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RANKING THE TERRITORY OF THE ALMATY AGGLOMERATION ACCORDING TO THE DEGREE OF POLLUTION

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Abstract. The article considers the assessment of the transfer of pollutants by the state of pollution of snow cover and soil to rank the study area by degree of pollution (2018–2020). The object of the study is one of the major megalopolises of the country — the territory of Almaty agglomeration (AA) with a total area - 939.5 thousand hectares. The area of the agglomeration includes 188 settlements of Almaty region, the center of which is the city of Almaty, includes parts of five administrative districts of Almaty region: Karasai, Talgar, Ili, Enbekshikazakh and Zhambyl, as well as cities of Kaskelen, Kapshagai, Talgar and Yesik. Assessment of the degree of pollution of the territory of the Almaty agglomeration is calculated one of the characteristics of soil and snow cover (SC) pollution, which are the total pollution index (Zc), which is determined by the degree of accumulation of the pollutant compared to the background point. Analysis of pollution of the AA area according to the values of metal concentration ratios for

2018–2020 showed that the largest contribution is copper, zinc and lead in the soil, while for SC mainly cobalt, nickel, copper and lead, which were also several times higher than the limit standards. Cartographic ranking of the territory of the AA showed that relatively high total pollution levels of SC were observed in 2020 in the areas that were most exposed to pollution from sources such as CHPP-2, power plants, household stoves, coal-fired and motor vehicles. According to the total values of soil pollution AA territory is characterized by a high level of pollution, and the territory of Almaty, according to the existing gradation, refers to a very high level of pollution in all the years studied.

Keywords: agglomeration, snow cover, soil, toxicology, pollutants, ranking

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АЛМАТЫ АГЛОМЕРАЦИЯСЫ ТЕРРИТОРИЯСЫН ЛАСТАНУ ДӘРЕЖЕСІ БОЙЫНША САРАЛАУ

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Аннотация. Мақалада зерттеу аумағы бойынша қар жамылғысы және топырақта ластаушы заттардың таралуын, ластану дәрежесіне қарай (2018–2020) саралау жұмыстары қарастырылған.Зерттеу нысаны еліміздің ең ірі мегаполистерінің бірі, жалпы ауданы — 939,5 мың гектар Алматы агломерациясының аумағы болып табылады. Агломерация аумағына орталығы Алматы қаласы болып табылатын, Алматы облысының 188 елді мекені кіреді, оның құрамына Алматы облысының бес әкімшілік округінің бөліктері қарайды: Қарасай, Талғар, Іле, Еңбекшіқазақ, Жамбыл және Қаскелең, Қапшағай, Талғар, Есік қалалары. Алматы агломерациясы аумағының ластану дәрежесін бағалау ластанудың жиынтық көрсеткіштері (Zc) болып табылатын топырақ пен қар жамылғысының ластану сипаттамаларының бірімен есептелген, бұл фондық нүктемен салыстырыла отырып ластаушы заттың жинақталу дәрежесімен анықталады. 2018–2020 жылдардағы металл концентрациясы коэффициентерінің мәндері бойынша АА аумағының ластануының қар жамылғысындағы мыс, мырыш және қорғасын, топырақта кобальт, никель, мыс және қорғасынға тиесілі, сонымен қатар шекті нормалардан бірнеше есе жоғары екенін көрсетті. АА аумағын картографиялық саралау барысында 2020 жылы қар жамылғысы ЖЭС-2, электр станциялары, тұрмыстық пештер, автокөліктер сияқты көздерден ластануға биім аймақтарда салыстырмалы түрде жоғары байқалғанын көрсетті. Топырақтың ластануының жиынтық мәндері бойынша АА аумағы ластанудың жоғарғы деңгейімен сипатталады, Алматы қаласының аумағы қолданыстағы градиция бойынша барлық зерттелген жылдары ластанудың өте жоғарғы деңгейіне жатады.

Түйін сөздер: агломерация, қар жамылғысы, топырақ, токсикология, ластаушы заттар, саралау

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РАНЖИРОВАНИЕ ТЕРРИТОРИИ АЛМАТИНСКОЙ АГЛОМЕРАЦИИ ПО СТЕПЕНИ ЗАГРЯЗНЕНИЯ

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Аннотация. В статье рассматривается оценка переноса загрязняющих веществ по состоянию загрязнения снежного покрова и почвы для ранжирования исследуемой территории по степени загрязнения (2018–2020 годы). Объектом исследования является одна из крупных мегаполисов страны – территория Алматинской агломерации с общей площадью — 939,5 тыс. га. В зону агломерации входят 188 населенных пунктов Алматинской области, центром которого является город Алматы, в состав входят части пяти административных районов Алматинской области: Карасайского, Талгарского, Илийского, Енбекшиказахского и Жамбылского, а также города Каскелен, Капшагай, Талгар и Есик. Оценка степени загрязнения территории Алматинской агломерации рассчитана одним из характеристик загрязнения почвы и СП, которые являются суммарными показателями загрязнения (Zc), что определяется степенью накопления загрязняющего вещества по сравнению с фоновой точкой. Анализ загрязненности территории АА по значениям коэффициентов концентрации металлов за 2018–2020 гг. показал, что наибольший вклад приходится на медь, цинк и свинец в почвенном покрове, тогда как для СП в основном на кобальт, никель, медь и свинец, которые были также выше предельных норм в несколько раз. Картографическое ранжирование территории АА показало, что относительно высокие суммарные уровни загрязнения СП отмечались в 2020 г. в зонах, которые были наиболее подвержены загрязнению такими источниками, как ТЭЦ-2, электростанций, бытовые печи, работающие на угле и автотранспорт. По суммарным значениям загрязнения почв территория АА характеризуется высоким уровнем загрязнения, а территория г. Алматы по существующей градации относится к очень высокому уровню загрязнения во все исследованные годы.

Ключевые слова: агломерация, снежный покров, почва, токсикология, загрязняющие вещества, ранжирование

Introduction

There are different methods of atmospheric air condition estimation, but one of the most accessible is SC monitoring (Ardakov et al., 2004; Sayet et al., 1990). This method is a cheap and informative indicator of pollution in winter period. Snow, having a number of properties, is a convenient indicator of pollution not only of atmospheric precipitation itself, but also the state of the atmospheric layer (where clouds are formed, gas exchange occurs and from which precipitation falls), as well as for subsequent pollution of waters and soils (Rezhim dostupa: http://www.normacs.ru/Doclist/doc/12590.html....), so it gives an objective assessment of all atmospheric pollution during the winter period (Sergeyeva et al., 2017).

SC pollution occurs in two stages. Firstly, it is the pollution of snowflakes during their formation in the cloud and precipitation on the terrain — wet precipitation of pollutants with snow. The second is the pollution of already fallen snow as a result of dry deposition of pollutants from the atmosphere, as well as their entry from the underlying soils and rocks (Vasilenko et al., 1985; Skugoreva et al., 2011).

The relationship between dry and wet deposition depends on many factors, the main ones being: the duration of the cold period, the frequency of snowfalls and their intensity, the physical and chemical properties of pollutants, and the size of aerosols (Buyvolov et al., 1997).

When snow forms and falls as a result of dry and wet leaching processes, the concentration of pollutants in it is usually 2–3 orders of magnitude higher than in the atmospheric air. For this reason, measurements of the content of these substances can be made by fairly simple methods and with a high degree of reliability. The layer-by-layer sampling of SC allows obtaining the dynamics of pollution for the winter season, and only one sample over the whole SC thickness gives representative data on pollution during the period from the formation of a stable SC up to the moment of sampling. In order to study pollution using this method, several selected points are examined. Based on the results obtained, a map of SC pollution can be drawn and the sources of air pollution, as well as the extent and boundaries of their influence, can be determined. Such sources of pollutants as boilers, motor transport, enterprises of heavy and fuel-energy industry are most easily identified. Study of chemical composition of SC is a mandatory part of the study of environmental pollution processes. It is the quality of SC vividly demonstrates the influence of different sources of atmospheric air pollution on the surface of the earth. The analysis of SC quality allows to trace the spatial distribution of pollutants over the territory and to receive a reliable picture of zones of influence of specific industrial enterprises and other objects on the state of the environment (Rezhim dostupa: https://cyberleninka.ru/article/n/vozmozhnost-otsenki-sostoyaniya-atmosfery-po-harakteristikam-zagryazneniya-snega-i-pochvy Daunov et al., 2018).

In the work of A. Sergeeva, studied the degree of pollution of the air environment of Blagoveshensk using snow as an indicator. Determined the quantitative distribution of solid sediment and studied the content of the heavy metals (HM), studied the sources of pollution, previously divided the territory of the city into functional zones. An area less exposed to anthropogenic impact was selected as a background zone. To assess the content of the HM (Cd, Pb, Cu, Zn, Co, Ni and Cr) used anthropogenic concentration ratios (Kc) compared with the background and to determine the degree of pollution SC used the total pollution index (Zc). The maximum content of solid emissions in the city, where the main component is sand, installed in areas with the most intensive vehicular traffic: Citizenskaya Street – 50 years of October > bus station > private residential sector. The content of dust emissions in these points is 40–240 times higher than the background. Maximum values of total SC pollution on the territory of Blagoveshchensk are established in Astrakhanovka (Zc=20) and CHPP (Zc=15). At sampling points located in the zone of TPP influence, Zc values decrease with distance from the main source of emissions. Increased total anthropogenic pollution index (Zc = 11–12) revealed in the areas of private residential sector (Connaya – Shimanovsky), shipyard, Botanical Garden and city parks. The main sources of pollution in the industrial and residential areas of the city are products of incomplete combustion of fuel and motor transport. Also one of the causes of the increased HM content in SC is the transfer of toxicants from emission sources along the wind rose towards the park area, the transboundary transfer of pollutants falling out in the city with precipitation is not excluded.

Similar work has been done by other authors (Smirnova et al., 2017; Lebedev et al., 2017), since this methodology (Sayet et al., 1990) is well enough developed.

In the work of Smirnova S.M. (Smirnova et al., 2011), the ecological and geochemical indicators of pollution Zn, Ni, Cu, Mn, Fe in SC of Nikolaev city. As follows from the work, the cumulative effect of aerotechnogenic inflow of metals into the joint venture is expressed contrasting in zonal differentiation of urban areas. The content of metals in SC on the territory of the city is much higher than the background values. The index of the total pollution load of the snow cover within the city decreases in the series: Ni (10.1), Fe, Zn (6.8), Mn (4.7), Cu (1.0). The coefficient of relative increase in the total load increases significantly in the transport area with the maximum indicators: Zn (186.6), Ni (174.2), Cu (64.5). According to the total load index ($Zr < 1000$) the territory of the city refers to a low level of pollution.

Methodology for assessing the spatial heterogeneity of HM distribution is found in the work of S. Lebedev. B., within Vasileostrovsky district of St. Petersburg. The results of the study showed asymmetrical nature in the distribution of HM (Zn, Pb, Cu, Ni, Cr) in the area, which significantly affected the definition of soil pollution category. Apparently, such a character of metal distributions is natural for urban areas, when as a result of technogenic load there are local areas with anomalously high concentrations of pollutants. The maximum contribution to the total index of pollution SC and soils contributes Zn. A high positive correlation (coefficient of more than 0.7) between the pollution index Zc in SC and in soils, which may indicate a constant receipt of this pollutant in the components of the environment. The most noticeable difference in the nature of pollution of soil and snow cover was noted for Pb. For soils, Pb concentration largely determines the total pollution index.

Methodology and results

Against this background, the distribution patterns of pollutants in the study area are considered. It is well known that the main sources of air pollution of the city of Almaty, nearby settlements and small towns are soot, dust, HM, are power plants, household furnaces, coal-fired thermal power plants and motor transport. Among the main pollutants in the air basin of the AA territory are metals belonging to the I and II classes of hazard. Their negative impact on humans is manifested not only in the direct impact of high concentrations, but also in the long-term consequences associated with the ability of many metals to accumulate in the body (Kasimov et al., 2012).

As is known, HMs are contained in many types of industrial, manufacturing, energy and motor transport emissions into the atmosphere and are the main indicators of the anthropogenic impact of these emissions on the environment. The distribution of HM in various components of the environment fixes the sources of pollution and zones of their impact (Revich et al., 1982).

Assessment of the transfer of pollutants according to the results of the study (2018–2020) on the state of pollution of snow cover and soils, makes it possible to rank the territory of the AA on the degree of pollution. Assessment of the degree of pollution of the AA area is calculated by one of the characteristics of soil and SC pollution, which are the total pollution indicators (Zc), which is determined by the degree of accumulation of the pollutant compared to the background point. Background points were selected throughout the study area is not exposed to pollution or experiencing it to a minimum degree separately for each metal.

At the same time, the background approach to estimating the degree of SC pollution has a number of drawbacks, because the choice of site for sampling is arbitrary, the values of background indicators depend on the character of meteorological conditions and change annually due to a complete change of SC (in our studies, background indicators of individual metals of different years differed several times), there is no possibility to determine the real amount of pollutant on the territory unit. Such a method was used in (Stepanova et al., 2003), and the toxicity class of elements was not taken into account when calculating the total coefficient of HM concentrations. In this connection, it would be logical to consider that the background method of evaluation in its "pure" form has no practical value when studying the pollution of snow cover.

Calculation of the total pollution index for soil and SC was carried out according to the following formulas:

$$Kc = \frac{Ci}{Cf} \tag{3}$$

$$Zc = \Sigma Kc - (n - 1) \tag{4}$$

where, Kc - the coefficient of concentration of the pollutant;

Ci - concentration of the pollutant;

Cf - concentration of the pollutant in the background point;

n - the number of elements to be determined.

On the basis of the obtained total indices of soil and snow pollution maps of metal distribution over the territory of the AA were constructed. Gradation intervals in the construction of maps were taken according to the evaluation scales and four levels of pollution were identified (see table 1).

Table 1 - Levels of SC (Zc) and soil (Zc) metal pollution

Level	Cumulative SC pollution index	Total soil pollution index
Low	32-64	8-16
Medium	64-128	16-32
High	128-256	32-128
Very High	256	128

Assessment of the danger of pollution of snow and soil with HM on the relevant indicators that reflect the differentiation of AA pollution of the territory was carried out by approximate assessment scales (Rezhim dostupa: http://www.normacs.ru/Doclist/doc/12590.htm et al., 1990; Revich et al., 1982; Rezhim dostupa: http://docs.cntd.ru/document/1200003852 et al., 1999) (tables 2,3).

Table 2 - Indicative assessment scale of the danger of pollution of SC on the total pollution index (Zc)

Level	Total pollution index of SC (Zc)	SC pollution categories
Low	32-64	Non-hazardous
Medium	64-128	Moderately dangerous
High	128-256	Dangerous
Very High	256	Extremely dangerous

Table 3 - Approximate assessment scale of soil pollution hazard by the total pollution index (Zc)

Zc value	Level	Soil pollution categories	Changes in the health indicators of the population in the foci of pollution
Less than 16	Low	Tolerable	The lowest morbidity rate for children and the lowest frequency of functional abnormalities
16-32	Medium	Moderately hazardous	Increase in overall morbidity
32-128	High	Dangerous	Increase in the overall morbidity rate, the number of children who fall ill frequently, children with chronic illnesses and functional disorders of the cardiovascular system
More than 128	Very High	Extremely dangerous	Increase in the morbidity rate among children, violation of the reproductive function of women

Several approaches are used to assess the contrast and ecological hazard of technogenic HM halos in soils. Pollution indication, as for air and snow, is based primarily on comparison of polluted urban soils with their background counterparts. This is achieved by calculating the coefficient of anthropogenic concentration or anomaly (Kc), which shows how many times the content of an element in urban soils is higher than its content in background soils. Coefficient Kc reflects the intensity of pollution, but does not directly indicate its danger (Rezhim dostupa: http://medbiol.ru/medbiol/ecology/000305f4.htm).

In the composition of man-made emissions, metals tend to be deposited in SC, and during snow melting form the mineral and mobile forms. The mobile forms of HM are considered to be the most aggressive, because in addition to deposition in the soil with all the ensuing consequences, they are also accessible to living organisms.

In order to determine the quantitative content of HM in the air and soil of AA territory during the winter period, we determined concentration ratios (Kc) of the metals (Cu, Zn, Pb, Cd, Co and Ni) studied in snow and soil relative to background points, which are presented in Tables 4,5.

Table 4 - AA average coefficients of HM concentration in SC

Years	Kc					
	Cu	Zn	Pb	Cd	Co	Ni
2018	1,0-2,3 1,7	1,0-6,6 3,6	1,0-2,4 1,7	1,0-2,6 1,7	0,99-36,9 16,5	1,0-29,2 13,2
2019	1,0-27,3 11,8	1,0-20,5 4,0	1,0-3,7 2,1	1,0-4,6 2,3	1,0-3,1 2,0	1,0-15,2 7,1
2020	1,0-3,4 1,6	1,0-13,7 3,3	0,0-34,7 15,2	0,0-44,0 12,6	1,0-15,3 8,1	0,0-63,3 20,9
Note: Limits in the numerator and averages in the denominator						

Table 5 - AA average coefficients of HM concentration in soil

Years	Kc					
	Cu	Zn	Pb	Cd	Co	Ni
2018	1,0-245 24,0	1,1-81,7 15,6	1,1-1079 106	1,0-58,2 5,4	1,0-11,8 3,0	1,0-2,3 1,3
2019	1,2-21677 747	0,97-207 26,4	0,99-338 25,9	1,0-3,7 1,9	1,0-7,1 2,4	1,0-24,8 8,0
2020	1,0-91,0 27,5	1,0-69,5 7,9	1,0-305 79,8	1,0-19,6 6,0	1,0-3,2 1,8	1,0-33,9 13,5
Note: Limits in the numerator and averages in the denominator						

A comparison of HM concentration coefficients revealed both similarities and differences in their behavior in both snow and soil. The comparison showed that for SC, the average concentration factor decreased in the series:

- In 2018: Co Ni Pb = Cd Cu Zn,
- In 2019: Cu Ni Zn Pb = Cd = Co,
- In 2020: Ni Pb Cd Co Zn = Cu,

whereas for soil, the series of decreases in the concentration coefficients were quite different:

- In 2018: Pb Cu Zn Cd Co Ni,
- In 2019: Cu Zn = Pb Ni Cd = Co,
- In 2020: Pb Cu Ni Zn Cd Co.

When comparing the coefficients of HM concentration for the studied years, high Kc values relative to background values in 2018 were characteristic of Co (36.9), Ni (29.2) and Zn (6.6), in 2019 Cu (27.3), Zn (20.5), Ni (15.2) and in 2020 Ni (63.3), Cd (44.0), Pb (34.7), Co (15.3), Zn (13.7) (Table 4).

Coefficients of HM concentrations in soil had a different character and were much higher than in snow and relative to its background values, so in 2018. – Pb (1079), Cu (245), Zn (81.7), Cd (58.2), Co (11.8), in 2019 Cu (21677), Pb (338), Zn (207), Ni (24.8) and in 2020 - Pb (305), Cu (91.0), Zn (69.5), Cd (44.0), Ni (33.9), and Co (19.6) (Table 5).

Analysis of pollution of the AA area according to the values of the concentration ratios of metals for 2018–2020 showed that the largest contribution is copper, zinc and lead in the soil cover, while for SC mainly cobalt, nickel, copper and lead, which were also several times higher than the limit standards.

The results of the assessment of the danger of pollution of snow and soil with HM AA given in the tables, allow us to identify areas with different levels of pollution. Based on the total pollution indexes (Zc) SC and soil HM for 2018–2020 were identified 5 zones, which differ in their location.

As can be seen from Table 2, an indicative assessment scale of the danger of pollution SC for 2018-2020 on the total index of the low level (Zc = 32–64), the category - non-hazardous, was characteristic of the entire territory of the AA.

High values of the total snow pollution index (Zc) to 81 were found for sampling points Orman (zone I) and Otegen Batyr (zone IV), to 88 – Arna (zone V), to 94 and 98 – Boraldai (zone III) and Northern bypass road (zone II), respectively. According to the approximate rating scale (Table 6) refer to the average level of pollution, ie, the category of pollution - moderately hazardous.

Table 6-Total indices of pollution of SC and soils by zones of the territory of the AA

Zones		Total pollution index of SC (Zc)			Total soil pollution index (Zc)		
		2018	2019	2020	2018	2019	2020
I	Mountain territories	16*	9-28 17	13-81 38	42	20-57 36	46-105 78
II	Territory of Almaty	13-43 31	24-40 32	25-98 57	18-474 438	78-22253 4553	117-299 186
III	Small towns, urban settlements	15-40 31	18-44 28	23-94 62	36-161 81	49-181 77	77-314 128
IV	Small settlements	23-62 38	15-39 23	29-81 54	10-235 66	9-121 58	76-347 137
V	The coast of the Kapshagai Reservoir	24	15-32 23	48-88 62	22	17-27 22	68-143 114
Note – in numerator - limits, in denominator - averages, 16* - unit points							

In 2018 and 2019, totals were in the category of non-hazardous, low-level pollution, both by zone and by individual point. Relatively high total pollution values were observed in 2020: zone II - Zc = 57, zone III and V - Zc = 62, zone IV - Zc = 54 (table 6), which were most exposed to pollution, the sources of which are power plants, domestic furnaces, coal-fired CHPP and motor vehicles.

In the zone of influence of CHPPs and heating zones in SC very voluminous sludge is formed, though by weight insignificant, which includes soot and other products of coal combustion. These products are dispersed by air flows almost throughout the territory of the agglomeration, polluting the snow, and after its melting and the soil cover. In addition, the products of incomplete combustion can have a negative impact on humans, because they contain PAHs, which have a carcinogenic effect, HM, etc. A special danger of fine soot emissions is that they contribute to deep penetration of toxicants into the human body through the respiratory organs (Goldovskaya et al., 2005).

The level of anthropogenic pollution of soils is characterized by rather high values compared to SC, which is explained by the cumulative effect of soil cover (Table 6). Intensive technogenic load on the soil cover depends not only on the biochemical conditions, granular composition, water permeability and sorption properties of soils, but also on the rate of migration of HM and other pollutants, which largely depend on the alkaline-acid and redox conditions (Glazovskaya et al., 1997).

According to the total indices of soil pollution in the territory of the AA for the years under study was in the range from medium (Zc 16) to very high level (Zc 128). The low level of pollution was recorded in a single case at the Sorbulak sampling point in 2018 (Zc = 10) and 2019 (Zc = 9), by category of pollution — allowable.

According to the data of 2018 to the "very high level" of pollution (extremely dangerous) can be attributed sampling points: Institute of Geography (Zc = 1474), Northern bypass road (Zc = 436), the Park of the First President (Zc = 179) in Almaty, also Kapshagay city (Zc = 161) and village. Baidibek bi (Zc = 235). In 2019, the total pollution indicators had a slightly different character, so, at the sampling point of Northern bypass road - Zc increased to 22253, at other points varied from average to high level. This anomaly in the nature of soil pollution in the area of the northern ring, due to the high content of copper and lead in the soil, their concentrations exceed to 72.3 MAC and 2.2 MAC, respectively, which are considered among the most mobile metals in hypergenic processes. At the same time, in the area of the northern ring there is a very high load of motor transport, thus the loamy soil, characteristic of that area, actively absorbs and retains pollution coming from exhaust gases in higher concentrations than it is in the environment. To "extremely dangerous" pollution of soils were also recorded: on the territory of Almaty Institute of Geography (Zc = 187), Altyn Orda (Zc = 156) and Kaskelen (Zc = 181).

In 2020, due to the addition of sampling points and a wider coverage of the AA territory, the points exposed to pollution in all zones increased. So, in the point of Izvestkovy (zone I) Zc up to 150, on the whole territory of Almaty (zone II) Zc ranging from 117 to 300, by small towns - Kapshagay (zone III) Zc = 315, by small settlements (zone IV) Zc from 146 (Kyrbaltabay) to 348 (Kosmos) and the coast of the Kapshagai reservoir (zone V) Zc from 131 (recreational zone) to 143 (Akzhal), which belong to a very high level of pollution, category "extremely dangerous".

Values of soil pollution indicators (Table 6) by zones shows that the territory of the agglomeration refers to a high level, except for the coast of KR, which refers to the average level (2018 and 2019) and the territory of Almaty to a very high level in all the years studied.

Thus, for the years under study, Zc values indicate that in all snow and soil samples taken in different points of the territory of the agglomeration exceeded the limit levels as follows:

- In 2018: SC – 60 %, soil – 91 %;
- In 2019: SC – 23 %, soil – 97 %;
- In 2020: SC – 80 %, soil – 100 %.

The number of samples exceeding the limit levels in soils is much higher than in snow, because soils are a depositing environment, accumulating pollutants for the entire period of anthropogenic impact on the environment. Snow is also a depositing medium, but unlike soils, it serves as an indicator of seasonal pollution, mainly atmospheric pollution (Lebedev et al., 2017). Another factor of soil pollution in the absence of precipitation, pollutants can also precipitate on the underlying surface and vegetation. This process of removing pollutant compounds from the atmosphere is called dry deposition or dry deposition (Semenchin et al., 1993). Dry deposition is direct transport followed by adsorption of gases and particles by natural surfaces (vegetation, water, soil). Numerous studies (Berlyand et al., 2004; Berlyand et al., 1975; Kolmogorov et al., 1942; Samarskiy et al., 1989; Madibekov et al., 2023; Madibekov et al., 2022) carried out in recent years have shown that the rate of deposition depends on the chemical properties of the substance. Thus, gaseous compounds with higher reactivity have a higher deposition rate. Dry deposition is carried out mainly because there is a thin layer of air with a thickness of 10 to 100 microns in the immediate vicinity of the surface. Since this layer is practically motionless, particles or gases penetrating it come into direct contact and interaction with soil particles or vegetation due to the Brownian motion. Due to such interaction (chemical reactions, physical or chemical sorption) pollutants are removed from the said thin boundary layer of air. The influence of the boundary fixed layer may also be insignificant if there is intensive turbulent exchange in higher air layers, contributing to an increase in the entry of gases or aerosols into the fixed layer, in which they are subsequently lost (Zhermen et al., 1965).

According to the results of calculations of the total indicators of SC and soil pollution, maps processed in the ArcGIS environment were built, which allow us to clearly rank the territory of the AA by the degree of anthropogenic load. Such maps will reveal regional features of pollution of conjugated geographical environments: low thickness of snow cover during the entire winter period; formation of toxic smog, not dispersed for several days (sometimes weeks); high concentration of aerosol emissions, located in a limited area. The maps made by the category of snow and soil pollution hazards are shown in Figures 1–3.

The total indicators of SC and soil pollution for 2018 are shown in Figure 1. On the territory of the agglomeration the low level of pollution was distinguished by mountainous areas (Zc 15), settlements (Kaskelen, Talgar), located in the foothills, the eastern part of Almaty city and the northern coast of KR (Zc = 15–25). In the rest of the AA the level of pollution was within Zc = 25–45, but, not reaching the low level limits (Zc = 36–64). In the eastern part of the study area, where the small settlements Tolkyn and Baidibek bi are located, the total index of pollution of SC was the average level of Zc 65. Pollution of SC caused by a high coefficient of concentration in the SC of metals such as Co (36.9), Ni (29.2), Zn (6.6) and Pb (2.4). The level of pollution of soils by metals on the territory has a different character, so, the low level was distinguished by small settlements (Kargaly, Sorbulak) Zc = 8–16. To the average level of soil pollution in the territory are — Altyn Orda (territory of Almaty), Otegen Batyr, Turgen (small settlements) and recreation area (coastal KR), the total index of which ranges from 16 to 32. The high level is registered in the SHSB "Shymbulak", Eastern bypass road, small towns (Kapshagay, Esik, Kaskelen) and small settlements (Shamalgan, Otegen Batyr, Kyrbaltabai, Tolkyn) with a total index up to 128. Very high level of soil pollution was distinguished by the territory of Almaty city (Kabanbai Batyr street corner of Pushkin street, First President Park, Northern bypass road) and small settlement Baidibek bi Zc 128. It should be particularly noted Northern bypass road, whose soil pollution level reaches 1474, associated with very high concentrations of Pb (86 mg/kg), Zn (41 mg/kg) and Cu (25 mg/kg) in the soil.

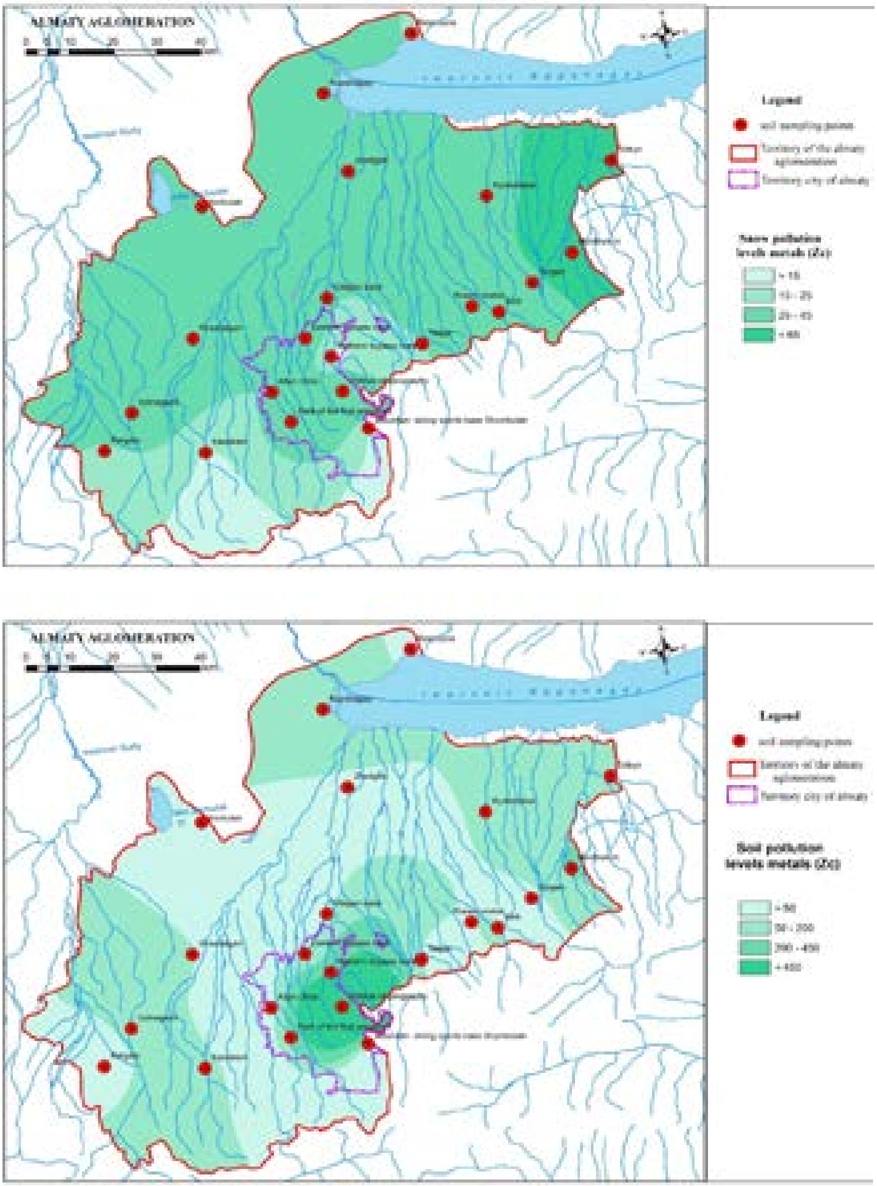


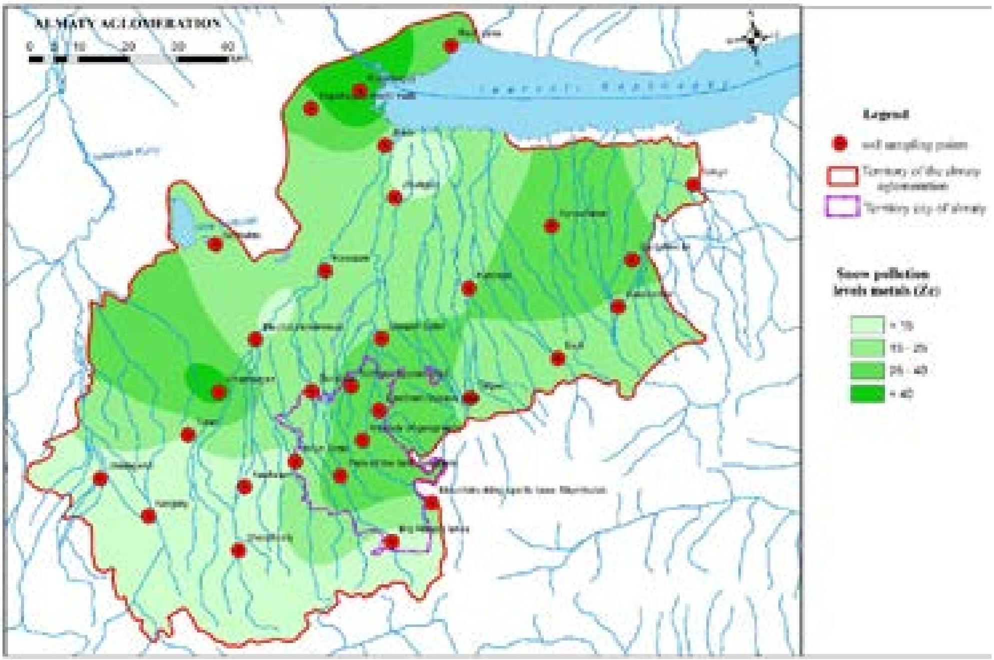
Fig. 1 - Ranking of the territory of the AA by the level of pollution of SC and soil in 2018.

In general, in the conditions of the agglomeration in 2018, the level of SC and soil pollution is at a satisfactory level, except for some local zones, caused by the technogenic influence of vehicles and CHPP. At the same time, an important role is played by the location of zones relative to the wind rose, which during the winter period leads to intensive transfer of pollutants, which are sorbed in SC, and in the process of melting they pass into the soil.

In 2019, the cumulative SC pollution in most of the agglomeration area is very low (Zc > 32), also low level from 32 to 64, the main pollution occurs in the area of Almaty (Figure 2). SC pollution in 2019 is due to high concentrations of lead, zinc and copper, which cover mainly major highway routes, i.e. Northern bypass road (Zc = 40), Eastern bypass road (Zc = 35), and railways - Shamalgan station (Zc = 39), also small towns - Kapshagai (Zc = 44) and Kaskelen (Zc = 34). A similar trend can be observed for the level of soil pollution in the same year, especially highlighting the zone - Northern bypass road, which is located in the zone of maximum vehicular traffic (Figure 2). The total index of soil pollution in Northern bypass road reached Zc = 22253, where the main pollutants were Cu, Pb and Zn, with concentration ratios (Kc) – 21677, 339 and 208, respectively.

In 2020, as discussed in Section 2, the sampling points were increased to 75 for SC, to 41 for soil, this allowed us to increase the detail of the ranking maps. As a result of the increase in sampling points, we can observe a more detailed picture of the level of pollution of the territory, both by SC and soil.

The average level of pollution SC up to 90 % occupies the territory of Almaty, with a total index (Zc) from 72 to 110. In mountainous areas it is necessary to note VSC "Medeu" and Orman, extreme mountain areas with a total index of 75 and 81 respectively (figure 3). In small towns Kapshagay and Boraldai these values reached 79 and 94, and some settlements with average pollution level – 80, expressed by high concentration ratios of Cu, Zn, Pb, Cd and Co. Identified pollution by Cd content in 2020 is probably due to the mass use of boilers that do not have smoke cleaning systems and for which the main fuel is coal with a high degree of ash content. Small commercial boiler plants often use automobile tires, plastic, and other combustible garbage as fuel, which significantly degrades air quality and contributes to air and snow pollution. The rest of the agglomeration was characterized by low levels of snow pollution, but also with some increases in the metals noted above. These metals are the most dangerous and aggressive for biota and are characterized by high mobility, ability to biotransformation and accumulation in the soil cover and biomass.



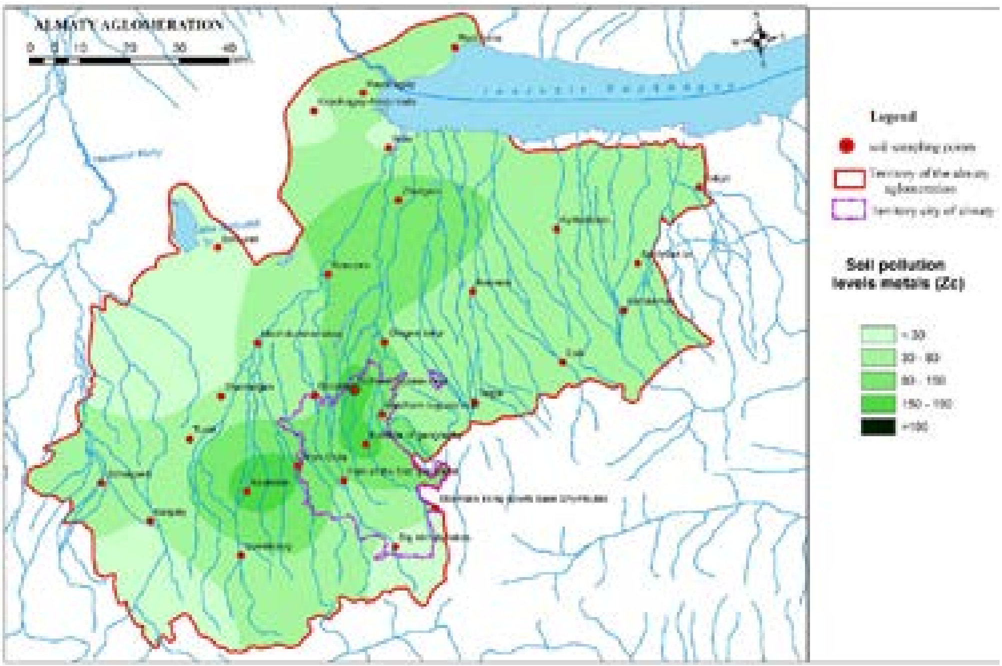


Fig. 2 - Ranking of the AA area by SC and soil pollution in 2019.

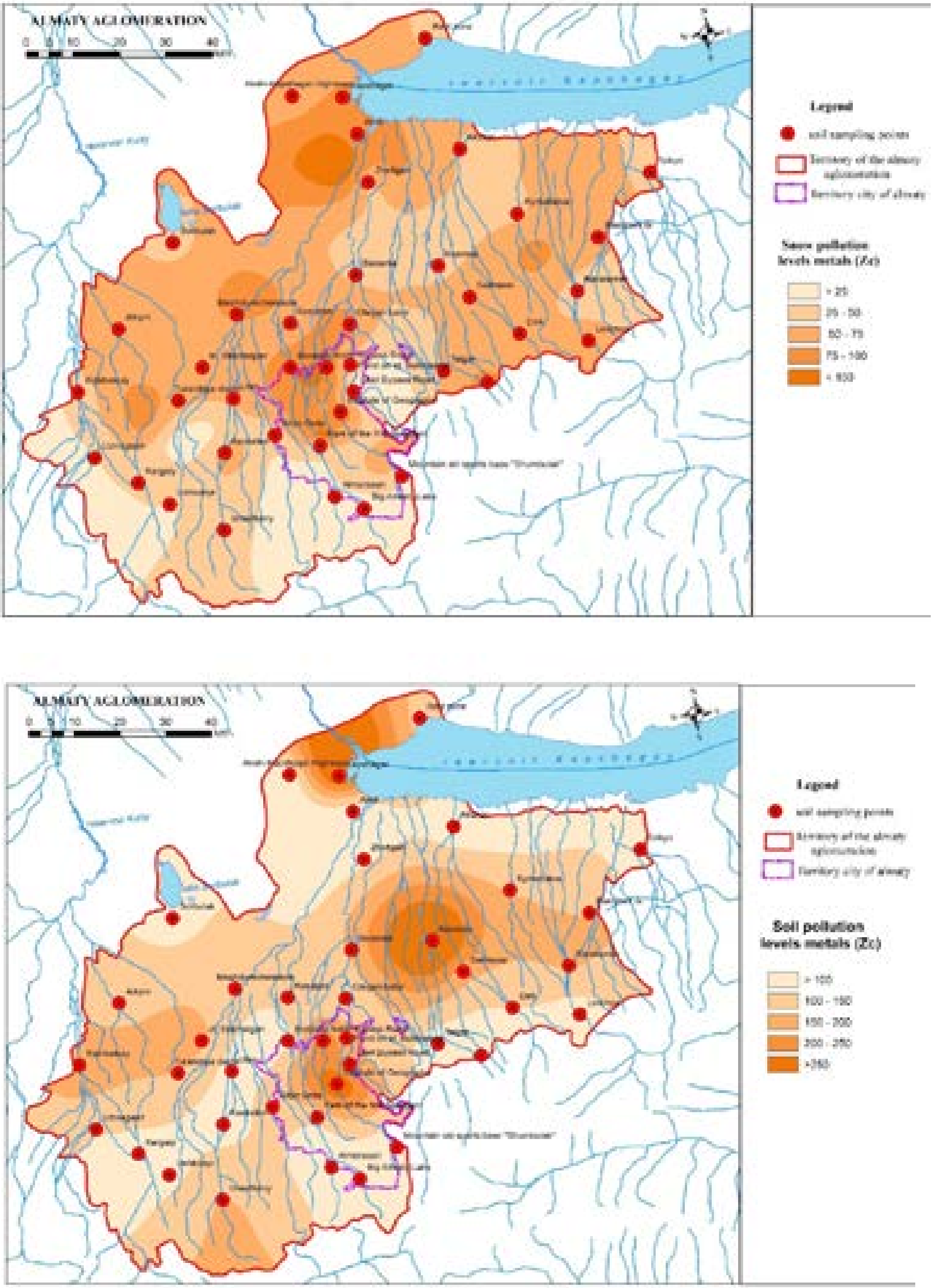


Fig. 3 - Ranking of the AA territory according to the level of SC and soil pollution in 2020.

The level of soil pollution, the whole territory of the agglomeration, in 2020 ranged from 47 to 348. The nucleus of the agglomeration - the city of Almaty and some small settlements — belong to the high level of pollution in territorial respect (Figure 3). In this regard, the type of heating fuel plays an important role, as in the western part of the agglomeration mostly in all settlements gasification is carried out, while in the north-eastern, eastern and central parts solid fuel is used.

Thus, the ranking of the AA territory according to the degree of anthropogenic load showed uneven nature in both inter-annual and migratory pollution, as snow pollution occurs mainly due to high concentrations of zinc, and soil - lead. Mapping survey of the urbanized area showed that the ecological condition of the environment, mainly has anthropogenic load due to heavy metals, namely by high concentrations of metals of the 1st and 2nd hazard class.

Thus, in 2018 and 2019, the total pollution indicators of SCs were in the category of non-hazardous, low-level pollution, both by zones and by individual points. Relatively high total pollution indicators were observed in 2020: zones II, III, V and IV, which were the most susceptible to pollution, the sources of which are power plants, domestic furnaces, coal-fired CHHP and motor vehicles. As a result, volumetric sediment is formed, which is dispersed by air flows over the territory of the agglomeration, polluting the snow, and after its melting, the soil cover.

The level of anthropogenic pollution of soils is characterized by fairly large values compared to SC, which is explained by the cumulative effect of the soil cover. Values of soil pollution indicators by zones show that the territory of the agglomeration refers to a high level, with the exception of the KR coast, which refers to an average level (2018 and 2019) and the territory of Almaty to a very high level in all the years studied. In 2020, due to the addition of sampling points and a wider coverage of the AA territory, the points exposed to pollution increased in all areas: Izvestkovy, throughout the Almaty city, Kapshagay city, small settlements (villages Kyrbaltabay, Cosmos) and the coast of Kapshagay reservoir, which refer to a very high level of pollution, category "extremely hazardous". These pollutions are caused primarily by exhaust gases from motor vehicles that use low-quality gasoline (gasoline with an addition of tetraethyl lead) and heating with solid fuel, even in urban areas.

Conclusion

Analysis of pollution of the AA territory by the values of the concentration ratios of metals for 2018–2020 showed that the largest contribution is copper, zinc and lead in the soil cover, while for SC mainly cobalt, nickel, copper and lead, which were also several times higher than the limit standards.

According to the total indicators of soil pollution in the territory of the AA for the years under study was in the range from average ($Zc < 16$) to very high level ($Zc > 128$). The low level of pollution was recorded in a single case.

According to the results of the calculations of the total indicators of SC and soil pollution, maps were built, processed in the ArcGIS environment, which allow a clear ranking of the territory of the AA according to the degree of technogenic load.

Cartographic survey of the urbanized area showed that the ecological condition of the environment, mainly has anthropogenic load due to heavy metals, namely high levels of metals of hazard class 1 and 2. In 2018 and 2019, the total pollution indicators of SC were in the category of non-hazardous, low level pollution both by zones and by individual points. Relatively high total pollution values were observed in 2020: zone II, III, V and IV, which were the most exposed to pollution, the sources of which are power plants, domestic furnaces, coal-fired CHPP plants and motor vehicles.

The values of soil pollution indicators by zone indicate that the territory of the agglomeration refers to a high level, with the exception of the KR coast, which refers to the medium level (2018 and 2019) and the territory of Almaty to a very high level in all years studied. In 2020, due to the addition of sampling points and wider coverage of the AA area, the points exposed to contamination increased in all zones.

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