al., 1980; Kolesnik et al., 1987; Zhuk et al., 1990; Lukens, 1967; Tjioe, 1977;

The laboratory of nuclear geochemical research methods at Tomsk Polytechnic University, headed by Ph.D. Vertman E.G., conducted instrumental neutron activation analysis using thermal neutron irradiation at the Tomsk research nuclear reactor IRT-T. The senior researcher, Sudyko A.F., served as the analyst for this study.

Table 3.6. - Lower limits for determining element contents using the INAA method

Element	Limit, mg/kg	Element	Limit, mg/kg
Na	20	Ba	3
Ca	300	La	0.007
Sc	0.002	Ce	0.01
Cr	0.1	Sm	0.01
Fe	100	Eu	0.03
Co	0.1	Tb	0.001
Zn	2	Yb	0.05
Rb	0.6	Lu	0.01
Sr	1	Hf	0.01
Ag	0.02	Au	0.002
Sb	0.007	Th	0.01
Br	0.3	U	0.01
Se	1	As	1

In this analytical approach, the signal emanating from the nucleus of chemical elements is eliminated, so ensuring that the physical condition of the sample does not influence the outcome. This enabled the identification of a diverse array of components in plant ash. The impact of altering the makeup of the sample matrix is solely defined by components that interfere and absorb neutrons. Thus, neutron activation analysis employs a single standard operating procedure (SOP) to effectively analyse a wide range of items under examination (Arnautov, 1990).

This approach enables the determination of the chemical composition of various samples over a broad range, from $n \times 1\%$ to $n \times 10^{-6}\%$.

The observations were conducted using a gamma spectrometer equipped with a germanium-lithium detector. The table (Table 3.6) provides the thresholds for identifying items using the approach described above. The laboratory utilises the INAA technique for certifying both local and international composition reference materials (CRM) from various countries such as IAEA, Germany, Japan, India, and others. The analysis's dependability is validated by several control determinations conducted on various media, such as soil and coal (refer to Table 3.7).

Table 3.7. Comparative assessment of the results of elemental analysis obtained at the YAGL department of PIGR TPU with passport data of national standards of Russia

Element	BIL – 1 (Russia)		SD-M2/TM (IAEA)		SGHM - 4		ZUK - 1	
	passport	YAGL	passport	YAGL	passport	YAGL	passport	YAGL
Na (%)	1.93	1.74	1.35	1.35	-	-	0.24	0.205
Ca (%)	1.86	6.76	11.2	7.9	-	-	20.98	12.04
Sc	13	16	10.3	10.5	8 ± 2	8	12.6	13
Cr	67	69	77.2	79.0			45	44
Fe(%)	7.01	7.13	2.71	2.87	3.67	3.64	6.26	6.28
Co	18.5	17	13.6	14.4	9 ± 2	7.4	17	14
Sb	1.5	1.52	0.99	1.19	170 ± 30	190	1.58	1.58
Rb	96	118	99.7	104	190 ± 30	150	16	45.6
Ba	670	864	252	247	-	-	2380	2500
Cs	5.9	6.7	8.05	8.3	18	21.1	2.25	2.25
La	51	40	26.2	27.2	32 ± 4	22.4	23	18.8
Ce	81.5	70	54.3	50.3	55	17.8	39	31
Sm	7.9	6.79	4.27	4.78	-	-	4.6	3.75
Eu	1.65	1.96	0.85	0.92	0.45	0.5	1.2	1.3
Tb	0.95	0.94	0.52	0.58	-	-	0.8	0.8
Yb	3	2.44	1.62	1.69	2.4 ± 0.2	-	2.8	2.4
Lu	0.44	0.46	0.243	0.26	-	-	0.44	0.44
Ta	0.9	0.9	0.84	0.95	-	-	0.57	0.57
Hf	4.1	5.13	2.83	2.95	3.8	4.5	2.7	3.74
Th	12	12.5	8.15	8.2	-	-	5.25	5.67
U	12	10.7	2.49	2.76	-	-	3.5	4.6

Statistical processing of the research results was carried out using the Statistica 6 software package, charts and graphs were built in Microsoft Excel, the distribution of elements, construction of diagrams and maps were carried out using Adobe Photoshop 6.0, Golden Software Surfer 7.0, Corel DRAW 9, ArcGis.

4. Assessing Pavlodar's natural environment quality using bioindication markers

4.1. Herbaceous plant reproduction (dandelion *Taraxacum officinale* sl)

A thorough bioindication evaluation was conducted to evaluate the ecological condition of Pavlodar city. The study used a promising cytogenetic approach to analyse pollen sterility. A study was conducted to analyse the reproductive capacity of pollen grains from the medicinal dandelion *Taraxacum officinale* sl, a perennial herbaceous plant widely distributed across the city of Pavlodar.

Plants are very vulnerable to the impacts of technogenic variables due to their sessile nature and the need to adjust to challenging environments. The pioneers of evolutionary teaching accorded a small significance to anthropogenic stress as an evolutionary and adaptive component. While Darwin's evolutionary theory focused on adaptation to environmental circumstances, he acknowledged that intra- and interspecific competition has more significance in terms of evolution than harsh environmental conditions (Geraskin et al., 2005). The precise contribution of microevolutionary processes to the response of natural populations to low-level technogenic influences is still not fully understood. However, it is now shown that such impacts may indeed alter the genetic composition of these populations (Shevchenko et al., 1992).

N.S. Eiges used the cytogenetic technique of sterility analysis to examine the fertility and sterility of pollen. This approach allowed for the identification of the underlying factors contributing to meiotic abnormalities in winter wheat mutants (Eiges, 1982). Shchapova and Potapova (1989) conducted a study on pollen fertility in hybrid plants, using an individualised method. Their research revealed a notable variability in this feature across all hybrid combinations examined.

Pollen grains, essential for the process of plant pollination, are little entities that densely occupy the anther cavities. The pollen grains were seen with a magnification of 7200x (Fig. 4.1.1).

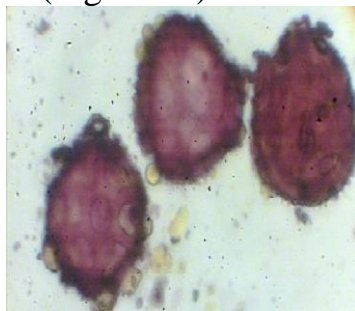


Figure 4.1.1. Pollen cells of *Taraxacum officinale* sl x7200.

Pollen grains consist of two distinct cells: a larger vegetative cell with its own nucleus, and a smaller generative cell that is lenticular in shape and lacks a cellulose shell. The generative cell is positioned to the side of the vegetative cell.

Typically, each half of the anther has two pollen nests. Within these nests, microspores are generated from spore-forming tissue by cellular division. Pollen nests are microsporangia, which are organs responsible for the formation of microspores. The cells that produce microspores undergo division in a manner that results in a reduction in the number of chromosomes. As a result, the set of chromosomes in the nucleus of the spores is haploid. Every spore has two distinct layers, an exterior shell and an interior shell.

Inside flowering plants, microspores undergo germination inside the microsporangium (also known as the pollen nest) where they originate, without leaving the parent plant. Through cellular division, the microspore cell gives rise to pollen, which is composed of two cells - a vegetative cell and a generative cell. The generative cell further splits to generate two sperm cells, resulting in a total of three cells - one vegetative cell and two sperm cells. Pollen cells are situated behind the membranes that once enveloped the spore. The exterior shell of pollen exhibits many sculptural structures such as spines, tubercles, denticles, ridges, and more. The morphology of pollen and the composition of its exine remain consistent within a certain plant species (Green et al., 1990; Troshin et al., 1970).

In the Pavlodar region, the level of pollen sterility ranges from 15.8 to 89.7 (with an average of 48.2) sterile cells per 3000 pollen cells, which is 5.1 times higher than the background level of 3.12 sterile cells per 3000. On average, the number is 28.8 times, while specifically it is 15.4 times.

A total of about 8000 pollen cells were analysed in the background region. The city has almost 105,000 pollen grains.

During the investigation, we have identified three distinct groups based on the frequency of occurrence of sterile pollen grains:

Group 1 - 5-12 sterile cells per 3000 pollen grains;

Group 2 - 13-20 sterile cells per 3000 pollen grains;

Group 3 - 21-29 sterile cells per 3000 pollen grains

The indicator $K_f = 3.12$ sterile cells was taken as a basis.

The sterility over the region of Pavlodar exhibits an irregular and fragmented spatial distribution, as shown in Figure 4.1.2. The locations with the highest sterility index values are located in the northeastern and central residential sections of the city. These include the crossroads of important highways like as Kutuzov and Lomov, Kutuzov and Tolstoy streets, as well as Aimanov, Lvovsky, Krylov streets, and others.

A comprehensive investigation was conducted on many markers of sterility, including the count of sterile cells per 3000 cells, the sterility coefficient relative to the background, and the frequency of sterile cell occurrence in different sections of the city (as shown in Table 4.1.1÷4.1.6).

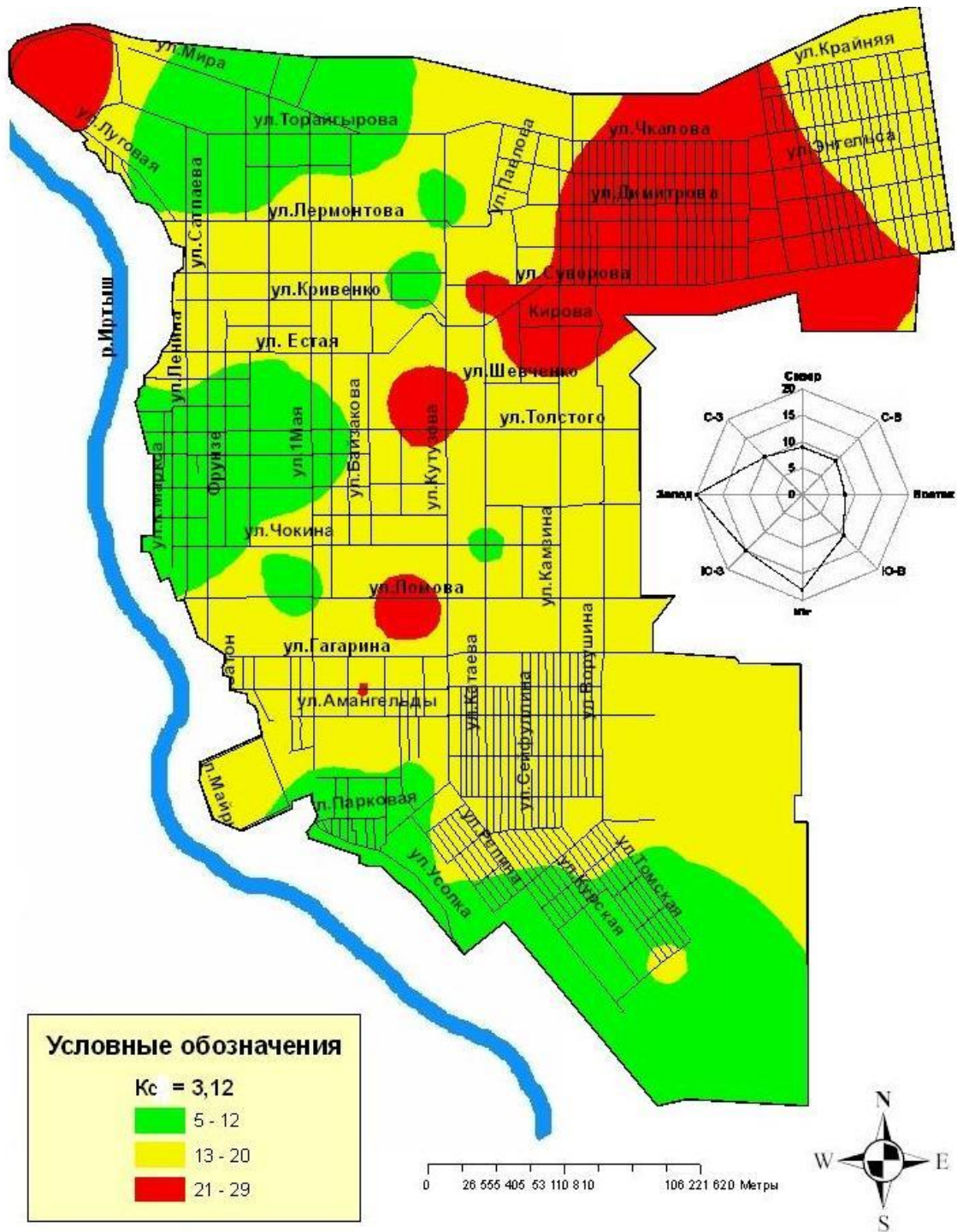


Figure 4.1.2. Pollen sterility *Taraxacum officinale* sl on the territory of Pavlodar, for 3000 cells.

Table 4.1.1. Sterility of dandelion pollen in area 1

No.	Gathering place	For 3000 pollen grains	in relation to the background (Bayanaul 3.12)	3 groups according to frequency of occurrence
1	Central Mosque	28.9	9.26	1
2	St. Ak. Satpayeva + Toraigyrova	15.8	5.06	1
3	Manakbay b.	43.0	13.8	2
4	Lermontov St.	49.4	15.8	2
5	Nazarbayeva	31.8	10.2	1
6	PPU	26.5	8.5	1
7	Microdistrict Khim. towns	89.7	28.7	3
8	pl. Victory	55.9	17.9	2
	Average value	42.62	28.7-5.1 /13.65	

Site 1 is situated in the northwestern region of the city and encompasses the embankment, the park on Victory Square, and shares a boundary with the northern industrial zone.

The pollen sterility range is reported as 15.8 to 55.9 per 3000 cells, with an average of 42.62 (Table 4.1.1). The mean value surpasses the backdrop by a factor of 13.65 (with a range of 5.1 to 28.7 times). The most desirable location inside the site is the junction of the street. Ak. Satpayev and Toraigyrov (5.06) is a park characterised by its location and abundant greenery.

The common dandelion population in the microdistrict of St. Aymanova is experiencing an unfavourable reproductive environment, as indicated by a score of 28.7. Khimgorodki. Site 1 is situated in close proximity to the northern industrial zone and the embankment of the Irtysh River.

Plot 2 is situated in the northeastern section of the city, next to the northern industrial area and the Pavlodar-2 region, which includes Afghan Park and other private home projects. The pollen sterility range varies from 43.8 to 84.6, with an average of 66.9 per 3000 cells. The indication surpasses the backdrop by a factor of 21.3 (within the range of 5.5-27.0). Within the premises, the most desirable location is Tallinskaya Street, while the least advantageous street is the most disadvantaged. Krylov is referenced in Table 4.1.2.

Table 4.1.2. Dandelion pollen sterility in area 2

No.	Gathering place	For 3000 pollen grains	in relation to the background (Bayanaul 3.12)	3 groups according to frequency of occurrence
1	Nazarbayeva + Toraigyrova	43.8	14.0	2
2	Malaysary + Kataeva	71.6	22.9	3
3	St. Tallinnskaya	52.8	16.9	2
4	Lvovskaya street	82.7	26.5	3
5	Krylova street	84.6	27.0	3
6	Shchedrina street	65.0	20.8	2
7	St. Malaysary	68.3	21.8	3
	Average value	66.9	27.0-5.5 /21.3	

Site 3 is situated in the western region of the city. The level of pollen sterility varies from 17.1 to 81.6 times on average, which is equivalent to 42.6 (per 3000 cells) compared to the background. The indicator surpasses the background by 13.6, and the variation ranges from 5.5 to 26.1 (Table 4.1.3). On the site, Lenpark is considered the most favourable location with a rating of 7.1, while the street is regarded as the least favourable spot with a rating of 26.1. Lunacharsky.

Table 4.1.3 - Sterility of dandelion pollen *Taraxacum officinale* sl, section 3

No.	Gathering place	For 3000 pollen grains	in relation to the background (Bayanaul 3.12)	3 groups according to frequency of occurrence
1	Childhood Park	22.4	7.1	1
2	River port	29.8	9.5	1
3	Bokeykhan St. (pedagogical college)	45.7	14.6	2
4	Lunacharsky St.	81.6	26.1	3
5	Shopping center "Gulliver"	66.6	21.3	3
6	St. Malaysary batyr	19	5.5	1
7	St. Malaysary batyr	35.0	11.2	1
	Average value	42.6	26.1-5.5 /13.6	

Site 4 is located in the eastern part of the city. The range of pollen sterility is expressed, from 34.5 to 79.9 times on average, representing 49.48 (per 3000 cells), in relation to the background, the indicator exceeds the background by 15.82 (Table 4.1.4.).

Table 4.1.4 - Sterility of dandelion pollen *Taraxacum officinale* sl, area 4

No.	Gathering place	For 3000 pollen grains	in relation to the background (Bayanaul 3.12)	3 groups according to frequency of occurrence
1.	Railways	34.5	11.0	1
2.	Lomov St. 188 (Lyceum No. 9)	36.6	11.7	1
3.	Kamzina street 56	79.9	25.6	3
4.	Chokina+Kataeva street	36.5	11.7	1
5.	Tchaikovsky street 12	59.9	19.1	2
6.	Average value	49.48	25.6-11.0 /15.82	

The Children's Railway (11.0) is the most favoured place within the property, whilst Kamzina Street (25.6) is the least favoured location. An observed variation of 11.0 to 19.1 was noted in the region, in comparison to the surrounding context.

Site 5 is located in the southwest area of the city. The pollen sterility varies between 22.5 and 80.6, with an average of 49.57 per 3000 cells. The indication exceeds the background by 15.85, as shown in Table 4.1.5. St. Kamskaya is the most sought-after place in this region, boasting a rating of 7.2. On the other hand, St. Lomova, 1st City Hospital is the least desirable, with a rating of 25.8. An observed variation of 7.2 to 25.8 was noted in the region, in comparison to the background.

Table 4.1.5.- Sterility of dandelion pollen *Taraxacum officinale* sl, area 5

No.	Gathering place	For 3000 pollen grains	in relation to the background (Bayanaul 3.12)	3 groups according to frequency of occurrence
1	2nd South street	34.4	11.0	1
2	St. Zhayau Mussa Children's region. hospital	39.0	12.5	1
3	Kamskaya street (Usolka)	22.5	7.2	1
4	UITeplova+Baizakova	67.7	21.7	3
5	St. Olzhabay batyr, school	47.4	15.1	2
6	Satpayev / Gagarin street	55.4	17.7	2
7	1 city hospital	80.6	25.8	3
	Average value	49.57	25.8-7.2/15.85	

Site 6 is located in the southeastern part of the city. The range of pollen sterility ranges from 18.3 to 61.4, with an average of 49.3 per 3000 cells. The indication exceeds the background by a margin of 14.04. The most favourable sector within the site is St. Kutuzov, which has a rating of 5.9. On the other hand, the most unfavourable intersection is St. Amangeldy and Vorushin, with a rating of 19.6 (Table 4.1.6). After assessing the location, a range of variation from 5.9 to 19.6 was identified in relation to the backdrop.

Table 4.1.6 Sterility of dandelion pollen *Taraxacum officinale* sl plot 6

No	Gathering place	For 3000 pollen grains	in relation to the background (Bayanaul 3.12)	3 groups according to frequency of occurrence
1	Aluminum plant	52.7	16.9	2
2	Nazarbayev ost Dachny	18.3	5.9	1
3	Semenchenko St. (School No. 26)	51.1	16.3	2
4	St. Kamzina / Ladozhskoe	41.9	13.4	2
5	St. Amangeldy / Vorushina	61.4	19.6	2
6	St. Bayanaulskaya / st. Krasnodar	40.5	13.0	2
7	St. Kamzina / Volochaeva	41.4	13.2	2
	Average value	43.9	19.6-5.9 /14.04	

An analysis conducted in Pavlodar compared the sterility of *Taraxacum officinale* sl pollen. The study found that in region 1, located in the northwestern part of the city, the range of pollen sterility is between 15.8 and 89.7, with an average of 42.6 per 3000 cells. Regarding the background, the indication exceeds 13.7 times, ranging from 5.1 to 28.7 times.

Section 2 pertains to the geographical area situated in the northeastern part of the city. The reported range of pollen sterility is 43.8 to 84.6, with an average of 66.9. This surpasses the baseline level by a magnitude of 21.3, ranging from 5.5 to 27.0 times.

Section 3 pertains to the western portion of the city. The range of pollen sterility varies from 19.0 to 81.6, with an average of 42.6. The indicator exceeds the background by a factor of 13.6, ranging from 5.5 to 26.1.

Section 4 pertains to the eastern portion of the city. The pollen sterility typically falls between the range of 34.5 to 79.9, with an average value of 49.5. The indication is 15.8 times higher than the background, with a range of 11.0 to 25.6 times.

Section 5 is the term used to describe the southern portion of the city. The pollen sterility varies between 22.5 and 80.6, with an average of 49.6. The indication is 15.9 times higher than the background, with a range of 7.2 to 25.8 times.

Section 6 is situated in the southeastern part of the city. The normal range of pollen sterility is between 18.3 and 61.4, with an average value of 43.9. The indicator exceeds the background by a factor of 14.04, ranging from 5.9 to 19.6 times.

In Pavlodar city, the pollen of *Taraxacum officinale* showed a notable level of sterility across the entire area, ranging from 42.6 to 66.9 (per 3000 cells), compared to the background level of 13.6 to 21.3. The citations for Table 4.1.7 and Figure 4.1.3 are given.

Table 4.1.7 - Sterile pollen grains of dandelion *Taraxacum officinale* sl on the territory of Pavlodar (by area)

Plot	Number of sterile pollen grains	
	for 3000 pollen grains	in relation to the background (Bayanaul 3.12)
1	42.62	13.65
2	66.9	21.3
3	42.6	13.6
4	49.48	15.82
5	49.57	15.85
6	43.9	14.04
Average by city	49.18	15.71

The measure of complete sterility in the city is 49.18 (per 3 thousand cells), which means it is greater than the normal level. The sterility coefficient (Kc), relative to the background, for the city is 15.71, with a range of 13.6 to 21.3. The sterility of *Taraxacum officinale* is unevenly expressed and is seen in different sections of the city in the following decreasing order: The sequence is as follows: 2 is greater than 5, which is greater than 4, which is greater than 6, which is greater than

The highest level of pollen suppression was detected in the northeastern region of the city, which is located near the northern industrial zone.

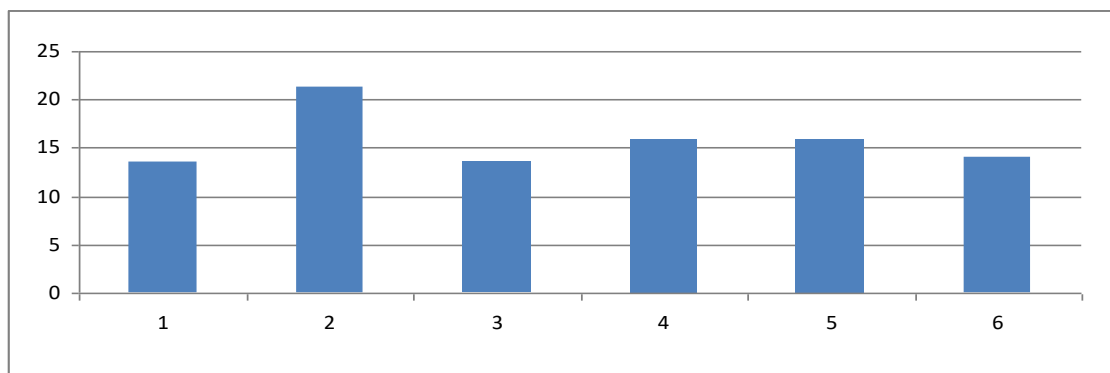


Figure 4.1.3 Manifestation of sterility of pollen grains of dandelion *Taraxacum officinale* sl in areas on the territory of Pavlodar

The analysis of sterility at the locations is represented in these indicators (Table 4.1.2. ÷4.1.7).

A schematic map was created using the ArcGIS programme based on the acquired data (Fig. 4.1.2). Foci of sterility are exhibited in aberrant patches of pollen sterility. The area with the most unfavourable (21-29 background values) is the northeastern section of the city, namely the land of site 2. Areas with reduced pollen concentration are located in the centre region of the city, namely at the junctions of Kutuzov - Tolstoy streets, on Lomov street, and on Aimanov street. The high sterility seen in the north-eastern portion of the city, particularly on Aimanov Street, might be attributed to its near proximity to the northern industrial zone. Similarly, the sterility observed at the Kutuzov-Tolstoy crossroads and on Lomov Street can be attributed to the heavy traffic flow in these areas.

When evaluating several indications of sterility, locations were categorised based on ecological circumstances that support the presence of *Taraxacum officinale* populations. The ranking is presented in decreasing order: The sequence 2>5>4>6>1>3 is seen in Table 4.1.8.

Table 4.1.8 Indicators of pollen sterility in the territory of Pavlodar

Plots	Absolute number of sterile cells (per 3 thousand)	According to the frequency of grade 3 sterility	Maximum Kf	Rank
1	5	3	5	5
2	1	1	1	1
3	6	2	6	6
4	3	3	3	3
5	2	2	2	2
6	4	4	4	4

Thus:

1. *The use of the technique for examining the sterility of Taraxacum officinale sl pollen revealed an undesirable condition in the reproductive capacity of the plant. The discrepancy of this indicator in the city compared to the background value varies from 5 to 29 times, with an average of 15.3 times. The city's average pollen sterility is 48.2, with a range of 15.8 to 89.7. In comparison, the background average is 3.12 per 3000 pollen grains.*

2. *The city's terrain exhibits a varied and uneven distribution of sterility, with the most unfavourable conditions found in the north-eastern sector and places where the biggest roads, namely Nazarbayev, Tolstoy, and Lomov streets, connect. The progression of sterility is seen in a descending order by area: 2 > 5 > 4 > 6 > 1 > 3.*

3. *The technique of assessing pollen sterility is highly recommended for bioecomonitoring in the city of Pavlodar due to its sensitivity, simplicity of implementation, and applicability to a wide range of blooming plants.*

4.2. Zoning of the city territory according to asymmetry indicators silver birch leaves *Betula pendula Roth*.

An urban centre characterised by industrialization is facing escalating strain on its natural ecosystem. To evaluate environmental risks, it is important to establish criteria for measuring the environmental quality in relation to disruptions in the stability of plant organism growth. The morphogenetic technique, which involves evaluating the within-individual variation of morphological structures known as fluctuating asymmetry, has gained popularity in recent times.

The slight, non-directional disparities between the right and left sides of the leaf blade arise from developmental mistakes occurring in the individual organism. The level of asymmetry grows with the growing technogenic effect, as indicated by studies conducted by Kryazheva et al. (1996), Zakharov (2000), and Soldatova and Shadrina (2007).

The leaf asymmetry approach in biological monitoring allows for the indirect evaluation of the environmental condition and the correlation between the morphophysiological traits of plants and the ecological circumstances.

The proposed approach involves evaluating the asymmetry of bilateral traits by considering the inherent properties of live organisms. It is observed that the symmetry of dimensions or quantitative traits is only achieved when the organisms develop under optimal conditions. During periods of stress, this signal rises, indicating variations in the ontogenetic process. It is considered that there is a known genetic standard for development, and any

divergence from symmetry in a trait indicates a deviation from this standard. The conventional method for evaluating fluctuating asymmetry (FA) in a population sample involves determining the mean value or frequency of occurrence of asymmetric features (Zakharov et al., 2000, 2001; Gelashvili et al., 2004).

Despite the undoubted promise of using the FA method in bioindication studies, the question of the ecotoxicological significance of the obtained indicators remains open. The presence of developmental abnormalities does not clearly determine the fate of the organism, including such an important characteristic as the reproductive success of the individual. This fully applies to changes in the viability of populations of indicator species in which an increased level of FA has been determined. (Bezel, 2006, pp.114-115).

In this study, the bioindicative indicator - leaf asymmetry, was studied using the example of silver birch (*Betula pendula Roth.*) in the conditions of the city of Pavlodar at 33 collection points and is reflected in several indicators: the ratio of asymmetry to the average for the city of Pavlodar and to the background (Fig. 3.1 in chapter Materials and methods)).

Territorial distribution of the asymmetry index of sheet plates *Betula pendula Roth.* reflected on the schematic map (Fig. 4.2.1).

The studied material according to the nature of the asymmetry is conditionally grouped into 5 groups in accordance with the classification of Zakharov V.M., Krysanova E.Yu. (1996):

- 1 gr. up to 0.055 USD - conditional norm
- 2 gr. up to 0.060 USD - weak asymmetry
- 3 gr. up to 0.065 USD - average asymmetry
- 4 gr. up to 0.070 USD - strong asymmetry
- 5 gr. more than 0.070 USD – critical asymmetry

The primary region is distinguished by the dispersion of the asymmetry indicator, specifically group 1, which refers to the typical asymmetry of birch leaves (*Betula pendula Roth.*). The distribution of normal asymmetry (1 group) is well delineated in the northeast, central, and southern parts of the city (Fig. 4.2.1).

A subtle asymmetry, weighing 2 grammes, is evident as an abnormality in the northern, northwestern, and western regions of the city, and is also observed in the southern section.

The average degree of asymmetry (3 gr.) is prominent in distinct regions within the northwestern, western, eastern, and southern sections of the city's territory.

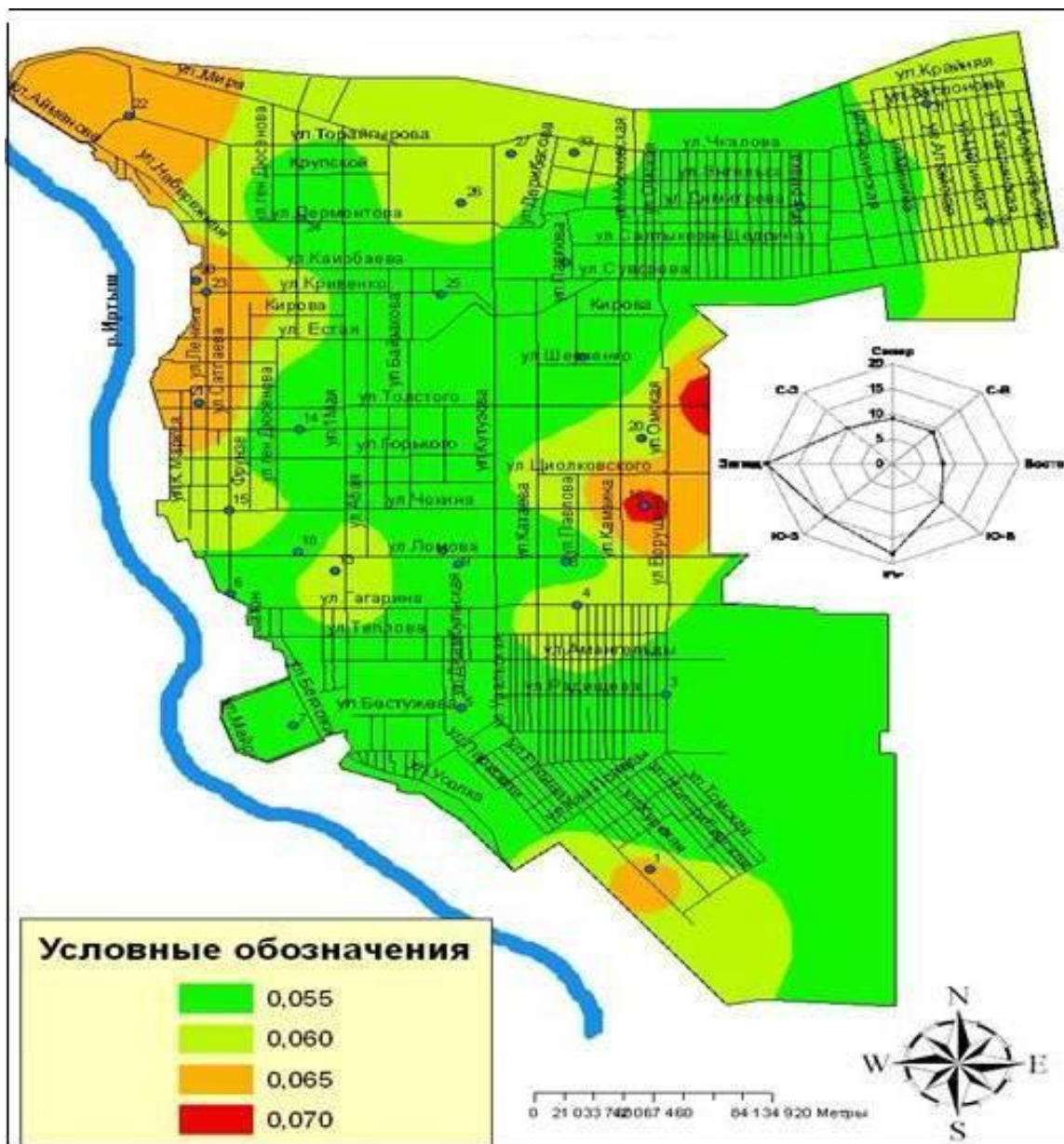


Figure 4.2.1 Schematic map of the spatial distribution of the asymmetry index of *Betula pendula* Roth. in Pavlodar

A pronounced level of asymmetry (4g.) was identified in the eastern section of the city.

To choose the background, samples were collected from various sites located far from Pavlodar in different directions, considering the prevailing wind (Table 4.2.1).

The data collected from three sources conform to the conditional norm (1 gramme, up to 0.055 c.u.) as prescribed by the Zakharov V.M. school. For our analysis, we selected the lowest indicator from the village of Aktogay (0.0419) as a reference point for future comparisons.

Table 4.2.1 Indicator of leaf asymmetry of *Betula pendula* Roth.

N o.	Gathering place	Asymmetry indicator	Degree of asymmetry
1.	Aktogay district, Aktogay village	0.0419	1 gr.
2.	Zhelezinsky district, Zhelezinka village	0.0450	1g.
3	Bayanaul NPP	0.0491	1g.
4	Pavlodar	0.0547	1-2g.

A comparative analysis was conducted to evaluate the extent of asymmetry in technogenic conditions in the city of Pavlodar, in comparison to the surrounding area. The asymmetry in the city of Pavlodar (0.0547) is, on average, 1.3 times higher than the background indication (Table 4.2.2, Fig. 4.2.2).

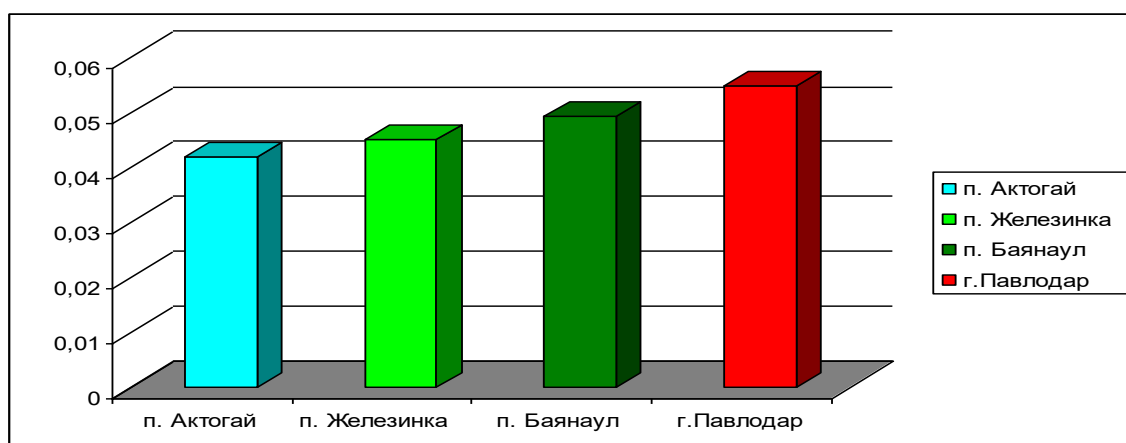


Figure 4.2.2. Asymmetry of leaves in Pavlodar and background areas

This study examines the presence of asymmetry in birch leaves (*B. pendula* Roth) at several collecting places inside the city, comparing them to background indications. An increase in the asymmetry of birch leaves *B. pendula* Roth was observed, with the ratio going from 1.00 to 1.59 times, as shown in Table 4.2.1 and Fig. 4.2.3.

There is a small surplus of the background, ranging from 1.0 to 1.14 times, that can be detected in the centre and eastern areas of the city in the shape of spots. In the central, southeast, and southwest parts of the city, there are significant levels of asymmetry, ranging from 1.15 to 1.29 in the backdrop. Local areas in the northeast, northern, northwestern, centre, eastern, and southern parts exhibit background excesses ranging from 1.3 to 1.4 times. Leaf asymmetry was most pronounced, ranging from 1.4 to 1.6

times larger than the background, in both the coastal zone and the eastern half of the city.

The analysis of the asymmetry distribution in specific areas of the city is examined (Table 4.2.2).

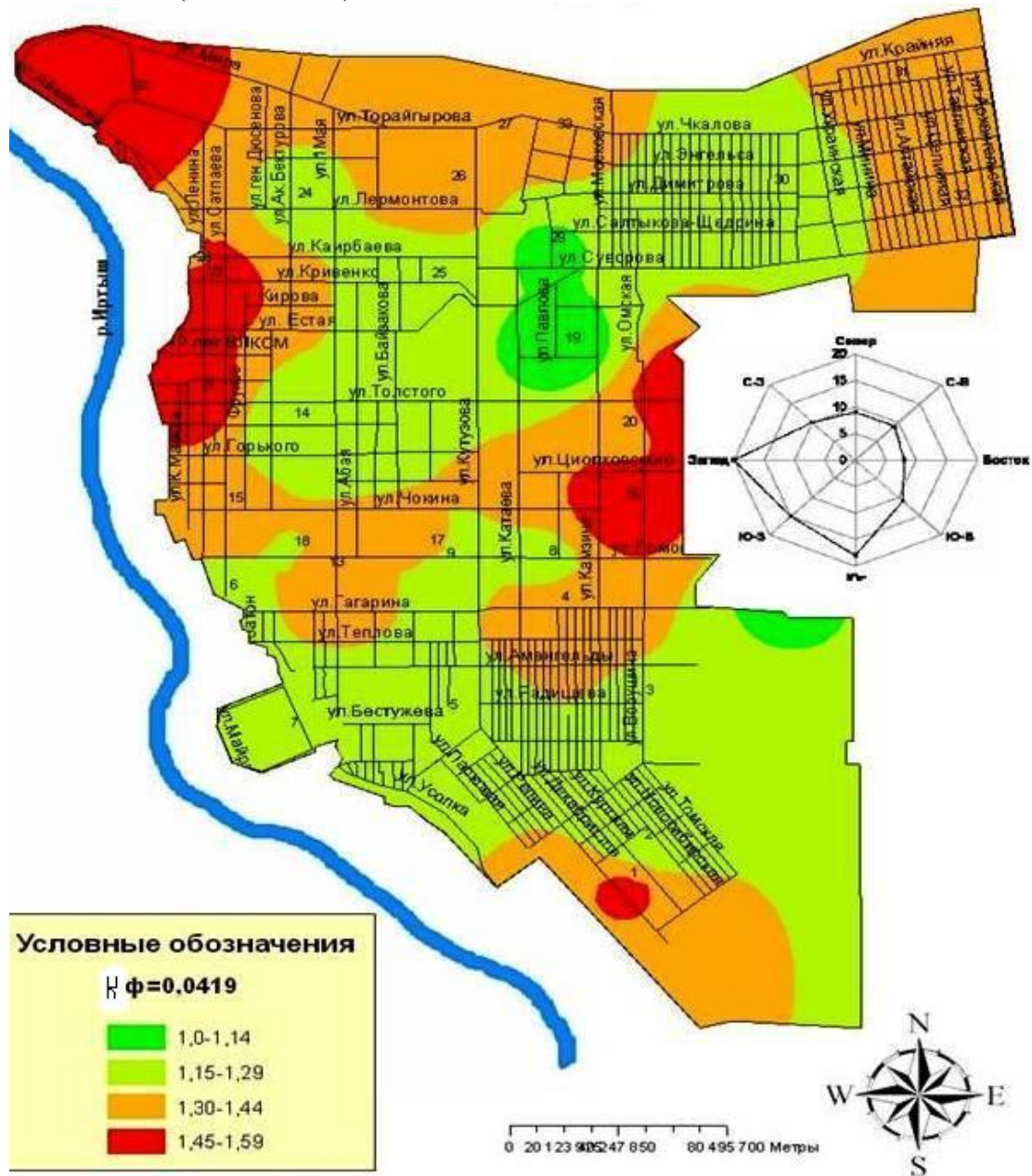


Figure 4.2.3 Asymmetry of silver birch leaves (relative to the background) on the territory of Pavlodar

The mean asymmetry indicator for location No. 1 is 0.05795 (2 g). The asymmetry value is expressed as a conditional norm only on Krivenko Street 85. Subtle asymmetry is seen in the streets: Lermontov-Bekturov, Uritsky,

and Naberezhnaya. The streets of Toraigyrov-Aimanov and Krivenko-Lenin exhibit a typical asymmetry.

The mean asymmetry value in section No. 2 is -0.053 (conditional norm). A slight imbalance (0.056) was observed on the following streets: Kutuzova-Toraigyrova, Zaslonoa-Dneproperovskaya, Shchedrina-Sakhalinskaya, and Dvinskaya-Engelsa. The conditional norm is indicated at the intersection of Pavlova 38 and Ermaka-Dimitrov streets, with values of 0.047 and 0.049, respectively.

The mean value at site No. 3 is 0.056, indicating a weak degree of asymmetry. There is an imbalance at the intersection of Bekturov and Dostoevsky, deviating from the usual standard. The streets of Chokina / Satpayeva, Lomova, 1 May exhibit a noticeable but mild asymmetry. The Lenpark data showed an average asymmetry of 0.064.

The investigation revealed that there is an asymmetry present on Tchaikovsky Street and in the vicinity of the machine-building plant, according to the customary norm. Lomov Street and the vicinity of the Children's Railway exhibit a subtle asymmetry. The city has a clear and pronounced asymmetry, which may be observed at Gagarin Park and at the Kamzin-Tolstoy monument (park). The mean asymmetry indicators at site No. 4 is 0.056, indicating modest asymmetry. The mean value of the asymmetry index on the site is 0.052. The leaf asymmetry values in the Usolsky microdistrict conform to the established norm, whereas in the remaining area, there is a presence of mild asymmetry. Section No. 6, on average, exhibits an asymmetry index of 0.053, which aligns with the traditional norm. The values of asymmetry at the junctions of Orlovskaya and Azovskaya streets, in the vicinity of the aluminium plant, are within the normal range. An imbalance of birch leaves is noticed at the junctions of Vorushin and Radishchev, Gagarin and Semenchenko streets. Significant imbalance was seen in the Dachny microdistrict, specifically on Kutuzova Street.

When analysing the indicators of birch asymmetry in six different regions of Pavlodar, it was seen that the highest level of asymmetry was detected in one specific area, as indicated in Table 4.2.2 and Figure 4.2.4. Sections 4 and 3 exhibit a reduction in asymmetry. The indicator is within the standard in sections 2, 6, and 5.

Table 4.2.2. Indicators of asymmetry in the territory of Pavlodar

Plot number	Average value asymmetry	Group number according to Zakharov	In relation to the background
1	0.058	2g.	1.38
2	0.053	Norm -1	1.27
3	0.056	2 gr.	1.32
4	0.056	2 gr.	1.33
5	0.052	Norm 1 gr.	1.25
6	0.053	Norm 1 gr.	1.26

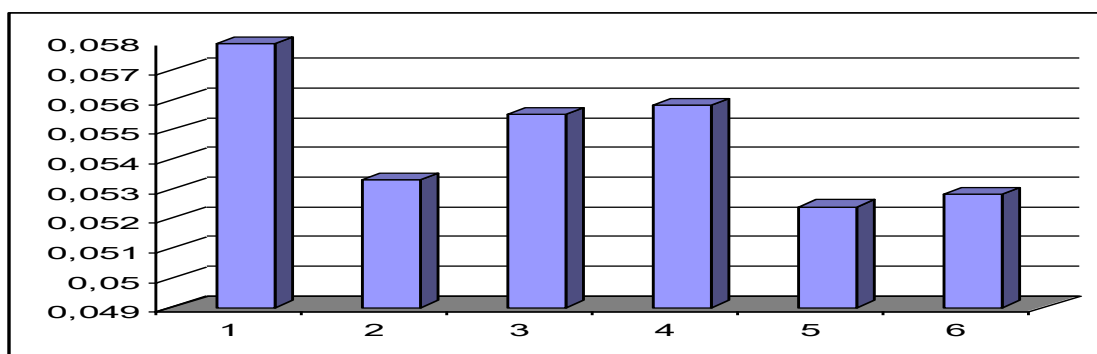


Figure 4.2.4. Manifestation of asymmetry in areas of Pavlodar

In all areas of the city, a steady excess of asymmetry over the background value was noted, the decreasing series is expressed: $1 > 4 > 3 > 2 > 6 > 5$. The excess of the background values was established to be 1.18 - 1.38 times.

Birch stands with asymmetry indices of 3 and 4 gr. those. medium and strong asymmetry are confined to streets with good landscaping (Table 4.2.3). These areas, located in different places of the city, are recreational areas with dense and numerous tree stands. These are the city's park areas, which act as a buffer, retaining the main dust flows and toxic components on the leaf surface.

Table 4.2.3 Manifestation of abnormal asymmetry of leaves of silver birch *Betula pendula* Roth. on the territory of Pavlodar

Gathering place	Asymmetry indicators	Group	Relation to background	No. of plots
Toraigyrova-Aimanova	0.064	3gr.	1.53	1
Krivenko-Lenin	0.065	3gr.	1.54	1
Lenpark	0.064	3gr.	1.53	3
Tolstoy-Kamzin	0.067	4g.	1.59	4
Gagarin Park	0.065	4g.	1.56	4
Dachny	0.062	3gr.	1.47	6

The degree of ranking of the studied areas of Pavlodar according to the manifestation of maximum fluctuating asymmetry is expressed in a descending order: 1=4>3>2=6>4 (Table 4.2.4.)

Table 4.2.4. Indicators of fluctuating asymmetry of Pavlodar

Plots	Relative to background	max. indicators (3.4 g)	Degree of asymmetry (according to Zakharov)	Rank
1	1	2	1	1
2	4	4	2	3
3	3	3	1	2
4	2	1	1	1
5	6	4	2	4
6	5	3	2	3

Therefore, by employing the technique of analysing the asymmetry of silver birch leaves, it was feasible to identify the disparity in the degree of fluctuating asymmetry throughout the Pavlodar region.

The anomaly is distributed unevenly, with the most significant occurrence in areas 1, 4, and 3 (specifically the northwestern, western, and eastern regions).

An excessive amount of asymmetry was observed throughout the city, ranging from 1.12 to 1.59 times higher than the background indications in Aktogay village. The most pronounced instances of asymmetry (3, 4 degrees) are observed in regions with extensive tree plantations, namely in the park sections of the city. These places serve as a protective barrier, effectively capturing the primary dust emissions and poisonous substances on the surface of the leaves.

The leaf asymmetry approach employed in this study enables us to indirectly evaluate air pollution, as well as the extent and risk of the influence of a combination of man-made contaminants on the vegetation of the urban ecosystem.

Overall, the application of this technique in environmental monitoring is highly valuable for evaluating the impact of human activities on the plant aspect of the urban ecosystem.

4.3 Life status of common tree species in technogenic conditions of Pavlodar

The chapter provides the findings of a study on the overall status of five prevalent tree species in the city of Pavlodar, subjected to prolonged technogenic stress. A study was conducted on the condition of various plant species, including silver birch (*Betula pendula* Roth.), black poplar (*Populus nigra* L.), Scots pine (*Pinus silvestris* L.), pinnate elm (*Ulmus pinnato-*

ramosa Dieck.), and ash maple (*Acer negundo* L.). The primary component of urban plantings consists of trees that are over 40 years old, surpassing the stage of maturity.

In the examined region of Pavlodar, 5 distinct areas were discovered, which encompass the residential portion of the city. These areas include the northwestern, western, and southeastern parts of the city, as well as the industrial zones located in the eastern and northern sectors.

According to the categorization by N.A. Cheremisinov (Cheremisinov, 1973), three categories of life status were distinguished:

Group 1 – satisfactory vital condition (conditionally healthy trees, no more than 20% of slightly damaged trees);

Group 2 – unsatisfactory vital condition (moderately damaged trees, no more than 50% of damaged trees);

Group 3 – critical vital condition (fresh and old dead wood).

Analysis of the life status of silver birch (*Betula pendula* Roth)

The number of silver birch in all areas of the city of Pavlodar is 3267; of which the largest number of trees is 2608 copy (79.8%) is characterized by a satisfactory condition (Table 4.3.1.); the smallest number - 206 copies, which is 6.3% of the trees - is in critical condition.

In the northwestern area, most of the silver birch stand (86.5%) is in satisfactory condition, the smallest part is in critical condition (4.3%).

Table 4.3.1. Life status of silver birch (*Betula pendula* Roth)

No. plot	Quantity trees	Life status					
		Satisfactory		Unsatisfactory		Critical	
		Qty	%	Qty	%	Qty	%
Northwestern part	1617	1396	86.5	151	9.36	70	4.3
West Side	32	28	87.5	4	12.5	-	-
South-eastern part	1026	947	93.2	71	6.92	8	0.77
Eastern industrial zone CHPP, PAZ	266	195	74.4	67	25.5	4	1.52
northern industrial zone oil refinery, PTZ	326	42	12.9	160	49.0	124	38.0
total	3267	2608	79.8	453	13.8	206	6.3

In the western part of the city, 87.5% of silver birch trees are in satisfactory condition, and 12.5% are in unsatisfactory condition. The southeastern part of the city is located in the leeward part of the city, which may affect the low percentage of trees with critical indicators (0.77%). In this area, the silver birch plantings are healthy (93.2%).

In the industrial zones of the city, the degree of oppressed trees increases sharply. Thus, in the eastern industrial zone, a quarter of the birch tree stand is in unsatisfactory and critical condition (25.5% and 1.5%, respectively). The northern industrial zone of the city is characterized by the highest rates of critical and unsatisfactory condition (49% and 38%, respectively). This area can be considered the most disadvantaged, which can be associated with the technogenic impact of numerous industrial enterprises.

Thus, the manifestation of a satisfactory condition in *B. droopy* on the territory of Pavlodar is expressed in a decreasing order: south-eastern part > western part > north-western part > eastern industrial zone > northern industrial zone. The unsatisfactory condition is manifested in the series: northern industrial zone > eastern industrial zone > western part > northwestern part > southeastern part. The critical state is reflected as follows: northern industrial zone > northwestern part of the city > eastern industrial zone > southeastern industrial zone > western part.

The degree of disadvantage of *B. povisla* in the surveyed areas of Pavlodar is expressed in a decreasing order: northern industrial zone > eastern industrial zone > northwestern part > western part > southeastern part of the city (Table 4.3.2).

Table 4.3.2 - Ecological ranking by degree of disadvantage of Silver Birch (*Betula pendula* Roth)

Plots	Indicators	Point	Rank
Northern industrial zone	1+ 1+ 1/ 3	1	1
Eastern industrial zone	2 + 2 +3 / 3	2.3	2
Northwestern part	3+4+2 / 3	3	3
West Side	4 + 3 + 5 / 3	4	4
South-eastern part	5 + 5 + 4 / 3	4.6	5

Overall, it was observed that silver birch trees in the city of Pavlodar exhibit predominantly favourable health conditions. Specifically, this species thrives in urban plantings, as 79.8% of the birch tree population is in a suitable

state. In the residential area of Pavlodar, out of the selected sample of birch trees (2,675 plants), 88.6% of the trees are in a satisfactory state, whereas in the industrial zones (592 plants) only 40% are in good health. The city's environmental ranking, which assessed the condition of birch trees, identified the northern and eastern industrial zones as having the most worst status.

Analysis of the vital state of Acer nugundo. The total number of ash-leaved maple in the study areas is 22,993 specimens, of which 11,510 (50.0%) of the tree stand are in satisfactory condition, 7,343 specimens are in satisfactory condition. (31.9%) in unsatisfactory condition, 4140 copies. (18.0%) in critical condition (Table 4.3.3.).

Northwestern part of the city:The largest number of ash maple 76.6% is in satisfactory condition, 22.6% is in unsatisfactory condition, and the smallest 0.72% is in critical condition.

Western part of the city:70.4% of the forest stand is in satisfactory condition, 26.2% is in unsatisfactory condition and the least amount of 3.35% is in critical condition.

South-eastern part of the city:the most favorable situation is in a satisfactory condition of 88.3% of the tree stand, 11.4% of ash maple is in unsatisfactory condition.

Eastern industrial zone of the city:it is characterized that 65.0% of the maple is in satisfactory condition and 5.9% is in critical condition

Table 4.3.3. Life status of ash maple (*Acer nugundo*)

No. plot	Number of trees	Life status					
		Satisfactory		Unsatisfactory		Critical	
		Qty	%	Qty	%	Qty	%
Northwestern part of the city	2193	1680	76.6	497	22.6	16	0.72
West Side	477	336	70.4	125	26.2	16	3.35
southeastern part of the city	6210	3454	88.3	445	11.4	2311	37.2
eastern industrial zone TPP, PAZ	7333	4770	65.0	2124	28.9	439	5.9
northern industrial zone oil refinery, PTZ	6780	1270	18.7	4152	61.2	1358	20.0
Total	22993	11510	50.0	7343	31.9	4140	18.0

Northern industrial zone of the city:It was noted that 61.2% of maple is in unsatisfactory condition, 18.7% is in satisfactory condition.

The ash-leaved maple trees are present in different proportions across various parts of the city. In the south-eastern part, they make up 88.3% of the tree population, while in the north-western part, they account for 76.6%. In the western part, the proportion is 70.4%, in the eastern industrial zone it is 65.0%, and in the northern industrial zone, it is only 18.7%.

The tree stand in the northern industrial zone is 61.2%, in the eastern industrial zone it is 28.9%, in the western portion it is 26.2%, in the northwestern section it is 22.6%, and in the southern part of the city it is 11.4%. The critical state of ash maple trees varies throughout different areas of the city. In the southeastern portion, 37.2% of the trees are in critical condition. In the northern industrial zone, the percentage is 20.0%, while in the eastern industrial zone it is 5.9%. The western part of the city has 3.35% of ash maple trees in critical condition, and the smallest percentage is found in the northwestern region, with only 0.72%.

An ecological assessment was conducted to determine the level of dominance of the ash-leaved maple in the city of Pavlodar. The ranking was done in descending order. Based on the criteria of satisfactory condition, the ranking is as follows: The northern industrial zone is located to the east of the eastern industrial zone, which is situated in the western half.

The northwestern part is further west than the western part, while the southeastern part is located to the southeast of the northwestern part. The unsatisfactory condition is ranked in the following order: northern industrial zone, eastern industrial zone, western part, northwestern part, and southeastern part. Based on the critical state, the ranking degree is as follows: The sequence of locations is as follows: the northwestern part, followed by the western part, then the eastern industrial zone, followed by the northern industrial zone, and finally the southeastern part.

The level of disadvantage of *Acer nugundo* in the surveyed areas of Pavlodar can be ranked in descending order as follows: the eastern industrial zone has the highest degree of disadvantage, followed by the northern industrial zone, the western section, the northwestern part, and finally the southeastern part of the city (Table 4.3.4).

Table 4.3.4. Ecological ranking according to the degree of disadvantage of ash maple (*Acer nugundo*)

Plots	Indicators	Point	Rank
Northern industrial zone	1+1+4/3	2	2
Eastern industrial zone	1+1+3/3	1.6	1

Plots	Indicators	Point	Rank
Northwestern part	4+4+1/3	3	4
West Side	3+3+2/3	2.6	3
South-eastern part	5+5+5/3	5	5

Analysis of the life state of Scots pine (Pinus silvestris) on the territory of Pavlodar.

The total number of Scots pine is 14,726, of which 7,147 are in satisfactory condition. (48.5%), the number in unsatisfactory condition is 6751 copies. (45.8%), 828 copies. (5.6%) in critical condition (Table 4.3.5).

In the northwestern part of the city It is observed that 81.7% of the forest stand is in satisfactory condition, 17.5% is in unsatisfactory condition and the smallest amount of 0.81% is Scots pine in critical condition.

Western part of the city characterized by the largest number of 65.6% - Scots pine, which is in satisfactory condition, 31.3% - in unsatisfactory condition, 3.1% - in critical condition.

In the southeastern part of the city a larger number of 62.0% are in unsatisfactory condition, 37.0% are in satisfactory condition, 8.5% are in critical condition.

Table 4.3.5. Life status of Scots pine (Pinus silvestris)

No. plot	Quantity trees	Life status					
		satisfactory		unsatisfactory		critical	
		Qty	%	Qty	%	Qty	%
Northwestern part of the city	3291	2691	81.7	578	17.5	22	0.8
West Side	67	44	65.6	21	31.3	2	3.1
southeastern part of the city	7844	2708	37.0	4470	62	666	8.5
eastern industrial zone TPP, PAZ	1512	240	15.8	1252	82.8	20	1.3
northern industrial zone oil refinery, PTZ	2012	1464	72.7	430	21.3	118	5.8
total	14726	7147	48.5	6751	45.8	828	5.6

Eastern industrial zone of the city the most unfavorable situation is observed 82.8% - in unsatisfactory condition, then 15.8% - in satisfactory condition, the minimum number of 1.3% - in critical condition.

Northern industrial zone of the city in this area there is a more favorable situation: 72.7% - in satisfactory condition of Scots pine, 21.3% - in unsatisfactory condition, 5.8% - in critical condition.

Based on the collected data, the following percentages were observed: 81.7% in the northwestern part of the city, 72.7% in the northern industrial zone, 65.6% in the western portion, 37.0% in the southeastern part, and 15.8% in the eastern industrial zone.

The unsatisfactory condition is prevalent in several areas of the city. Specifically, 82.8% of the eastern industrial zone, 62.0% of the south-eastern portion, 31.3% of the western part, 21.3% of the northern industrial zone, and 17.5% of the northwestern section are affected. The critical condition rates are as follows: 8.5% in the south-eastern portion of the city, 5.87% in the northern industrial zone, 3.1% in the western part of the city, 1.3% in the eastern industrial zone, and 0.81% in the northwestern part of the city.

Therefore, based on the level of escalation in the critical condition of *Pinus silvesteris*, the examined regions can be categorised in a certain sequence. An ecological assessment was conducted to determine the level of dominance of Scots pine in the city of Pavlodar. The ranking was done in descending order.

Based on the criteria of satisfactory condition, the ranking is as follows: The eastern industrial zone is located in the south-eastern part, which is situated to the west of the northern industrial zone and to the north-west of the north-western part. The unsatisfactory condition is ranked as follows: the eastern industrial zone is better than the south-eastern section, which is better than the western part, which is better than the northern industrial zone, which is better than the north-western part. The order of priority, from most critical to least critical, is as follows: the northwestern part, the eastern industrial zone, the western section, the northern industrial zone, and finally the southeastern part.

Therefore, the level of disadvantage in the surveyed localities of Pavlodar is shown in a descending order: The eastern industrial zone is located in the south-eastern section of the city, which is then followed by the north-western part, the western part, and finally the northern industrial zone (Table 4.3.6).

Table 4.3.6 Ecological ranking according to the degree of disadvantage of Scots pine (*Pinus silvestris*)

Plots	Indicators	Point	Rank
Northern industrial zone	4+4+4/3	4	4
Eastern industrial zone	1+1+2/3	1.3	1
Northwestern part	5+5+1/3	3.6	3
West Side	3+3+3/3	4	4
South-eastern part	2+2+5/3	3	2

Analysis of the life state of pinnate elm (Ulmus pinnato-ramosa). The total number of pinnate elms is 10,078, of which 4,666 are in satisfactory condition. (46.2%), in unsatisfactory condition - 4624 copies. (45.8%), in critical - 788 copies. (7.8%) (Table 4.3.7).

Table 4.3.7 Life status of pinnate elm (*Ulmus pinnato-ramosa*)

No. plot	Number of trees	Life status					
		Satisfactory		Unsatisfactory		Critical	
		Qty	%	Qty	%	Qty	%
Northwestern part of the city	575	356	61.9	204	35.4	15	2.6
West Side	385	266	69.0	103	26.7	16	4.15
South-eastern part of the city	1007	461	79.2	115	19.7	431	42.8
eastern industrial zone TPP, PAZ	587	219	37.3	360	61.3	8	13.6
northern industrial zone oil refinery, PTZ	7524	3364	44.6	3842	51.0	318	4.22
Total	10078	4666	46.2	4624	45.8	788	7.8

Northwestern part of the city characterized by the largest number of 61.9% of pinnate elm being in satisfactory condition, and the smallest 2.6% in critical condition. Western part of the city: in this area there is the largest amount of tree stand in satisfactory condition 69.0%, in unsatisfactory condition 26.7%, in critical condition 4.15%. The south-eastern part of the

city: characterized by the most favorable situation, 79.2% of the forest stand is in satisfactory condition, 42.8% is in critical condition.

Eastern industrial zone of the city: in this area it is observed that 61.3% of the pinnate elm is in unsatisfactory condition.

Northern industrial zone of the city: like the eastern industrial zone, a larger number of trees were noted to be in unsatisfactory condition (51.0%).

Based on the data collected, it was observed that 79.2% of trees in the southeastern area of the city are in satisfactory condition. In the western area, this percentage is 69.0%, while in the northwestern area it is 61.9%. The northern industrial zone has the lowest percentage of trees in satisfactory condition, with only 44.6%, followed by the eastern industrial zone with 37.3%. The unsatisfactory condition of the forest stand is distributed as follows: 61.3% in the eastern industrial zone, 51.0% in the northern industrial zone, 35.4% in the northwestern section, 26.7% in the western part of the city, and 19.7% in the southeast. The critical condition is most severe in the south-eastern part of the city, where 42.8% of the tree stand is affected. In the eastern part of the industrial zone, 13.6% of the trees are in critical condition. In the northern industrial zone, 4.22% of the trees are affected. In the western part of the city, 4.15% of the trees are in critical condition, and in the northwestern part, 2.6% of the trees are affected. The researched locations can be classified in a certain order based on the extent of rise in the critical state caused by human activities. An ecological assessment was conducted to determine the level of dominance of pinnate elm in the city of Pavlodar. The ranking was done in descending order.

Based on the acceptable criteria, the subsequent row has been identified: The eastern industrial zone is located to the east of the northern industrial zone, which is situated to the northwestern section of the area. Moving further west, we find the western part, and to the southeast of that is the southeastern part. The rankings of the several areas based on their condition, from least satisfactory to most satisfactory, are as follows: eastern industrial zone, northern industrial zone, northwestern part, western part, and southeastern part. However, in terms of critical condition, the rankings are as follows: south-eastern part, eastern industrial zone, northern industrial zone, western part, and north-western part. Therefore, the level of disadvantage of *Ulmus pinnato-ramosa* in the surveyed locations of Pavlodar is ranked in a descending order: The order of the zones, from east to west, is as follows: eastern industrial zone, northern industrial zone, northwestern part, southeastern part of the city, and finally the western part (Table 4.3.8).

Table 4.3.8 - Ecological ranking according to the degree of disadvantage of pinnate elm (*Ulmus pinnato-ramosa*)

Plots	Indicators	Point	Rank
Northern industrial zone	2+2+3/3	2.3	2
Eastern industrial zone	1+1+2/3	1.3	1
Northwestern part	3+3+5/3	3.6	3
West Side	4+4+4/3	4	4
South-eastern part	5+5+1/3	3.6	3

Analysis of the life state of Black Poplar (Populus nigra) in the city of Pavlodar.

In total, in the studied areas of the city, the total number of black poplars was 22,192 specimens, of which 12,480 specimens are in satisfactory condition. (56.2%), in unsatisfactory 5647 copies. (25.4%), in critical condition 4065 copies. (18.3%) (Table 4.3.9).

Table 4.3.9 - Life status of black poplar (*Populus nigra*)

No. plot	Quantity trees	Life status					
		satisfactory		unsatisfactory		critical	
		Qty	%	Qty	%	Qty	%
Northwestern part of the city	853	633	74.2	211	33.3	9	1.05
West Side	175	118	67.4	52	29.7	5	2.85
southeastern part of the city	7593	2154	83.5	2540	11.8	2899	5.15
eastern industrial zone TPP, PAZ	6149	4233	68.6	1748	28.4	178	2.89
northern industrial zone oil refinery, PTZ	7422	5342	71.9	1096	14.7	974	13.1
Total	22192	12480	56.2	5647	25.4	4065	18.3

The northwestern part of the city is characterized by: 74.2% of black poplar is in satisfactory condition, and the smallest amount of 1.05% is in critical condition

Western part of the city characterized by the fact that 67.4% of the forest stand is in satisfactory condition, 29.7% is in unsatisfactory condition, and 2.8% is in critical condition.

South-eastern part of the city the most favorable situation is 83.5% is in satisfactory condition, the least number is in satisfactory condition and in critical condition 11.8% and 5.1%.

Eastern industrial zone of the city: the largest amount of black poplar is in poor and critical condition (31.29%)

Northern industrial zone of the city: in satisfactory condition 71.9%, in unsatisfactory condition 14.7%, in critical condition 13.1%.

Under satisfactory conditions, the following is noted: The prevalence of black poplar is 83.5% in the south-eastern portion of the city, 74.2% in the north-western part, 71.9% in the northern industrial zone, 68.6% in the eastern industrial zone, and 67.4% in the western part. Unsatisfactory condition is defined by the following characteristics: The distribution of black poplar in the city is as follows: 33.3% is found in the northwestern portion, 29.7% in the western part, 28.4% in the eastern industrial zone, 14.7% in the northern industrial zone, and 11.8% in the southeastern section. The critical condition report indicates that the northern industrial zone has the highest percentage (13.1%) of trees in a depressed state. Following this, the south-eastern industrial zone has 5.1% of black poplar trees in a depressed state, the eastern industrial zone has 2.89%, the western part has 2.8%, and the northwestern part has the lowest percentage (1.05%) of trees in a depressed state.

An ecological assessment was conducted to determine the extent of the impact of black poplar on the territory of Pavlodar city. Based on the above criteria, the order of satisfactory conditions is as follows: the western section is better than the eastern industrial zone, which is better than the northern industrial zone, which is better than the northwestern part, and finally, the southeastern part is the least satisfactory. Based on the subpar condition, the ranking order is as follows: The sequence of locations is as follows: the northwestern part, followed by the western part, then the eastern industrial zone, followed by the northern industrial zone, and finally the southeastern part. Based on the critical state, the ranking degree is as follows: The northern industrial zone is located in the southeastern section of the area, followed by the eastern industrial zone. Moving towards the west, we find the western part, and finally, the northwestern part.

Therefore, the level of disadvantage experienced by *Populus nigra* in the surveyed locations of Pavlodar is ranked in a descending order: The sequence of areas in the city is as follows: the western section, the northern

industrial zone, the eastern industrial zone, the northwestern part, and finally the southeastern part (Table 4.3.10).

Table 4.3.10 - Ecological ranking by degree of disadvantage of black poplar (*Populus nigra*)

Plots	Indicators	Point	Rank
Northern industrial zone	3+4+1/3	2.6	2
Eastern industrial zone	2+3+3/3	2.6	2
Northwestern part	4+1+5/3	3.3	3
West Side	1+2+4/3	2.3	1
South-eastern part	5+5+2/3	4	4

Analysis of the life status of five common tree species

Since 2001, a thorough investigation has been conducted to evaluate the risk and forecast the future environmental conditions of Pavlodar's plant component in the face of prolonged technogenic pollution. This study involves a comprehensive inventory and phytopathological examination of the local greenery. (Kadenova A.B. et al., 2001; Kadenova et al., 2002; Shaimardanova, 2002; Shaimardanova et al., 2005). According to the authors' findings, urban plantings in Pavlodar are susceptible to a range of illnesses. The silver birch tree is distinguished by two specific characteristics: the drying out of its branches, caused by the *Cytospora betulina Ehr.* fungus, which affects 1.4% of the tree population, and bacterial dropsy, caused by the *Erwinia multivora* bacterium, which affects 0.2% of the trees. The incidence of pitch cancer, caused by *Peridermium pini Lev. et Kleb.*, in Scots pine is 10.4%, while the occurrence of common pine, caused by *Lophodermium pinastri Chev.*, is 1.03%. The pinnate elm is affected by Dutch elm disease, caused by the fungus *Graphium ulmi Schw.*, with an incidence rate of 87.7%. The ash-leaved maple has branch drying or necrosis, caused by the fungus *Nectria cinnabarina Fr.*, at a rate of 12.4%. Additionally, black spots caused by the fungus *Rhytisma acerinum Fr.*, with an occurrence rate of 0.54%, affect the maple leaves. The prevalence of cytosporosis, caused by the pathogen *Cytospora chrysosperma (Pers) Fr.*, in black poplar is 1.55%. The prevalence of wet ulcerative-vascular cancer, caused by the bacteria *Pseudomonas remifaciens Konig.*, is 0.19%.

There are around 73 thousand surveyed tree stands in Pavlodar. The percentage of trees in urban plantings is expressed in a descending order of abundance: In Table 4.3.11, the order of the trees from highest to lowest is as follows: C. ash-leaved, T. black, S. common, V. pinnate, and B. drooping.

Out of the plantings that were evaluated, 52.4% are in good health, while 47.6% are in unsatisfactory and critical condition, with 33.8% being unsatisfactory and 13.6% being critical.

The series below represents the descending order of the satisfactory condition that was discovered: The percentage of silver birch is 79.8%, followed by black poplar at 56.2%, ash maple at 50.0%, Scots pine at 48.5%, and elm pinnately branched at 46.2%.

The level of dissatisfaction is particularly high in Scots pine (45.8%) and pinnate elm (45.8%), and to a lesser degree in ash maple (31.9%), black poplar (25.4%), and silver birch (3.8%). The severity of the situation is shown by the following percentages: black poplar (18.3%), ash maple (18.0%), pinnate elm (7.8%), silver birch (6.3%), Scots pine (5.62%). Within the Pavlodar region, the silver birch is the most resilient to adverse technogenic influences and has successfully adapted to the prevailing environmental conditions. Conversely, the pinnate elm is the least capable of withstanding such impacts.

Table 4.3.11 - Characteristics of the vital state of common tree species in Pavlodar

View	Total		Life status					
			Satisfactory		Unsatisfactory		Critical	
	Qty	%	Qty	%	Qty	%	Qty	%
Silver birch	3267	4.4	2608	79.8	453	13.8	206	6.3
Scots pine	14726	20.1	7147	48.5	6751	45.8	828	5.62
Poplar black	22192	30.2	12480	56.2	5647	25.4	4065	18.3
Elm pinnately	10078	13.7	4666	46.2	4624	45.8	788	7.81
Ash maple	22993	31.3	11510	50.0	7343	31.9	4140	18.0
Total	73256		38411	52.4	24818	33.8	10027	13.6

The ranking of the assessed locations in Pavlodar based on the level of tree oppression is as follows, in descending order: eastern industrial zone, northern industrial zone, northwestern portion, western part, southeastern part (Table 4.3.12).

The environmental sustainability rating of the researched species was derived based on the markers of vital state and morbidity of 5 common tree species. The ranking is as follows, in descending order: The sequence of trees is as follows: silver birch, black poplar, Scots pine, clear-leaved maple, and pinnate elm.

Table 4.3.12. Ecological ranking of sites in Pavlodar

Plots	Indicators	Point	Rank
Northern industrial zone	1+2+2+4+2/5	2.2	2
Eastern industrial zone	2+1+1+1+2/5	1.4	1
Northwestern part	3+3+4+3+3/5	3.2	3
West Side	4+4+3+4+1/5	3.2	3
South-eastern part	5+3+5+2+4/5	3.8	4

The causes of the extensive suppression of trees are both natural and anthropogenic factors. Technogenic pollution variables encompass the release of airborne emissions from industrial enterprises. The soil pollution in Pavlodar is characterised by the presence of many metals and is dispersed in a mosaic pattern, generating distinct areas of contamination. The soils in the central residential zone have a tolerable level of pollution, while the soils in the northern and eastern industrial zones have a significant amount of contamination (Geldymamedova, 2007).

An examination of the geographical arrangement of oppressed trees uncovered disparities, concentration of illness, and the restriction of trees exhibiting unfavourable signs of vitality to regions in proximity to the industrial zones located in the northern and eastern parts of the city. The collected findings align with the research conducted by M.S. Panin, E.A. Geldymamedova, and G.S. Azhaev, who discovered a patchwork of heavily contaminated soil and snow cover in the industrial areas of Pavlodar. The primary contaminants in the city are strontium, mercury, cadmium, lead, and molybdenum.

The series was determined based on the average total pollution coefficient in the city. The order of zones, as stated by Panin (2006) and Azhaev (2007), is as follows: the northern industrial zone, followed by the eastern industrial zone, and finally the central residential zone.

Due to the prevailing westerly and southwest winds, the majority of the trees in the floodplain area of the city, which is next to the Irtysh River, act as a barrier to prevent the transmission of dust along the river valley. This may elucidate the most significant ecological anguish for trees in the western region of the city. The northern and eastern industrial zones are unsuitable for tree stands due to prolonged technogenic impact.

Therefore, within the Pavlodar region, the species that exhibits the highest level of resilience to adverse technogenic influences and has successfully adapted to the present circumstances is the silver birch, while the pinnate elm demonstrates the lowest level of adaptability. Poplar, maple,

and pine have equal levels of resistance. It is necessary to add indicators of the health of trees and the presence of plant diseases in the complete environmental monitoring of the city of Pavlodar. These indicators will help assess the ecological condition of the city's natural environment.

5. Biogeochemical characteristics of the territory of Pavlodar

5.1. Accumulations of elements in leaf ash black poplar *Populus nigra L.* on the territory of Pavlodar

Industrial companies, based on their size and the type of production, have the ability to impact the geochemical properties of areas at both local and broader scales, including regional and global levels (Vinogradov, 1985, etc.). Human industrial activities lead to the development of specific areas in the environment that have an excessive concentration of chemical elements. These areas are known as technogenic geochemical provinces (Saet et al., 1981, 1990; Zhuk, 1991, etc.). Additionally, the accumulation of radioactive elements gives rise to radiogeochemical provinces (Rikhvanov, 1999). Research on geosystems exposed to major human influence reveals a notable rise in metal concentrations across different environments, with priority given to elements with low clarke values (Geochemistry of the Environment., 1990). Their distinct diversity emerges as technogenic microprovinces succeed one another in relatively small regions (Oliger et al., 1994, etc., Baranovskaya, 2003). Chemical elements, unlike other contaminants, do not undergo self-purification processes. When they migrate, they merely undergo changes in their content level or occurrence form. Participating in many forms of migratory and biological cycles, they unavoidably result in the contamination of crucial life-sustaining natural habitats, including water, air, and food (Sayet et al., 1990).

Vegetation plays a crucial role in the biosphere by influencing the biogeochemistry of microelements. Microelements play an active role in numerous molecular-level life processes in plants.

The absorption mechanisms of microelements from the environment are primarily linked to their main source of entry into plants, which is the soil. Additionally, these processes are also involved with the entry of chemical elements from the atmosphere. Consequently, the chemical makeup of plants frequently mirrors the chemical makeup of their environment (Ermokhin, 2004).

The elemental makeup of vegetation serves as a clear reflection of the environmental qualities, encompassing both its natural components and the influence of human activities. An integrated methodology for analysing the microelement composition of plants enables their utilisation in various fields, including ecology (for evaluating the influence of industries on the environment) and geology (for biogeochemical exploration of mineral reserves), among others. Several writers have examined this matter, however, the investigation of microelements in biota has been restricted until recently. Specifically, the focus has primarily been on studying Cr, Zn, Pb,

Cu, Co, Ni, and a few other elements. Advancements in the field of analysing the microelement composition of natural settings have enabled the research and examination of a diverse array of chemical elements (Baranovskaya, 2003).

We have conducted a comprehensive study on several chemical elements, namely 26 elements, with 21 of them being rare, rare-earth, radioactive, and noble elements. These elements were analysed in the ash of leaves from the black poplar tree, scientifically known as *Populus nigra L.*

Examination of the collected materials reveals that there is an uneven dispersion of nearly all the examined constituents within the Pavlodar region. Table 5.1.1 demonstrates the existence of regions with noticeable abnormal values of the analysed elements, as shown by metrics such as standard deviation and coefficient of variation.

Based on the idea that with a symmetric (normal) distribution the indicators of the mean, mode and median are approximately equal (Shestakov, 1988), it was found that the distributions of the following sample elements are close to it: Sc, Ag, La, Sm, Ta, Zn, Th, Eu, U.

A significant coefficient of variation (60-79) is reported for the chemical elements Hf, Lu, and Au, with roughly similar means, modes, and medians. Given the presence of such a disproportionate distribution, it is more suitable to utilise the mode rather than the arithmetic mean.

One characteristic of artificial halos is the presence of a varied and uneven distribution of chemical components within them. In order to compare and analyse the statistical findings obtained from ecological-geochemical studies using the INAA method, histograms were created to assess the normality of the distribution of microelements in the ash of black poplar leaves in the city of Pavlodar (Fig. 5.1.1).

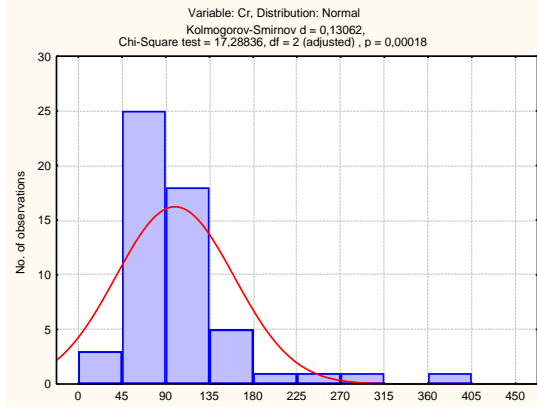
Table 5.1.1. Variation-statistical indicators of the content of chemical elements in the ash of black poplar (*Populus nigra L.*) leaves on the territory of Pavlodar (55 samples)

Elements, mg/kg	$\bar{x} \pm S\bar{x}$	σ	lim	Cv,(%)	Back-ground	KS
Cr	99.5±8.2	61	1.4-369.8	61	4.7	21.6
Co	9±0.5	3.99	2.7-19.3	43	6.2	1.5
Zn	1145±69.6	516	420-7087	45	168.5	6.7
Br	5.45±0.59	4.40	0.2-23	81	< p.o.	
Rb	58.9±5.4	40.2	21-301	68	50.35	1.2
Ag	0.51±0.01	0.11	0.5-1.3	21	< p.o.	
Sb	0.8±0.05	0.39	0.1-1.71	48	0.1	8.2
La	2.24±0.11	0.39	0.8-4.7	17	< p.o.	
Ce	2.7±0.3	1.97	0.4-9.3	73	2.5	1.0
Sm	0.4±0.02	0.2	0.18-1.05	41	0.40	1.0
Yb	0.2±0.01	0.1	0.1-0.52	58	0.10	1.9
Lu	0.02±0.002	0.02	0.01-0.09	79	0.01	2.2
Th	0.52±0.03	0.2	0.02-1.2	44	0.50	1.0
U	0.22±0.01	0.09	0.2-0.8	43	0.2	1.1
Hf	0.29±0.02	0.2	0.06-1.0	60	0.28	1.0
Au	0.04±0.005	0.02	0.008-0.117	61	< p.o.	
Ba	225±10	75.7	69-470	34	128	1.7
Sr	932±60	445	6.0-1971	48	800	1.2
Cs	0.46±0.05	0.34	0.1-1.21	73	< p.o.	
Tb	0.046±0.007	0.05	0.02-0.2	120	0.02	2.3
Ta	0.05±0.002	0.02	0.05-0.19	36	0.05	1.1
Eu	0.1±0.007	0.05	0.05-0.28	40	0.09	1.5
Na	3075±482	3574	600-14200	116	1400	2.5
Ca	143764±5104	37851	67000-233000	26	82001	1.8
Fe	3138±194	1441	700-8200	46	2500	1.3

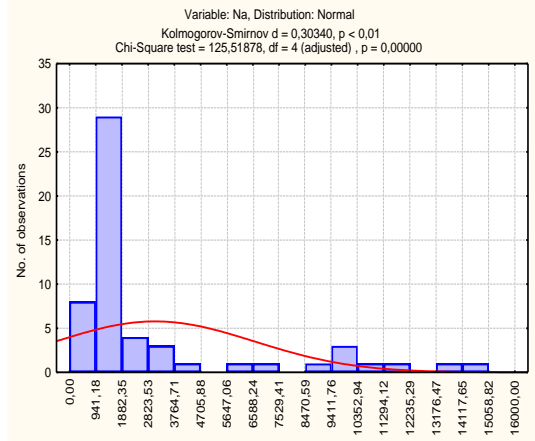
Note: lim - fluctuation limit, $\bar{x} \pm S\bar{x}$ -arithmetic mean and its error, σ - standard deviation, Cv - coefficient of variation, Kc - concentration coefficient, < p.o. - element value below definition limits

The ratio of the asymmetry and kurtosis indicators to their standard errors is used as a criterion to determine the consistency between the empirical distribution and the normal theoretical distribution (Mikhailchuk et al., 2006). The histograms depicting the distribution of chemical components in leaf ash reveal that, in the majority of situations, there is a noticeable asymmetry either towards the left or the right side.

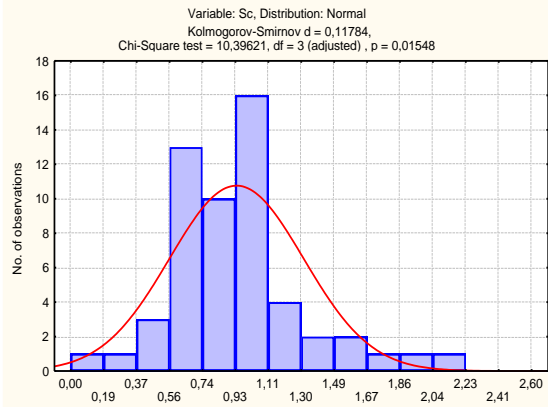
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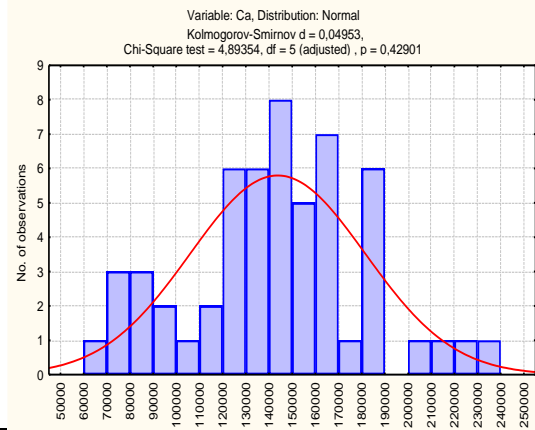
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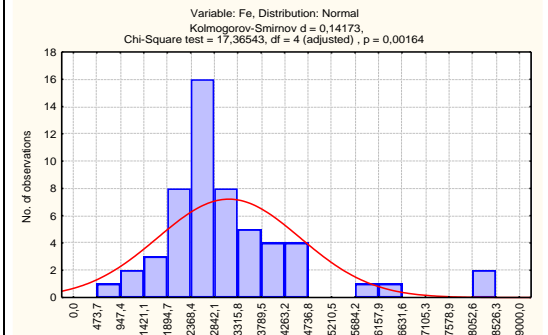
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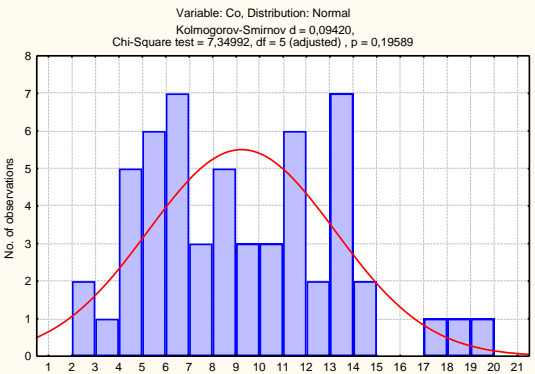
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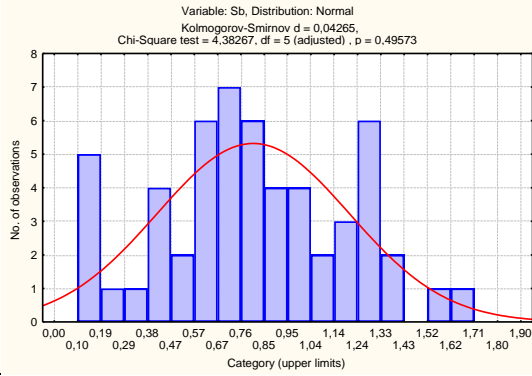
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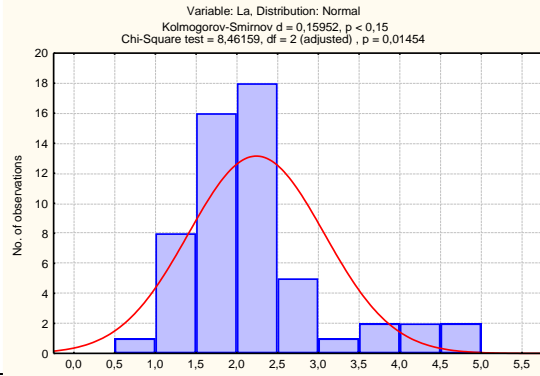
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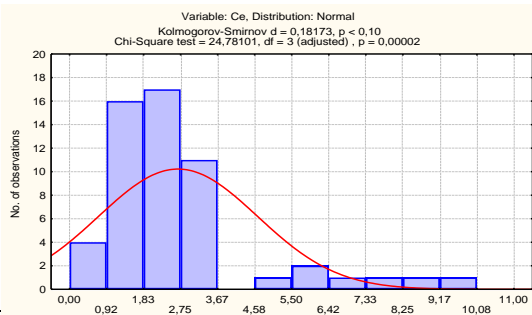
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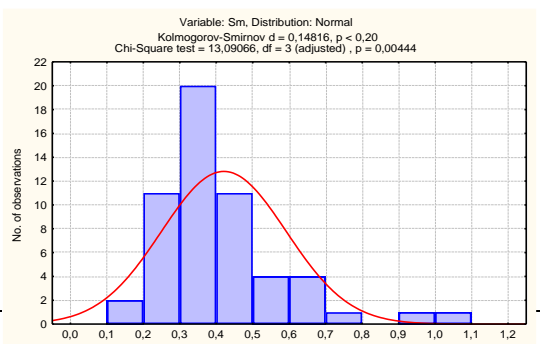
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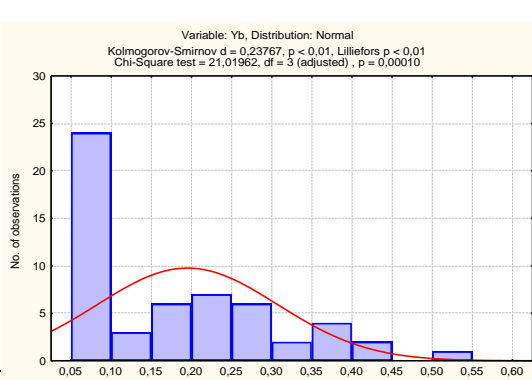
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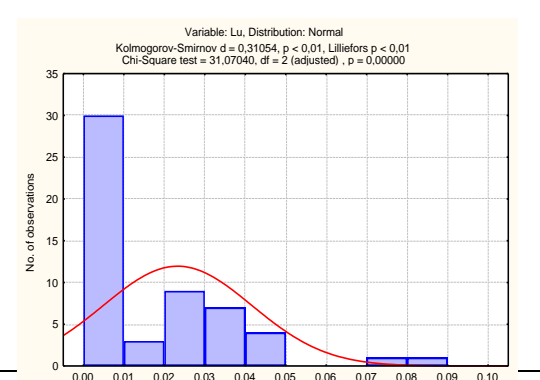
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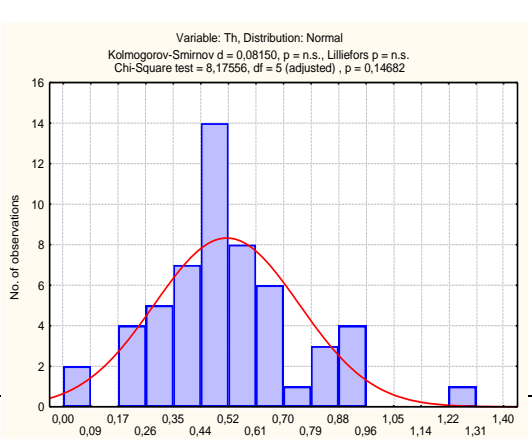
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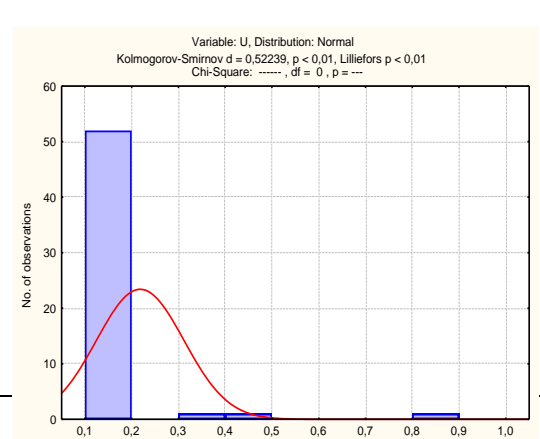
Lu

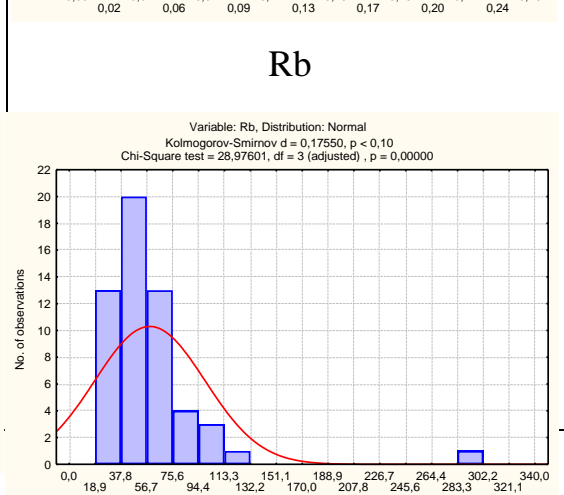
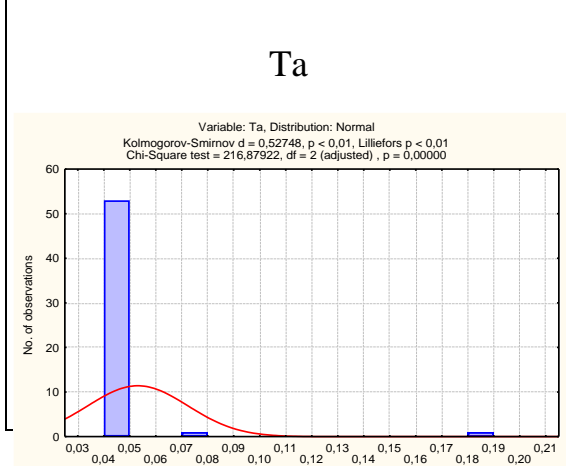
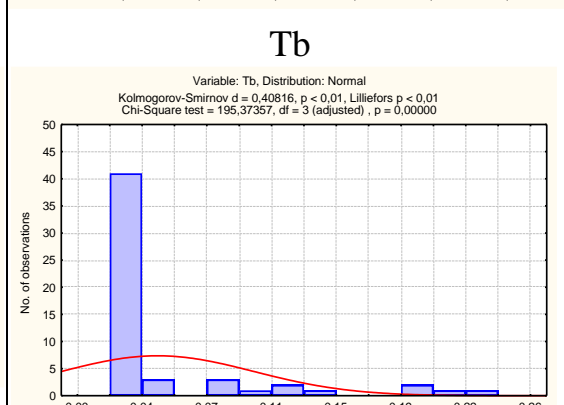
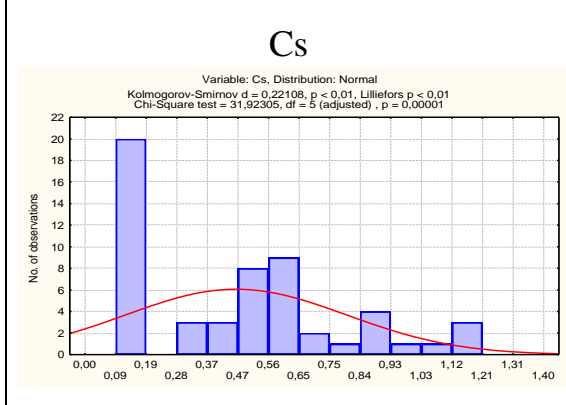
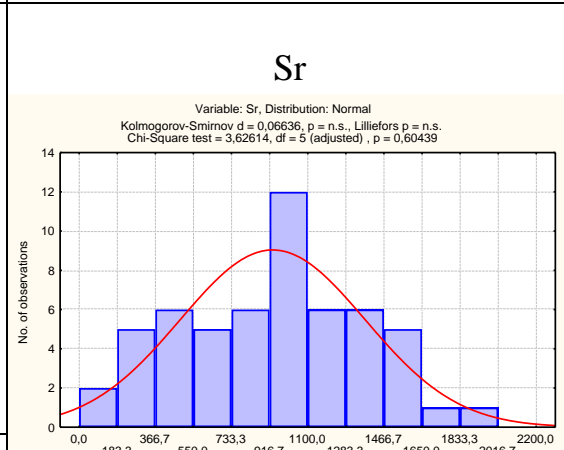
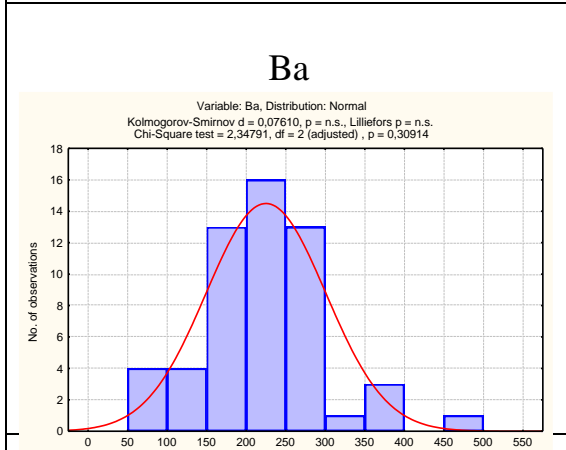
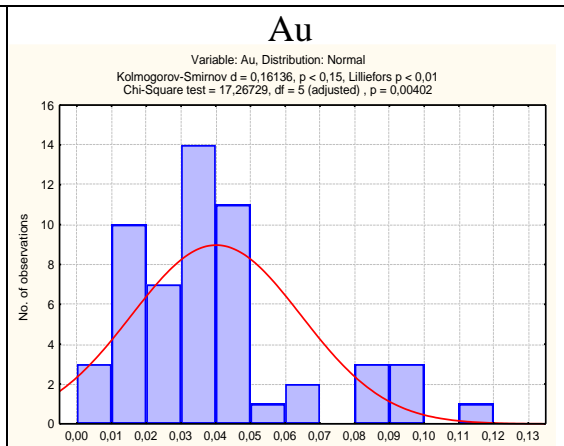
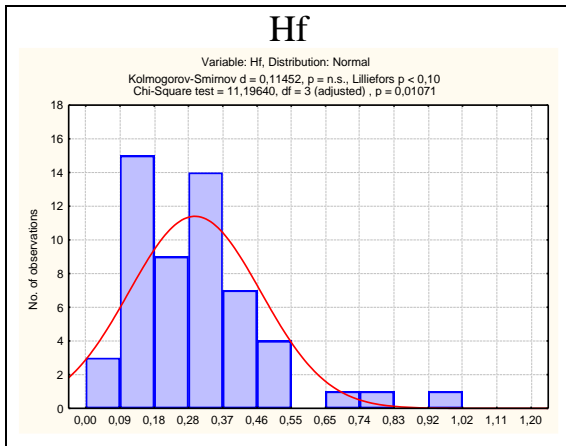


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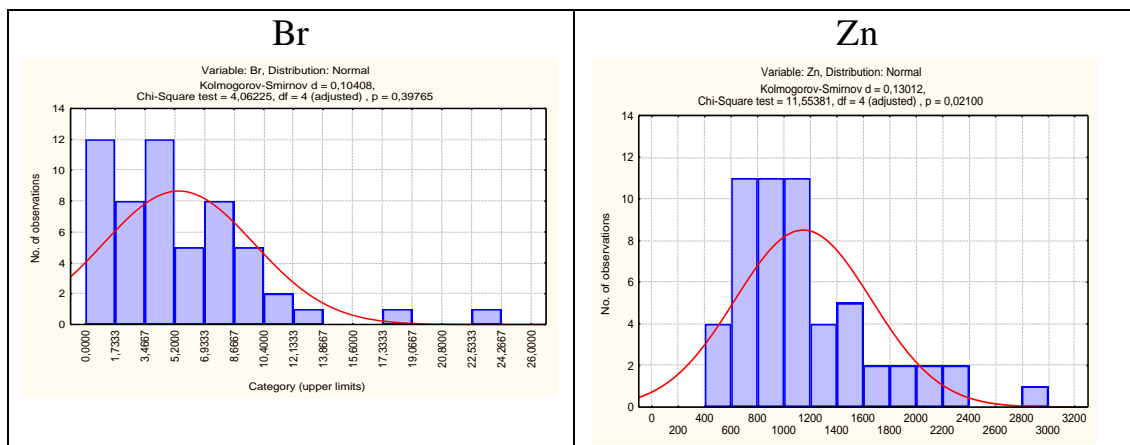


Figure 5.1.1. Histogram of the distribution of microelements in the ash of black poplar leaves according to the Kolmogorov-Smirnov criteria

It is important to acknowledge that the abnormal concentrations of elements, which exceed the curve of normal distribution fluctuation, are detected in the following elements: Sodium, Chromium, Iron, Cobalt, Zinc, Bromine, Rubidium, Lanthanum, Cerium, Samarium, Ytterbium, Lutetium, Thorium, Uranium, Hafnium, Gold, Barium, Terbium, Tantalum.

The dendrogram generated from cluster analysis of elemental composition enables the grouping of chemical components based on their pairwise Pearson correlation coefficients (r), with the highest values indicating greater similarity.

The ash of black poplar leaves exhibits notable correlations of microelement geochemical spectra, as depicted in Figure 5.1.2.

There are five distinct categories of associations that can be discovered. These groups include elements that are related to dust and aerosol industrial emissions, such as those from thermal power plants (Eu, Fe, Yb, Lu, Ce, Hf, Sm, La, Th, Sc; Sr, Co, Ba, Ca), as well as elements associated with petrochemical production (Cs, Rb, Au, Br).

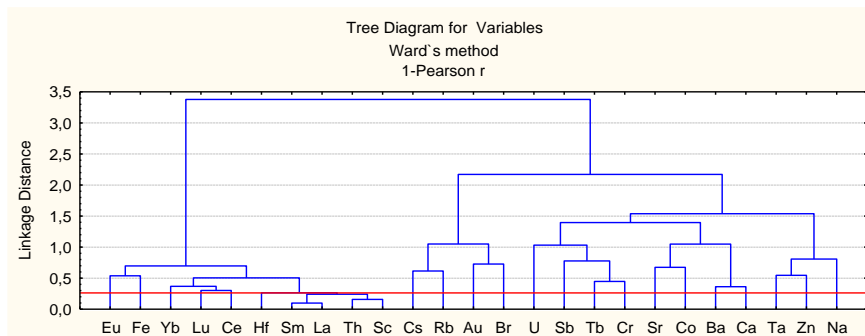


Figure 5.1.2. Dendrogram of the correlation matrix of the geochemical spectrum of microelements in the ash of black poplar leaves using the INAA method on the territory of Pavlodar.

The most significant (more than 95%) microassociations on the territory of Pavlodar are divided into 2 groups: Lu, Ce and Sm, La, Th, Sc. These microelements characterize emissions of ash origin.

In addition, we examined the coefficient of biological absorption to establish the specifics of the accumulation of elements by plants from soils. It was calculated as the ratio of the composition of elements in leaf ash to their content in the soil. (A.I. Perelman). (A.P. Solovova, A. 1990).

Ah characterizes the intensity of absorption of elements from the soil by plants. $A_x = C_x/P_x$, where C_x is the content of elements in plant ash; *P_{hew}* – its content in soil or rock.

The ranked A_x values form series of biological absorption characteristic of a given landscape and make it possible to establish the possibility of forming anomalies in the biogenic accumulation of elements in the A horizon of soils. Such accumulation is possible only for elements for which $A_x > 1.0$.

Judging by the data in the table, the coefficient of biological absorption is higher than unity for three elements, calcium, chromium and gold ($Ca = 8.9$; $Cr = 1.36$; $Au = 1.33$), which makes it possible to establish the possibility of the formation of natural anomalies in the city. The maximum manifestation is characteristic of calcium, which indicates the specificity of the rocks of this territory.

We analyzed the general biogeochemical picture according to the following indicators: clarke concentration (defined as the content of an element relative to the clarke of the noosphere, K_c), clarke concentration relative to background indicators (K_b).

Geochemical series built according to these indicators characterize the specifics of the territory of Pavlodar in the ash of black poplar leaves (Table 5.1.2).

Table 5.1.2. Geochemical specialization on the territory of Pavlodar

Magnitude	Geochemical series
KS	Cr21.6>Sb8.2>Zn6.7>Na2.5>Tb2.3>Lu2.2>Yb 1.9>Ca1.8>Ba1.7>Co1.5= Eu1.5>Fe1.3>Sc1.2= Rb1.2>Sr1.1=U1,1= Ta1,1>Ce1,0= Sm1,0= Th1,0= Hf1,0
Kk	Au59> Zn25 >Sr23> Ca9.1>Ba6.2>Sb3.3>Cr2.0>Rb0.6>Co0.4>Na0.2= La0.2> Sc0.1= Fe0.1= Br0.1= U0.1= Hf0.1> Ce0.08> Tb0.07= Cs0.07 = Th0.07> Lu0.05> Ag0.03= Ta0.03> Yb0.006
K(growing) Tkalich	Zn(1.27) Ca(0.96),Co(0.62),Rb(0.59) Ag (0.51) U(0.44) Cr (0.40)

By K_c elements from three toxicity classes are arranged in the following order: $Cr21.6 > Sb8.2 > Zn6.7 > Ba1.7 > Co1.5 > Sr1.1$

Comparing data on the accumulation of toxic elements in the ash of black poplar leaves with geochemical indicators of the liquid phase of the snow cover (according to G. Azhaev, 2007), a regional feature is noted, characterized by increased concentrations of chromium, zinc, strontium and cobalt (Azhaev, 2007. 11 p.). Consecutive accumulations of elements from the residential zone in the water fraction of snow are presented in the series: Cr5.6>Zn3.1>Sr2.8>Co2.5, i.e. are similar to the geochemical series obtained by us from the results of a study of the elemental composition of black poplar (*Populus nigra* L.) leaves in the city.

5.2. Regional specificity of the elemental composition of leaf ash of black poplar *Populus nigra* L.

The establishment of a wide range of industries distinguishes metropolitan areas. It is challenging to forecast the combined effect of all pollution sources. Geochemical mapping of the natural components of the urban landscape is the only way to accurately evaluate the overall impact of different manufacturing facilities on the environment. The spatial arrangement of multiple pollution sources has a crucial role in determining the spread of pollutants. Each urbanised area will have its own particular structure. The complexity of this situation is influenced by the strategic placement of businesses within the city, the prevailing wind patterns, and the kind of emissions from neighbouring areas. The dispersion of chemical components caused by human activities, known as technogenic halos, varies depending on the porphyritic and dispersed structure of the industrial site (Sayet, Revich, 1990 (pp. 195,147)). The production of geochemical anomalies in Kazakhstan is determined by a combination of causes, including radiogeochemical parameters influenced by coal, metallurgical, and other industrial activities.

To determine the regional variation in the elemental composition of T. black poplar leaves, we conducted a comparative analysis using existing literature data (Alekseenko V.A., 2000) and the results of leaf ash analysis from black poplar in the Tomsk region, generously provided by colleagues from TPU (Rikhvanov L. P., Baranovskaya N.V.). The table labelled 5.2.1 provides the average composition of components found in poplar leaves.

An investigation comparing the chemical element concentration in leaf ash revealed that the Zhelezinka hamlet, which we chose as the backdrop area, has the lowest rates of accumulation.

Table 5.2.1 - Comparative characteristics of element content in the ash of poplar leaves from different regions (mg/kg ash)

Element	Our data		Data from other studies based on literature sources		
	Pavlodar, Kazakhstan	Background	Tomsk, Russia	Europe Asia*	Western Caucasus**
Va	225	128	142 ± 29	358	320
Co	9.23	6.2	4.8 ± 0.9	61	9
Cr	99.5	4.7	7.8 ± 3.3	26.6	eleven
Sc	0.93	0.75	0.71 ± 0.1	1.8	1
Sr	932	800	361 ± 109	1190	1300
Yb	0.2	0.1	0.33 ± 0.07	0.9	0.3
Zn	1145	168.5	n.d.	375.7	330
Th	0.52	0.50	0.57 ± 0.08	n.d.	n.d.
U	0.2	0.2	Less than 0.5	n.d.	n.d.
Rb	58.9	50.35	20.1 ± 3.7	n.d.	n.d.
Hf	0.29	0.28	0.48 ± 0.08	n.d.	n.d.
Ta	0.05	0.05	0.06 ± 0.007	n.d.	n.d.
Ce	2.7	2.5	7.63 ± 1.9	n.d.	n.d.
Sm	0.4	0.4	0.66 ± 0.1	n.d.	n.d.
Eu	0.1	0.09	0.21 ± 0.04	n.d.	n.d.
Tb	0.046	0.02	0.11 ± 0.02	n.d.	n.d.
Lu	0.02	0.01	0.05 ± 0.01	n.d.	n.d.
Ca	143764	82001	118400 ± 10847	n.d.	n.d.
Na	3075	1400	850 ± 234	n.d.	n.d.
Fe	3138	2500	2500 ± 377	n.d.	n.d.
Sb	0.8	0.1	0.51 ± 0.08	n.d.	n.d.

* Moscow, St. Petersburg, Petrozavodsk, Samara, Arkhangelsk, Krasnoyarsk, Barnaul, Kazan, Vladikavkaz, Yerevan, Donetsk, Freiberg, Vienna, Paris, etc.; **Novorossiysk, Anapa, Gelendzhik, Sochi, Tuapse Lazarevskoye, Divnomorsk, etc. n.d. - no data

The concentration of chromium in the leaves of black poplar in the city of Pavlodar is 21 times higher than the natural background level. Other studies have reported chromium concentrations ranging from 3 to 7 times higher than the background level. The zinc buildup is 7-fold greater than the background level, whereas the signs from other locations are 3-fold higher.

By comparing the variables from table 5.2.1, we can conclude that the territory of Pavlodar has distinct biogeochemical characteristics. Therefore,

the land of Pavlodar exhibits higher concentrations of elements such as chromium and zinc, as depicted in Figure 5.2.1.

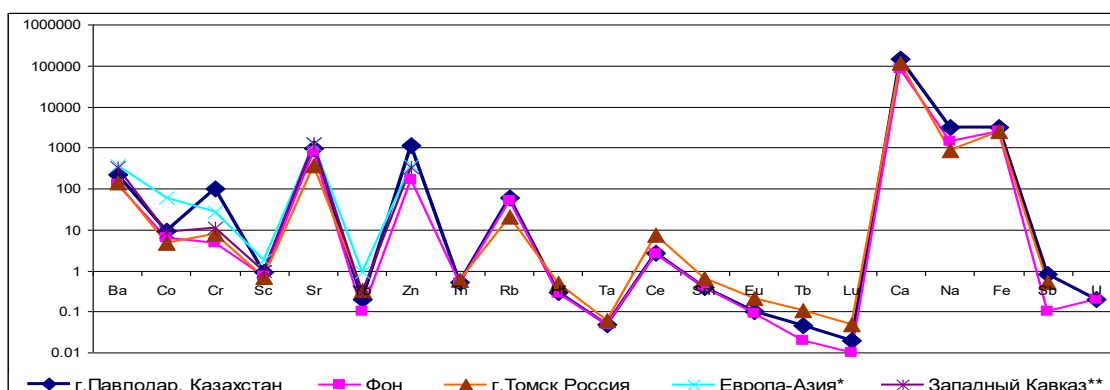


Figure 5.2.1. Comparative characteristics of the content of elements in the ash of poplar leaves

Graphic analysis allows us to conclude that minimal accumulation of all similar chemical elements is manifested in the ash of leaves from the village of Zhelezinka, Pavlodar region.

In addition, we have established the specificity of the accumulation of elements in urban areas relative to rural settlements. Thus, the highest concentrations of Zn in the samples were noted in the city of Pavlodar (1145 mg/kg). In plant materials from the villages of Bayanaul, Shcherbakty and Aktogay, the values are lower at 1.6; 2.5 and 3.4 times respectively. The lowest indicator is in the village of Zhelezinka, where the zinc content is 6.8 times lower than the average content for the city of Pavlodar (Fig. 5.2.2.)

Content of cobalt, chromium and antimony in leaves of *Populus nigra* L.

Analysis of data on the content of hazard class II elements in the assimilation organs of woody plants showed the following. The maximum Co content was found in the leaves of *P.nigra* in the city of Pavlodar (9.2 mg/kg). Contained 1.5 times lower in samples on the territory of the village. Bayanaul and Zhelezinki. The cobalt content is 2.4 and 2.5 times lower in the village. Shcherbakty and Aktogay, respectively (Fig. 5.2.3).

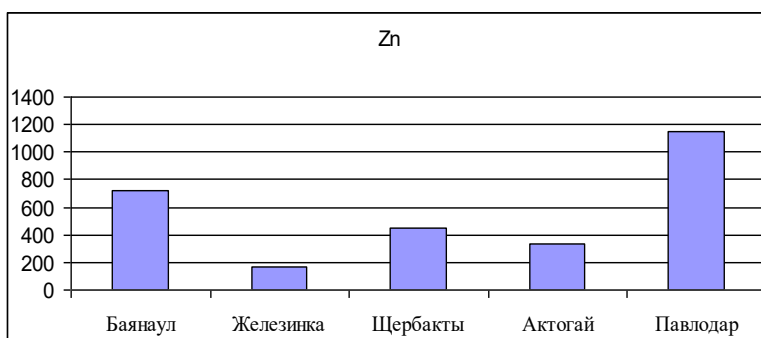


Figure 5.2.2. – Zn content (mg/kg) in leaves of *Populus nigra* L. on the territory of Pavlodar region

The accumulation of chromium in samples from the city of Pavlodar exceeds the data from the villages of Bayanaul, Aktogay, Zhelezinka and Shcherbakty by 3; 8.2; 21.2 and 21.6 times, respectively (Fig. 5.2.4). The maximum content of antimony is observed in the territory of Pavlodar (0.8 mg/kg), 2 times lower in plant samples of Aktogay village, in Bayanaul – 4 times lower.

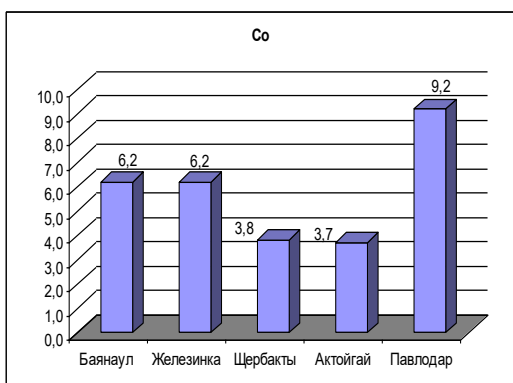


Figure 5.2.3. Co content (mg/kg) in leaves of *Populus nigra* L. in Pavlodar region

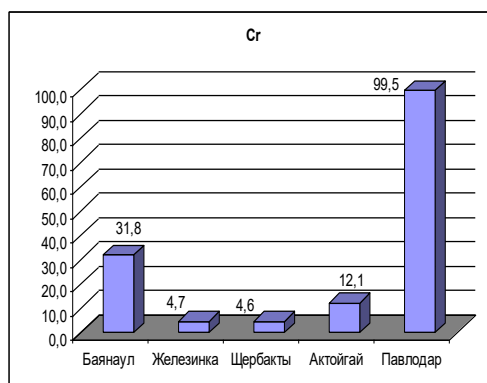


Figure 5.2.4. Cr content (mg/kg) in leaves of *Populus nigra* L. in Pavlodar region

The same minimum Sb value was detected in samples from the village. Zhelezinka and Shcherbakty are 8 times lower than in Pavlodar (Fig. 5.2.5.).

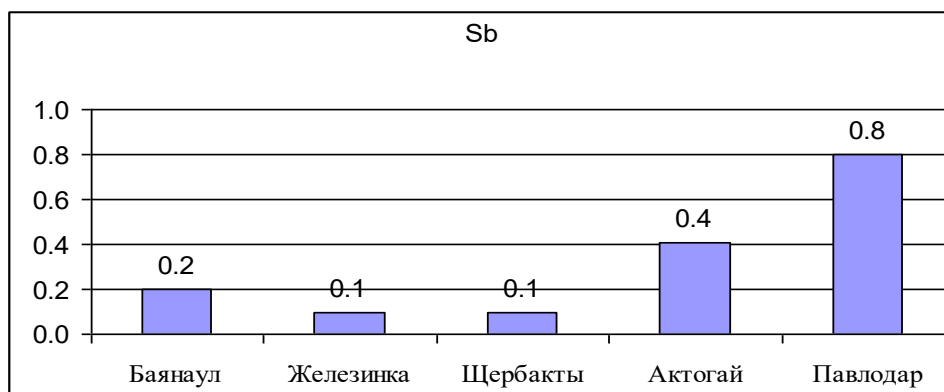


Figure 5.2.5. – Sb content (mg/kg) in leaves of *Populus nigra* L. in Pavlodar region

Barium and strontium content in leaves of *Populus nigra* L.

A significant content of hazard class 3 heavy metals (Ba, Sr) was revealed in the vegetation in the study areas (Fig. 5.2.6., 5.2.7). The maximum amount of Ba was shown by samples of *P.nigra* leaves from the village of Shcherbakty (314 mg/kg), 1.4 times lower - in the territories of

Bayanaul and Pavlodar, the lowest values (2-2.4 times lower) - in the village of Aktogay and the village of Zhelezinka.

The data obtained indicate that the Sr content in poplar leaves is maximally expressed in Aktogay village (1431 mg/kg). In the village of Shcherbakty and the city of Pavlodar - 1.5 times, in the village of Bayanaul - 1.6 times lower and minimally - 1.8 times lower in the village of Zhelezinka.

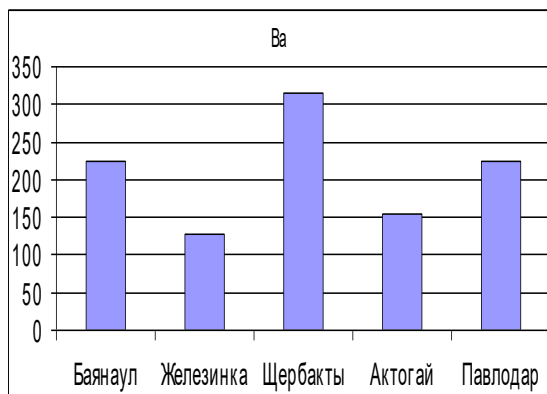


Figure 5.2.6. Ba content (mg/kg) in leaves of *Populus nigra* L. in Pavlodar region

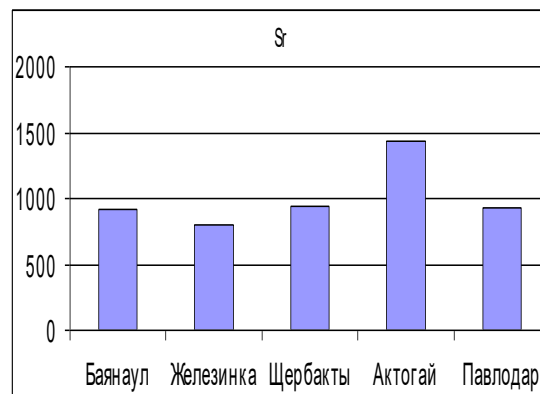


Figure 5.2.7. Sr content (mg/kg) in leaves of *Populus nigra* L. in Pavlodar region

Content of radioactive elements (uranium, thorium) in *Populus nigra* leaves

The uranium content in plant samples in all surveyed areas is below the detection level. The maximum accumulation of thorium (Th) was noted in samples of *P.nigra* from the village of Shcherbakty, 1.3-1.4 times lower - in Bayanaul, Zhelezinka and Pavlodar, the lowest indicator (5.7 times lower) - in Aktogay (Fig. .5.2.8.).



Figure 5.2.8. Th content (mg/kg) in leaves of *Populus nigra* L. in Pavlodar region

The content of rare metals (Cs, Hf, Ta, Rb) in the leaves of Populus nigra L. The highest content of Cs, Hf, Ta was found in plant samples from Shcherbakty. The largest amount of Cs in the foliage was observed in the village of Shcherbakty (0.97 mg/kg), the average amount in the village of Aktogay and in the village of Zhelezinka, 1.5 and 1.8 times less. The smallest amount is in Pavlodar and Bayanaul (0.45 mg/kg), i.e. 2.2 times lower.

Analysing the accumulation of Hf in P.nigra leaves, a series of sites was established: the highest values were found in the village of Shcherbakty (0.68 mg/kg), followed by a 1.6 times lower concentration in the village of Aktogay, a 1.8 times lower concentration in the city of Pavlodar, a 1.9 times lower concentration in the village of Zhelezinka, and the lowest concentration was 3.2 times lower in the village of Bayanaul.

The highest concentration of Ta was seen in P.nigra samples from Shcherbakty, with a value of 0.29 mg/kg. In comparison, the level in other regions was 5.8 times lower.

An analysis of Rb content revealed a substantial surplus of this element in the leaves of P.nigra in the village of Bayanaul compared to all other areas examined. The indication in samples collected from the city of Pavlodar and the town of Shcherbakty is half as much, while in the village of Zhelezinka it is 2.4 times lower. The village of Aktogay has the lowest indication, which is 3.1 times lower than the minimum.

The concentration of rare earth elements in the leaves of Populus nigra L. includes La, Sc, Ce, Sm, Eu, Tb, Yb, Lu, Au, and Aq.

Upon studying the samples of P.nigra leaves from the backdrop, it was discovered that the highest concentration of La is found in P.nigra in the Bayanaul village, with a value of 4.4 mg/kg. This is the average content in the Shcherbakty village. The concentration of the substance in the town of Zhelezinka and the city of Pavlodar ranged from 2.2 to 2.6 milligrammes per kilogramme. The lowest quantity is found in Aktogay, measuring 0.1 mg/kg. Examination of the Sc content reveals that the identical minimum quantity of 0.75 mg/kg is seen in both the hamlet of Bayanaul and the village of Zhelezinka. The upper limit for the concentration of elements was determined in the villages of Shcherbakty and Aktogay at a range of 1.15-1.20 mg/kg.

The highest concentration of Ce was found in the leaves of P.nigra collected in the Shcherbakty area, while the lowest concentration was seen in the village of Bayanaul (1.4 mg/kg). Average values ranging from 2.5 to 2.7 mg/kg were determined in different regions.

There is no significant difference in the amount of Sm content found in P. nigra leaves across the background plots. The town of Shcherbakty

recorded the highest value (0.46 mg/kg), while the settlement of Aktogay recorded the lowest concentration (0.38 mg/kg).

When analyzing the Eu content, its minimum value (0.09 mg/kg) was established in the village of Zhelezinka relative to other background sites.

In the leaves of *P.nigra* from the Aktogay sample site, a significant accumulation of Tb is -0.12 mg/kg, which is very different from other sites. The indicator is 1.7 times lower in the village of Shcherbakty. Below the maximum indicator is 2.6 times - in the city of Pavlodar and 6 times lower in collections from test sites in the villages of Bayanaul and Zhelezinka.

When studying the content of the Yb element in the leaves of *P.nigra*, two areas with maximum values were identified: Aktogay village and Shcherbakty village (0.19-0.21 mg/kg), the minimum content was 0.10 mg/kg in the territories of the village. Bayanaul and Zhelezinka village.

The maximum Lu content was noted in samples of *P.nigra* from the village of Shcherbakty (0.05 mg/kg), lower at 1.7 in Aktogay. The minimum content of this component is in Bayanaul and Zhelezinka (0.01 mg/kg).

Comparison of sites for the accumulation of such a chemical element as Au revealed one site with the maximum content of the element (0.076 mg/kg) - the village of Zhelezinka, and the minimum accumulation - in the village of Aktogay (0.030 mg/kg), at other sample sites the average content varies (0.040 - 0.048 mg/kg).

The Aq element content in the foliage of *P.nigra* in all sample plots in the Pavlodar region was observed to be below the detectable limit.

Based on the data analysis, it was found that the highest sodium (Na) content was detected in plant collections from the village of Shcherbakty, with a concentration of 8900 mg/kg. On the other hand, the lowest Na content was found in the village of Aktogay, which was 14.8 times lower at 600 mg/kg. In the remaining locations, the Na content ranged from 3075 to 1400 mg/kg.

The concentration of calcium (Ca) in *P.nigra* samples collected from several sampling sites in the Pavlodar region ranges from 168,000 to 82,001 mg/kg. The highest number was recorded in the area of Shcherbakty village, surpassing the statistics from Bayanaul, Aktogay, and Zhelezinka by 1.3, 1.4, and 2 times respectively.

The analysis of all research regions revealed that the plant sample of *P.nigra* from the hamlet of Bayanaul had the highest Fe content, with a maximum value of 4450 mg/kg. Comparatively, the sample sites of Shcherbakty and Aktogay had a lower Fe content, approximately 1.3-1.4 times less than that of Bayanaul. The foliage of black poplar from the village of Zhelezinka has the lowest iron concentration, measuring at 2500 mg/kg.

The Zhelezinka sample site exhibits the highest concentration of Br, with a value of 16.1 mg/kg. The indicator from the village of Shcherbakty was found to be 1.6 times smaller. The vegetation samples collected from the Pavlodar, Bayanaul, and Aktogay study sites exhibited a notable decrease in bromine concentration, ranging from 4.9 to 5.4 mg/kg.

The concentration of chemical elements such as arsenic (As), uranium (U), and silver (Ag) in the leaves of *P.nigra* at all background sites in the Pavlodar region was found to be below the detectable level.

Therefore, an examination of the regional characteristics of element accumulation revealed that Pavlodar stands out from other urbanised areas due to its high levels of chromium, zinc, cobalt, and antimony.

Through a comparative analysis of the urban region and the surrounding background areas, it was discovered that harmful substances have a higher tendency to concentrate in the foliage of trees in the urbanised area. This could be attributed to the substantial influence of urban industrial businesses and autos. Overall, the elemental composition of black poplar leaves serves as a reliable signal for determining the extent and specificity of technogenic influence.

5.3. Zoning of the territory of Pavlodar according to biogeochemical data

Currently, zoning a territory based on the extent of human-induced transformation, considering the level of accumulation of specific chemical elements in different parts of natural landscapes (such as water, soil, etc.) and living organisms, is a widely used technique to evaluate the environmental health of a particular area or region for human settlement. Baranovskaya (2003) Schematic maps illustrating the distribution of black poplar *Populus nigra* L. leaves across the Pavlodar territory were created using data acquired on their chemical composition (Fig. 5.3.1÷5.3.3).

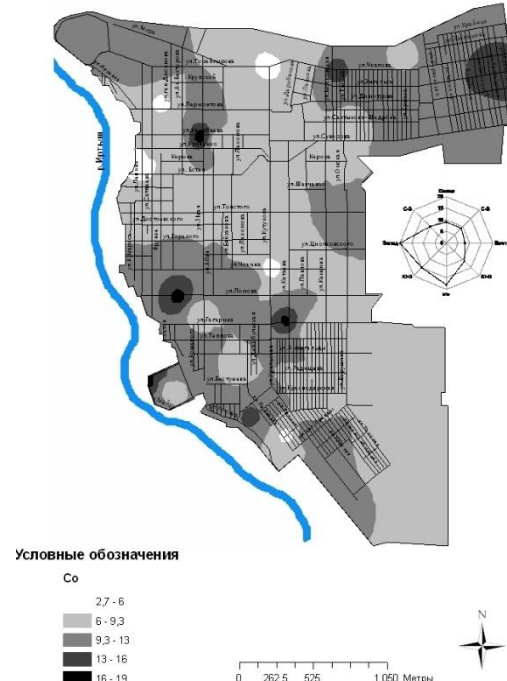
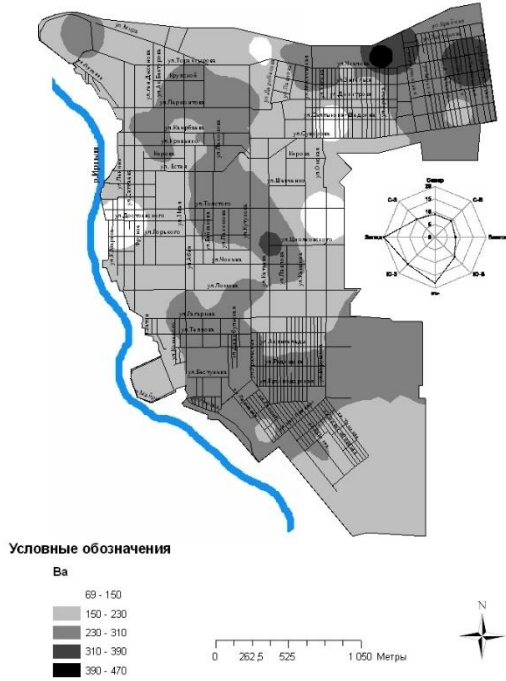
The map depicting the dispersion of harmful substances in the ash of black poplar trees in the city reveals distinct regions exhibiting noticeable irregularities. Sections 2 and 5 of the city, specifically the north-eastern and south-western parts, are affected by the presence of the ferroalloy plant in Aksu and the state district power station. This distribution of Ba, Co, Sr, and Sb is likely due to the influence of these industrial facilities, which are positioned on the leeward side. Upon examining the distribution pattern of elements like zinc and chromium, it is possible to identify localised regions in the central and northwestern sections of Pavlodar city.

Schematic maps illustrating the spatial distribution of uncommon elements (Hafnium, Tantalum, Rubidium) were created using data from the ash of poplar leaves (Figure 5.3.2). The created schematic maps facilitated

the detection of abnormal regions along the Kc. Therefore, the centre section of the city exhibits the highest Hf content, surpassing the background levels by a factor of 3.9. In other areas of the city, the Hf values range from 0.9 to 1.6 Ks.

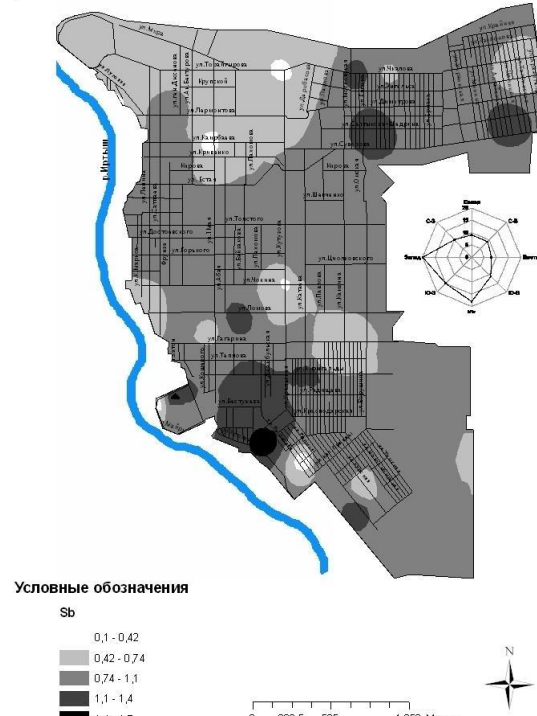
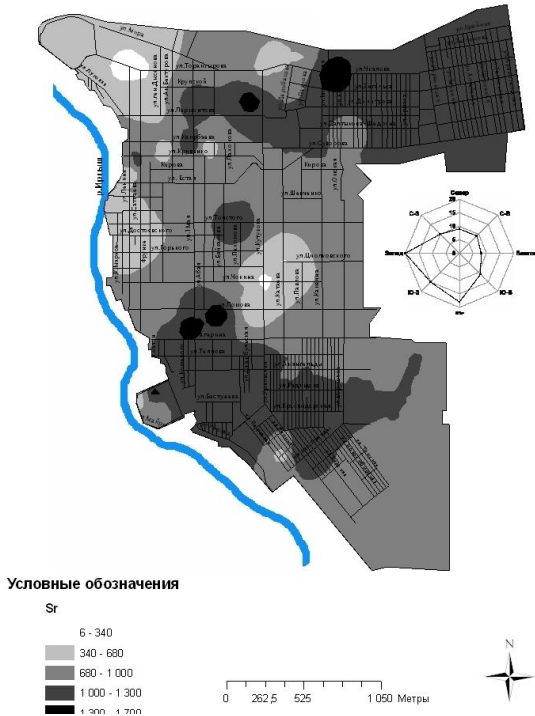
Barium content in leaf ash on the territory of Pavlodar

Cobalt content in leaf ash on the territory of Pavlodar



Strontium content in leaf ash on the territory of Pavlodar

Antimony content in leaf ash on the territory of Pavlodar



Chromium content in leaf ash on the territory of Pavlodar

Zinc content in leaf ash on the territory of Pavlodar

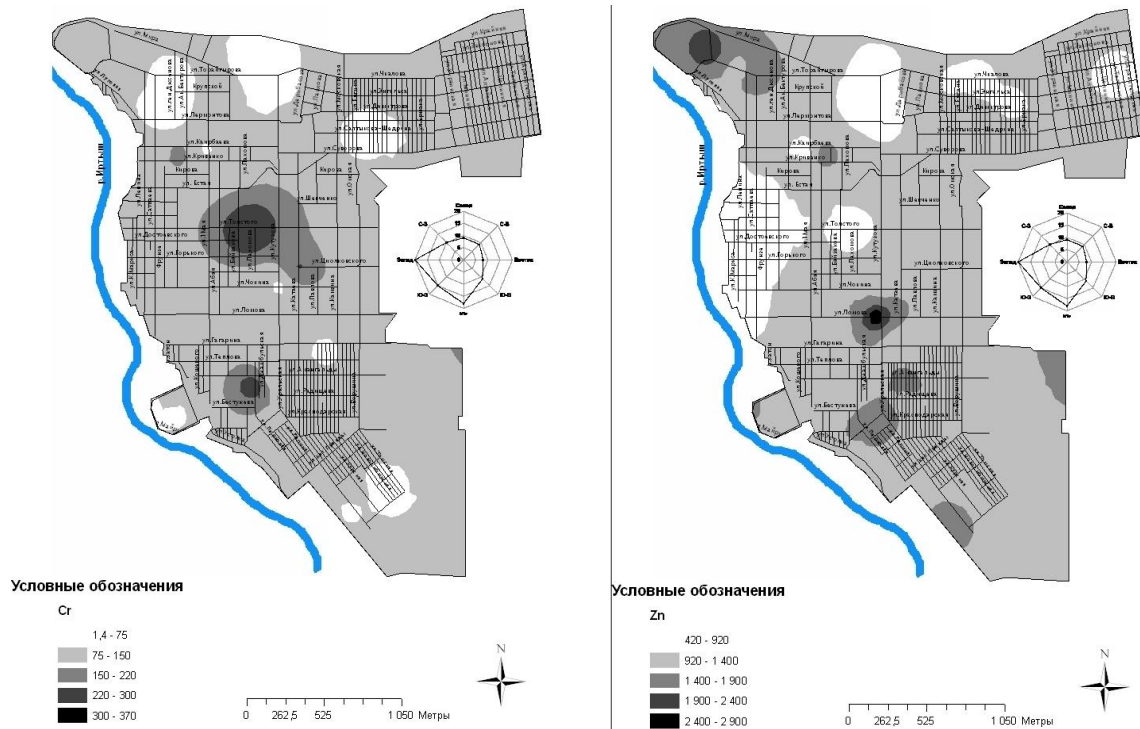
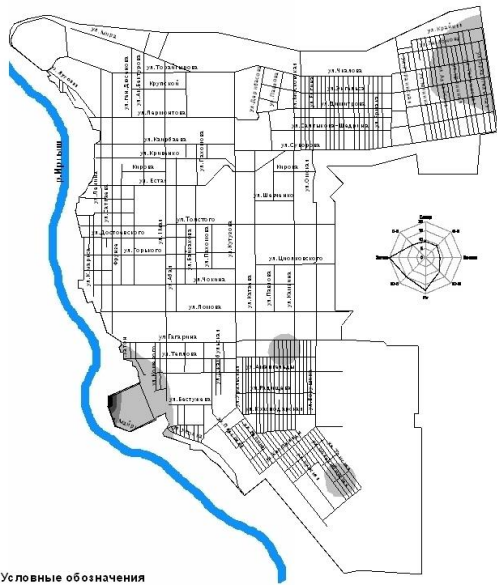


Figure 5.3.1. Schematic maps of the distribution of toxic elements in the leaf ash of black poplar *Populus nigra* L. Mg/kg dry weight

When examining the distribution of rubidium, it is evident that the concentration levels in the majority of the city fall between 0.4 and 1.5. The distribution pattern is mostly concentrated in the northeastern and eastern areas of the city. The highest concentration, ranging from 4.9 to 6 Ks, is found in the southeastern section of the city. western section of the city. The dispersion of this phenomenon might also be attributed to the impact of emissions originating from the Aksu ferroalloy plant.

The distribution of Ta content is similar across the city, ranging from 1-1.6 times the background level (Kc). However, the highest value is found only in the centre section of the city, which is up to 3.8 times greater than the background.

Rb



Условные обозначения

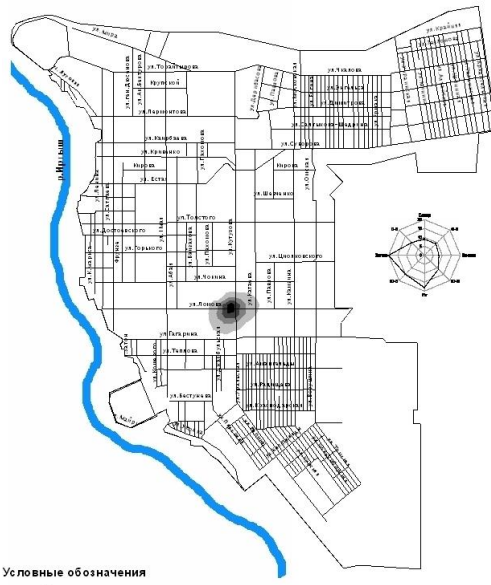
Rb



0 285 570 1140 Метры



Ta



Условные обозначения

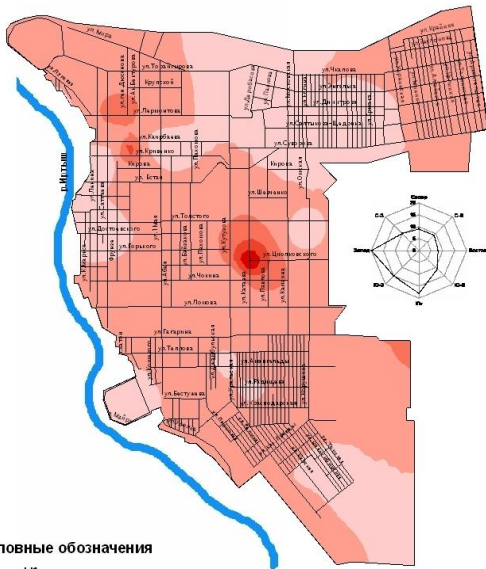
Ta



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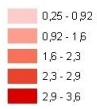


Hf



Условные обозначения

Hf



0 270 540 1080 Метры



Figure 5.3.2. Schematic maps of the distribution of rare elements in the ash of black poplar leaves on the territory of Pavlodar

The distribution of rare earth elements in the ash of black poplar leaves: (Sc, Ce, Sm, Eu, Tb, Yb, Lu) in the city relative to the background area is shown in Fig. 5.3.3.

Halos of the elements Ce, Sm, Sc Eu in the city are distributed in the eastern part of the city, in the center, and in the northwest. The eastern industrial zone (aluminum plant, CHPP-1) and the northern industrial zone (Porney Refinery, CHPP-2, 3 and other enterprises) can have a technogenic impact on the plant component of the natural environment of the urban ecosystem of Pavlodar.

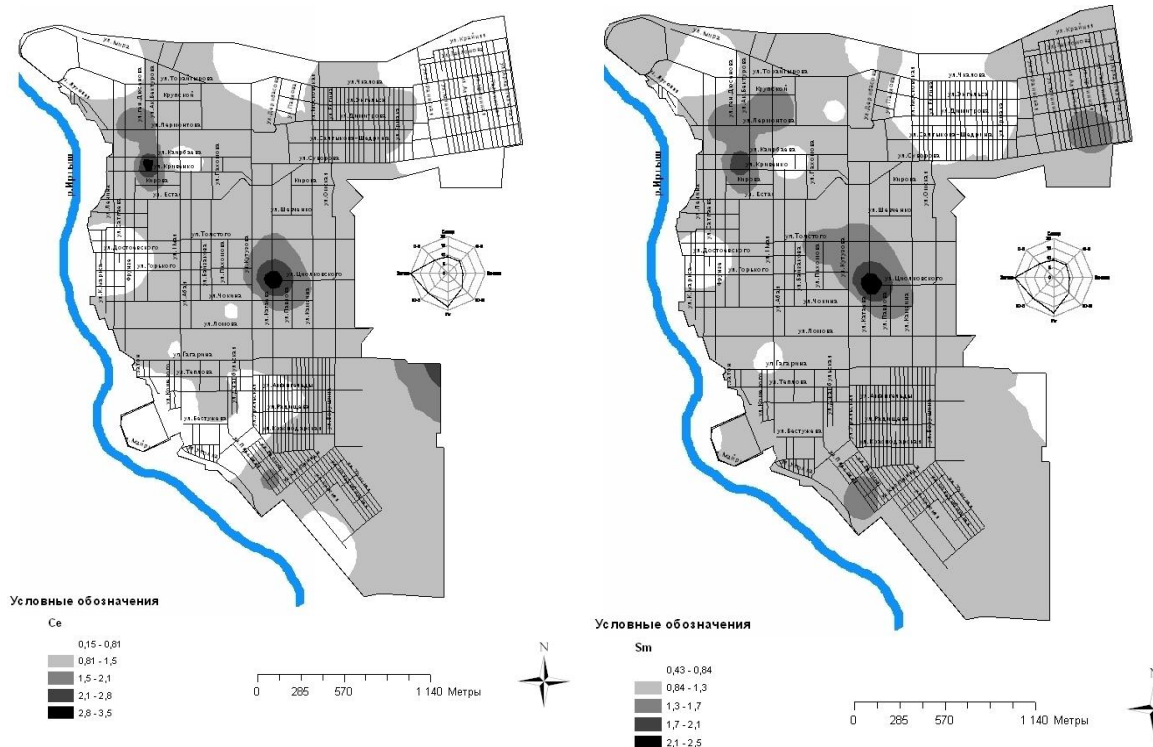
It is noteworthy that thorium and scandium (rare earth elements) form halos of increased values confined to the same areas (areas of intersections of Tsiolkovsky - Kataev streets)

Since technogenic anomalies usually have a polyelement composition, the total pollution indicators Z_c and load Z_p are calculated for them, characterizing the effect of a group of elements on soils (Saet Yu.E., Revich B.A. et al. 1990).

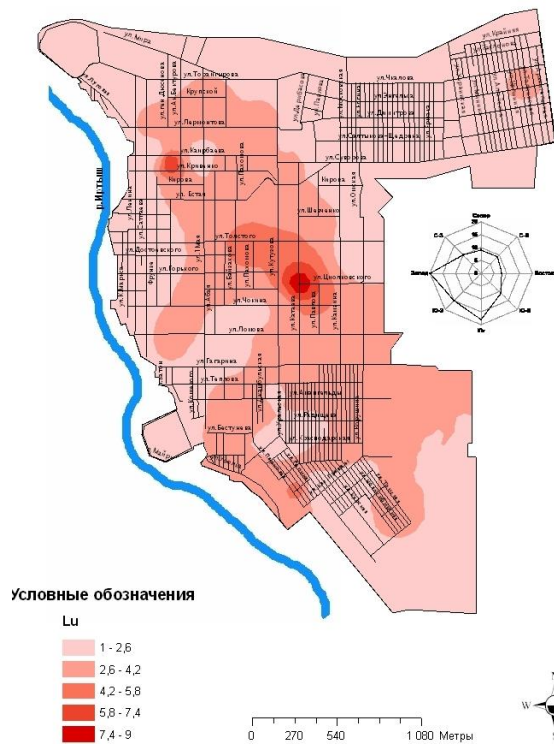
According to these indicators, in the territory of Pavlodar the value of the total indicator of toxic elements is 36.

Xie

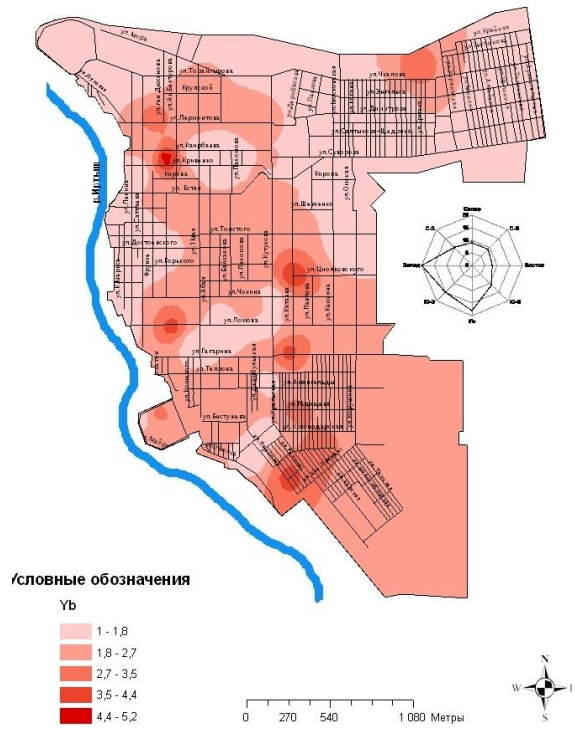
Sm



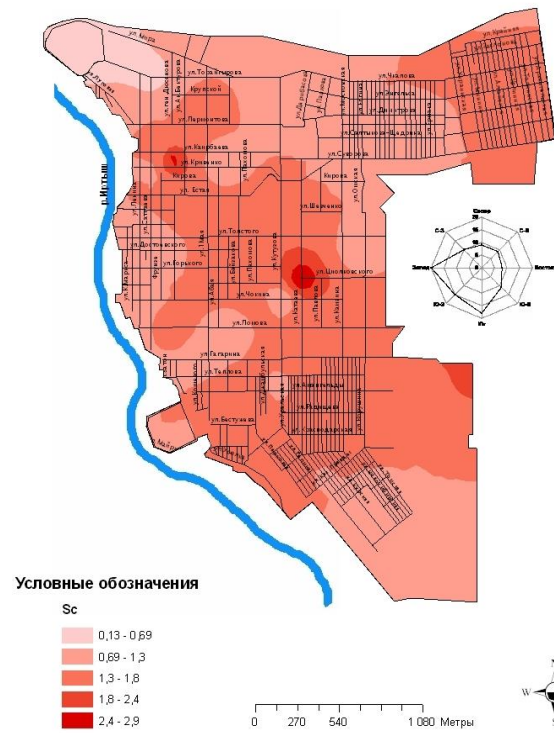
Lu



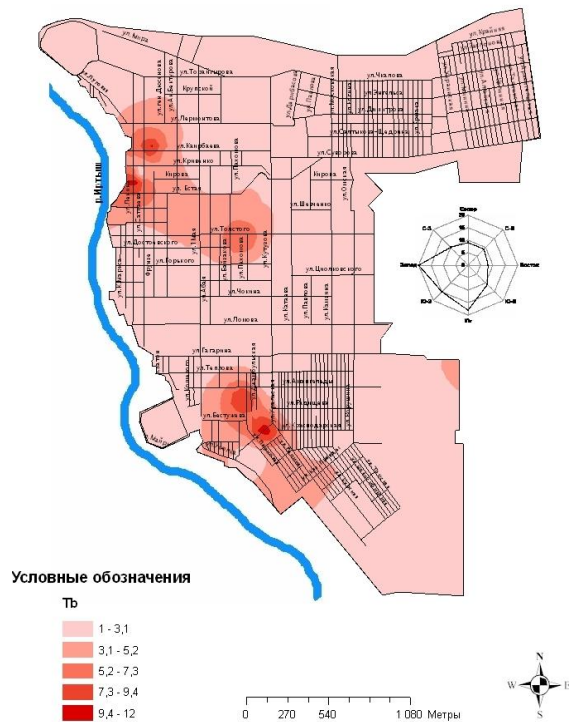
Yb



Sc



Tb



Eu

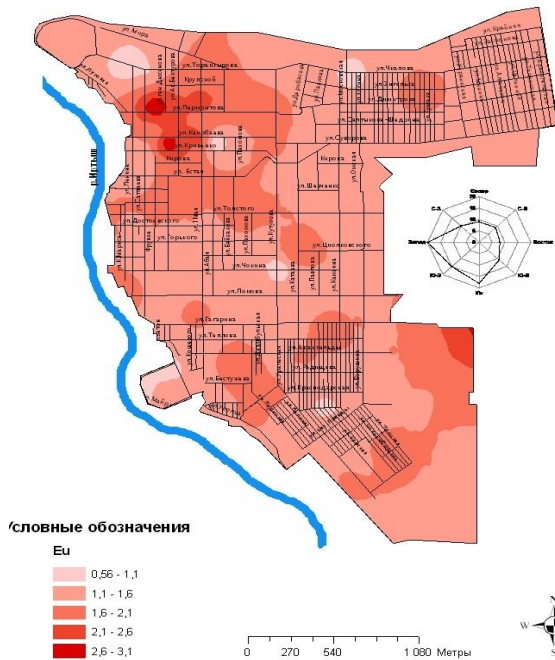


Figure 5.3.3. Schematic maps of the distribution of rare elements in the ash of black poplar leaves on the territory of the city of Pavlodar.

The total accumulation index (21 elements) was 43. The data obtained correspond to the high level of pollution (Table 5.3.1.) given by the authors of the methodology for soils. Since we are working with a plant object, we use this indicator as a guide.

Table 5.3.1. The total load indicator for Kc in the ash of leaves of T. black on the territory of Pavlodar

Elements		$Z_p = \sum_{i=1}^n K_c - (n - 1)$
Toxic elements	Cr, Co, Zn, Sb, Ba, Sr	36.0
All elements	Cr, Sb, Zn, Na, Tb, Lu, Yb, Ca, Ba, Co, Eu, Fe, Sc, Rb, Sr, U, Ta, Ce, Sm, Th, Hf	43

For the value of the total soil pollution indicator (Z_c) the following gradation is used (Methodological instructions... Tomsk. 2000):

- Less than 16 – low level of pollution;
- 16 - 32 - average level of pollution
- 32 - 128 - high level of pollution;
- More than 128 is a very high level of pollution.

Although there is currently no regulatory data available for plant objects, we consider this indicator to be relevant for comparing different parts of the city and assessing their ecological status. The data we collected

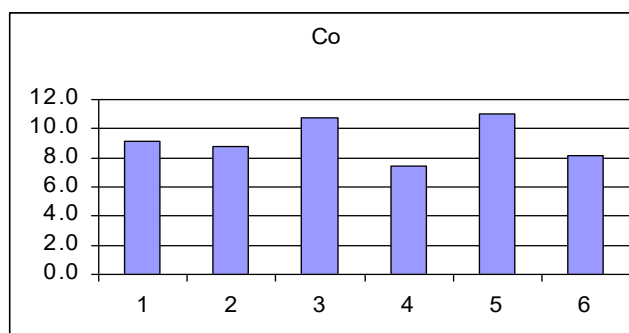
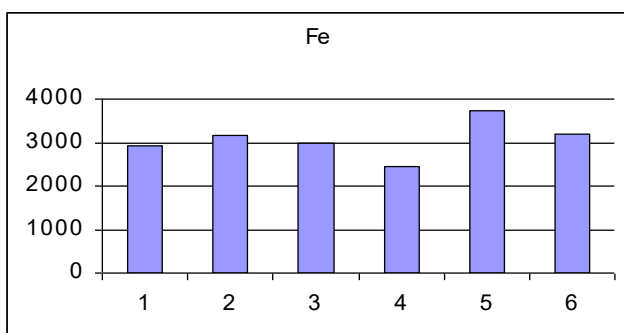
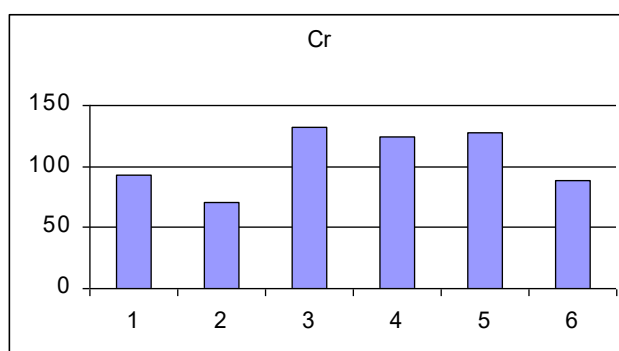
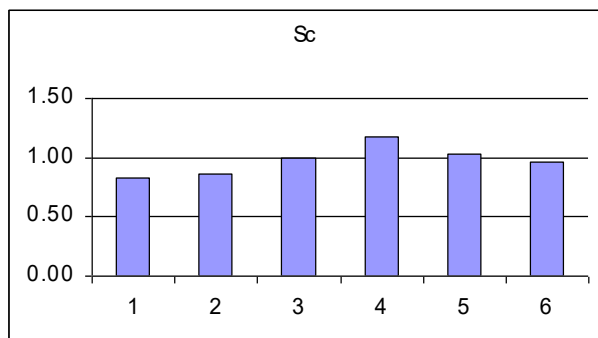
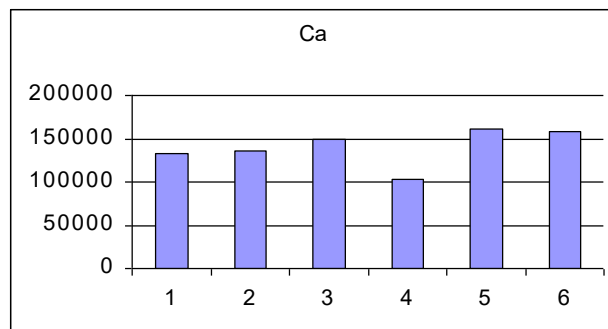
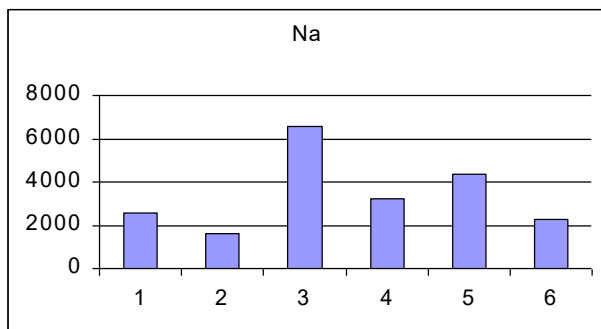
on this indicator align with the standards outlined in the methodological recommendations for evaluating soils. It is important to mention that the concentration of chromium in the leaves of black poplar in the city of Pavlodar is 21 times higher than the natural level, as indicated by previous research which report an increase of 3 to 7 times. The concentration of zinc is 7-fold higher than the background level, while the levels in other places are 3-fold higher.

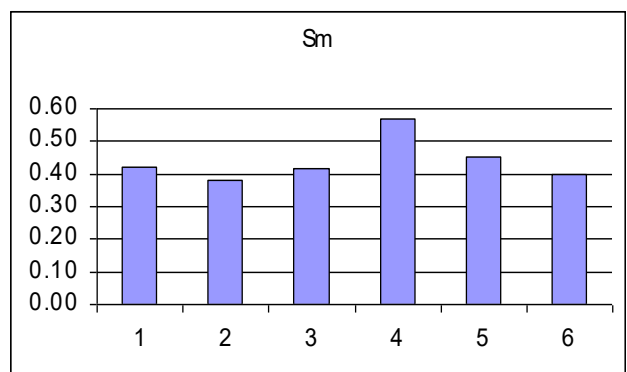
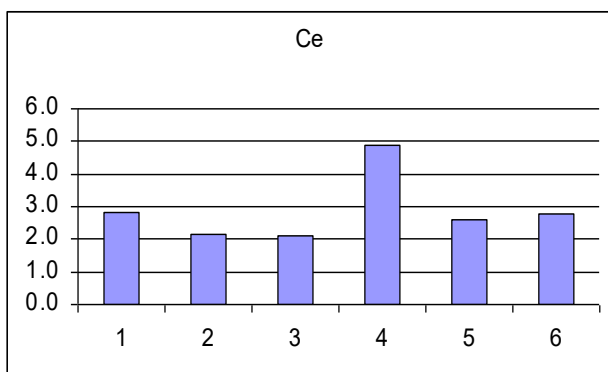
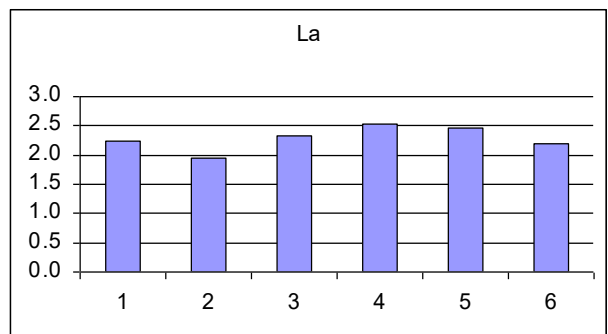
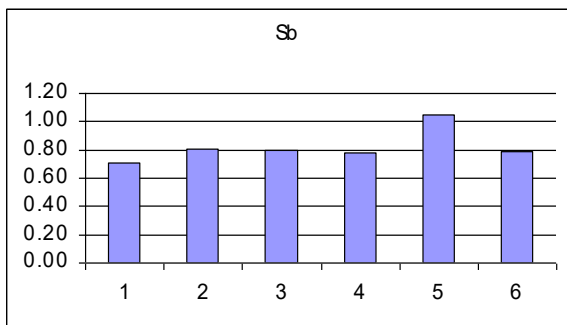
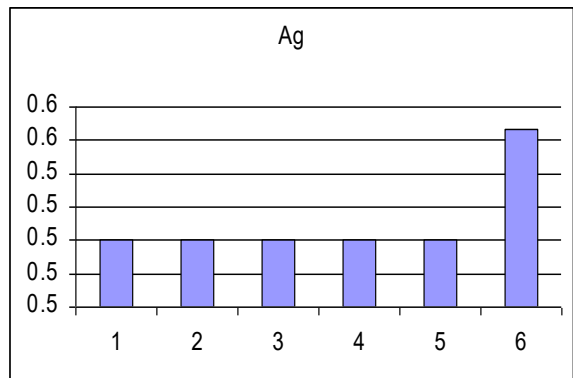
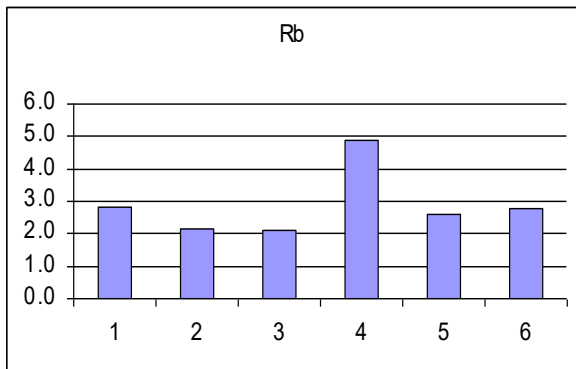
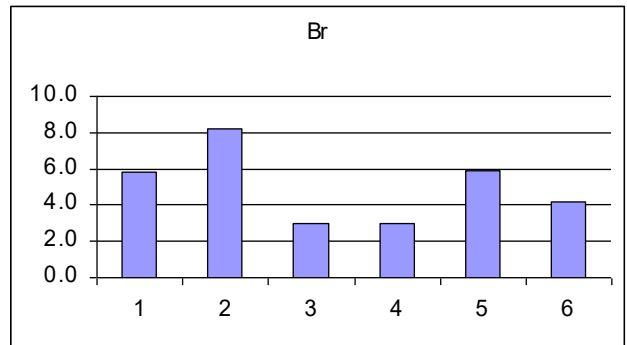
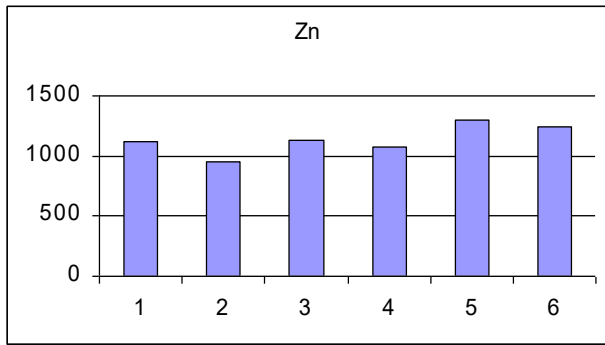
The examination of the available data regarding the levels of chemical element accumulation in the ash of black poplar leaves in Pavlodar city (Table 5.3.2) reveals the presence of areas with a significant concentration of the studied elements, as depicted in Figure 5.3.4.

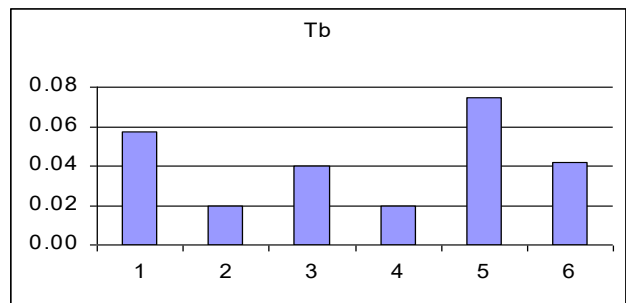
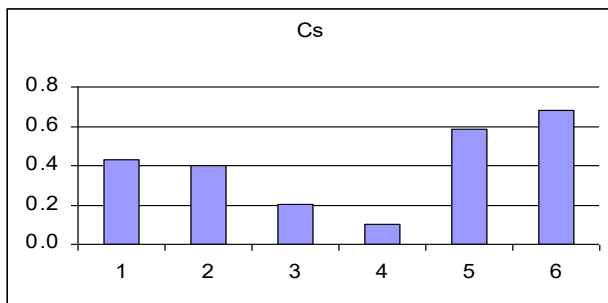
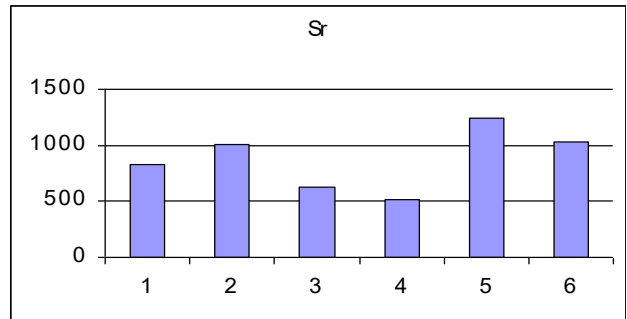
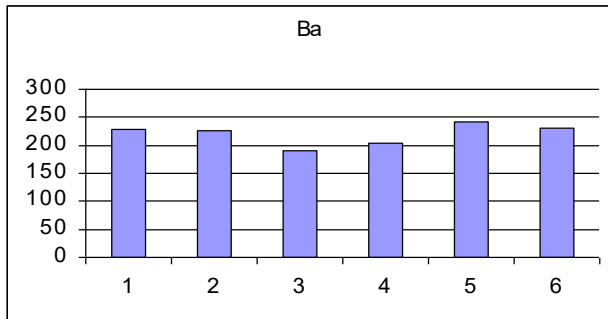
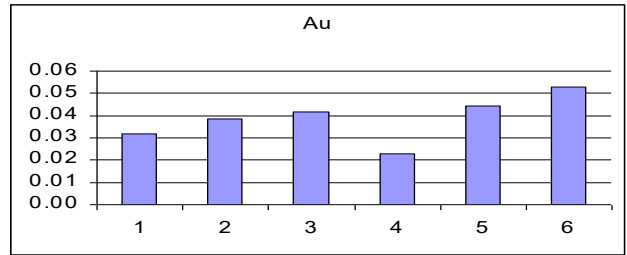
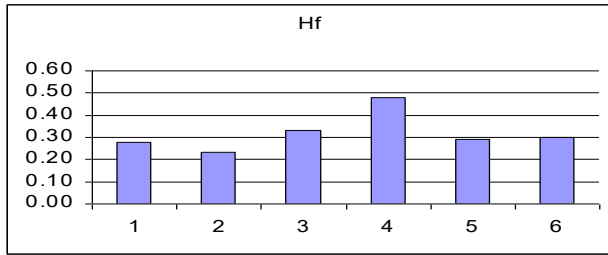
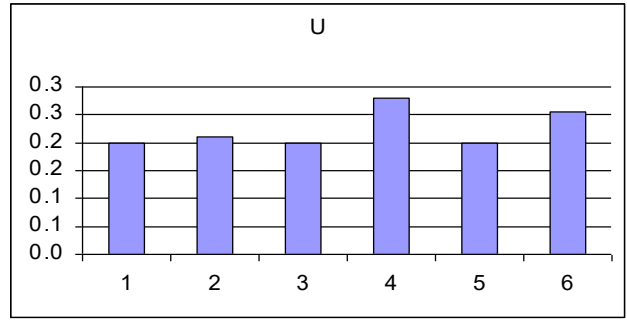
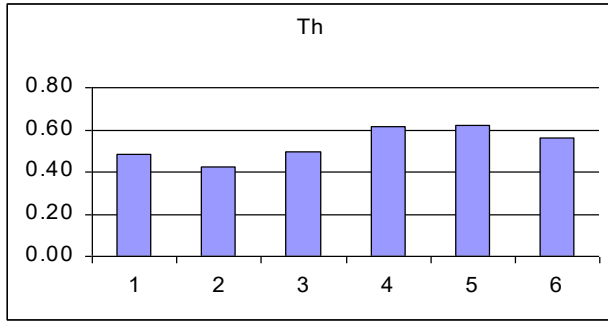
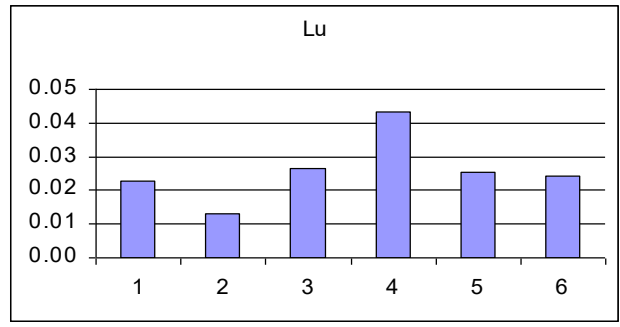
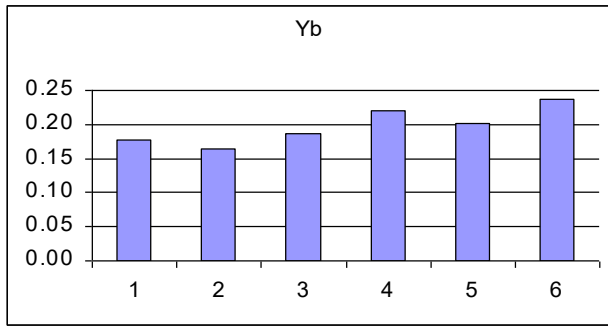
Table 5.3.2. The level of accumulation of chemical elements in the ash of black poplar leaves in Pavlodar.

Elements	Plot						Average
	1	2	3	4	5	6	
Na	2542	1584	6540	3233	4356	2250	3417
Ca	133000	136300	148833	103667	160889	158083	140129
Sc	0.83	0.86	0.99	1.17	1.03	0.97	0.98
Cr	93	70	132	125	127	89	106
Fe	2927	3170	2973	2446	3733	3183	3072
Co	9.1	8.8	10.7	7.4	11.0	8.1	9.2
Zn	1123	953	1132	1070	1295	1244	1136
Br	5.8	8.2	3.0	3.0	5.9	4.2	5.0
Rb	2.8	2.2	2.1	4.9	2.6	2.8	2.9
Ag	0.5	0.5	0.5	0.5	0.5	0.6	0.5
Sb	0.71	0.81	0.79	0.78	1.04	0.79	0.82
La	2.2	2.0	2.3	2.5	2.5	2.2	2.3
Ce	2.8	2.2	2.1	4.9	2.6	2.8	2.9
Sm	0.42	0.38	0.42	0.57	0.45	0.40	0.4
Yb	0.18	0.17	0.19	0.22	0.20	0.24	0.20
Lu	0.02	0.01	0.03	0.04	0.03	0.02	0.03
Th	0.48	0.42	0.49	0.62	0.62	0.56	0.53
U	0.2	0.2	0.2	0.3	0.2	0.3	0.2
Hf	0.28	0.24	0.33	0.48	0.29	0.30	0.32
Au	0.03	0.04	0.04	0.02	0.04	0.05	0.04
Ba	228	226	190	203	243	231	220
Sr	831	1004	624	510	1240	1025	872
Cs	0.4	0.4	0.2	0.1	0.6	0.7	0.40
Tb	0.06	0.02	0.04	0.02	0.07	0.04	0.04
Ta	0.05	0.05	0.07	0.05	0.05	0.05	0.05
Eu	0.14	0.13	0.14	0.12	0.14	0.13	0.13

The diagrams (Fig. 5.3.4) show that variability and variation in the elemental composition is characteristic of plants and is determined by a combination of factors in each specific case, reflecting the specific geochemical environment of the growing areas.







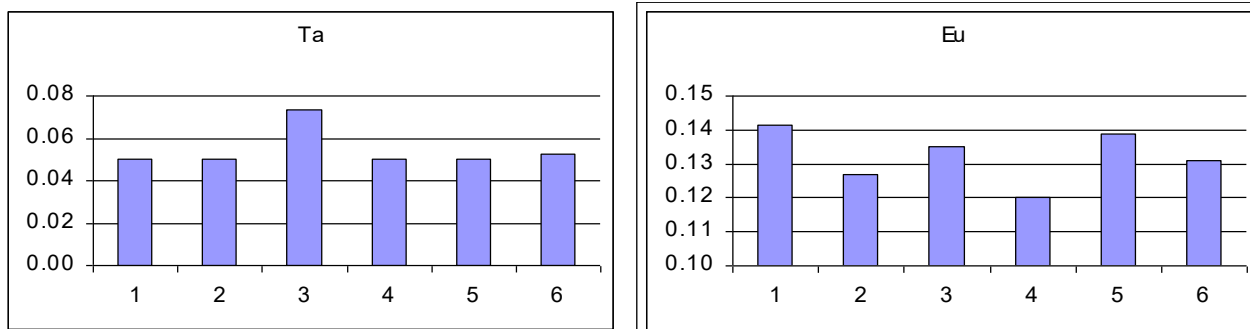


Figure 5.3.4. Content of elements in the ash of poplar leaves in designated areas of Pavlodar (mg/kg)

But, despite the differences, there are general patterns in the distribution of elements. The studied samples of leaves of black poplar *Populus nigra* L. contain macroelements in predominant concentrations, constituting the main part of the ash residue (Table 5.3.3). The biogeochemical spectrum clearly reflects the specifics of the transboundary transport of chemical elements along the Irtysh River valley.

The number of elements exceeding the average value decreases from site 5 to site 1. This indicates that the urban area acts as a place to contain the flow, and elements gradually settle on the foliage of trees. The ChE spectrum indicates the possible influence of coal production (Ekibastuz coal mines, ferroalloy plant).

Table 5.3.3 Biogeochemical features of sites on the territory of Pavlodar

Plot	Items above average	Maximum content
1	Br Ce Lu Tb	
2	Br	Br
3	Na Sc Cr Co (La) (Sm) La Hf Ta	Na Cr Co Ta
4	Br	Sc Rb Ce Sm Lu Hf
5	Br Na Sc Cr Fe Co Zn Rb Sb La Sm Cs Tb Lu Th =Au (Ba) Sr	Ca Fe Zn Sb Ba Sr Tb
6	Ag Ce Yb Lu Th U Au Cs	Yb Cs

Also, we examined the maximum content of chemical elements in all studied areas of Pavlodar (Table 5.3.3)

From the analysis of the data obtained, the largest number of chemical elements by maximum content appeared in the following series of decreasing sections: 5 > 4 > 3 > 6 > 2 > 1.

Table 5.3.4 Geochemical specialization in black poplar leaves on the territory of Pavlodar

Plots		Geochemical series
1	KS	Cr19.8>Sb7.05>Zn6.7>Tb2.87>Lu2.27>Na1.8>Ba1.8>Yb1.8>Ca1.6>Eu1.57>Co1.5>Fe1.2>Ce1.12>Sc1.1>Sm1.06>Sr1.04>Rb1.0=U1.0=Ta1.0>Hf1.0>Th1.0
	QC	Au46>Zn24>Sr21>Ca8.3>Ba6.3>Sb2.8>Cr1.9>Rb0.5>Co0.4>La0.2>Br0.1=Na0.1=Sc0.1=Fe0.1=U0.1=Hf0.1=Ce0.1=Cs0.1=Tb0.1>Th0.06>Lu0.05>Ag0.03=Ta0.03>Yb0.01
2	KS	Cr14.9>Sb8.1>Zn5.7>Ba1.8>Ca1.7>Yb1.6>Eu1.4>Co1.4>Fe1.3>Lu1.30>Sr1.26>Na1.1=Sc1.1=U1.1>Rb1.0=Tb1.0=Ta1.0>Sm1.0>Ce0.9>Hf0.8=Th0.8
	QC	Au56>Sr25>Zn21>Ca8.5>Ba6.3>Sb3.2>Cr1.4>Rb0.5>Co0.4>Br0.2=La0.2>Na0.1=Sc0.1=Fe0.1=Ce0.1=U0.1=Hf0.1>Cs0.07>Th0.05>Ag0.03=Lu0.03= Tb0.03= Ta0.03 >Yb0.005
3	KS	Cr28.1>Sb7.9>Zn6.7>Na4.7>Lu2.7>Tb2.0>Yb1.9>Ca1.8>Co1.7>Ta1.5=Eu1.5=Ba1.5>Sc1.3>Fe1.2=Hf1.2>Rb1.0=U1.0=Th1.0=Sm1.0>Ce0.8>Sr0.8
	QC	Au60>Zn25>Sr16>Ca9.3>Ba5.3>Sb3.2>Cr2.6>Co0.5= Rb0.5>Na0.3>La0.2>Sc0.1=Fe0.1=U0.1=Hf0.1>Ce0.07>Th0.06=Lu0.06=Br0.06= Tb0.06>Ta0.04>Ag0.03=Cs0.03>Yb0.01
4	KS	Cr21>Sb7.7>Zn6.3>Na2.5>Lu2.1>Tb2.0>Yb1.8>Ca1.7>Ba1.7>Co1.5=Eu1.5>Sc1.2=Fe1.2=Ta1.2>Rb1.0=U1.0=Hf1.0= Sr1.0=Sm1.0>Ce0.9=Th0.9
	QC	Au54>Zn23>Sr21>Ca8.7>Ba6>Sb3>Cr2>Rb0.5>Co0.4>Na0.2=La0.2>Sc0.1=Fe0.1=Br0.1=U0.1=Hf0.1>Ce0.07>Th0.06= Tb0.06=Cs0.06>Lu0.05>Ag0.03= Ta0.03 >Yb0.006
5	KS	Cr27>Sb10.4>Zn7.7>Tb3.7>Na3.1>Lu2.6>Ca2.0= Yb2.0>Ba1.9>Co1.8>Rb1.7>Sr1.5=Eu1.5=Fe1.5>Sc1.4>Th1.2>Sm1.1>Ce1.0=Ta1.0=Hf1.0=U1.0
	QC	Au64>Sr31>Zn28>Ca10>Ba6.7>Sb4.2>Cr2.5>Rb0.9>Co0.5>Na0.2=La0.2= Fe0.2>Sc0.1= Br0.1= U0.1= Hf0.1= Cs0.1= Tb0.1> Th0.08= Ce0.08 >Lu0.06 >Ta0.03 =Ag0.03> Yb0.006
6	KS	Cr18.9>Sb7.8>Zn7.4>Lu2.4>Yb2.4>Tb2.1>Ca1.9>Ba1.8>Na1.6>Eu1.4>Sc1.3=Fe1.3=Co1.3=U1.3= Sr1.3>Rb1.2 >Th1.1=Ce1.1=Hf1.1=Ta1.1=Sm1.1
	QC	Au76>Zn27>Sr26>Ca9.9>Ba6.4>Sb3.1>Cr1.8>Rb0.6>Co0.4>La0.2>Na0.1= Sc0.1= Fe0.1= Br0.1= Ce0.1= U0.1= Hf0.1=Cs0.1>Th0.07= Tb0.07>Lu0.05>Ag0.03= Ta0.03>Yb0.01
We d. city	KS	Cr22>Sb8.2>Zn6.7>Na2.5>Tb2.3>Lu2.2>Yb1.9>Ca1.8>Ba1.7>Co1.5=Eu1.5>Fe1.3>Sc1.2= Rb1.2 = Sr1.1=U1.1= Ta1.1>Ce1.0=Sm1.0=Th1.0=Hf1.0
	QC	Au59>Zn25>Sr23>Ca9.1>Ba6.2>Sb3.3>Cr2.0>Rb0.6>Co0.4>Na0.2=La0.2>Sc0.1=Fe0.1= Br0.1= U0.1= Hf0.1> Ce0.08> Tb0.07= Cs0.07 =Th0.07>Lu0.05>Ag0.03= Ta0.03>Yb0.006

Geochemical series of microelement specialization of city areas are expressed in table. 5.3.4. Thus, in all areas and in the city as a whole, high concentrations (Kc) appeared in the following order: chromium, antimony, zinc - related to toxic elements. The subsequent order is with little difference: in areas 1, 5 - terbium, in area 2 barium - these elements belong to rare earth elements, in areas 3, 4 and throughout the city - sodium (Na), an alkaline element.

In general, all areas have high Kc values for toxic elements: chromium, antimony and zinc. It should be noted that gold, strontium, zinc, barium, antimony and chromium have high concentrations (above one) relative to Clark. Comparing the data of two geochemical series, we note fairly high clarke values of the noosphere.

We calculated the total accumulation index of elements (Zp), by analogy with ZSPZ (Saet Yu.E. et al., 1990).

In terms of the number of elements exceeding Kc by two or more times, the 5th region was maximally manifested. The same number of elements is fixed in sections 3, 4 and 6, and the minimum number of elements is fixed in section 2.

Analysis of the total accumulation indicator in the territory showed that in all areas of the city the level of pollution is high (Table 5.3.5.).

The total indicator of the accumulation of toxic elements in the areas is located in the following descending order: 5>3>4>6>1>2. The sites were also ranked according to ZSPN (calculations for 21 HE): 5 >3 >4 = 6 >1 >2.

Table 5.3.5. The total accumulation rate of black poplar leaves in the ash on the territory of Pavlodar

Plots	$Z_p = \sum_{i=1}^n Kc - (n - 1)$	
	Toxic elements (GOST 17.4.4.02-84 ")	For all elements (21)
1	32.9	39
2	28.2	thirty
3	41.7	51.3
4	34.2	40.9
5	45.3	56.1
6	33.5	40.9
city	36.2	43.3

From the data obtained, sections 5 and 3 (the western and southwestern coastal sections of the city), as well as section 4, located in the eastern part of the city, clearly emerged.

These areas are located in the direction of the wind rose, which corresponds to the location of the Aksu ferroalloy plant, and transboundary transport along the Irtysh River is also possible (the cities of Semipalatinsk and Ust-Kamenogorsk are located above).

As a result of our biogeochemical studies, we compiled a summary ranking scheme based on the level of accumulation of chemical elements in the ash of black poplar leaves (Table 5.3.6).

Based on the results of a biogeochemical study, it was established that the coastal areas of the city (5 and 3 - southwestern and western) are the most anomalous, 4 and 6 - unfavorable, they are located near the eastern industrial zone.

Table 5.3.6. Ranking scheme for the level of accumulation of chemical elements in the ash of black poplar on the territory of Pavlodar (55 samples)

U h A W i t h T O T o	Rank (place)					Summary place for all indicators	
	In terms of the number of elements exceeding Kc by 2 times	Zptoxic (6 el.)	Zp for 21 (el.)	According to the spectrum of specifics	Max.content of elements	Sum	Rank
1	5	5	4	4	6	24	5
2	6	6	5	5	5	27	6
3	3	2	2	2	3	12	2
4	3	3	3	5	2	16	3
5	1	1	1	1	1	5	1
6	3	4	3	3	4	17	4

The huge industrial zones of Pavlodar, which include a wide range of enterprises such as an oil refinery, aluminium smelter, and many combined heat and power plants (TPP-1,2,3), significantly impact the environmental conditions in the urbanised area.

Through population statistical analysis, we have discovered a correlation between the chemical element composition in the ash of black poplar leaves in Pavlodar and bioindicative indicators. These indicators include the asymmetry of silver birch and the sterility of dandelion pollen. The correlation is measured using the Pearson correlation coefficient (r) and the determination index (R²). The Chaddock scale, a qualitative assessment, was employed to gauge the degree of proximity in the connection.

Overall, the correlation analysis did not find any significant positive associations between the amount of major chemical components in leaf ash and sterility. There is a noticeable but mild positive association between

sterility and the levels of Rb, Sb, La, Sm, and Tb in the ash of leaves. The correlation coefficient (r) falls within the range of 0.56 to 0.58.

A strong negative correlation was found between the calcium level and zinc content in leaf ash in the Pavlodar region. The correlation coefficients were $r = -0.96$ and $r = -0.95$, with corresponding coefficients of determination (R^2) of 0.92 and 0.90, respectively. The p -values were less than 0.05 in both cases. A strong negative correlation was seen between the chemical elements Fe, Rb, Th and asymmetry ($r=-0.86$, $R^2=0.74$, $p<0.05$; $r=-0.84$, $R^2=0.71$, $p<0.05$; $r=-0.94$, $R^2=0.88$, $p<0.05$, respectively).

The environment in Pavlodar undergoes both natural and man-made changes, as evidenced by the findings of bioindication studies. These studies have revealed significant differences in various parameters such as leaf asymmetry, sterility of grass pollen, vitality of common tree species, and elemental composition of biosubstrates, when compared to the normal regional and noospheric conditions.

Table 5.3.7. Ecological ranking of the territory of Pavlodar according to a set of bioindication indicators

Index	Plots					
	I	II	III	IV	V	VI
Leaf asymmetry	1	3	2	1	4	3
Pollen sterility	5	1	6	3	2	4
Elemental content of black poplar leaves	5	6	2	3	1	4
Rank	3	2	2	1	1	3

It is important to observe that bioindication indicators are highly responsive to a broad spectrum of environmental conditions, encompassing both inorganic and organic contaminants such as benzene, phenol, and chlorine-containing pollutants. It is important to consider that biogeochemical indicators, which refer to the elemental composition of plant biosubstrates, directly indicate the characteristics of emissions from certain industrial complexes and automobiles. On the other hand, bioindicative indicators only indirectly show the effects of human-made activities.

CONCLUSION

1. A detrimental condition has been uncovered regarding the reproductive capacity of herbal plants, including the medicinal dandelion *Taraxacum officinale* sl. The sterility index of *T. officinale* pollen in the city (Kc) is, on average, 15.3 times higher than the background value, ranging from 5 to 29 times higher. The diverse character of sterility's manifestation has been confirmed across the city, with the most unfavourable places located in the northeastern and southern parts. A high level of fluctuating asymmetry (FA) of leaves of silver birch *Betula pendula* Roth was established on the territory of Pavlodar. Everywhere in the areas, an excess of the FA indicator compared to the background was observed from 1.25 to 1.38 times. The distribution of FA is local and focal in nature, with the most pronounced anomalies in the northwestern, eastern and western parts of the city. The highest manifestation of asymmetry (3 and 4 degrees) is expressed in the form of loci in areas with dense tree plantings.
2. The territorial zoning of Pavlodar reflects the vitality of five common tree species in a falling order: the eastern industrial zone has the highest vitality, followed by the northern industrial zone, the northwestern section, the western part, and finally the southeastern part. The ranking of trees based on their environmental sustainability is as follows, from highest to lowest: silver birch, black poplar, ash maple, Scots pine, and pinnate elm. The most acceptable tree species for planting in a technogenically hostile urban environment, due to their high adaptability to unfavourable external impacts, are silver birch, black poplar, ash maple, and Scots pine.
3. The elemental composition of black poplar leaves is an indicator that allows us to establish the degree and specificity of technogenic impact. On the territory of Pavlodar, the 2 most significant (more than 95%) microassociations of chemical elements have been identified: Lu, Ce and Sm, La, Th, Sc, which can enter the environment as part of ash emissions. In a comparative analysis of the urban area with background areas, it was found that in the urbanized area toxic elements accumulate in the foliage of trees to a greater extent, which may be due to the significant impact of urban industrial enterprises and vehicles.
4. A study on the regional distribution of harmful components in black poplar leaves revealed that the city of Pavlodar had a higher concentration of chromium, zinc, cobalt, and antimony compared to other urban areas.
5. Ecological zoning, determined by the cumulative indicators, reveals the areas with the most environmental degradation in the southwestern and eastern regions of the city. This indicates a consistent and significant increase in the degree of human-induced pollution in the Pavlodar territory.

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