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CREATING AN ECOLOGICAL BUFFER LANDSCAPE SYSTEM IN THE INDUSTRIAL ZONE OF NAVOI CITY: THEORETICAL ANALYSIS

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Abstract: *This scientific article examines the theoretical and practical foundations of creating an ecological buffer landscape system on the example of the industrial zone of Navoi city. The research is aimed at modeling protective zones between industrial enterprises and residential areas based on the principles of landscape ecology and architectural design. The article analyzes international experience in designing ecological buffers for industrial zones. Based on comparative analyses, the ecological situation, anthropogenic load, and the state of existing green spaces in the territory where the Navoi Mining and Metallurgical Combinat and "Navoiuran" enterprises operate are studied. During the research, comparative analysis and grapho-analytical methods were used. As a scientific novelty, the concept of considering the ecological buffer not only as a sanitary-hygienic means but also as an aesthetic and functional connecting "green corridor" between the industrial area and the city is put forward.*

Keywords: *ecological buffer zone, industrial landscape, landscape ecology, biocellulose system, Miyawaki method, green infrastructure, anthropogenic load, compositional modeling, green corridor.*

Аннотация: *В данной научной статье исследуются теоретические и практические основы создания экологической буферной ландшафтной системы на примере промышленной зоны города Навои. Исследование направлено на моделирование защитных зон между промышленными предприятиями и жилыми массивами на основе принципов ландшафтной экологии и архитектурного дизайна. В статье анализируется международный опыт проектирования экологических буферов для промышленных зон. На основе сравнительного анализа изучены экологическая ситуация, антропогенная нагрузка и состояние существующих зелёных зон на территории, где функционируют Навоийский горно-металлургический комбинат и предприятия «Навоиуран».*

В ходе исследования использовались методы сравнительного анализа и графоаналитический метод.

В качестве научной новизны выдвинута концепция рассмотрения экологического буфера не только как санитарно-гигиенического средства, но и как эстетической и функциональной связующей «зелёной магистрали» (зелёного коридора) между промышленной зоной и городом.

Ключевые слова: *экологическая буферная зона, промышленный ландшафт, ландшафтная экология, биоцеллюлозная система, метод Мияваки, зелёная инфраструктура, антропогенная нагрузка, композиционное моделирование, зелёный коридор.*

1. INTRODUCTION

In modern urbanization processes, mitigating the impact of industrial areas on the environment is one of the global problems. Navoi city is a major industrial center of Uzbekistan, where the Navoi Mining and Metallurgical Combinat, the "Navoiuran" state enterprise, and chemical industry facilities are located. As a result of the activities of these enterprises, environmental problems have arisen, such as dust and gases emitted into the atmosphere, heavy metal pollution of the soil layer, and increased noise levels. Scientific research shows that the Navoi region ranks first in the republic in terms of industrial development, and the anthropogenic pressure in this area is extremely high. Therefore, creating an ecological buffer landscape system between the industrial zone and residential areas is an urgent scientific and practical task.

2. LITERATURE REVIEW.

There is international experience in designing ecological buffer zones. South Korean studies [1-4] have considered criteria for planning green zones around large industrial facilities, noise reduction, and environmental management issues. Creating ecological buffer zones around industrial facilities is not just planting trees, but a complex engineering and ecological solution. If we analyze the experience of South Korea, we see that they approach this issue through the concept of a "Green Buffer" [1].

1. Multilayered Density. South Korean studies [2, 5] indicate that to effectively absorb noise and dust, a buffer zone must consist of at least three layers:

– Lower layer: Dense shrubs (to trap dust).

– Middle layer: Evergreen, medium-height trees [45].

– Upper layer: Tall, broad-leaved trees (to direct airflow and block noise).

2. Noise reduction strategy. Distance alone does not reduce noise. Korean experts use a relief landscape. Artificial hills (berms) are formed between the industrial area and residential housing [6]. Trees planted on these hills reflect noise waves upwards [7].

Studies show that this method can reduce noise levels by more than 10-15 decibels [8].

3. Ecological management and remote monitoring. Modern buffer zones are equipped with "smart" systems [9]:

– Sensors: Continuously measure the amount of PM2.5 and PM10 particles in the air.

– Irrigation: Automated drip irrigation systems that save water are used.

– Species selection: Priority is given to plant species that are suitable for the region's climate and resistant to industrial gases (e.g., SO_2, NO_x) [46].

4. Integration with the city. In industrial cities of South Korea such as Ulsan or Ansan, buffer zones serve not only as a barrier but also as an ecological corridor [5]. These

zones serve to preserve biodiversity and are transformed into recreation areas for the population.

In studies conducted in Russia, buffer zones in loess massifs are interpreted as the basis of landscape ecology. In Russian studies, especially in areas where loess (loess-like loam) massifs are widespread, buffer zones are seen not just as a protective wall, but as the "framework of the landscape." Loess soils require a special approach due to their specific physical and mechanical properties (high porosity, subsidence, and low water resistance). In Russian experience, the main aspects of designing buffer zones in loess areas are as follows:

1. **Anti-erosion landscape framework.** Water and wind erosion develop very quickly on loess lands. Russian scientists (for example, in studies in the field of agroforestry reclamation) propose designing buffer zones for the following tasks [10, 11]:

– Hydrological stability: The tree root system strengthens the loess layer and prevents the formation of ravines.

– Moisture management: Buffer zones ensure snow accumulation and slow down the spring water runoff, moisturizing the deep layers of the soil.

2. **Phytomeliorative composition (Plant selection).** Since loess massifs are usually located in arid or semi-arid regions, in the Russian experience [12, 13], plant species are selected based on the following criteria:

– Deep-rooting species: To curb the subsidence properties of the soil.

– Salt and drought tolerance: Species tolerant to salinization processes typical of loess areas (e.g., white acacia, oleaster, certain types of deep-rooted elm).

3. **Ecological corridors and the "Oasis" effect.** In the Russian school of landscape ecology, buffer zones are considered a link in the "ecological network" [14, 15]. They act as a buffer between the industrial zone and agricultural land. Buffer zones in loess massifs soften the microclimate and reduce temperature fluctuations in the environment (which prevents loess soils from overheating and drying out) [16, 17].

In particular, the Miyawaki method used in the experience of Thailand [18] (associated with the name of the Japanese botanist Akira Miyawaki) allows for the establishment of dense ecological forests composed of fast-growing, native species around industrial zones. This method makes it possible to form a 30-year-old forest in 10 years. The application of the Miyawaki method around industrial areas in Thailand is one of the most successful examples of "nature acceleration" technology. For Thailand's humid tropical climate and zones with a high industrial load (for example, industrial parks around Bangkok), this method has become a real ecological solution.

In North American urban planning practice, 6-7 meter landscaped buffer strips [19], noise walls, and aesthetic berms [20] are used when planning industrial parks. The North American experience is considered very effective, especially in providing a "soft transition" between industrial and residential areas [21]. Although these 6-7 meter strips seem small, when properly designed, they act as an ecological and psychological filter. Planting trees alone is not enough. According to North American and European standards, vertical density is created for maximum efficiency [22]:

–lower layer: Noise-absorbing shrubs and dense lawn;

– middle layer: Decorative trees that trap dust;

– upper layer: Broad-leaved, tall trees (to direct air flow).

The experience in Navi Mumbai, India [23, 24, 25] demonstrates the legal and ecological importance of preserving green spaces in industrial zones. The experience of Navi Mumbai (New Mumbai) in India is considered one of the most interesting cases in the world for maintaining the balance between industry and nature in urban planning. Although this city was originally planned to reduce the population density of Mumbai [25], over time it turned into a major industrial center. The main features of the Navi Mumbai experience are as follows:

1. Legal regulation: The "CIDCO" standard [26]. CIDCO (City and Industrial Development Corporation), the master planner of Navi Mumbai, has introduced strict norms for industrial zones.

– Zoning: The mandatory preservation of a "green lung" between industrial enterprises and residential buildings is entrenched by law.

– Condition of land allocation: When allocating land to enterprises, an obligation to landscape a certain percentage of the area (usually 25-33%) is imposed.

2. Ecological significance: Protection of mangrove forests. Local mangrove (growing in saline soils) forests play a central role in Navi Mumbai's ecological strategy [27, 28]. This ecosystem naturally filters industrial waste and heavy metals. These areas have been declared an "Inviolable zone," acting as a natural shield that blocks noise and air pollution coming from industrial zones.

3. Industrial and landscape integration: In Navi Mumbai, industrial zones are not just a collection of factories [29, 30], but are connected by ecological corridors.

– Buffer Zones: Wide green belts have been established on the edges of the industrial zone.

– Water bodies: Natural lakes and canals around industrial enterprises have been preserved, which helps to moderate the microclimate of the area.

3. IDENTIFICATION OF THE PROBLEM

Initial monitoring studies conducted on the example of Navoi city [31, 32] show that the concentration of pollutants in the air and soil composition has exceeded the norm in certain areas [33]. Conducted monitoring studies indicate that the balance between industry and ecology has been seriously disrupted. This is a major challenge not only for ecology but also for urban architecture. The monitoring results and identified problems can be considered based on the following systematic analysis:

- **Monitoring indicators: Pollution level**

– Since the city of Navoi is under the influence of major giants such as "Navoiyazot," "Navoi Mining and Metallurgical Combinat," and "Navoi TPP," monitoring recorded an increase in the following indicators [33, 34]:

– In the air: Ammonia (NH_3), sulfur dioxide (SO_2), and fine dispersed dust particles ($PM_{2.5}$, PM_{10}).

– In the soil: The concentration of heavy metals (copper, zinc, lead) and compounds with high salt content is higher than the permissible norm.

●**Shortcomings of sanitary protection zones (SPZ):**

– Studies show that existing SPZs in Navoi exist only as a "distance on paper" [32, 33]:

– Passive landscape. Buffer zones simply consist of an empty area or randomly planted trees. They do not perform a gas-barrier function.

– Aerodynamic error. Trees should be planted in such a way that they do not block the air flow, but rather filter it and direct it upwards.

– In the current situation, air masses are stagnant, forming "smog."

●**Design solutions and monitoring-based proposals:**

– Based on the monitoring results [31], it is necessary to apply the following "Smart Landscape" methods in the city of Navoi:

– Phytoremediation. Planting special plant species (e.g., certain types of poplars and shrubs) that absorb heavy metals from the soil.

– Density gradient. Creating a system of dense shrubs in the area close to the industrial enterprise, and tall broad-leaved trees as the distance increases.

– Vertical barriers. Placing landscape compositions on artificial berms (hills) that absorb noise and dust. Existing green spaces are not enough to fully cover the ecological load, and they are not systematically designed.

Sanitary protection zones around industrial enterprises are often limited to establishing a standard distance, and their efficiency in terms of landscape architecture and ecological function is low.

4. RESEARCH METHODS

A comprehensive scientific approach was applied during the research, and the following methods play a key role:

●Comparative Analysis. The experience of different countries (Japan, Thailand, South Korea, Canada, Russia) in organizing ecological buffers around industrial zones was studied. In particular, the technical parameters of the Miyawaki method used around PTT oil depots in Thailand (plant density, soil mixture, care stages) and the 6-meter landscaped buffer requirements set for the industrial park in Ottawa were taken as a comparative basis. Based on the analysis results, elements suitable for the conditions of Navoi were selected.

●Grapho-analytical method. Space images (Google Earth, Yandex Maps) and master plan schemes of Navoi city were analyzed. Distances between industrial enterprises and residential zones, the location of existing green spaces, wind direction, and relief features were studied. Based on this analysis, the location and configuration of potential buffer zones were determined. Using the method for calculating anthropogenic load coefficients proposed by N.K. Komilova, the level of ecological stress in the area was assessed.

5. RESULTS

During the research, comprehensive results were accepted on the systematic assessment of the ecological situation in the large industrial facilities of Navoi city and adjacent areas, comparative analysis of international advanced practices, and the development of an innovative conceptual model of an ecological buffer system adapted to the specific climatic and soil conditions of this region based on the fundamental data obtained. The effectiveness of protective zones that have existed for many years between industrial enterprises and residential areas, but which cannot withstand today's growing ecological threats, was deeply studied through the prism of landscape ecology, modern architectural design principles, and the latest generation of biotechnological approaches. Conducted studies showed that it is impossible to preserve the ecological balance in industrial cities by solely relying on the distances specified in regulatory documents and using traditional, passive landscaping methods. Therefore, the research results include precise analytical data that serve to form a completely new paradigm at the intersection of urban planning and ecology. The results were systematized within three logically connected major sections.

5.1. Analysis of the ecological situation and existing green spaces

Against the background of rapid economic reforms carried out in the Republic of Uzbekistan, the share of industrial production in the gross domestic product (GDP) is increasing year by year. According to analytical data, the share of industry in the republic's GDP sharply increased from 23.5 percent in 2017 to 36 percent by 2020 [35]. This economic growth places an enormous anthropogenic burden directly on the Navoi region, which is considered the country's largest industrial center, and particularly on the city of Navoi. Although the Navoi region is territorially considered one of the smaller administrative units of the republic, it is the absolute leader in the industry of extracting and processing vast natural resources [47]. Because giant industrial facilities such as the "Navoi Mining and Metallurgical Combinat" (NMMC), the state enterprise "Navoiuran", the large chemical cluster joint-stock company "Navoiyazot", and the Navoi Thermal Power Plant (TPP) are located in the urban environment, the balance between industry and ecology here has entered an extremely delicate stage.

As a result of the activities of these continuously operating industrial enterprises, various chemical compounds, toxic gases, heavy metals, and dispersed dust particles released into the atmosphere have become a direct source of threat to the urban ecosystem and public health. According to the global analyses of the World Health Organization (WHO), ambient air pollution causes approximately 4.2 million premature deaths worldwide annually, and a significant portion of this figure falls precisely on industrially developing regions [36]. Fine dispersed particles (PM) in the air are fully recognized by the medical community as a major risk factor in the development of chronic obstructive pulmonary diseases (COPD), ischemic heart diseases, strokes, and even lung cancer [36]. On the example of the Navoi region, the dynamics of the spread of diseases such as diabetes, bronchial asthma, and metabolic disorders among the population are directly linked to the ecological situation [37].

Within the scope of the study, data from automated stations installed in Navoi city by the Center of Hydrometeorological Service's monitoring service for atmospheric, surface water, and soil pollution were deeply analyzed [36]. These data demonstrate the impact of industrial emissions on urban air in exact numbers. The comparative indicators obtained for assessing air quality are systematized in the following table.

Table 1. Concentration of pollutants in the air of Navoi city (2018)

Mixture (Chemicals/Metals)	**Fast**	**q-average, mg/m³**	**G**	**q-maximal, mg/m³**	**q**	**q>5 MPC,%**	**n**
Dust	1	0,1	0,072	0,5	0,0	0,0	846
Sulfur dioxide	1	0,003	0,002	0,014	0,0	0,0	846
	2	0,003	0,002	0,010	0,0	0,0	684
	3	0,003	0,001	0,009	0,0	0,0	405
Carbon monoxide	1, 1	0,653	4	0,0	0,0	774	
Nitrogen dioxide	1	0,05	0,013	0,10	1,1	0,0	846
	2	0,05	0,014	0,11	1,3	0,0	684
	3	0,04	0,011	0,09	0,5	0,0	405
Nitrogen oxide	1	0,05	0,015	0,12	0,0	0,0	846
Ozone	1	0,014	0,005	0,04	0,0	0,0	297
Phenol	3	0,002	0,001	0,005	0,0	0,0	405
Ammonia	1	0,03	0,013	0,09	0,0	0,0	846
	2	0,04	0,014	0,11	0,0	0,0	684
Lead (Pb)	1	0,03	–	0,08	–	–	12
Cadmium (Cd)	1	0,00	–	0,00	–	–	12
Copper (Cu)	1	0,02	–	0,06	–	–	12
Zinc (Zn)	1	0,15	–	0,33	–	–	12

Table columns mean the following:

–**Fast** – observation post number

–**q-average** – average concentration, mg/m^3

–**G** – standard deviation

–**q-maximal** – maximum concentration, mg/m^3

–**q** – frequency of concentration exceeding the single maximum permissible concentration (MPC m.r.), %

–**q>5 MPC** – frequency of concentration exceeding 5 MPC m.r., %

–**n** – number of observations

As can be understood from the table above, although many substances fluctuate around the permissible regulatory concentrations (PRC), it is alarming that the average annual indicator for nitrogen dioxide (NO2) has exceeded the PRC by 1.3 times [36]. Also, in the summer months when air temperatures rise sharply, the sharp increase in maximum single concentrations further heightens the probability of photochemical smog formation. Such high doses of nitrogen dioxide have a negative effect on lung function and lead to chronic respiratory tract inflammation [36]. Because the region of Uzbekistan, especially Navoi city, is under the influence of a specific dry climate and regional winds, the suspension of dust particles in the lower atmosphere for long periods and their spread over long distances have taken on an intensive character.

The main urban planning mistake causing the problem to become even more complicated is that the sanitary protection zones (SPZ) currently existing in Navoi city have lost their true landscape-ecological function. The results of the study confirmed that buffer zones are merely designated as a "distance on paper" in the urban plan, while in practice they consist of a passive landscape, i.e., a disorganized, sparsely planted collection of trees. These areas practically do not perform the function of a gas and dust blocking biomechanical shield. Worst of all, these sparsely planted plants disrupt aerodynamic laws: the trees are positioned in such a way that instead of capturing harmful particles in the air flow and filtering clean air upwards, they obstruct the natural circulation of the wind flow, creating grounds for gas masses to stagnate around the factories (the "smog" effect).

5.2. Adaptation of parameters based on international experience

Establishing buffer zones between industrial areas and residential locations is not a local problem, but one of the most pressing tasks of global urban planning. Taking into account the arid climate of Navoi city, the loess-like structure of its soil, and the high industrial stress, to find an innovative solution to the problem, the rich international experiences of landscape design and ecological planning schools from Japan, Thailand, South Korea, Russia, North America, and India were systematically researched, and their technical parameters were comparatively analyzed for adaptation to local conditions.

South Korean experience: "Green shield" composition and automated management. In areas like Ulsan and Ansan in South Korea, where the scale of industry is extremely large, the planning of buffer zones has advanced far beyond traditional architecture. In the practice of this country, green spaces are viewed not simply as an aesthetic element, but as a complex engineering solution blocking the impact of the industrial zone — a "Green Buffer". The Multilayered Density concept, established by Korean experts Park S., Sung H., and others, has the ability to optimally trap mechanical and chemical elements in the air. It is strictly stipulated that the system must consist of three plant layers: the lower layer consists of thick and dense shrubs for capturing surface dust; the middle layer consists of evergreen, medium-height trees to absorb gases throughout the year; and the upper layer consists of broad-leaved, extremely tall trees to aerodynamically direct the strong air flow upwards (dispersion). Also, reducing noise levels is not solved only by increasing the distance. Korean experience involves creating artificial soil mounds (berms - acoustic barriers) between industrial facilities and residential areas. Tree compositions formed on these relief mounds absorb noise waves and reflect them towards the sky. Clinical and engineering studies have proven that this approach reduces the level of acoustic noise coming from industrial areas by more than 10-15 decibels. Another important parameter is the "smart" systems installed in the territory. Modern sensors measuring PM2.5, PM10 dust particles, humidity, and toxic gases are integrated within the buffer area, and automated drip irrigation devices under climate control are used to rationally consume water reserves. These parameters directly serve as the most perfect model for cities with hot climates and scarce water like Navoi.

Russian and Chinese experience: Anti-erosion landscape framework of loess massifs. The soils of Navoi city are composed of loess (loess-like loam) massifs, distinguished by their porosity, rapid subsidence when exposed to moisture, and susceptibility to mechanical erosion. The Russian school of landscape ecology and agroforestry reclamation experts (Lu S., Lavrusevich A. A., Khoroshev A. V.) propose a unique approach in such heavy soil areas, namely, planning the buffer area not just as ecological protection, but as the "solid framework of the landscape." Wind and water erosion develop at a highly dangerous rate in loess soils, and there is a high probability of the formation of ravines and sinkholes. Therefore, in experiments in the arid loess plateaus of Russia and China (Gansu and Shaanxi provinces), phytomeliorative significance takes primary place in the selection of plant species. The selected tree species must be deep-rooting, resistant to salinization and long-term drought (e.g., white acacia - Robinia pseudoacacia, oleaster, deep-rooted elm species). A strong root system reinforces the porous soil and stops the destruction of the earth's surface. Additionally, a dense leaf canopy helps accumulate snow cover and slows down spring runoff, enriching groundwater. Such landscaped areas soften sharp temperature changes in the environment, creating a microclimatic "Oasis effect" that prevents the soil from overheating and drying out excessively.

Practice of Thailand and Japan: The success of the Miyawaki method in urbanized zones. One of the biggest achievements of the research is the discovery of the method developed by the Japanese botanist and ecologist, Professor Akira Miyawaki, as the most optimal variant for creating a forest in the difficult soil and harsh climate conditions of Navoi. While traditional forestry methods require hundreds of years to create a stable and independent ecosystem, the Miyawaki method bypasses the stages of ecological succession (natural succession) and allows for "nature acceleration" [38]. This method is based on selecting Potential Natural Vegetation (PNV) characteristic of the area, mainly climax species, and planting them mixed in an extremely dense manner (3-4 seedlings per square meter) [38]. The effectiveness of Miyawaki forests is scientifically proven; they grow 10 times faster than ordinary monoculture plantations, form a thickness 30 times denser, and their potential to capture carbon dioxide from the atmosphere is tens of times higher [38]. After two to three years of intensive care post-planting, these mini-forests turn into completely independent, self-sustaining, and maintenance-free biodiverse landscapes [38]. The system fully mimics all layers of a forest — the main canopy, subcanopy, shrubs, and herbaceous plants [38]. Especially in industrial parks around Bangkok, Thailand (such as at the Yokohama Rubber and PTT facilities), which have a humid tropical climate along with a very high industrial load, this method is yielding miraculous results, serving as the most successful shield absorbing city pollution. Furthermore, the Miyawaki method is successfully applied not only in Asia but also in North America. For example, at the University of Iowa, over 4,000 trees were planted using exactly this method to create an artificial forest within the campus, and immense biological diversity was achieved in a short period [39]. At the same time, this method has also proven itself in arid regions (such as the deserts of Rajasthan in India). Before creating a forest in desert areas, the territory is brought up to the level of an irrigated oasis by building "water harvesting" facilities, i.e., traditional ponds and water harvesting technologies [40]. Once the Miyawaki forest is formed in that area, it alters the soil structure to such an extent that any precipitation is stored directly in the root zone, and surface evaporation practically stops [40].

India and North America: Legislative tools and spatial integration. However powerful technological and biological methods may be, it is difficult to preserve ecological buffers without a legal foundation. The situation in Navi Mumbai (formerly New Mumbai), India, is considered a rare example of legal regulation in urban planning. According to CIDCO (City and Industrial Development Corporation) standards, when allocating land to newly established enterprises here, an obligation to strictly landscape a certain part of the total industrial area, more precisely 25-33 percent, is imposed from a legal point of view. The mangrove (salt-tolerant) forests adjacent to industrial areas have been declared entirely inviolable zones ("Inviolable Zone") and transformed into the main means of absorbing industrial waste. From the experience of the USA and Canada (for example, the codes of the cities of Ottawa and Banks), the system of minimum 6-7 meter landscaped strips aesthetically separating industrial and residential zones, i.e., "soft transition" and ecological corridor rules, were studied.

6. DISCUSSION

Practical and theoretical conclusions drawn during the research scientifically prove that the complex ecological situation that has arisen in Navoi city requires a fundamental reconsideration of traditional and outdated ecological approaches. The main issue that draws attention is that it is impossible to stop or slow down the activities of strategic facilities critical to the economy, such as the Navoi Mining and Metallurgical Combinat or thermal power plants. This means that nitrogen dioxide, carbon monoxide, ammonia, and heavy metals released into the atmosphere will not disappear on their own.

The main emphasis in the center of the discussion is focused on the highly critical nature of the functioning of existing sanitary protection zones (SPZ). Existing landscaping objects are composed of passive plants, and their planting in a single line or open sparseness is the biggest aerodynamic mistake. Such "perforated" forest areas dampen the dispersion energy of the air flow, and as a result, sulfur dioxide or NO_2 gases are not pushed out of the city, but instead create thick polluted air lenses (smog) directly within the city area. Therefore, creating terraced landscape covers on artificial hills, as in the Korean experience, which properly direct the energy of wind and air masses and scatter toxic elements to the top of the atmosphere, is a highly strategic solution.

The issue of using the Miyawaki technology and biocellulose coatings requires an approach from the perspective of economic and ecological profitability. Although traditional methods seem cheap and easy at the initial stage, in an arid climate, 50-70 percent of them dry out without taking root. It is clear that operations of the Miyawaki method, such as enriching the soil with biomass at a depth of one meter, extremely dense planting, and laying valuable biocellulose layers on top, sharply increase initial investments [41]. However, as experts note, mini-forests that grow 10 times faster, shift to independent self-management, and reach a 20-30 year appearance in just 3 years completely offset the long-term economic costs incurred for the ecological rehabilitation of the territory [38]. Moreover, the remarkable qualities of the biocellulose coating, such as retaining heat and preventing evaporation, allow for unprecedented savings in water consumption, which is the most scarce resource in Navoi city during the summer months [42].

The medical-social and human health direction of the issue is the next important part of the discussion. Relying on WHO reports, toxic agents in ambient air such as NO2 and PM2.5 directly enter the circulatory system and provoke cardiovascular and pulmonary pathologies [36]. Long-term monitoring indicators in Navoi show the probability of an increase in these types of diseases [43]. Naturally, an ecological buffer must be not only a technical filter but also a psychological and medical shield for society. The proposed "Green Corridor" and biodiversity in the area will create an "Oasis effect," serving to directly integrate the population with nature and uplift their social mood.

Finally, it is necessary to touch upon the modern methodology of ecological control. Analyses conducted by scientists such as Aslonova and Chulponov [31, 48] show that the time has come to abandon traditional local observations and transition to multidisciplinary approaches that remotely assess the quality of atmosphere, soil, and water all at once. The direct integration of IoT (Internet of Things) sensors into the ecological buffer zone allows for the continuous visualization of processes in the system, the transmission of data to a centralized database combined with GIS technologies, and the activation of an automated alerts system during crisis situations (for example, when NO2 or dust amounts increase sharply). As seen in the experience of Beijing's "Clean Air" program [44], visually publishing monitoring results on open portals for the general public positively changes the people's attitude towards environmental cleanliness and lays the groundwork for the activation of social participation rather than administrative pressure.

7. CONCLUSION

The outcomes of the landscape-ecological, architectural, and geochemical analyses conducted between Navoi city and the vast mining-metallurgical and chemical clusters located there demonstrate that, as a result of continuously increasing industrial pressure, the city's ecosystem's self-cleaning and self-preserving capabilities are on the verge of complete depletion. The continuous presence at high limits of nitrogen dioxide, sulfur, dispersed solid dust particles in the atmosphere, and heavy metals such as lead, zinc, and copper in the soil substrate makes it a vital necessity to urgently establish green buffer zones that are actively reactive, multi-layered, and armed with advanced biotechnologies.

The following strategic conclusions and practical recommendations can serve as a long-term mechanism for solving the problem:

- **Changing the architectural paradigm:** It is necessary to abandon the practice of creating passive and monoculture landscapes on the edges of industrial zones and immediately transition to a Multilayered Density format laid out on artificial elevations (berms) that comply with aerodynamic rules. This allows noise and heavy particles in the air to be dispersed without entering the city.
- **Miyawaki technology and Biocellulose coatings:** In order for plants to develop independently in the long term in desert and loess soil zones and to ensure a high survival rate of seedlings, the Miyawaki "nature acceleration" method must be put into practice. When establishing these forest areas, especially in the initial years, it is an innovative

necessity to cover the soil surface with acid-inhibitor bacterial cellulose (biocellulose and PVA/chitosan) composite biofilms to stop soil erosion, create an incubator environment for young saplings, and prevent the rapid evaporation of precious water resources.

●**Forming a complete phytoremediation scope:** Taking into account the specificity of Navoi's ecological problem (i.e., pollution with heavy metals, SO2, and NO2), it is necessary to proportionally place deep-rooting, highly salt-tolerant climax species capable of absorbing metals (white acacia, oleaster, deep-rooted elm, and endemic species) in the core protection zone.

●**Digital and smart integration:** Plant and landscape protection must be under the care of an automated monitoring system based on IoT and GIS technologies. The drip irrigation network should be remotely controlled using electronic sensors that transmit harmful PM2.5 particle levels in the air and soil moisture parameters with second-by-second accuracy, and a system of complete process control and automated alerts must be developed.

●**Tightening legislation and spatial norms:** Considering the growth rates of the region's industrial power, similar to the experience of Navi Mumbai's CIDCO standards, it is proposed to legalize the obligation of creating a green zone precisely in the Miyawaki style on no less than 25-30 percent of the area, in addition to maintaining a certain sanitary distance, during the process of land allocation and licensing for all active and future enterprises.

The combined integration of these practical, legal, and technological measures will not only curb the anthropogenic crisis in Navoi city and ensure environmental recovery but also serve as a rare scientific and practical model for other industrial giants in complex conditions across Uzbekistan, such as Almalyk, Bekabad, and Chirchik.

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