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ECOLOGICAL ASSESSMENT OF AEROTECHNOGENIC POLLUTION BY HEAVY METALS IN THE NORTH KAZAKHSTAN REGION

Annotation. This article presents an ecological assessment of air and soil pollution in the North Kazakhstan region caused by heavy metals. Modern analytical methods, including mapping, statistical data processing, and comparative analysis, were applied to evaluate contamination levels and their environmental impact. The study provides graphical and tabular data on pollutant concentrations, spatial distribution, and potential health risks for the local population.Environmental pollution by heavy metals is a pressing issue due to their persistence, bioaccumulation potential, and toxic effects on ecosystems and human health. The North Kazakhstan region is influenced by various anthropogenic factors, including industrial emissions, agricultural practices, and vehicular traffic, which contribute to atmospheric and soil contamination. Heavy metals such as lead (Pb), cadmium (Cd), zinc (Zn), nickel (Ni), and mercury (Hg) are released into the environment through industrial activities, transportation exhaust, and the application of agrochemicals. These pollutants settle into the soil, posing long-term risks to agricultural productivity, groundwater quality, and biodiversity.The research methodology involves field sampling, laboratory analysis, and geospatial assessment using GIS technologies to visualize contamination hotspots. Concentrations of heavy metals in air and soil were compared against national and international environmental safety standards to determine the extent of pollution. The study also assesses the ecological risks associated with metal contamination, focusing on their potential impact on human health. Chronic exposure to heavy metals can lead to serious health issues, including respiratory disorders, neurological impairments, and carcinogenic effects.The findings highlight the most affected areas and suggest measures to mitigate pollution, such as improved emission controls, sustainable land-use practices, and stricter environmental regulations. The study contributes to developing a framework for long-term monitoring and pollution management strategies to ensure ecological safety in the region.

Keywords: ecological assessment; heavy metals; atmospheric air; soil; pollution.

Introduction

Environmental safety, as an integral part of the national security of the Republic of Kazakhstan, is a fundamental prerequisite for sustainable development. It serves as the foundation for preserving natural systems and maintaining the appropriate quality of the environment and living conditions for the population [1].

The issues related to the dependence of public health on environmental factors are of paramount state importance, which is particularly relevant for Kazakhstan due to its significant range of ecological problems [2].

To prevent and mitigate the negative anthropogenic impact on the environment and to create a high-quality living environment, it is essential to conduct a reliable, objective, and timely assessment of the ecological situation. Only through such an approach can well-founded decisions be made regarding the regulation of the qualitative and quantitative characteristics of the natural environment [3].

Environmental pollution caused by heavy metals is a growing concern worldwide due to its long-term impacts on ecosystems and human health [4]. Heavy metals, such as lead (Pb), cadmium (Cd), nickel (Ni), zinc (Zn), and mercury (Hg), are known for their toxicity, persistence in the environment, and ability to bioaccumulate [5]. Unlike organic pollutants, heavy metals do not degrade over time, leading to their continuous accumulation in air, soil, and water resources. In particular, aerotechnogenic pollution—caused by industrial and transportation emissions—plays a crucial role in the contamination of atmospheric air and the subsequent deposition of pollutants onto soil surfaces [6].

The North Kazakhstan region, located in the northern part of Kazakhstan, is a territory with a diverse landscape that includes agricultural lands, industrial zones, urban areas, and natural reserves. While the region is not traditionally considered an industrial hub, various anthropogenic activities contribute to environmental pollution. Industrial emissions from power plants, processing facilities, and manufacturing industries release heavy metals into the atmosphere, which later settle onto soil surfaces, affecting agricultural productivity and ecosystem stability [7]. Agricultural practices, including the use of pesticides, fertilizers, and irrigation with contaminated water, further exacerbate the accumulation of heavy metals in the environment [8]. Additionally, transportation corridors, particularly in urban centers, significantly increase atmospheric pollution due to exhaust gases and wear of vehicle components such as brakes and tires, which release metal particles into the air [9].

The ecological assessment of aerotechnogenic pollution by heavy metals is essential for understanding the extent of contamination, identifying pollution hotspots, and evaluating the potential risks posed to the population [10]. Long-term exposure to heavy metals has been linked to various adverse health effects, including respiratory diseases, neurological disorders, cardiovascular problems, and an increased risk of cancer [11]. Children and vulnerable populations are particularly at risk, as heavy metals can interfere with cognitive development and immune system function [12]. Given the health and environmental implications, it is imperative to conduct comprehensive monitoring and analysis to develop effective mitigation strategies [13].

This study aims to provide a detailed ecological assessment of air and soil pollution in the North Kazakhstan region, focusing on the concentration of heavy metals, their spatial distribution, and the associated environmental risks [14]. The research employs modern analytical methods, including geographic information system (GIS) mapping, statistical data analysis, and comparative assessment of pollution levels against national and international environmental standards [15]. By integrating these methods, the study seeks to offer a clear understanding of the pollution sources and their impact on local communities [16].

The soil cover of the North Kazakhstan region consists primarily of chernozems of two subtypes: leached and ordinary medium-humic soils [17].

According to **SanENR 2.1.7.1287-03 (Sanitary and epidemiological norms and rules)**, exceedances of Maximum Permissible Concentrations (MPC) or Tentative Safe Levels (TSL) of chemical contaminants are not allowed in residential areas. This restriction is even more stringent for high-risk zones, including childcare and educational institutions, sports and playgrounds in residential areas, recreational zones, sanitary protection zones of water bodies, and coastal areas [18].

Materials and methods of research

Study Area and Sampling Sites. The study was conducted across multiple administrative districts of the North Kazakhstan region, covering a diverse range of land use types, including.Residential areas – urban and suburban zones with dense population exposure [19]. Industrial zones – sites near manufacturing plants, power stations, and processing facilities [20]. Agricultural lands – farmland subject to pesticide and fertilizer application [21].Recreational areas – parks, nature reserves, and public green spaces [22].Transport corridors – highways, major roads, and urban intersections with high vehicular traffic [23].

Soil and air samples were collected from each of these zones to determine the levels of heavy metal contamination and assess the associated environmental risks. Sampling points were georeferenced using a GPS system to ensure accurate spatial mapping of pollution distribution [24]. Sampling Methods. The collection of atmospheric air and soil samples was performed in accordance with GOST 17.2.3.01-86, which regulates air and soil sampling for pollution analysis [25].

Soil Sampling. Soil samples were collected from the top 0-20 cm layer using a stainless-steel auger to minimize contamination [26]. Each sampling site consisted of a composite sample, combining five subsamples taken within a 10-meter radius to account for local variability [27]. The samples were placed in polyethylene containers, labeled, and transported to the laboratory under controlled conditions to prevent alteration of chemical composition [28]. Soil pH, organic matter content, and texture were also recorded to assess the potential influence of soil properties on metal retention and mobility [29].

Air Sampling. Air samples were collected using high-volume air samplers equipped with quartz fiber filters to capture particulate-bound heavy metals [30].The filters were weighed before and after sampling to determine total suspended particulates (TSP) [31].Samples were taken at different times of the day to evaluate variations in metal concentrations due to traffic patterns and industrial activity [32].

Laboratory Analysis Methods. To determine the concentration of heavy metals, a combination of advanced analytical techniques was employed to ensure high precision and accuracy. The following methods were used.Atomic Absorption Spectroscopy (AAS). Used to measure the concentrations of Pb, Cd, Zn, Ni, Cr, Cu, and Co in soil and air samples. Samples were digested in a mixture of nitric acid (HNO_3) and hydrochloric acid (HCl) before analysis. AAS provided high sensitivity in detecting trace metal concentrations [33].

X-ray Fluorescence Analysis (XRF). Used for rapid, non-destructive screening of heavy metals in soil samples. Provided data on Mn, Fe, V, and Mo without requiring chemical digestion. Allowed quick identification of pollution hotspots for further detailed analysis [34].Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Applied for ultra-trace detection of metals such as As, Hg, and Se in soil and air samples. Offered a wide dynamic range and high precision for low-concentration metals [35].

Statistical Data Processing and GIS Mapping. Data analysis was conducted using RStudio for statistical computations, including.Descriptive statistics (mean, median, standard deviation) [36]. Principal Component Analysis (PCA) to identify dominant pollution sources [37].Correlation analysis to assess relationships between metal concentrations [38].Geographic Information System (GIS) software was used to visualize spatial pollution patterns, enabling the creation of heat maps of contamination levels [39].

Research Results

Identification of Priority Pollutants. Preliminary data analysis identified priority soil pollutants in the North Kazakhstan region and highlighted the need for further examination due to environmental concerns. The study established average concentrations, median values, and interquartile ranges for each metal.

Exceedances of the Maximum Permissible Concentration (MPC) and exceedances of Background Values (Fig. 1).

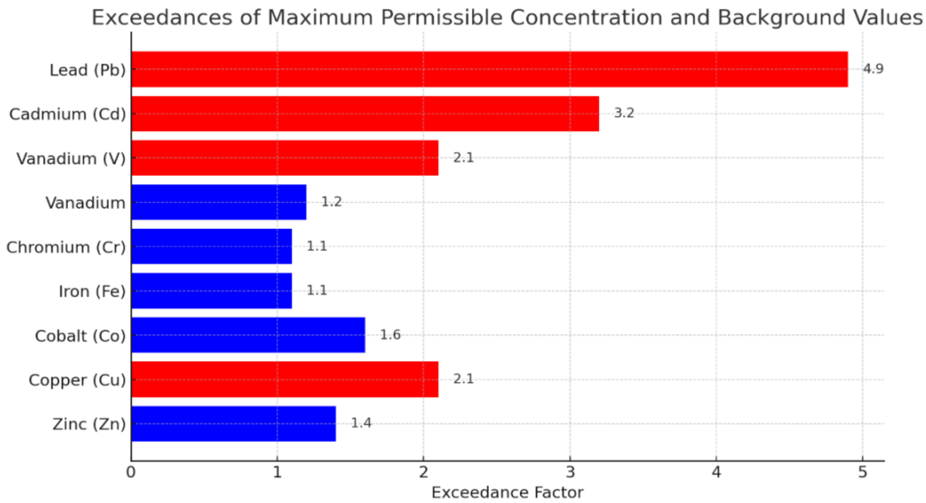

Figure**1 -** Exceedances of the Maximum Permissible Concentration (MPC) and deviations from background values

Figure1 shows the excess coefficients for various heavy metals and elements the context of the environment. Lead (Pb) has the highest exceedance factor at 4.9, indicating a significant contamination level. Cadmium (Cd) follows with an exceedance factor of 3.2, also presenting a high level of contamination. Vanadium (V) and Copper (Cu) both show an exceedance factor of 2.1.Cobalt (Co) exceeds permissible levels by 1.6 times. Zinc (Zn) exceeds by 1.4 times. Chromium (Cr) and Iron (Fe) both have relatively low exceedances at 1.1.

Areas with maximum soil pollution were identified, indicating a direct need for further analysis due to environmental instability. A comparative analysis of heavy metal content was conducted for key sites in each administrative district of the North Kazakhstan region. The highest concentrations of toxic metals were observed in urban and industrial areas, with agricultural and recreational zones demonstrating relatively lower pollution levels. The main sources of atmospheric pollution are industrial enterprises and motor vehicles.

To assess the level of soil contamination with heavy metals, the average concentrations of lead (Pb), cadmium (Cd), zinc (Zn), and nickel (Ni) were compared with their respective maximum permissible concentrations (MPCs). The results are shown in Figure 1.

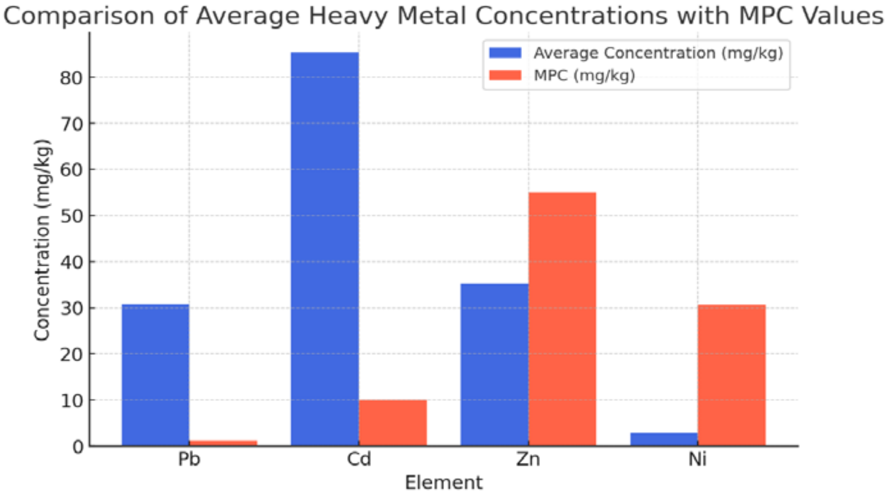

Figure 2 - Comparison of Average Heavy Metal Concentrations with Maximum Permissible Concentrations (MPC)

An analysis of the impact of heavy metals showed that the exceedance of maximum permissible concentrations (MPC) was observed in 30% of soil samples and 15% of atmospheric air samples. The most hazardous elements are Pb and Cd, which have a cumulative effect.

Figure 2 compares the average concentrations of heavy metals (Pb, Cd, Zn, Ni) with their maximum permissible concentrations (MPC) in mg/kg. Lead (Pb): The average concentration is significantly higher than the MPC. Cadmium (Cd): The average concentration is extremely high compared to the MPC, indicating a serious exceedance. Zinc (Zn): The MPC value is higher than the average concentration, suggesting that Zn levels are within acceptable limits. Nickel (Ni): The MPC value is much higher than the average concentration, meaning Ni contamination is not a concern. The chart suggests that Cd and Pb exceed permissible limits, whereas Zn and Ni remain within acceptable thresholds.

Here is the bar chart comparing the average heavy metal concentrations with MPC values **(Fig. 3)**.

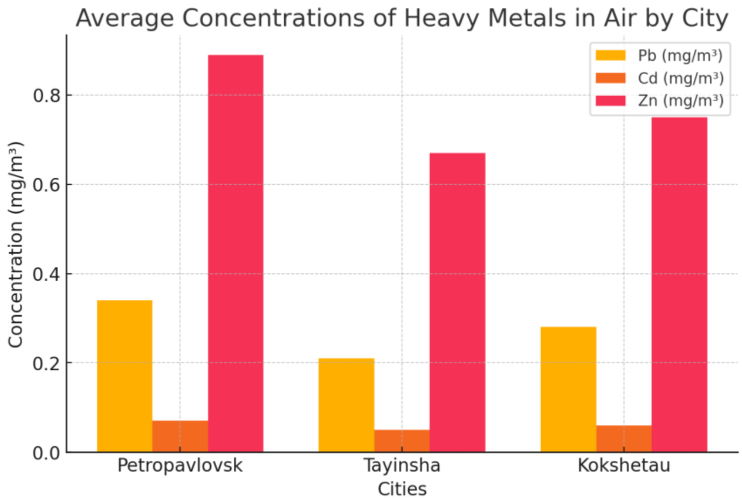

Figure 3 - Average concentrations of heavy metals in the air by city.

In Figure 3, the average concentrations of heavy metals (Pb, Cd, Zn) in the air are presented for three cities: Petropavlovsk, Tayynsha, and Kokshetau. Zinc (Zn) shows the highest concentration in all cities, with Petropavlovsk having the highest level (~0.85 mg/m³), followed by Kokshetau and Tayynsha. Lead (Pb) concentrations are moderate across all cities, with Petropavlovsk and Kokshetau having similar values, while Tayynsha has a slightly lower level. Cadmium (Cd) exhibits the lowest concentration among the three metals, remaining relatively consistent across all cities.The data suggests that Zn pollution is the most significant concern, particularly in Petropavlovsk, while Pb and Cd are present at lower levels.

These findings indicate that Petropavlovsk has the highest recorded levels of lead and zinc, likely due to industrial emissions and vehicle traffic.A detailed analysis of heavy metal accumulation in soil was performed across different landscape-geochemical conditions.

To provide a comprehensive characterization of the chemical element content in the soil cover, the minimum, maximum, mean, and median concentration values were calculated for each element **(Fig. 4)**.

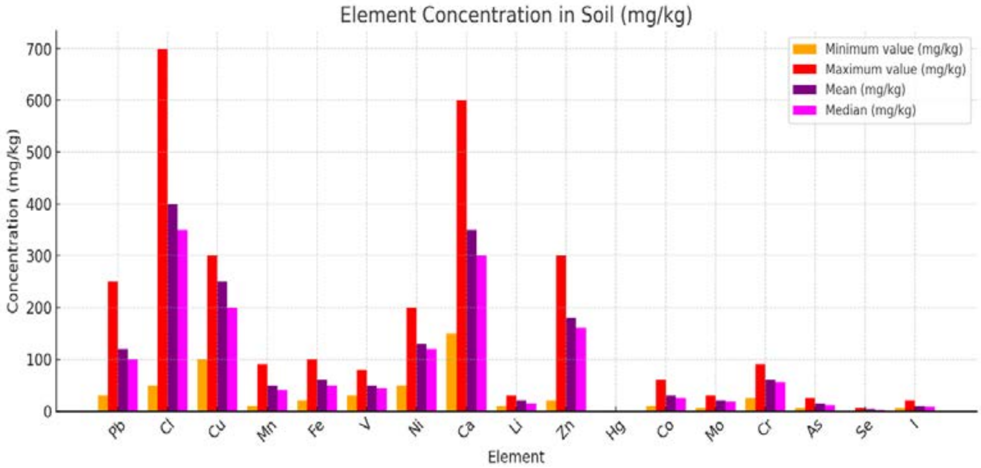

Figure 4 – Element Concentration in Soil (mg/kg)

In Figure 4, the concentrations of various elements in the soil (mg/kg) are presented, showing minimum, maximum, mean, and median values for each element. Chlorine (Cl) and Calcium (Ca) exhibit the highest maximum concentrations, with Cl reaching approximately 700 mg/kg and Ca around 600 mg/kg. Zinc (Zn) and Lead (Pb) also have relatively high concentrations, with significant variation between their minimum and maximum values. Copper (Cu), Nickel (Ni), and Manganese (Mn) show moderate concentrations, with the mean and median values closely aligned, indicating a more consistent distribution. Elements like Mercury (Hg), Cobalt (Co), Molybdenum (Mo), and Selenium (Se) have very low concentrations compared to others. The difference between maximum and minimum values is quite large for elements like Cl, Ca, Zn, and Pb, suggesting potential contamination or natural variability in soil composition. This figure highlights significant variations in elemental concentrations, with certain elements exceeding expected background levels, possibly indicating anthropogenic influence or geochemical anomalies. The highest concentrations of Pb, Cu, and Zn were recorded near major industrial facilities. To quantify soil contamination, the pollution index (Zc) was calculated. To assess soil pollution levels across different functional land-use zones, an integrated soil pollution index (Zc) was calculated. The distribution of pollution shares by zone type is illustrated in Figure 5.

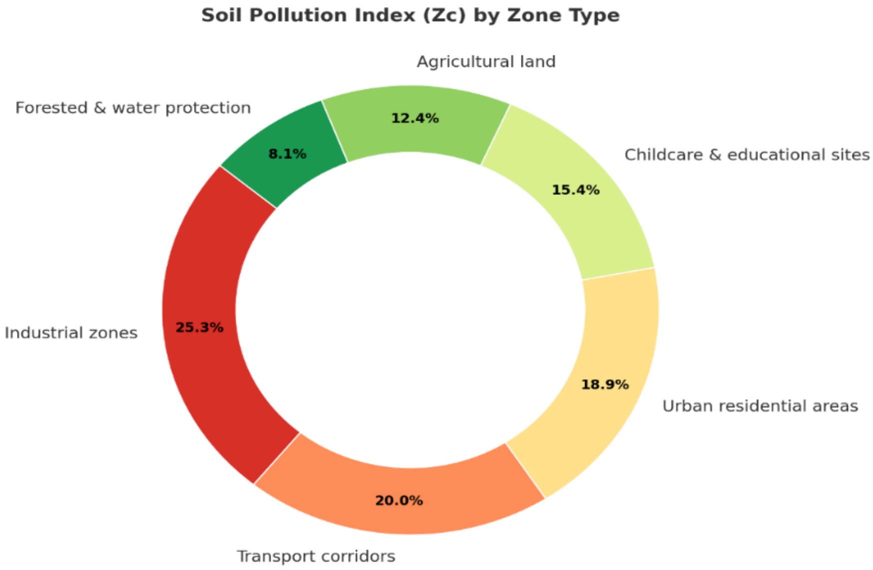

Figure **5 - Soil Pollution Index**

Figure 5 shows the Soil Pollution Index (Zc) distribution by zone type in the form of a donut chart. Industrial zones have the highest soil pollution index at 25.3%, indicating significant contamination likely due to industrial activities.Transport corridors follow with 20.0%, suggesting a notable impact from vehicle emissions and road-related pollution.Urban residential areas account for 18.9%, reflecting moderate pollution levels, possibly from household waste and urban runoff.Childcare & educational sites show 15.4%, highlighting concerns about pollution exposure in sensitive areas.Agricultural land contributes 12.4%, which may indicate pollution from fertilizers, pesticides, or other agricultural activities.Forested & water protection areas have the lowest soil pollution index at 8.1%, suggesting better environmental conditions in these regions.

The figure 6 shows a comparison of the average concentrations of heavy metals in the soils of Northern Kazakhstan with their maximum permissible concentrations (MPC).

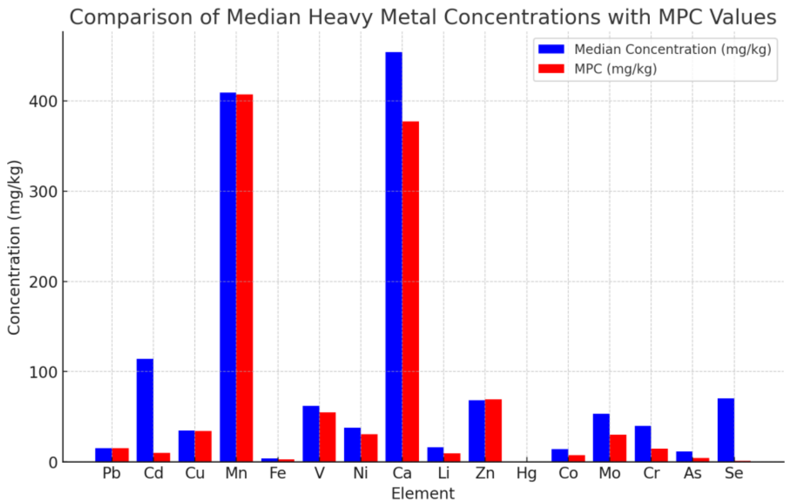

Figure 6 - Comparison of average concentrations of heavy metals in the soils of Northern Kazakhstan with their maximum permissible concentrations (MPC)

From Figure 6, it is evident that the median concentrations of sever. Calcium (Ca) and Manganese (Mn) have the highest concentrations, with their median values (blue) either exceeding or closely matching the MPC values (red).Copper (Cu), Nickel (Ni), and Zinc (Zn) also show significant concentrations, with median values either above or near the regulatory limits. Cadmium (Cd) and Lead (Pb) exhibit relatively low concentrations but still need monitoring due to their toxicity. Arsenic (As) and Selenium (Se) have notable concentrations, indicating potential risks of contamination.For most elements, the median concentration is either comparable to or exceeds the MPC, highlighting potential concerns for soil contamination and environmental safety. This figure suggests that Mn, Ca, Ni, and Zn contamination is particularly significant, warranting further investigation and possible remediation efforts.

Discussion

The results of this study reveal critical insights into the spatial distribution, concentration levels, and potential ecological risks associated with heavy metal contamination in the soils and atmospheric environments of the North Kazakhstan region. The identification of lead (Pb), cadmium (Cd), copper (Cu), vanadium (V), and zinc (Zn) as the primary pollutants underscores the anthropogenic pressures on the regional environment, particularly from industrial and vehicular sources. The exceedance coefficients presented in Figure 1 confirm that Pb and Cd pose the greatest concern, with exceedance factors of 4.9 and 3.2, respectively—indicating significant contamination levels. These findings align with global concerns regarding the persistence and toxicity of these metals, both of which are known to bioaccumulate and exert adverse health effects even at low concentrations. Moderate exceedances by elements such as V, Cu, Co, and Zn also signal cumulative risk, particularly in zones with high human activity.

Figure 2 and Figure 6 further illustrate that the average and median concentrations of several metals surpass maximum permissible concentrations (MPCs). While zinc and nickel remain largely within acceptable limits in some locations, their elevated levels in certain hotspots require continued observation. Notably, the elevated calcium (Ca) and manganese (Mn) levels seen in Figure 6 may be attributable to natural soil mineralogy but could also indicate geochemical anomalies or cumulative agrochemical inputs. The airborne concentrations shown in Figure 3 reveal that zinc is the most dominant heavy metal pollutant in urban air, particularly in Petropavlovsk. This may be explained by high vehicular density and industrial discharges in the area. Despite lower airborne levels of cadmium and lead, their potential for long-range transport and deposition means they remain ecologically and epidemiologically relevant.

Figure 4 highlights wide variations in element concentrations across soil samples. The significant spread between minimum and maximum values, particularly for chlorine, calcium, lead, and zinc, suggests heterogeneous contamination patterns—possibly driven by land use intensity, historical emissions, and natural soil variability. High concentrations of toxic metals near industrial facilities further support the hypothesis of localized point-source pollution. The calculated Soil Pollution Index (Zc) presented in Figure 5 reinforces the dominance of industrial zones (25.3%) and transport corridors (20.0%) as major contributors to regional pollution loads. These findings are consistent with other studies conducted in post-industrial landscapes, where heavy metal accumulation is commonly attributed to metallurgical, chemical, and vehicular emissions. Alarmingly, childcare and educational sites (15.4%) and urban residential areas (18.9%) also exhibit notable pollution shares, indicating potential long-term health risks for vulnerable populations, including children.

From an environmental management perspective, these findings warrant immediate attention. First, it is crucial to strengthen soil and air monitoring networks, particularly in urban and industrial areas, where pollutant concentrations and exceedance coefficients are highest.

Second, effective remediation and containment strategies must be implemented in zones identified with high levels of lead (Pb) and cadmium (Cd) contamination, as these elements pose the greatest toxicological risk. Third, pollution buffer zones should be established around childcare facilities, residential neighborhoods, and agricultural lands to minimize human and ecological exposure. Additionally, the promotion of cleaner production technologies and stricter vehicular emissions control in industrial regions can significantly reduce ongoing sources of contamination.

This study highlights the need for a targeted and multi-scalar soil management strategy tailored to the environmental conditions of Northern Kazakhstan. Such a strategy should integrate scientific monitoring frameworks with policy-driven interventions aimed at pollution control and land-use regulation. Future research should prioritize the assessment of seasonal variations in heavy metal accumulation, the bioavailability of contaminants, and their long-term effects on human health and agricultural productivity.

Conclusion

The study revealed significant air and soil contamination with heavy metals in the North Kazakhstan region, primarily in industrial zones and transport corridors. Pb, Cd, and Zn concentrations in urban air exceed safe limits, with Petropavlovsk being the most affected city. Soil pollution hotspots are concentrated in industrial and urban zones, with lead and cobalt posing the highest risks. Soil pH and geochemical factors influence heavy metal mobility and bioavailability.Chronic exposure to heavy metals may lead to significant health risks.

The priority soil pollutants among heavy metals include chromium, cobalt, copper, zinc, vanadium, and iron, as well as arsenic, for which exceedances of Maximum Permissible Concentrations (MPC) and background values were observed. A significant exceedance of MPC (more than five times) was characteristic of arsenic in soil samples. The proportion of soil samples exceeding the MPC for lead was 33%, with lead concentrations in samples collected from residential areas being statistically significantly higher than those in other zones.

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СОЛТҮСТІК ҚАЗАҚСТАН ОБЛЫСЫНДА АУЫР МЕТАЛДАРМЕН АЭРОТЕХНОГЕНДІК ЛАСТАНУДЫ ЭКОЛОГИЯЛЫҚ БАҒАЛАУ

Аңдатпа. Бұл мақалада Солтүстік Қазақстан облысындағы ауыр металдармен ауаның және топырақтың ластануына экологическиялық баға беру мәселесі қарастырылады. Ластану деңгейін және ониң қоршаған ортаға әсерін бағалау үшін заманауи аналитикиқ әдістер, соның ішінде картографиялау, статистическилық деректерді өңдеу және салырмастылы талдау қолданылды. Зерттеу барысында ластаушы заттардың концентрации, олардың кеңістіктік таралуы және жергілікті халық үшін ықтимал қауіптері туралы графиклық және кестелік мәліметтер ұсынылған. Ауыр металдармен қоршаған ортаның ластануы олардың тұрақтылығы, биожиналу қабілеті және экожүйелер мен адам денсаулығына уытты әсері салдарынан өзекти мәселе болып табылады. Солтүстік Қазақстан облысы өнеркәсіптік шығарындылар, ауыл шаруашылығы қызметі және көлик қозғалысы сияқты әртүрлі антропогендік факторлардың ықпалына ұшырайды, бұл атмосфера мен топырақтың ластануына алып келеді. Қорғасын (Pb), кадмий (Cd), мырыш (Zn), никель (Ni) және сынп (Hg) сияқты ауыр металдар өнеркәсіптик қызмет, көлік шығарындылары және агрохимикаттарды қолдану нәтижесінде қоршахан ортаға түседі. Бұл ластаушы заттар топыраққа жиналып, ауыл шаруашылығы өндірісіне, жер асты суларының сапасына және биологическиелық әртүрлілікке ұзақ мерзімді қауіп төндіреді. Зерттеу әдістемесі даллық сынама алуды, зертханалық талдауды және ластану ошақтарынок визуализации үшін ГАЖ технологииларын қолдана отырып, геокеңістіктік бағалауды қамтиды. Ауыр металдардың ауа мен топырақтағы концентрации ластану деңгейин анықтау үшін ұлттық және халықаралық экологическиялық қауіпсіздік стандарттарымен салыстырылды. Сонымен қатар, зертеу металдармен ластанудың экологическиялық қауіптерін және олардың адам денсаулығына әсерін бағалауға бағытталған. Ауыр металдардың созылмалы әсері тыныс алу ауруларына, неврологиялық бұзылуларға және канцерогендік әсерлерге әкелуі мүмкін.

Зерттеу нәтижелері ең қатты зардап шеккен аймақтарды анықтап, ластануды азаиту шараларын, соны ішінде шығарындыларды бақылауды күшейту, тұрақты жер пайдалану тәжірибесин на английском языке және экологическиялық нормаларды қатаңдату жөнінде ұсыныстар береді. Бұл зерттеу аймақтың экологическиялық қауіпсіздігін қамтамасыз ету үшін ұзақ мерзімді мониторинг жүйесін және ластануды басқару стратегияларынок әзірлеуге ықпал етеді.

Кілтті сөздер: экологиялық бағалау; ауыр металдар; атмосферлық ауа; топырақ; ластану.

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ЭКОЛОГИЧЕСКАЯ ОЦЕНКА АЭРОТЕХНОГЕННОГО ЗАГРЯЗНЕНИЯ ТЯЖЕЛЫМИ МЕТАЛЛАМИ В СЕВЕРО-КАЗАХСТАНСКОЙ ОБЛАСТИ

Аннотация. Загрязнение окружающей среды хрупкими металлами является актуальной проблемой из-за их устойчивости, способности к биоаккумуляции и токсического воздействия на экосистемы и здоровье человека. Северо-Казахстанская область усиливает влияние различных антропогенных факторов, включая промышленные выбросы, сельскохозяйственные практики и автомобильный транспорт, способствующие загрязнению окружающей среды и окружающей среды. Тяжелые металлы, такие как свинец (Pb), кадмий (Cd), цинк (Zn), никель (Ni) и ртуть (Hg), попадают в окружающую среду в результате промышленной деятельности, выхлопной транспортировки газа и применения агрохимикатов. Эти загрязнители накапливаются в почве, создают долгосрочные риски для сельскохозяйственного производства, качества грунтовой воды и биоразнообразия. Методология исследования включает в себя полевые отборы проб, лабораторный анализ и геопространственную оценку с применением ГИС-технологий для визуализации очагов загрязнения. Концентрации металлов в атмосфере и почве сопоставляются с национальными и международными стандартами безопасности для определения степени загрязнения. В ходе регулирования также контролируются экологические риски, связанные с загрязнением металлами, с акцентом на их контролируемом воздействии на здоровье человека. Хроническое воздействие вредных металлов может привести к серьезным проблемам со здоровьем, включая респираторные заболевания, неврологические нарушения и канцерогенные эффекты. Результаты исследований выявляют наиболее пострадавшие районы и меры по снижению загрязнения, такие как улучшение контроля загрязнений, устойчивое землепользование и ужесточение экологических норм. Исследование проводится по разработке систем долгосрочного и стратегий управления загрязнением для обеспечения безопасности.

Ключевые слова: экологическая оценка; тяжелые металлы; атмосферный воздух; почва; загрязнение.