DOI: 10.22616/lbtuthesis/2024.010

Latvijas Biozinātņu un tehnoloģiju universitāte
Meža un vides zinātņu fakultāte
Ainavu arhitektūras un vides inženierijas institūts

Mg.sc.ing., **Jovita Pilecka-Uļčugačeva**

promocijas darbs – tematiski vienotu zinātnisko publikāciju apkopojums

PILSĒTAS GAISA PIESĀRŅOJUMA AR SMAGAJIEM METĀLIEM TELPISKĀS IZPLATĪBAS RISKA NOVĒRTĒJUMS

THE RISK ASSESSMENT OF SPATIAL SPREAD OF URBAN AIR POLLUTION BY HEAVY METALS

zinātnes doktora grāda

zinātnes doktore (Ph.D.) inženierzinātnēs un tehnoloģijās

iegūšanai

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Jelgava 2024

Promocijas darbs izstrādāts: Latvijas Biozinātņu un tehnoloģiju universitātes Meža un ūdens resursu zinātniskajā laboratorijā un Meža un vides zinātņu fakultātes, Ainavu arhitektūras un vides inženierijas institūtā laika posmā no 2020. līdz 2024. gadam.

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Māris Kļaviņš, Dr.habil.chem., Latvijas Universitātes Ģeogrāfijas un zemes zinātņu fakultātes Vides aizsardzības katedras profesors, vadošais pētnieks, promocijas padomes priekšsēdētāja vietnieks;

Zane Vincēviča-Gaile, Dr.chem., Latvijas Universitātes Ģeogrāfijas un zemes zinātņu fakultātes Vides zinātnes nodaļas vadošā pētniece;

Laima Bērziņa, Dr.sc.ing., Latvijas Biozinātņu un tehnoloģiju universitātes Meža un vides zinātņu fakultātes, Ainavu arhitektūras un vides inženierijas institūta, vadošā pētniece, asociētā profesore;

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Promocijas darba aizstāvēšana notiks LBTU vides inženierijas un enerģētikas nozares promocijas padomes atklātā sēdē 2024. gada 16. oktobrī plkst. 14:00 Meža un vides zinātņu fakultātes sēžu zālē, Akadēmijas ielā 11, Jelgavā.

Ar promocijas darba kopsavilkumu var iepazīties LBTU Fundamentālajā bibliotēkā, Jelgavā, Lielā ielā 2.

Atsauksmes sūtīt promocijas padomes sekretārei, PhD **Lindai Grinbergai** (Jelgavā, Akadēmijas ielā 11, LV-3001, Jelgava, Latvija, e-pasts: linda.grinberga@lbtu.lv).

ANOTĀCIJA

Vairāk nekā puse jeb 56% pasaules iedzīvotāju dzīvo pilsētās. Tiek prognozēts, ka iedzīvotāju skaita īpatsvars pilsētās tikai pieaugs. Latvijas pilsētās dzīvojošo iedzīvotāju skaita īpatsvars tuvojas 70%. Palielinoties iedzīvotāju skaitam pilsētās, aizvien aktuālās paliek jautājums par gaisa kvalitāti pilsētvidē, kas ikdienā ietekmē ikvienu. Jau tagad, liela daļa pasaules iedzīvotāju dzīvo vietās, kur gaisa kvalitāte neatbilst pieļaujamām normām. Gaisa piesārņojums dzīves kvalitāti ietekmē ikvienam pilsētas iedzīvotājam, jo tas skar gandrīz visas cilvēku grupas un ir īpaši bīstams cilvēkiem ar hroniskām saslimšanām. Pēdējos gados arvien vairāk tiek veikti pētījumi par sniega piesārņojuma slodžu izpēti mērenajā klimata joslā. Pilsētvidē tiek pētīti dažādi bioindikatori, kas sniedz precīzus rezultātus par gaisa kvalitāti pilsētā.

Pasaulē līdz šim ir veikti dažādi fragmentāri pētījumi, apskatot specifiskus objektus un specifisku piesārņojuma veidu un to tuvumā esošo piesārņojumu, neveicot kompleksu pilsētas izpēti. Pilsēta ir sarežģīta, komplekss kopums ar izteiktu mainību laikā un telpā, lai veiktu pilnīgu tās izpēti ir, jāizmanto vairākas gaisa piesārņojuma notikšanas metodes un pilsēta jāskata kompleksi kā viens vesels laikā un telpā dinamisks objekts.

Promocijas darbā ir izvirzīta hipotēze, ka kompleksi vērtējot ilglaicīgo un īslaicīgo gaisa piesārņojumu ir iespējams novērtēt pilsētvides gaisa piesārņojuma dinamiku laikā un telpā.

Promocijas darba mērķis ir izstrādāt metodiku gaisa piesārņojuma telpiskās izplatības riska novērtēšanai, balstoties uz bioindikācijas metodēm un smago metālu koncentrācijām sniegā.

Promocijas darbā veiktā teorētiskā sadaļa apskata smago metālu un gaisā suspendēto cieto daļiņu (PM) ietekmi uz cilvēka veselību, sniedz ieskatu dažādu gaisa piesārņojuma noteikšanas metožu izmantošanai pilsētvidē, kompleksi skatot dažādu metožu mijiedarbību. Darbā apskatīta galveno transporta koridoru ietekme uz pilsētvides gaisa kvalitāti.

Pētījumā pirmo reizi Eiropā iegūti nepārtraukti septiņu gadu dati par dažādu smago metālu un citu ķīmisku elementu uzkrāšanos sniega segā pilsētvidē ar augstu izšķirtspēju 1 km^2, pārklājot visu pilsētas teritoriju. Liela daļa Latvijas iedzīvotāju dzīvo pilsētās, tādēļ gaisa kvalitātes pētījumi, kuros iekļauti sniega un ielu putekļu analīze ir ļoti svarīgi, lai noteiktu smago metālu izcelsmi, izplatību un līmeni pilsētvidē, ielu un ceļu tuvumā. Pilsētvides gaisa kvalitātes pētījumi ir vitāli nepieciešami pilsētvides plānošanas dokumentu izstrādē un pilsētas ilgtspējīgas attīstības stratēģijas mērķu nospraušanai.

Šis promocijas darbs sastāv no trīspadsmit tematiski vienotām zinātniskajām publikācijām.

ABSTRACT

More than half, or 56%, of the world's population lives in cities. It is projected that the proportion of the population living in cities will continue to increase. In Latvian cities, the proportion of inhabitants is approaching 70%. As the urban population grows, the question of air quality in urban environments becomes increasingly relevant, affecting everyone on a daily basis. Already, a large portion of the world's population lives in areas where air quality does not meet acceptable standards. Air pollution affects the quality of life for every urban resident, as it impacts nearly all demographic groups and is particularly dangerous for people with chronic illnesses. In recent years, there has been an increasing amount of research conducted on snow pollution loads in temperate climate zones. Various bioindicators are being studied in urban environments, providing precise results on urban air quality.

Until now, various fragmented studies have been conducted worldwide, examining specific objects and specific types of pollution and the pollution in their vicinity, without conducting a comprehensive study of the city. The city is a complex and dynamic entity with pronounced changes over time and space, to conduct a thorough study, multiple methods of air pollution occurrence must be used, and the city must be viewed holistically as a dynamic object over time and space.

The hypothesis proposed in the doctoral thesis is that by comprehensively assessing long-term and short-term air pollution, it is possible to evaluate the dynamics of urban air pollution over time and space. The objective of the doctoral thesis is to develop a methodology for assessing the spatial distribution risk of air pollution based on bioindication methods and heavy metal concentrations in snow.

The theoretical section of the doctoral thesis examines the impact of heavy metals and particulate matter (PM) suspended in the air on human health, provides an overview of various methods for determining air pollution in urban environments, and examines the complex interaction of various methods. The study also examines the impact of major transport corridors on urban air quality.

For the first time in Europe, continuous seven-year data on the accumulation of various heavy metals and other chemical elements in snow cover in urban areas have been obtained with high resolution of 1 km^2, covering the entire city's territory. A large portion of Latvia's population lives in cities, therefore, studies on air quality, including analysis of snow and street dust, are crucial to determine the origin, distribution, and level of heavy metals in urban areas, near streets, and roads. Studies on urban air quality are vital for the development of urban planning documents and the establishment of sustainable development strategies for cities.

This doctoral thesis consists of thirteen thematically unified scientific publications.

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PUBLIKĀCIJU SARAKSTS

Promocijas darbs balstīts uz trīspadsmit publikācijām, uz kurām atsauces tekstā veidotas, izmantojot romiešu ciparus:

I **Pilecka, J.,** Grinfelde, I., Valujeva, K., Straupe, I., & Purmalis, O. (2018). The temporal and spatial analysis of transport impact on trace elements in snow samples. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 18(4.2), 671–677. https://doi.org/10.5593/sgem2018/4.2/S19.086 **(indeksēta SCOPUS un WoS datubāzēs).**

II **Pilecka, J.,** Grinfelde, I., Valujeva, K., Frolova, O., & Purmalis, O. (2018). The spatial analysis of air pollution with trace elements using snow sampling. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 18(4.2), 663–669. https://doi.org/10.5593/sgem2018/4.2/S19.085 ***(indeksēta SCOPUS un WoS datubāzēs).***

III **Pilecka, J.,** Valujeva, K., Grinfelde, I., Vebere, L. L., & Purmalis, O. (2019). Analyzing differently prepared snow samples to determine air quality in the city. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 19(4.1), 859–866. https://doi.org/10.5593/sgem2019/4.1/S19.109 ***(indeksēta SCOPUS un WoS datubāzēs).***

IV **Pilecka, J.,** Valujeva, K., Grinfelde, I., Eihe, P., & Purmalis, O. (2019). Snow in the cities as an indicator of air pollution caused by traffic. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 19(4.1), 1069–1076. https://doi.org/10.5593/sgem2019/4.1/S19.136 ***(indeksēta SCOPUS un WoS datubāzēs).***

V **Pilecka, J.,** Grinfelde, I., Purmalis, O., Valujeva, K., & Ulcugacevs, V. (2020). The heavy metal deposition in snow: case study of Jelgava city. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 2020-Augus(4.1), 507–514. https://doi.org/10.5593/sgem2020/4.1/s19.063 ***(indeksēta SCOPUS un WoS datubāzēs).***

VI **Pilecka, J.,** Grinfelde, I., Purmalis, O., & Burlakovs, J. (2020). Car transport intensity impact on heavy metal distribution in urban environment. IOP Conference Series: Earth and Environmental Science, 578(1). https://doi.org/10.1088/1755-1315/578/1/012032 ***(indeksēta SCOPUS un WoS datubāzēs).***

VII Stankevica, M., Grinfelde, I., Bakute, A., **Pilecka-Ulcugaceva, J.,** & Purmalis, O. (2021). Heavy metals air pollution in Jelgava city Latvia. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 21(4.2), 75–84. https://doi.org/10.5593/sgem2021V/4.2/s19.a12 ***(indeksēta SCOPUS un WoS datubāzēs).***

VIII **Pilecka-Ulcugaceva, J.,** Zabelins, V., Grinfelde, I., Liepa, S., & Purmalis, O. (2021). Distribution and pollution of chemical elements in Jelgava urban environment. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 21(4.1), 261–268. https://doi.org/10.5593/sgem2021/4.1/s19.43 ***(indeksēta SCOPUS un WoS datubāzēs).***

IX Grinfelde, I., **Pilecka-Ulcugaceva,** J., Bertins, M., Viksna, A., Rudovica, V., Liepa, S., & Burlakovs, J. (2021). Dataset of trace elements concentrations in snow samples collected in Jelgava City (Latvia) in December 2020. Data in Brief, 38. https://doi.org/10.1016/j.dib.2021.107300 ***(indeksēta SCOPUS un WoS datubāzēs).***

X **Pilecka-Ulcugaceva, J.,** Bakute, A., & Grinfelde, I. (2022). Prevalence of long-term and short-term pollution of chemical elements in the city of Jelgava. Research for Rural Development, 37, 288–292. https://doi.org/10.22616/rrd.28.2022.041 ***(indeksēta SCOPUS un WoS datubāzēs).***

XI **Pilecka-Ulcugaceva, J.,** Grinfelde, I., Mednis, R., Bakute, A., & Siltumens, K. (2022). The spatial and temporal distribution of zinc in snow: case study of Jelgava city. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 22(4.1), 421–428. https://doi.org/10.5593/sgem2022/4.1/s19.54 ***(indeksēta SCOPUS un WoS datubāzēs).***

XII **Pilecka-Ulcugaceva, J.,** Grinfelde, I., Bakute, A., Burlakovs, J., & Bertins, M. (2023). The spatial and temporal distribution of aluminum emissions in air from transport in Jelgava. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 23(4.1), 347–353. https://doi.org/10.5593/sgem2023/4.1/s19.44 ***(indeksēta SCOPUS un WoS datubāzēs).***

XIII **Pilecka-Ulcugaceva, J.,** Bakute, A., Bertins, M., Siltumens K., & Grinfelde, I. (2023). The distribution of tungsten in Jelgava city at 2022 and 2023. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 23 (4.2), https://doi.org/110.5593/sgem2023V/4.2/s19.39 (***indeksēta SCOPUS un WoS datubāzēs, vēl nav apstipināts).***

AUTORA IEGULDĪJUMS

Nr.	**Ideja**	**Pētījuma plāns**	**Datu ievākšana**	**Datu analīze**	**Manuskripta sagatavošana**	**Promocijas darba autora ieguldījums %**
I	JP	JP, IS	JP, IG	JP, IG, OP	JP, IG, KV	85%
II	JP	JP	JP, IG	JP, IG, OP	JP, OF, KV	85%
III	JP	JP	JP, IG	JP, IG, OP	JP, LLV, KV, IG	85%
IV	JP	JP, IG	JP, IG	JP, IG, OP	JP, PE, KV	85%
V	JP	JP	JP, IG	JP, IG, OP	JP, KV, VU	75%
VI	JP	JP, IG	JP, IG	JP, IG, OP	JP, JB	90%
VII	JPU	JPU; MS	JPU, IG	JPU, IG, OP	JPU, MS, AB	70%
VIII	JPU	JPU, VZ	JPU, IG	JPU, IG, OP	JPU, VZ, SL	75%
IX	JPU	JPU, IG	JPU, IG	JPU, IG, MB, VR	JPU, IG, AV, SL	60%
X	JPU	JPU	JPU, IG	JPU, IG	JPU, AB	90%
XI	JPU	JPU	JPU, IG	JPU, IG	JPU, RM, AB, KS	70%
XII	JPU	JPU, JB	JPU, IG	JPU, IG, MB	JPU, AB	90%
XIII	JPU	JPU, KS	JPU, IG	JPU, IG, MB	JPU, IG, AB	90%

JP un JPU-Jovita Pilecka-Uļčugačeva; IG-Inga Grīnfelde; KV-Kristīne Valujeva; IS-Inga Straupe; OP-Oskars Purmalis; AB-Anda Bakute; OF-Olga Frolova (Olga Šķiste); LLV-Lāsma Lūcija Vēbere; PE-Paula Eihe (Paula Miezāka); VU- Vadims Uļčugačevs; JB-Juris Burlakovs; MS-Madara Stankeviča; VZ- Valters Zabeļins; SL-Sindija Liepa; MB- Māris Bērtiņš; AV-Arturs Vīksna; VR-Vita Rudoviča; RM-Reinis Mednis; KS-Kristaps Siltumēns.

PROMOCIJAS DARBA APROBĀCIJA

Promocijas darbs ir ticis aprobēts vairākos līmeņos. Promocijas darba izstrādes laikā uzkrātās zināšanas un kompetences tika izmantotas zinātnisko projektu realizācijā. Ir sniegti vairāk nekā 14 ziņojumi starptautiskās zinātniskajās konferencēs, kur prezentēti promocijas darbā veiktā pētījuma rezultāti. Promocijas darba rezultāti ir publicēti zinātnisko rakstu krājumos un žurnālos, kas indeksēti SCOPUS datubāzē. Uzkrātās kompetences tiek pielietotas 4 studiju kursu realizēšanā (skat. 1.1. tab.), tiek vadīti 3 maģistra darbi. Notiek regulāra sadarbība ar Jelgavas pilsētu saistībā ar pilsētas gaisa kvalitāti.

Projekti

Promocijas darba izstrādes laikā ir ņemta dalība 7 projektos, kas ir tieši un pakārtoti saistīti ar gaisa kvalitāti:

1. 2019. – 2022. Augsnes ķīmiskā sastāva ietekme uz SEG emisijām no lauksaimniecībā izmantojamās zemes LLU pētniecības projekts, pētnieks
2. 2020. Meliorācijas ietekmes novērtēšana klimata pārmaiņu (plūdu riska) mazināšanā (S373) Valsts pārvaldes iestādes finansēts projekts, zinātniskais asistents
3. 2021. "Nacionāla un starptautiska mēroga pasākumu īstenošana izglītojamo talantu attīstībai" ESF projekts, eksperts - recenzents
4. 2021. Meliorācijas ietekmes novērtēšana klimata pārmaiņu (plūdu riska) mazināšanā (S401) Valsts pārvaldes iestādes finansēts projekts, zinātniskais asistents
5. 2020. – 2023. Aramzemes un ilggadīgo zālāju apsaimniekošanas radītās siltumnīcefekta gāzu (SEG) emisijas un oglekļa dioksīda (CO2) piesaistes uzskaites sistēmas pilnveidošana un atbilstošu metodisko risinājumu izstrāde Pētniecības (zinātnisko izstrāžu) līgumdarbs (pakalpojuma līgums) ar Latvijas vai ārvalstu uzņēmumiem, organizācijām (komersantiem), zinātniskais asistents
6. 2023. Meliorācijas ietekmes novērtēšana klimata pārmaiņu (plūdu riska) mazināšanā (S445) Valsts pārvaldes iestādes finansēts projekts, zinātniskais asistents
7. 2024. Meliorācijas ietekmes novērtēšana klimata pārmaiņu (plūdu riska) mazināšanā (S492) Valsts pārvaldes iestādes finansēts projekts, zinātniskais asistents

Publikācijas, kas indeksētas SCOPUS un/vai WoS datubāzēs

1. Pilecka-Ulcugaceva, J., Grinfelde, I., Valujeva, K., Berzina, L., & Purmalis, O. (2021). Assessment of chemical elements pollution from vehicle emissions: case study of Jelgava city. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 21(4.1), 211–220. https://doi.org/10.5593/sgem2021/4.1/s19.37
2. Pilecka, J., Grīnfelde, I., Valujeva, K., Straupe, I., & Purmalis, O. (2017). Heavy metal concentration and distribution of snow and Lichea samples in urban area: Case study of Jelgava. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 17(41), 459–466. https://doi.org/10.5593/sgem2017/41/S19.058
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Ziņojumi konferencēs

Promocijas darba izstrādes laikā ir sniegti 50 ziņojumu starptautiskās zinātniskās konferencēs, no kuriem 14, kas norādīti sarakstā zemāk, ir tieši saistīti ar promocijas darba pētījuma tēmu.

1. The Distribution of Tungsten in Jelgava City at 2022 and 2023. **Jovita Pilecka-Ulcugaceva**, Anda Bakute, Maris Bertins, Kristaps Siltumens, Inga Grinfelde, XXIIIrd SGEM GeoConference – "Green Science for Green Life",Vienna, Austria, 28 Nov - 1 Dec, 2023.
2. The spatial and temporal distribution of aluminum emissions in air from transport in Jelgava. **Jovita Pilecka-Ulcugaceva**, Inga Grinfelde, Anda Bakute, Juris Burlakovs, Maris Bertins, 23rd International Multidisciplinary Scientific GeoConference SGEM, Albena, Bulgaria, 03-09 July, 2023. Bulgarian Academy of Sciences, 2023.
3. Prevalence of long-term and short-term pollution of chemical elements in the city of Jelgava. **Jovita Pilecka-Ulcugaceva**, Anda Bakute, Inga Grinfelde, Research for Rural Development 2022, Jelgava, Latvia, 18-20 May, 2022.
4. The spatial and temporal distribution of zinc in snow: case study of Jelgava city. **Jovita Pilecka-Ulcugaceva**, Inga Grinfelde, Reinis Mednis, Anda Bakute, Kristaps Siltumens, 22nd International Multidisciplinary Scientific GeoConference SGEM, Albena, Bulgaria, 04-10 July, 2022. Bulgarian Academy of Sciences Albena, 2022.
5. The spatial and temporal distribution of zinc in snow: case study of Jelgava city. Reinis Mednis, Inga Grinfelde, **Jovita Pilecka-Ulcugaceva**,17th International Scientific Conference "Students on their way to science" (undergraduate, graduate, post-graduate students), Jelgava, Latvia, April 22, 2022, Latvia University of Life Sciences and Technologies Jelgava, 2022.
6. The spatial and temporal distribution of lead in snow: case study of Jelgava city. Kristaps Siltumens, Inga Grinfelde, Sindija Liepa, **Jovita Pilecka-Ulcugaceva**, Anda Bakute,

Linnaeus ECO-TECH 2022, 13th International conference "Establishment of cooperation between companies and institutions in the Nordic countries, the Baltic Sea region and the world", Kalmar, Sweden, November 21-23, 2022. Linnaeus University Kalmar, 2022.

7. Heavy metals air pollution in Jelgava city Latvia. Inga Grinfelde, Kristaps Siltumens, Sindija Liepa, **Jovita Pilecka-Ulcugaceva**, Anda Bakute, Linnaeus ECO-TECH 2022, 13th International conference "Establishment of cooperation between companies and institutions in the Nordic countries, the Baltic Sea region and the world", Kalmar, Sweden, November 21-23, 2022. Linnaeus University Kalmar, 2022.
8. Assessment of chemical elements pollution from vehicle emissions: case study of Jelgava city. **Jovita Pilecka-Ulcugaceva**, Inga Grinfelde, Sindija Liepa, Oskars Purmalis, Kristaps Siltumēns, Linnaeus ECO-TECH 2022, 13th International conference "Establishment of cooperation between companies and institutions in the Nordic countries, the Baltic Sea region and the world", Kalmar, Sweden, November 21-23, 2022. Linnaeus University Kalmar, 2022.
9. The spatial and temporal distribution of zinc in snow: case study of Jelgava city. **Jovita Pilecka-Ulcugaceva**, Inga Grinfelde, Sindija Liepa, Reinis Mednis, Anda Bakute, Kristaps Siltumens, Linnaeus ECO-TECH 2022, 13th International conference "Establishment of cooperation between companies and institutions in the Nordic countries, the Baltic Sea region and the world", Kalmar, Sweden, November 21-23, 2022. Linnaeus University Kalmar, 2022.
10. Heavy metals air pollution in Jelgava city Latvia. M. Stankevica, I. Grinfelde, A. Bakute, **J. Pilecka-Ulcugaceva**, O. Purmalis, 21st International multidisciplinary scientific GeoConference SGEM, Albena, Bulgaria, 7-10 December, 2021. Bulgarian Academy of Sciences Sofia, 2021.
11. Assessment of chemical elements pollution from vehicle emissions: case study of Jelgava city. **Jovita Pilecka-Ulcugaceva**, Inga Grinfelde, Kristine Valujeva, Laima Berzina, Oskars Purmalis, 21st International multidisciplinary scientific GeoConference SGEM 2021, Albena, Bulgaria, 16-22 August, 2021. Bulgarian Academy of Sciences Energy and clean technologies. Sofia, 2021.
12. Distribution and pollution of chemical elements in Jelgava urban environment. **Jovita Pilecka-Ulcugaceva,** Valters Zabelins, Inga Grinfelde, Sindija Liepa, Oskars Purmalis, 21st International multidisciplinary scientific GeoConference SGEM 2021, Albena, Bulgaria, 16-22 August, 2021. Bulgarian Academy of Sciences Energy and clean technologies. Sofia, 2021.
13. The risk assesment of air pollution caused by heavy metals using spatial modelling for 2018 and 2019. **Jovita Pilecka-Ulcugaceva**, Inga Grinfelde, 16th International Scientific Conference "Students on their way to science" (undergraduate, graduate, post-graduate students): collection of abstracts, Jelgava, Latvia, April 23, 2021. Latvia University of Life Sciences and Technologies Jelgava, 2021.
14. Trace elements footprint of transport in urban areas: case study of Jelgava city. **Jovita Pilecka-Ulcugaceva**, Inga Grinfelde, 12th International conference on establishment of cooperation between companies and institutions in the Nordic countries, the Baltic Sea region and the world, Kalmar, Sweden, 23–25 November 2020. Linnaeus University Kalmar, 2020.

Apbalvojumi

Jelgavas pilsētas domes balva izveidota, lai veicinātu Jelgavas pilsētas un Zemgales reģiona attīstību, atbalstītu zinātniskās izstrādnes un jaunatnes interesi par zinātni. Jelgavas pilsētas domes balvas konkursā (2018. gada nogalē) iegūta 1. vieta ar darbu “Ķīmisko elementu ilglaicīgā un īslaicīgā piesārņojuma izplatība Jelgavas pilsētā”.

Akadēmiskais darbs

Promocijas darba izstrādes laikā iegūtās zināšanas un iestrādnes tiek izmantotas Latvijas Biozinātņu un tehnoloģiju universitātes pamatstudiju studentu un maģistrantu zinātniskajos darbos. Promocija darba iestrādņu integrācija izglītojošā darbā ir apkopota 1.1. tabulā.

1.1.tabula **Promocija darba iestrādņu integrācija izglītojošā darbā**

N.p.k.	**Aktivitāte**	**Pilsētas gaisa piesārņojuma ar smagajiem metāliem telpiskās izplatības riska novērtējums izmantošana**
1.	Ievads vides inženierijā 2 KP	Smago metālu un gaisā suspendēto cieto daļiņu (PM) piesārņojuma izplatība pilsētvidē.
2.	Zinātniskās aktualitātes 5 KP	Iepazīstas pilsētas gaisa piesārņojuma ar smagajiem metāliem telpiskās izplatības riska novērtēšanas iespējām.
3.	Industriālo teritoriju projektēšana 8 KP	Ilglaicīgā un īslaicīgā gaisa piesārņojuma noteikšanas metožu pielietojums pilsētvidē.
4.	Ilgtspējīga resursu apsaimniekošana 3 KP	Gaisa kvalitāte, gaisa kvalitātes noteikšanas metodes, gaisa kvalitātes uzlabošana.

CITAS ZINĀTNISKĀS AKTIVITĀTES PROMOCIJAS DARBA IZSTRĀDES LAIKĀ

Promocijas darba izstrādes laikā ņemta dalība projektos, kas tieši nav saistīti ar promocijas darba tēmu, kā arī veikta pētnieciskā darbība dažādos zinātnes virzienos.

Projekti

1. 2019. – 2022. Klimata pārmaiņu samazināšanas pasākumu demonstrēšana auglīgu meliorētu organisko augšņu apsaimniekošanā Baltijas valstīs un Somijā – LIFE OrgBalt (LIFE01), zinātniskais asistents
2. 2020. – 2021. Atbildīga ūdens resursu apsaimniekošana lauku attīstībai vietējā līmenī un Baltijas jūras reģionā (R094) – WATERDRIVE (INT10), zinātniskais asistents
3. 2021. Lēmumu pieņemšanas atbalsta sistēmas izstrāde ziemas kviešu lapu un vārpu slimību ierobežošanai Valsts pārvaldes iestādes finansēts projekts, pētnieks
4. 2023. Dabisko un antropogēno faktoru ietekmes uz slāpekļa un fosfora savienojumu zudumiem no lauksaimniecības zemēm novērtējums (S466) Valsts pārvaldes iestādes finansēts projekts, zinātniskais asistents
5. 2023. Atsevišķu pārvaldes uzdevumu deleģēšana 2023. gadā (K96) Valsts pārvaldes iestādes finansēts projekts, zinātniskais asistents

Publikācijas, kas indeksētas SCOPUS un/vai WoS datubāzēs

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5. Burlakovs, J., Ozola-Davidane, R., Vincevica-Gaile, Z., Wdowin, M., Grinfelde, I., Pilecka-Ulcugaceva, J., & Zekker, I. (2022). Towards 'beyond the zero waste concept': innovative solutions for valorization of fine residual waste fraction from landfills: rare earth elements potential. Research for Rural Development, 37, 254–257. https://doi.org/10.22616/rrd.28.2022.036 Burlakovs, J., **Pilecka, J.,** Grinfelde, I., Arbidans, L., Arina, D., & Setyobudi, R. H. (2021). Sustainable landfill fine fraction of waste reuse opportunities in covering layer development. Research for Rural Development, 36, 303–310. https://doi.org/10.22616/rrd.27.2021.043
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7. Burlakovs, J., **Pilecka-Ulcugaceva, J.,** Grinfelde, I., Siltumens, K., & Vincevica-Gaile, Z. (2022). Potentiometrical screening of landfill mined fine fraction of waste. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 22(1.1), 491–498. https://doi.org/10.5593/sgem2022/1.1/s04.057
8. Burlakovs, J., Vincevica-Gaile, Z., Krievans, M., Jani, Y., Horttanainen, M., Pehme, K.-M., Dace, E., Setyobudi, R. H., **Pilecka, J.,** Denafas, G., Tamm, T., & Klavins, M. (2020). Platinum group elements in geosphere and anthroposphere: Interplay among the global reserves, urban ores, markets and circular economy. Minerals, 10(6), 1–19. https://doi.org/10.3390/min10060558
9. Butenaite, D., Grinfelde, I., **Pilecka-Ulcugaceva, J.,** Vincevica-Gaile, Z., & Liepa, S. (2021). The nitrous oxide isotope measurements for soil samples under laboratory conditions. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 21(5.1), 529–536. https://doi.org/10.5593/sgem2021/5.1/s21.114
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15. Grinfelde, I., Bakute, A., Pilecka, J., Berzina, L., & Vebere, L. L. (2019). The impact of landscape structure of catchment area on lake hydrology. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 19(3.1), 569–576. https://doi.org/10.5593/sgem2019/3.1/S12.073
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1. IEVADS

Vairāk nekā puse - 56% pasaules iedzīvotāju dzīvo pilsētās (World Bank, 2023). Tiek prognozēts, ka līdz 2050. gadam pilsētu iedzīvotāju īpatsvars pieaugs līdz 68 % (United Nations, 2018). Pēc 2021. gada datiem aptuveni 38,9% Eiropas Savienības iedzīvotāju dzīvo pilsētās, bet priekšpilsētās dzīvojošo skaita īpatsvars sasniedz 35,9% (Eurostat, 2023). Latvijas pilsētās dzīvojošo iedzīvotāju skaita īpatsvars 2023. gadā pieaudzis līdz 69,8% (Oficiālās statistikas portāls, 2023). Palielinoties iedzīvotāju skaitam pilsētās, aizvien aktuālāks paliek jautājums par gaisa kvalitāti pilsētvidē. Apmēram 92% no pasaules iedzīvotāju dzīvo vietās, kur gaisa piesārņojuma līmenis neatbilst pieļaujamajām robežvērtībām (Battista & de Lieto Vollaro, 2017). Satiksmes izraisītais gaisa piesārņojums ir svarīga vides un veselības problēma visā pasaulē (Wahab et al., 2020), kā arī satiksme ir galvenais gaisa piesārņojuma cēlonis lielākajā daļā pilsētu (Bućko et al., 2011; D'Amato et al., 2013; Sun et al., 2018), jo transportlīdzekļi gan rada, gan pārnes piesārņojumu, sausā laikā paceļot putekļus gaisā veicinot pilsētu piesārņojuma līmeņa paaugstināšanos (Faiz et al., 2009; Hoodaji et al., 2012; Lu et al., 2009; Wahab et al., 2020). Daudzpusīgs metālu maisījums gaisā nāk no automašīnu riepām, bremžu daļu nodiluma un izplūdes gāzēm (Faiz et al., 2009; Mortazavi et al., 2019; Wahab et al., 2020). Gaisā suspendēto daļiņu emisijas joprojām ir viena no aktuālākajām gaisa kvalitātes problēmām pilsētās visā pasaulē (Fosmire, 1990; Z. Li et al., 2013). Latvijā situācija ir sliktāka nekā vidēji ES tieši daļiņu PM2,5 ietekmes ziņā, kur Latvijai ir 17. sliktākā vieta starp 41 novērtēto Eiropas valsti (Turap et al., 2019; World Health Organization, 2021).

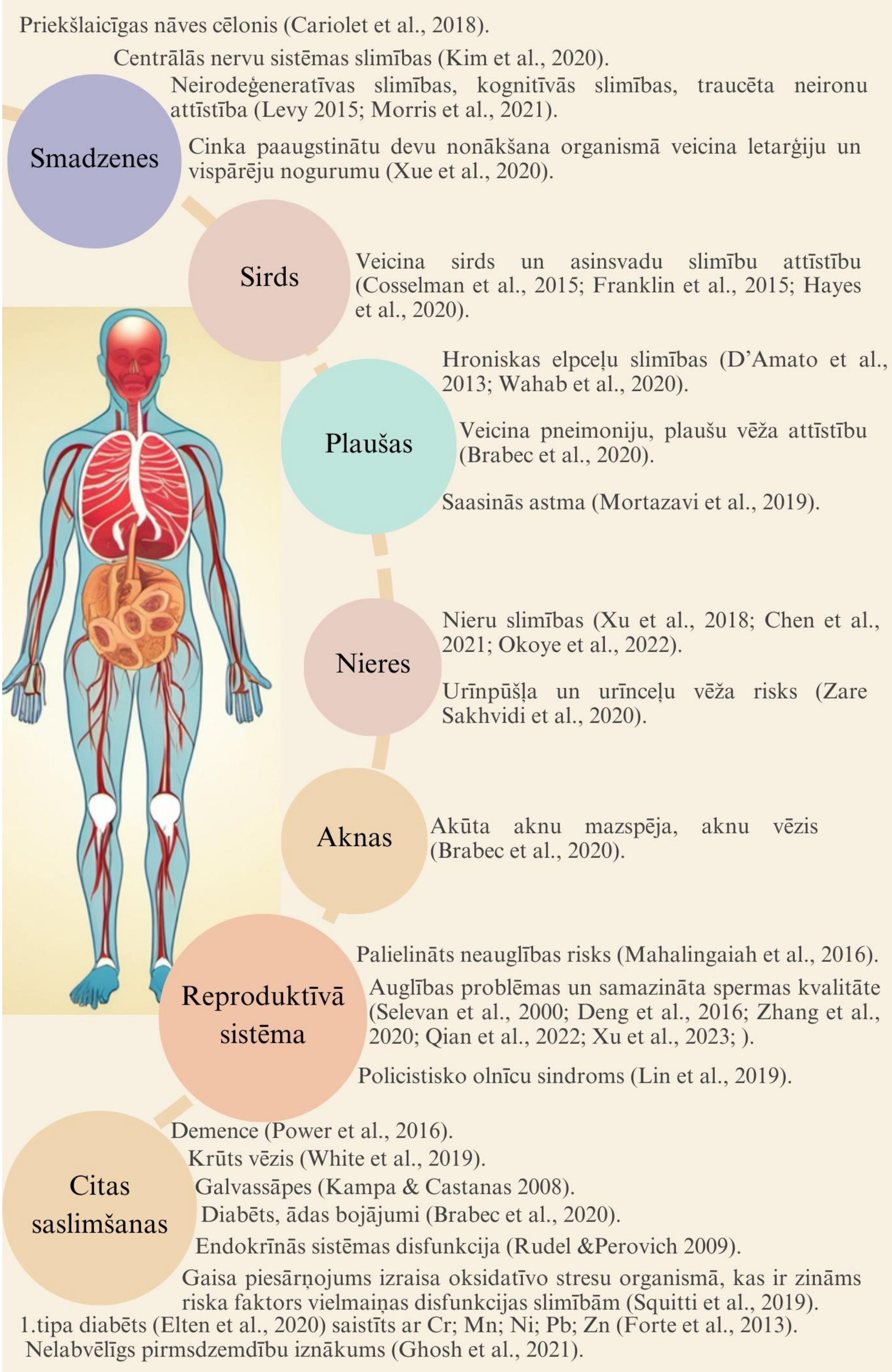
Apskatot jēdzienu, risks var atrast daudz un dažādas šī termina interpretācijas. Piemēram, Iveta Briška terminu risks definē šādi: "Risks - (angļu val. *risks, hazard, danger*) – ir rezultāts jeb galaprodukts, ko ik dienu veido mūsu lēmumu pieņemšana, ko rada lēmumu sekas. Risku var traktēt arī kā nākotnes kaitējuma bīstamību." Eiropas Vides aģentūra definē, ka gaisa piesārņojums ir vienīgais lielākais vides izraisīts risks veselībai Eiropā (EEA, 2018). Kopumā pilsētu gaisa piesārņojuma telpiskās izplatības riska novērtējums sniedz vērtīgu informāciju, lai izprastu sarežģīto mijiedarbību starp gaisa kvalitāti, cilvēku veselību un vides ilgtspējību pilsētvidē. Riska raksturojumā novērtē pilsētu gaisa piesārņojuma iespējamo ietekmi uz cilvēku populācijām, tostarp elpceļu slimības, sirds un asinsvadu sistēmas traucējumus, vēža risku un citus nelabvēlīgus rezultātus veselībai.

Šajā promocijas darbā ievāktie un uzkrātie dati, kā arī piesārņojuma telpiskās izplatības riska kvantitatīvā analīze paver iespējas veikt veselības riska novērtējumus, iedarbības un reakcijas attiecības, lai kvantitatīvi noteiktu veselības riskus, kas saistīti ar gaisa piesārņotāju iedarbību.

Slikta gaisa kvalitāte negatīvi ietekmē dzīves kvalitāti, īpaši pilsētu iedzīvotājiem, jo cilvēks ik dienu ir pakļauts putekļu daļiņu ietekmei (Mortazavi et al., 2019; Wahab et al., 2020). Gaisa piesārņojums ietekmē cilvēka veselību nepārtraukti, tostarp putekļi, kas satur dažādus metālus, ir atzīts par vienu no cilvēka veselības kritiskāko problēmu (She et al., 2017), jo tie viegli iekļūst cilvēka elpceļos (Alasfar & Isaifan, 2021; Cereceda-Balic et al., 2012; Kikaj et al., 2023). Lielākā daļa smago metālu nonāk atmosfērā kā aerosola daļiņas (Tsai et al., 2014). Smago metālu nogulsnēšanās var būt ar tiešu un netiešu ietekme uz ekosistēmām un cilvēku veselību (Cadelis et al., 2014; Ochoa-Hueso et al., 2017; Feng et al., 2019). Gaisa piesārņojums ietekmē visneaizsargātākās personu grupas, piemēram, grūtnieces, bērnus (Cadelis et al., 2014), vecāka gadagājuma cilvēkus, cilvēkus ar ierobežotiem ienākumiem un ierobežotu piekļuvi ārstiem. Īpaši tiek ietekmēti cilvēki, kuriem jau ir hroniskas saslimšanas, šiem cilvēkiem rodas komplikācijas un smagākas veselības problēmas (Cadelis et al., 2014; D'Amato et al., 2013; IARC, 2015; She et al., 2017). Gaisa piesārņojums var izraisīt virkni veselības problēmas un izraisīt nāvējošas saslimšanas (skat. 1.1.attēlu.). Pēdējos gados arvien vairāk tiek veikti pētījumi par sniega piesārņojuma slodžu izpēti mērenajā un arktiskajā klimata joslā (Kuoppamäki et al., 2014). Vairākos pētījumos sniegs izmantots kā pilsētas gaisa piesārņojuma indikators (Dossi et al., 2007; Engelhard et al., 2007; Liu et al., 2021), jo sniegs ir, ļoti labs, materiāls gaisa piesārņojuma noteikšanai vairāku iemeslu dēļ, tas darbojas kā dabisks filtrs dažādiem ķīmiskiem elementiem, daļiņām un putekļiem, īpaši tiem, kas rodas antropogēno darbību rezultātā, piemēram, ceļu satiksmē (Adamiec et al., 2013; Bućko et al., 2011) un rūpniecībā (Bućko et al., 2011; Engelhard et al., 2007; Z. Li et al., 2013). Sniega paraugus var viegli savākt un analizēt, gaisa piesārņojuma akumulēšanās laiku nosaka meteoroloģiskie apstākļi, sniegs labi absorbē no atmosfēras gan organiskos, gan neorganiskos piesārņotājus (Sun et al., 2018). Sedimentācija atmosfērā notiek gan mitros, gan sausos procesos, ko kopā dēvē par masu nogulsnēšanos. Mitrās nogulsnēšanās laikā daļiņas un gāzes tiek nogulsnētas ar nokrišņiem, t.i., lietus, sniega, krusas un miglas palīdzību (Tsai et al., 2014). Sniegpārslas no atmosfēras uzkrāj vairāk piesārņojošo vielu nekā ūdens pilieni (lietus lāses), jo tām ir lielāks virsmas laukums un lēnāks krišanas ātrums (Bućko et al., 2011; Engelhard et al., 2007; Telmer et al., 2004). Pateicoties tam, mērenajā un arktiskajā klimata joslu valstīs sniega savākšana ir laba gaisa kvalitātes noteikšanas metode (D'Amato et al., 2013; Engelhard et al., 2007). Sniegs efektīvi uzkrāj dažādus piesārņotājus no atmosfēras, sniega segā pie ceļiem (Sillanpää & Koivusalo, 2013), kā arī ielu putekļus, kurus veido ceļa nodiluma materiāls, smiltis un citi materiāli, kas izkaisīti uz ceļiem ziemas laikā (Furberg et al., 2019), kā arī riepu un bremžu nodilums, dzinēji (degšana un berze) un transportlīdzekļu korozija (Peltola & Wikström, 2006), riepu ar radzēm izmantošana pilsētā rada papildu nodilumu radzēm, kas satur volframu (Bäckström et al., 2003; Furberg et al., 2019). Galvenā uzmanība jāpievērš mikroelementu koncentrācijām, kas uzkrājas ilgtermiņā un var uzkrāties pilsētvides ekosistēmu barības ķēdēs (Faiz et al., 2009; Wahab et al., 2020).

Dažādu smago metālu avotus var iedalīt divās grupās dabiskie un antropogēnie avoti. Pētījumi par gaisa piesārņojumu, ko rada putekļi no dabīgiem avotiem tiek apskatīta putekļu daļiņu transportēšana no Sahāras tuksneša uz Eiropu, ietekmējot tādas valstis kā Spānija, Itālija un Grieķija (Querol et al., 2009). Turklāt vulkāna izvirdumi īpaši akcentējot Eiropas reģionu Itālijā un Īslandē var izdalīt atmosfērā lielu daudzumu pelnu un putekļu, ietekmējot tuvējos reģionus un pat sasniedzot tālus apgabalus atkarībā no atmosfēras apstākļiem (Arnalds 2010; Horwell et al., 2017). Ķīmisko elementu klātbūtne sniega ūdenī norāda uz vienu vai vairākiem specifiskiem piesārņotājiem, piemēram, dzelzs (Fe) klātbūtne sniegā norāda uz fosilā kurināmā, automašīnu dzinēju un transportlīdzekļu virsbūves nodilumu, varu (Cu), hromu (Cr), vanādiju (V) un arsēnu (As) iegūst, sadedzinot fosilo kurināmo (Pacyna et al., 2001; Rodella et al., 2017). Vara (Cu) klātbūtne sniegā vairāk saistīta ar transportlīdzekļu dažādu daļu nodilumu, nevis izplūdes gāzu emisiju (Hildemann et al., 1991). Cinks (Zn) norāda uz ogļu sadedzināšanu un satiksmes radītajām emisijām (Mijić et al., 2010). Cinks (Zn) (Apeagyei et al., 2011; Wahab et al., 2020), varš (Cu), niķelis (Ni), svins (Pb) (Pacyna et al., 2001) un mangāns (Mn) ir saistīti ar satiksmes putekļiem (Sofowote et al., 2019). Piemēram, alumīnija avotus var iedalīt šādi: dabiskie (laika apstākļi, kad alumīnijs augsnes daļiņu veidā tiek pārnests ūdenī un gaisā) un antropogēnie avoti (automobiļi, rūpniecība, atkritumu sadedzināšana, ogļu sadedzināšana) (Al-Thani et al., 2020; Alasfar & Isaifan, 2021; World Health Organization, 2021). Volframa koncentrācija strauji samazinās, attālinoties no brauktuves, kas liecina par neapstrīdamu transporta piesārņojuma avotu (Bäckström et al., 2003). Pateicoties zemajai volframa koncentrācijai dabiskajā vidē, tas var būt piemērots ceļu un satiksmes piesārņojuma identifikators (Bäckström et al., 2003). Volframs dabiski izplūst atmosfērā ar vēja izpūstiem putekļiem no augsnes, vai arī tas var iekļūt ūdeņos, izskalojoties. Vairākos pētījumos ir ziņots par palielinātu volframa saturu ceļu putekļu lietus ūdens notecē no ceļa un ceļmalas augsnēm, kas ir saistīts ar riepu radžu nodilumu, automašīnu nodilumu un intensīvu satiksmes plūsmu (Peltola & Wikström, 2006; Bućko et al., 2011).

Lielākā Latvijas iedzīvotāju daļa dzīvo pilsētās, tādēļ gaisa kvalitātes pētījumi, kuros iekļauti sniega un ielu putekļu analīze ir ļoti svarīgi, lai noteiktu smago metālu izcelsmi, izplatību un līmeni pilsētvidē, ielu un ceļu tuvumā. Pilsētvides gaisa kvalitātes pētījumi ir vitāli nepieciešami pilsētvides plānošanas dokumentu izstrādē un pilsētas ilgtspējīgas attīstības stratēģijas mērķu nospraušanai.



1.1.att. **Gaisa piesārņojuma radītas veselības problēmas**

1.1. Promocijas darba robežas

Ekoloģiskie riski (angļu val. ecological risks) ir saistīti ar iespējamo kaitējumu dabai, sabiedrībai un individuālajai veselībai, kas rodas sakarā ar dažādiem ekoloģiskiem faktoriem. Šie riski rodas gan cilvēka apzinātas darbības rezultātā, piemēram, piesārņojot vidi, gan arī nezināmas vai neinformētas darbības dēļ, kad cilvēki nav pilnībā apzinājušies to ietekmi. Ekoloģiskie riski apdraud cilvēku darba, dzīves un atpūtas apstākļus, kā arī veselību, un tie var ievērojami ietekmēt dzīves kvalitāti (Beck, 1995; Bartell, 2008). Saskaņā ar Pasaules Veselības organizācijas rekomendācijām veselības riska novērtējums ietver trīs posmus (World Health Organization, 2016). Pirmais posms ir novērtē iedzīvotāju pakļautību attiecīgo piesārņojošo vielu iedarbībai, otrais posms ir aplēst ar gaisa piesārņojumu saistīto veselības risku, un trešais posms ir aprēķināt nenoteiktību (EEA, 2018). Lai izprastu dažādu piesārņotāju ietekmi uz veselību, tiek izmantoti dati par iedzīvotāju pakļautība dažādu piesārņojošo vielu iedarbībai, epidemioloģiskie dati un toksikoloģiskie pētījumi. Pēc piesārņojuma līmeņa noteikšanas dati tālāk ir izmantojami, lai veiktu riska raksturojumu, kas ietver iedarbības datu integrēšanu ar datiem par ietekmi uz veselību, lai novērtētu negatīvas ietekmes uz veselību iespējamību populācijā, kas pakļauta noteikta līmeņa gaisa piesārņojumam.

Promocijas darbā ir veikts Pasaules Veselības organizācijas rekomendācijās noteiktā risku izvērtējuma pirmais posms: noteiktas dažādu piesārņojošo vielu koncentrācijas un izstrādātas piesārņojuma līmeņa telpiskās izplatības riska kartes.

1.2. Promocijas darba mērķis

Promocijas darba mērķis ir izstrādāt metodiku gaisa piesārņojuma telpiskās izplatības riska novērtēšanai, balstoties uz bioindikācijas metodēm un smago metālu koncentrācijām sniegā.

1.3. Promocijas darba pētnieciskie uzdevumi

1. Smago metālu un gaisā suspendēto cieto daļiņu (PM) gaisa piesārņojuma pētījumu pieredzies apkopošana;
2. Ilglaicīgā un īslaicīgā gaisa piesārņojuma noteikšanas metožu aprobācija Jelgavas pilsētā;
3. Gaisa piesārņojuma ar ķīmiskajiem elementiem koncentrāciju noteikšana Jelgavas pilsētā;
4. Gaisa piesārņojuma ar ķīmiskajiem elementiem izplatības telpiskās analīzes veikšana;
5. Gaisa piesārņojuma avotu identifikācija, izmantojot daudzveidīgas statistikas metodes.

1.4. Promocijas darbā aizstāvamās tēzes

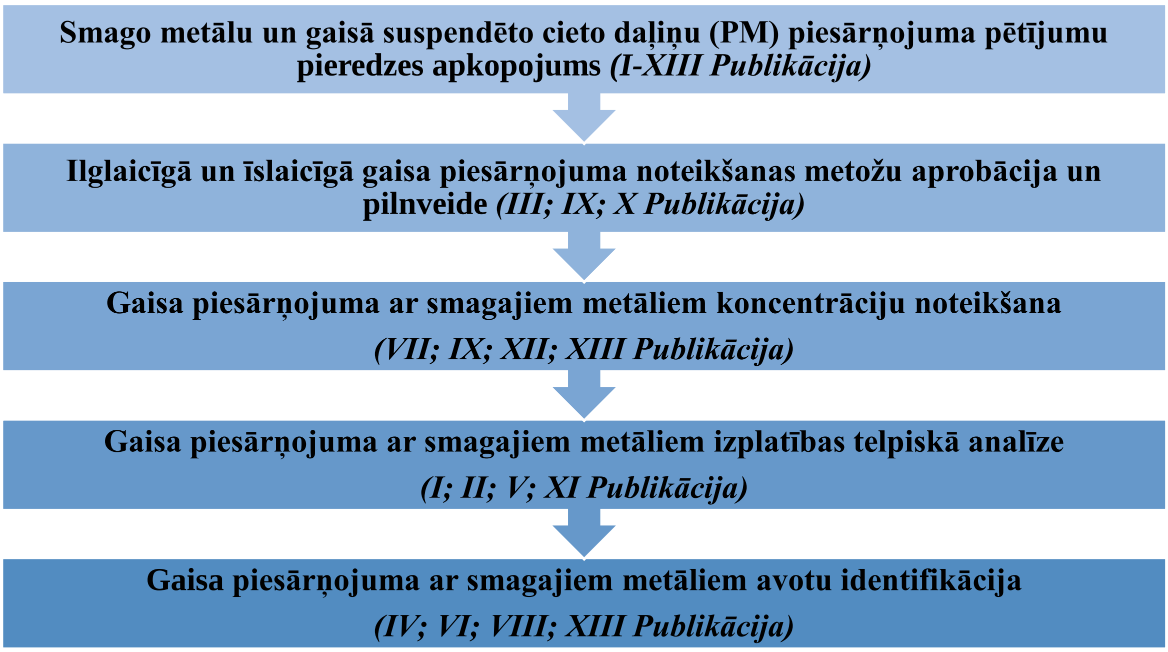
1. Sniegs ir labs indikators pilsētvides gaisa kvalitātes novērtēšanai.
2. Kompleksi vērtējot ilglaicīgo un īslaicīgo gaisa piesārņojumu ir iespējams novērtēt pilsētvides gaisa piesārņojuma dinamiku laikā un telpā.

1.5. Promocijas darba novitāte

1. Pētījumā pirmo reizi Eiropā iegūti nepārtraukti 7 gadu dati par dažādu smago metālu un citu ķīmisku elementu uzkrāšanos sniega segā pilsētvidē ar augstu izšķirtspēju, pārklājot visu pilsētas teritoriju.
2. Pirmo reizi veikti kompleksi pētījumi īslaicīgā un ilglaicīgā gaisa piesārņojuma identifikācijai, izmantojot ķīmiskās analīzes un bioindikācijas metodes.
3. Izmantojot ArcGIS un kompleksas statistikas metodes, ir veikta galveno piesārņojuma avotu radīto risku analīze urbānā vidē.
4. Precizēts gaisa kvalitātes parauglaukumu optimālais blīvums urbānā vidē.
5. Precizēta sniega paraugu sagatavošanas metode pirms ICP ķīmisko analīžu veikšanas.
6. Pārbaudīts, ka sniega parauga analīzēm vispiemērotākā ķīmisko analīžu veikšanas metode ir ICP-MS.

1.6. Promocijas darba pētījuma uzbūve

Promocijas darba pētījums veidots vairākās pakāpēs, lai sasniegtu promocijas darbam izvirzīto mērķi (skat.1.2.att.).



1.2.att. **Promocijas darba pētījuma galvenie soļi**

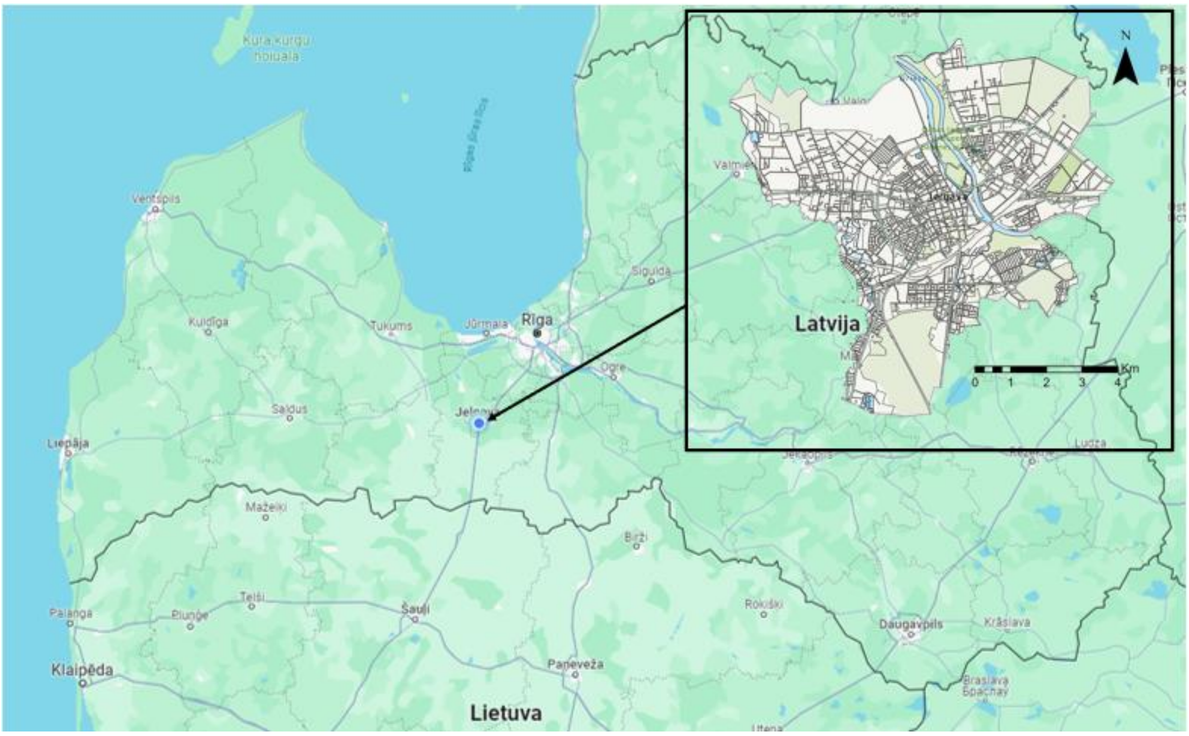
2. MATERIĀLI UN METODES

Balstoties uz promocijas darba mērķi, tika apskatītas dažādas iespējas novērtēt gaisa piesārņojuma līmeni pilsētvidē, izmantojot dažādas gaisa piesārņojuma noteikšanas metodes. Uzsākot pētījumus, tika veikta ķērpju inventarizācija (X Publikācija), veikta Dzeltenā sienas ķērpja *(Xanthoria parietina)* ķīmiskās analīzes (X Publikācija) un ķērpja Pūslīšu hipogimnija ***(****Hypogymnia physodes)* transplantu izvietošana Jelgavas pilsētā (X Publikācija).

Promocijas darbā apskatīts 7 gadu periods (2017. - 2023. gads) ievācot sniega paraugus un tos, analizējot (I-XIII Publikācija). Īpaši apskatīta transporta koridoru ietekme uz pilsētas gaisa kvalitāti (IV un VI Publikācijā). Apskatīta parauglaukumu ierīkošanas pilnveidošana un dažādu iekārtu nepieciešamība analizējot sniega paraugus, lai iegūtu maksimāli precīzus rezultātus.

2.1. Pētāmā objekta raksturojums

Jelgava atrodas Latvijas centrālajā daļā, iekļaujoties Zemgales līdzenumā (skat.2.1.att.). Pilsētu šķērso Lielupe un Driksa, savukārt Svētes upe tek pa tās teritoriju. Jelgavas pilsētas platība sasniedz 60,32 km^2. Visu Jelgavas pilsētas teritoriju iedala 11 funkcionālajās zonās (savrupmāju apbūves teritorija, mazstāvu dzīvojamās apbūves teritorija, daudzstāvu dzīvojamās apbūves teritorija, publiskās apbūves teritorija, jauktas centra apbūves teritorija, rūpnieciskās apbūves teritorija, transporta infrastruktūras teritorija, tehniskās apbūves teritorija, dabas un apstādījumu teritorija, mežu teritorija, ūdeņu teritorija). Jelgavas pilsētā dabas pamatnes teritorijas, kas ietver apstādījumus, pļavas, mežus, ūdenstilpes un ūdensteces, dabiskas ūdensmalas, dabas lieguma "Lielupes palienes pļavas" teritoriju, kā arī ielu un ceļu malas bez speciāli izveidotiem apstādījumiem aizņem 2610,9 ha jeb 43,3% no visas pilsētas teritorijas (Jelgavas pilsētas pašvaldība, 2017). Ar savu iedzīvotāju skaitu Jelgava ir viena no lielākajām Latvijas pilsētām. Saskaņā ar oficiālajiem statistikas portāla datiem no 2017. gada sākuma līdz 2023. gada sākumam iedzīvotāju skaits Jelgavā ir svārstījies no 56026 līdz 54836, un šis skaits katru gadu samazinās (Oficiālais statistikas portāls, 2023).



2.1.att. **Jelgavas pilsētas ģeogrāfiskā atrašanās vieta**

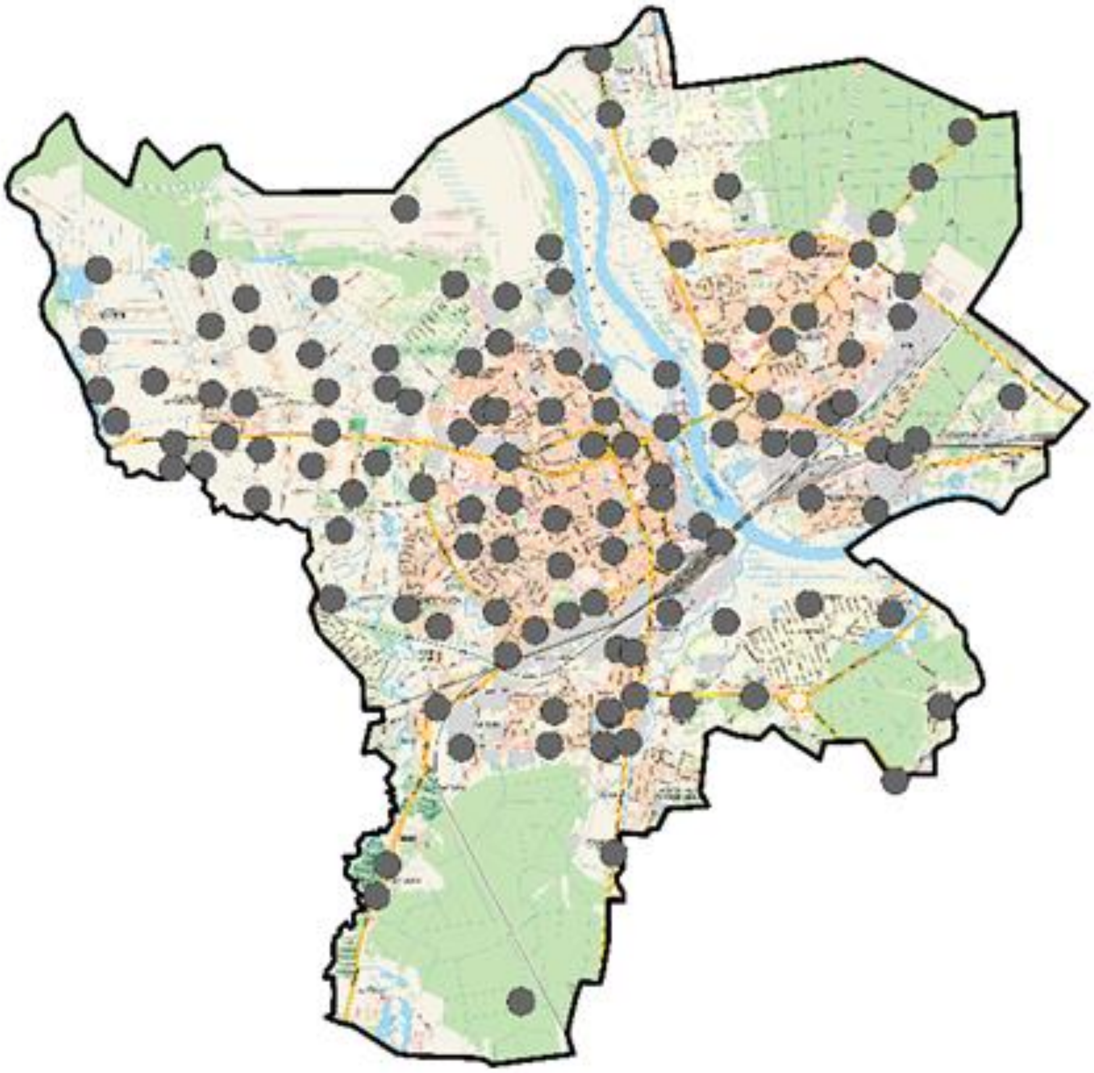
Jelgavas klimats pieder mēreni kontinentālajai zonai. Ziemas vidējā gaisa temperatūra ir ap -5,5 °C, bet vasarā tā sasniedz +17,1 °C. Mēneša vidējā temperatūras amplitūda gada laikā ir 22,1 °C. Vidēji gadā ir 150–155 dienas ar mākoņainu laiku un 170–180 dienas ar nokrišņiem. Vidējais gada nokrišņu daudzumi svārstās no 550 līdz 560 mm. Vislielākais absolūtais gaisa mitrums ir jūnijā, bet vismazākais - februārī. Bezsala periods ilgst no 135 līdz 145 dienām (Latvijas Vides, Ģeoloģijas un Meteoroloģijas centrs, 2020). Parasti pastāvīgā sniega sega veidojas decembra beigās. Sniega segas biezums ir ļoti mainīgs un svārstās no 10 līdz 25 cm (Latvijas Vides, Ģeoloģijas un Meteoroloģijas centrs, 2020).

Jelgavas pilsētā ir veikta kampaņveidīga automašīnu uzskaite. Automašīnu skaitīšanā, kas veikta 2020. gada jūlijā uz Dobeles šosejas pie Svētes upes tilta, vidēji 24 h saskaitītas 10488 vieglās automašīnas, 758 smagās automašīnas un 375 auto sastāvi. Automašīnu skaitīšanā, kas veikta 2021. gada 19. jūlijā, netālu no Miera ielas un Bauskas ielas krustojuma, kur atrodas viens no parauglaukumiem vidēji 24 h saskaitītas 11192 vieglās automašīnas, 949 smagās automašīnas un 986 auto sastāvi. Automašīnu skaitīšanā, kas veikta 2022. gada 21. maijā Viskaļu ielā vidēji 24 h saskaitītas 1476 vieglās automašīnas, 111 smagās automašīnas un 48 auto sastāvi. Kārniņu ceļā, kur atrodas divi no pētījumā iekļautajiem parauglaukumiem (N 56º 37' 33"; E 23º 46' 27" un N 56º 37' 33"; E 23º 46' 27"), automašīnu skaits no 2023. gada 18. janvāra līdz 24. janvārim, kur vidēji 24 h ir konstatētas 549 vieglās automašīnas, 37 smagās automašīnas un 21 auto sastāvs. Automašīnu skaitīšanas rezultāti no Rīgas ielas un Skautu ielas krustojuma, skaitīšana veikta 2023. gada jūnijā, vidēji 24h uzskaitītas 661 vieglā automašīna un 11 smagās automašīnas. Kalnciema ceļā pie Loka maģistrāles ar skatu uz centru automašīnu skaitīšana veikta 2023. gada martā, kur vidēji 24 h saskaitītas 2094 vieglās automašīnas, pārējās automašīnas nav skaitītas.

2.1.1. Ilglaicīgā piesārņojuma noteikšanas metodes

Lihenoindikācijas metode. Jelgavas pilsētas teritorijā ir daudzveidīgs ēku blīvums un uzņēmumu darbības intensitāte pa pilsētu sadalīta nevienmērīgi. Lihenoindikācijas nolūkā pilsētu sadalīja 104 parauglaukumos (1996. gada un 2006. gada pētījumos), ņemot vērā ēku blīvumu, rūpniecisko uzņēmumu klātbūtni un galveno transporta ceļu novietojumu. Centrālais rajons tika sadalīts 52 parauglaukumos ar platību 500 m x 500 m, bet pārējā pilsētas teritorija - 1000 m x 1000 m parauglaukumos, kas kopā veidoja vēl 52 parauglaukumus (X Publikācija). Šis parauglaukumu izvietojums tika izstrādāts, balstoties uz gaisa kvalitātes pētījumiem, kas veikti 1996. un 2006. gadā. Turpinot pētījumu 2016. gadā, teritorijai tika pievienots vēl 21 parauglaukums, atbilstoši pilsētas attīstībai un apbūves paplašināšanai (Grinfelde et al., 2017). Kopumā 2016. gadā lihenoindikācija tika veikta 125 parauglaukumos (skat.2.2.att.).

Jelgavas pilsētas pētījumā veicot, lihenoindikāciju kopumā tika atlasīti un apsekoti 1250 lapu koki: ābeles (*Malus spp.*), āra bērzi (*Betula pendula*), baltalkšņi (*Alnus incana*), bumbieres (*Pyrus spp.*), liepas (*Tilia spp.*), melnalkšņi (*Alnus glutinosa*), ošlapu kļavas (*Acer negundo*), parastie ozoli (*Quercus robur*), parastās kļavas (*Acer platanoides*), parastās zirgkastaņas (*Aesculus hippocastanum*), parastās gobas (*Ulmusglabra*), parastās vīksnas (*Ulmus laevis*), pīlādži (*Sorbus spp.*), plūmes (*Prunus spp.*) un vītoli (*Salix spp.*). Koki tika izvēlēti tā, lai tie būtu aptuveni vienādā augstumā, līdzīgu vainagu formu, līdzīgi izmērā un vecumā. Būtiski bija tas, lai tie augtu līdzīgās vietās – galvenokārt ielu un ceļu malās. Kopumā visā Jelgavas pilsētas teritorijā bija 125 parauglaukumi, katrā parauglaukumā tika izvēlēti 10 koku, ķērpju sugu skaitīšana tika veikta visiem desmit izvēlētajiem kokiem, visā koka stumbra platībā no 30 cm līdz 2 m augstumā. Ķērpju procentuālais segums pēc sugām tika novērtēts pēc tās koka stumbra puses, kurā bija visvairāk ķērpju (Grinfelde et al., 2017).



2.2.att. **Lihenoindikācijas parauglaukumu izvietojums Jelgavas pilsētā**

Pirmo reizi gaisa tīrības indeksa aprēķinu aprakstīja Leblanc un DeSloover 1970. gadā. Gaisa tīrības indeksu (IAP - *Index of Atmospheric Purity*) aprēķina katram parauglaukumam. Apskata un sastāda visu ķērpju sugu toksiskotolerances faktora Q vērtību un seguma sastopamības pakāpes f vērtību reizinājuma summu. To aprēķina pēc 1. formulas.

To aprēķina pēc 1. formulas:

$$IAP = \sum_{1}^{n} \frac{(Q \times f)}{10}, \quad (1)$$

kur:

IAP – gaisa tīrības indekss;

n – ķērpju sugu skaits pētāmajā teritorijā;

Q – toksikotolerances faktors (konstants katrai ķērpju sugai), ko aprēķina izmantojot 2.formulu:

$$Q = n_1 / n_2, \quad (2)$$

kur:

n_1 – visu ķērpju sugu kopējais skaits visos parauglaukumos, kuros ir interesējošā suga;

n_2 – parauglaukumu summa, kuros ir sastopama interesējošā suga;

f – seguma sastopamības pakāpe, ko nosaka pēc ķērpju sugas procentuālā seguma un ķērpju sugas sastopamības biežuma kombinējuma katrā parauglaukumā.

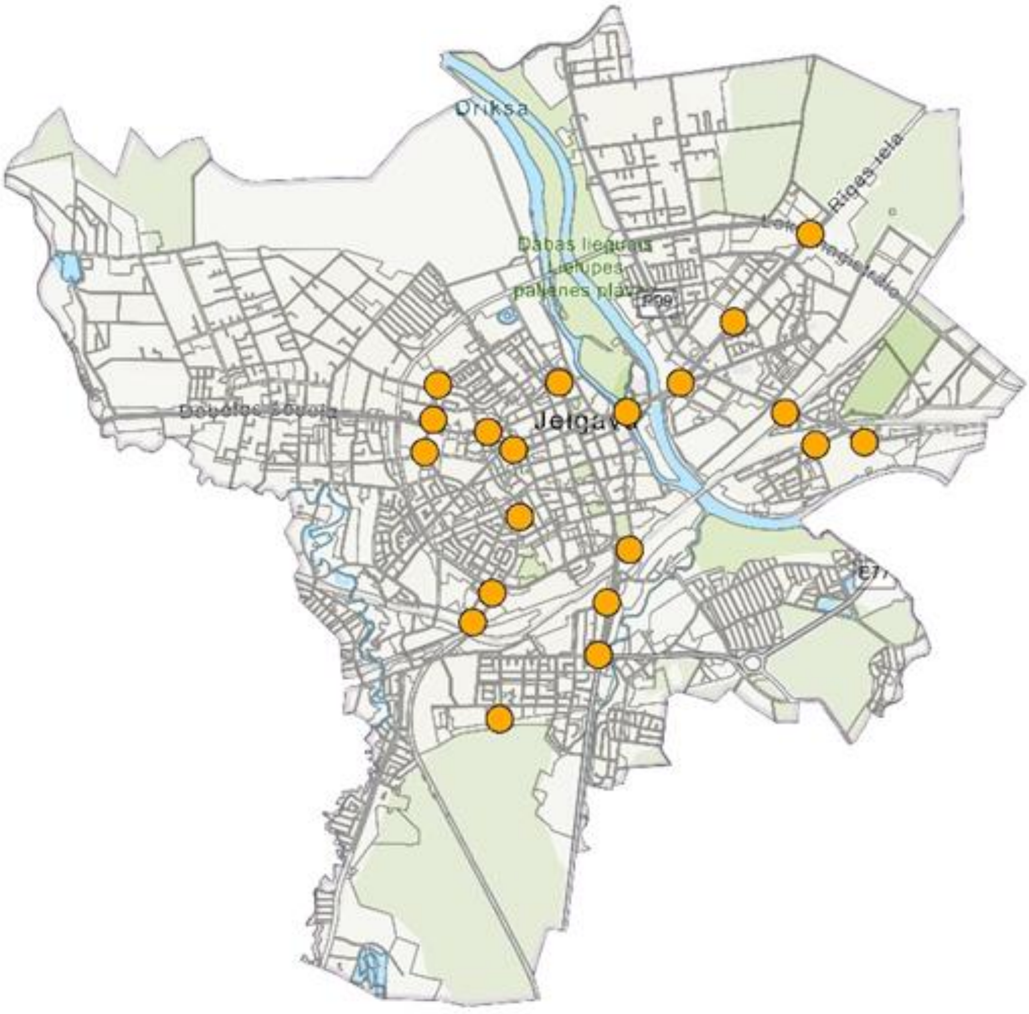
f vērtības:

1 – suga reta, ar niecīgu segumu;

2 – suga reti vai ar 1-5% segumu;
3 – suga ne bieži vai ar 5-10% segumu;
4 – suga bieži vai ar 10-20% segumu;
5 – suga ļoti bieži ar segumu, kas lielāks par 20% (Leblanc & DeSloover, 1970).

Ķērpju paraugu analīzes metode. Lai veiktu ķērpju ķīmisko analīzi, tika ievākts Dzeltenais sienas ķērpis *(Xanthoria parietina)*, lai varētu noteikt ilgtermiņa piesārņojumu, kas uzkrājies ķērpjos. Ķērpja paraugi tika iegūti no 20 parauglaukumiem (skat.2.3.att.), katrā no tiem 3 atkārtojumos. Dzeltenā sienas ķērpja *(Xanthoria parietina)* koordinātas norādītas Pilecka et al. (2017) publikācijā. Šie parauglaukumi atrodas Jelgavas pilsētas daļās, kurās ir visintensīvākā antropogēnā ietekme. Tie ietver gan daudzstāvu dzīvojamās ēku kvartālus, gan privātmāju rajonus, rūpniecības zonas, intensīvus satiksmes posmus un citas antropogēnas ietekmes raksturojošas vietas. Salīdzinājuma nolūkos tika savākti arī paraugi no dabiska meža, kas atrodas aptuveni 5 km attālumā no pilsētas robežas (X Publikācija).

Dzeltenais sienas ķērpis *(Xanthoria parietina)* tika savākts no lapu koku stumbriem aptuveni 1,3 – 1,5 metru augstumā virs zemes. Ķērpis tika ievākts atdalot tā laponi no koka stumbra ar pinceti, savāktie paraugi tika ievietoti absolūti tīros stikla traukos un ķērpju vākšanas laikā tika izmantoti putekļus nesaturošus nitrila cimdi (skat.2.4.att.).

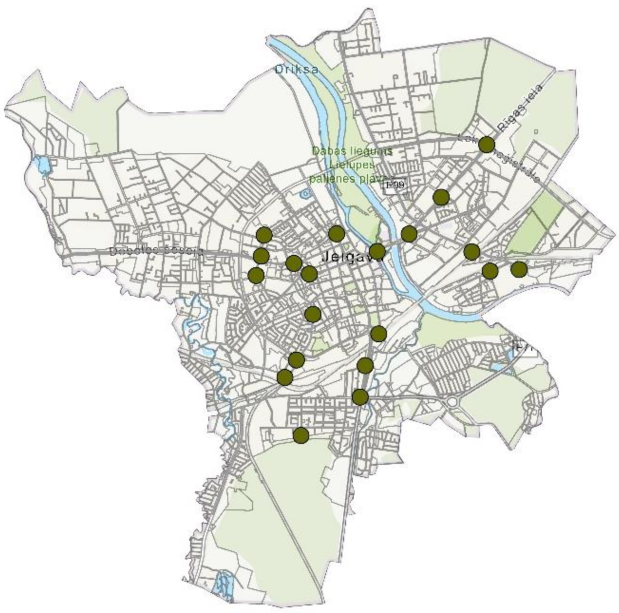


2.3.att. **Dzeltenā sienas ķērpja *(Xanthoria parietina)* paraugu ievākšanas vietas Jelgavas pilsētā**

2.4.att. **Dzeltenā sienas ķērpja *(Xanthoria parietina)* paraugs, kas ievākts no koka stumbra**

2.1.2. Īslaicīgā piesārņojuma noteikšanas metodes

Ķērpju transplantācijas metode. Pārskatot dažādus pētījumus un strādājot ar bioindikācijas metodēm, ir svarīgi ņemt vērā dažādus būtiskus parametrus, kas ietekmē piesārņojuma līmeni un tā izkliedi ielu kanjonos: ielu izmērus, vēja ātrumu un virzienu, ēku novietojumu, siltuma stratifikāciju, transportlīdzekļu kustību (izmēru, skaitu) un citus būtiskus parametrus (Xie et al., 2005). Ķērpju transplantācijas metode pieder pie vienas no īslaicīgā gaisa piesaŗņojuma noteikšanas metodēm. Parauglaukumi tika atlasīti pilsētas centrālajā daļā, kurā ir lielākā antropogēnā slodze un apdzīvotība (skat.2.5.att.). Parauglaukumu novietojums aptver gan daudzstāvu dzīvojamo ēku kvartālus, gan privātmāju rajonus, rūpniecības zonas, intensīvus satiksmes posmus un citas antropogēnas ietekmes raksturojošas vietas.

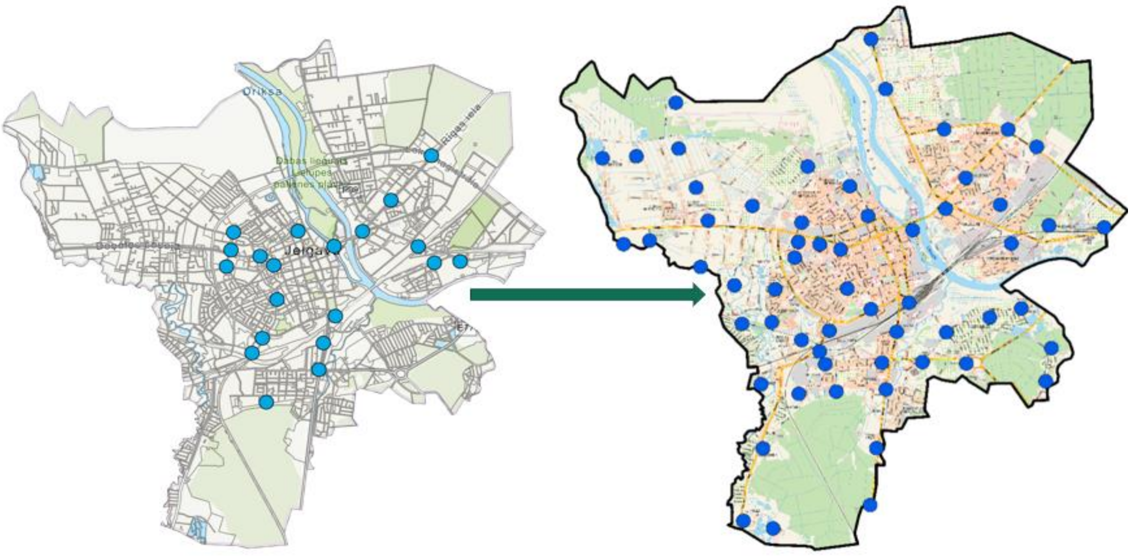


2.5.att. **Ķērpja Pūslīšu hipogimnija *(Hypogymnia physodes)* transplantu parauglaukumi (autores veidota karte)**

2.6. att. **Ķērpja Pūslīšu hipogimnija *(Hypogymnia physodes)* transplants Jelgavas dzlzceļa stacijā, 2016. gads**

Pūslīšu hipogimnija *(Hypgymnia phydosis)* ķērpja paraugi tika ievākti mežā aptuveni 5 km attālumā no Jelgavas pilsētas centra. Transplanti tika novietoti parauglaukumos, piestiprinot tos esošajiem koku zariem (transplanti tika piestiprināti tikai pie lapu kokiem) ar metāla stiepli, kas atradās 1,5 metru augstumā virs zemes (X Publikācija). Visi transplanti bija izvietoti koka DR pusē (skat.2.6.att.).

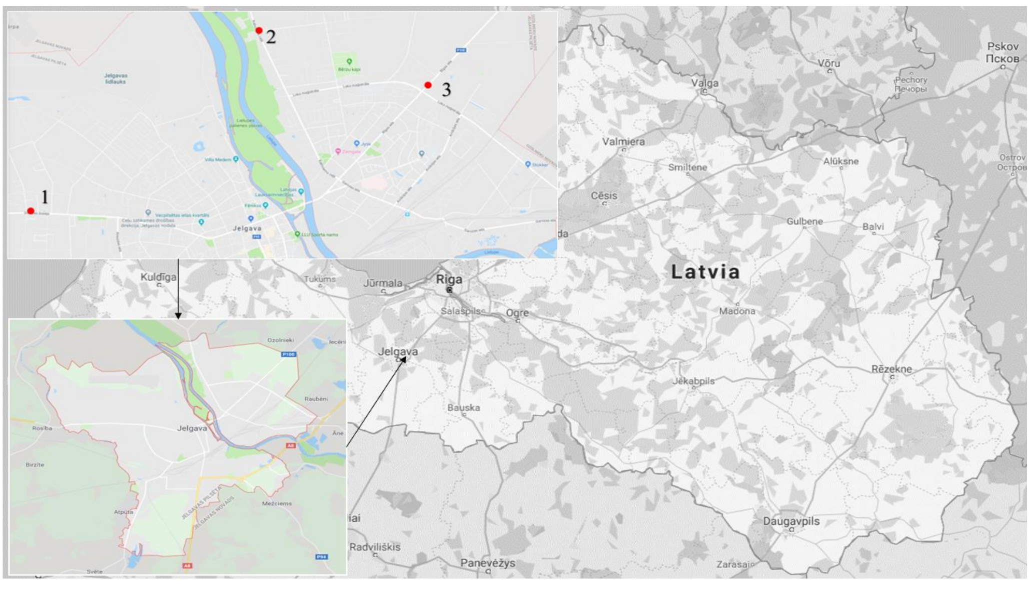
Sniega paraugu analīzes metode. Sniega paraugu analīze ir viena no metodēm, kas tiek izmantota, lai noteiktu īslaicīgo gaisa piesārņojumu ar ķīmiskajiem elementiem pilsētu teritorijās (Engelhard et al., 2007; Cereceda-Balic et al., 2012; Vasić et al., 2012; Xue et al, 2020). Kopumā sniega paraugi ir ievākti no 2017. gada līdz 2023. gadam (I-XIII Publikācija). Sniega uzkrāšanās periods ir no 5-9 dienām. Pētījumu uzsākot 2017. gadā, sniega paraugi tika ievākti 20 parauglaukumos tuvāk pilsētas centram (papildus 1 parauglaukums 5 km attālumā ārpus pilsētas, Mežciema meža masīvā), bet, sākot ar 2018. gadu, sniega paraugi ievākti 59 parauglaukumos, kas izvietoti Jelgavas pilsētā un 1 parauglaukumā, kas ir 5 km attālumā ārpus pilsētas, Mežciema meža masīvā (skat.2.7.att.). Lai nodrošinātu vienmērīgu un maksimāli precīzu rezultātu uz katru pilsētas kvadrātkilometru (vidēji uz 1 km^2 ir 1 parauglaukums) ir jāizveido viens parauglaukums. Katrā parauglaukumā tika ievākti 3 sniega paraugi, ievācot katru paraugu tiek paņemta visa sniega sega.



2.7. att. **Sniega parauglaukumu izvietojuma attīstība Jelgavas pilsētā no 2017. gada līdz 2023. gadam**

Sniegs tika savākts, izmantojot vienreizējās lietošanas putekļus nesaturošus nitrila cimdus. Šie paraugi tika iegūti 5 metru attālumā no ceļa braucamās daļas. Sniegs tika savākts sterilos plastmasas traukos, un nekavējoties nogādāti ledusskapī un tad transportēti uz laboratoriju.

Sniega paraugu ievākšana transporta piesārņojuma monitoringam. Sniegs ir labs materiāls, kas spēj uzkrāt informāciju par apkārtējo gaisa kvalitāti un to izmanto par indikatoru nosakot transporta ietekmi uz kopējo pilsētas gaisa kvalitāti (Adamiec et al., 2013; Kuoppamäki et al., 2014). Sniega paraugi tika ņemti no 3 dažādiem ceļiem Jelgavas pilsētā ar atšķirīgu satiksmes intensitāti (skat.2.8.att.). Katrā ceļa posmā bija 6 parauglaukumi, katrā ceļa pusē pa 3. Katra paraugu ņemšanas vieta atrodas trīs dažādos punktos pilsētā. Paraugi, kas ievākti 2018. gada janvārī ņemti 1 m, 50 m un 100 m attālumā no ceļa brauktuves (VI Publikācija). Paraugi ievākti 2019. gada janvārī, 1 m, 10 m un 20 m attālumā no ceļa brauktuves (IV Publikācija).



2.8. att. **Sniega parauglaukumu izvietojums transporta piesārņojuma monitoringam Jelgavas pilsētā**

2.2. Paraugu apstrāde un analizēšana

ICP spektrometri var tikt izmantoti, lai analizētu dažādus paraugus, piemēram, ķērpjus, sūnas u.c., kā arī ūdens paraugus. Ievāktie sniega paraugi laboratorijā tiek nogādāti izkusušā veidā. Paraugu sagatavošana katrai iekārtai ir aprakstīta publikācijās. Paraugu, kas analizēti ar ICP-AES, sagatavošana aprakstīta (I un II Publikācijā), paraugu, kas analizēti ar ICP-OES, sagatavošana aprakstīta (III-VIII, X-XII Publikācijā) (induktīvi savienotā plazmas atomu emisijas spektroskopija (ICP-AES) tiek saukta arī par induktīvi saistītās plazmas optiskās emisijas spektroskopiju (ICP-OES)). Paraugu, kas analizēti ar ICP-MS, sagatavošana aprakstīta (IX, XI-XIII Publikācijā).

Izmantojot un salīdzinot dažādu paraugu sagatavošanu ICP-OES iekārtai, tika apskatīti varianti, ka sniega paraugus filtrē caur papīra filtru un paskābina līdz 1% HNO_3, savukārt otrs variants, ka sniega paraugus paskābina līdz 1% HNO_3, iztur 3 dienas un pēc tam filtrē caur papīra filtru (III Publikācija).

Paraugi, kas ievākti 2017. gadā un 2018. gadā tika analizēti gan ar ICP-AES (*Inductively Coupled Plasma Atomic Emission Spectrometry*), gan ar ICP-OES (*Inductively Coupled Plasma Optical Emission Spectrometry)* spektrometru. Apskatot tabulu 2.1. var redzēt, ka dati, kas iebūti ar ICP-AES izmantoti divās publikācijās (I un II Publikācija). Paraugi, kas ievākti 2019. gadā, tika analizēti ar ICP-OES spektrometru. Paraugi no 2020. - 2023. gadam tika analizēti ar 8900 Triple Quadrupole ICP-MS (*Inductively coupled plasma mass spectrometry*) spektrometru (skat.2.1. tab.).

Analizējot, Dzelteno sienas ķērpi *(Xanthoria parietina)* tika izmantots ICP-OES (X Publikācija), ķērpis pirms analizēšanas ir izžāvētā veidā un atdalīts no vismazākajiem piemaisījumiem (koka lapām, mizām utt.). Precīza ķērpja sagatavošana analizēšanai skatāma X Publikācijā.

2.3. Pētījumā izmantotie dati un statistikas metodes

Pētījumā ir izmantota lihenoindikācijas metode, kur 125 parauglaukumos veikta ķērpju inventarizācija, kas sīkāk aprakstīts desmitajā publikācijā (X Publikācija), ķērpja Pūslīšu hipogimnija *(Hypogymnia physodes)* transplantu metode (Grinfelde et al., 2017). Izmantota metode, kur Dzeltenais sienas ķērpis *(Xanthoria parietina)* ievākts 20 parauglaukumos un veiktas ķīmiskās analīzes (X Publikācija). Sniega paraugu 2017. gadā ievākti 20 parauglaukumos (I un X Publikācija) un no 2018.-2023. gadam 60 parauglaukumos (II, III, V, VII, VIII, IX, XI, XII, XII Publikācija). Apskatot transporta koridorus, ievākti sniega paraugi 18 parauglaukumos 2018. un 2019. gadā (IV un VI Publikācija) (skat. 2.1. tab.).

Pētījumā izmantotās datu kopas un statistikas metodes, kas, izmantotas pētījumā, ir apkopots 2.1. tabulā. Ģeogrāfiskās informācijas sistēmas (GIS) nodrošina piemērotus rīkus telpisko attiecību aprakstīšanai. Lai izprastu gaisa piesārņojuma ar smagajiem metāliem telpisko izplatību, tika pielietots ArcGIS programmatūru. Telpiskās analīze veikta ar ArcGIS programmatūrā iebūvēto IDW *(Inverse-Distance Weighting)* metodi (I, II, V un XI publikācijas). Metode izvēlēta, balstoties uz literatūru par metodes atbilstību, analizējot gaisa piesārņojuma datus (Garcia et al., 2016; Chen et al., 2018), kā arī, salīdzinot ar citiem rīkiem, IDW ir viegli pielietojama programma, jo tai nav nepieciešama iepriekšēja datu modelēšana vai subjektīvi pieņēmumi (Jumaah et al., 2019; Xu et al., 2022).

2.1. tabula. **Pētījumā iekļautās datu kopas un statistikas metodes**

Publikācijas / Metodes un datu kopas	Monitoringa punktu koordinātas	Sniega Parauglaukumu skaits	Dzeltenā sienas ķērpja (*Xanthoria parietina*) parauglaukumu skaits	Ķērpju inventarizācijas parauglaukumu skaits	2017	2018	2019	2020	2021	2022	2023	Skābināšana pirms filtrācijas	Skābināts pēc filtrācijas	ICP-OES/ ICP-AES	ICP-MS	Descriptive statistiscs	Kastu diagramma	Cluster analysis ACH Eucledian distance Ward Method	Kruscal-Wallis	GIS IDW *(Inverse-Distance Weighting)*	Steel-Dwass-Crichlow-Fligner
I		20			X	X						X		X						X	
II		60				X						X		X		X				X	
III	X	60				X						X	X	X		X	X	X			
IV		18					X					X		X		X	X				
V		60					X					X		X		X				X	
VI		18				X						X		X		X			X		X
VII		60					X					X		X		X					
VIII	X	60					X					X		X				X			
IX	X	60						X				X			X						
X		20	20	125	X							X		X		X		X			
XI		60				X	X	X	X			X		X	X	X				X	
XII		60				X	X	X	X			X		X	X	X					
XIII		60								X	X	X			X	X	X	X			

Pētījumā kopumā iekļauti vairāk nekā 20 ķīmiskie elementi, no kuriem trīspadsmit ir smagie metāli, kam promocijas darbā ir pievērsta īpaša uzmanība. Visvairāk pētījumā ir analizēti un aprakstīti smagie metāli tādi kā svins, niķelis varš un cinks. Pētījumā, iekļautie ķīmiskie elementi, kas, apskatīti un aprakstīti dažādās publikācijās, ir apskatāmi 2.2. tabulā.

2.2. tabula. **Pētījumā iekļautie ķīmiskie elementi**

Ķīmiskais elements	**Publikācijas numurs**												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Svins (Pb)	X		X	X	X	X	X	X	X	X			
Niķelis (Ni)	X		X	X	X	X	X	X	X	X			
Varšs (Cu)	X	X	X	X	X	X	X	X	X	X			
Vanādijs (V)	X		X	X			X	X		X			
Dzelzs (Fe)	X	X						X	X	X			
Hroms (Cr)	X			X				X	X	X			
Arsēns (As)	X								X	X			
Cinks (Zn)	X	X	X	X	X	X	X	X	X	X	X		
Alumīnijs (Al)								X	X			X	
Mangāns (Mn)			X	X	X	X		X	X				
Silīcijs (Si)				X				X	X				
Kalcijs (Ca)							X	X					
Kālijs (K)								X					
Magnijs (Mg)								X					
Nātrijs (Na)								X					
Bārijs (Ba)								X	X				
Kadmijs (Cd)								X	X				
Kobalds (Co)								X					
Molibdēns (Mo)								X	X				
Stroncijs (Sr)								X					
Volframs (W)									X				X

* Smagie metāli iekrāsoti oranžā krāsā.

Jelgavas pilsētā ir aprobēts un izveidots ilglaicīgā un īslaicīgā piesārņojuma monitoringa tīkls, kas ļauj novērtēt gaisa piesārņojuma dinamiku laikā un telpā. Ir izveidota datubāze, kas satur ķīmisko elementu koncentrācijas sniegā 60 parauglaukumos no 2018.-2024. gadam, kas tiks uzturēta un papildināta katru gadu (Pilecka-Uļčugačeva 2024g; Pilecka-Uļčugačeva 2024f; Pilecka-Uļčugačeva 2024e; Pilecka-Uļčugačeva 2024d; Pilecka-Uļčugačeva 2024c; Pilecka-Uļčugačeva 2024b). Ķīmisko elementu koncentrācijas sniegā, kas raksturo 2020.gada datus ir publicētas IX publikācijā. Pirmā pētījuma gada dati kas iegūti no 20 parauglaukumiem 2017.gadā par ķīmisko elementu koncentrācijām sniegā ir pieejami Pilecka-Uļčugačeva (2024a) datubāzē.

3. REZULTĀTI UN DISKUSIJA

Šajā nodaļā ir apkopoti galvenie promocijas darba pētījuma rezultāti, kas iedalīti četrās apakšnodaļās, kur pirmajā apakšnodaļā atspoguļota ilglaicīgā un īslaicīgā gaisa piesārņojuma noteikšanas metožu aprobācija un pilnveide. Otrajā apakšnodaļā aprakstīta gaisa piesārņojuma ar smagajiem metāliem koncentrāciju noteikšana. Trešajā apakšnodaļā veikta gaisa piesārņojuma ar smagajiem metāliem izplatības telpiskā analīze. Gaisa piesārņojuma ar smagajiem metāliem avotu identifikācija aprakstīta ceturtajā apakšnodaļā.

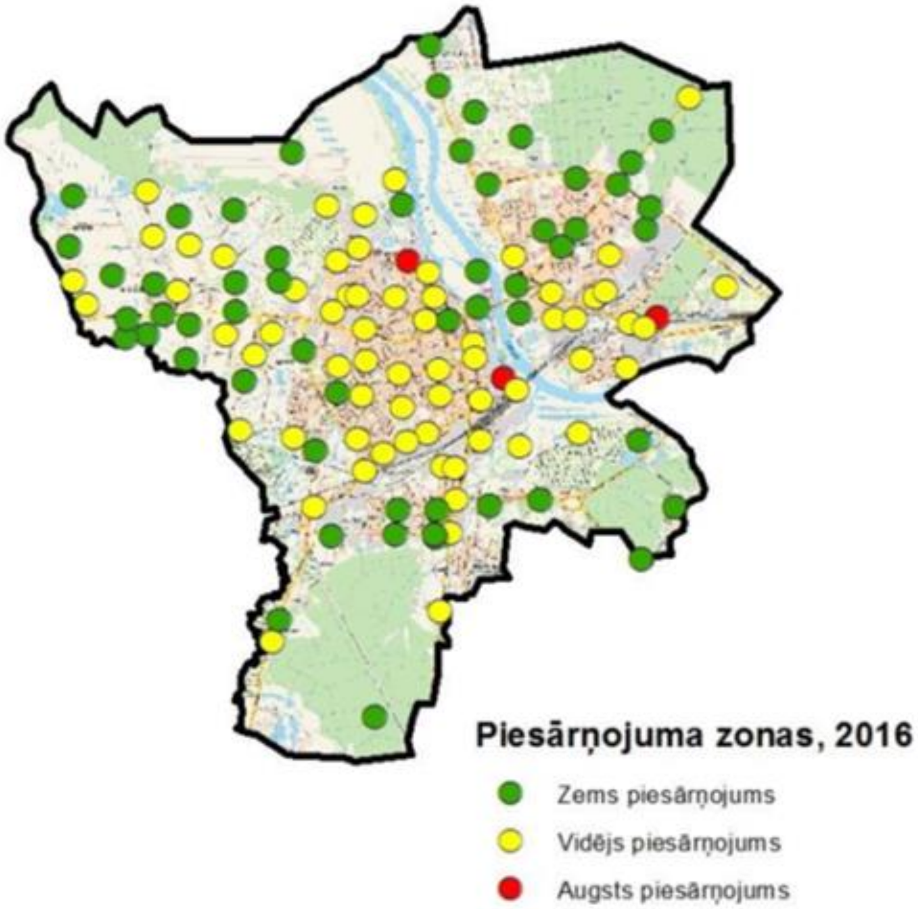
3.1. Ilglaicīgā un īslaicīgā gaisa piesārņojuma noteikšanas metožu aprobācija un pilnveide

Šajā apakšnodaļā ir apkopotas ilglaicīgā un īslaicīgā piesārņojuma noteikšanas metožu aprobācija un pilnveide. Sniegts detalizēts apraksts par metožu aprobāciju un pilnveidi. Gaisa piesārņojuma noteikšanai var izmantot ilglaicīgā un īslaicīgā gaisa piesārņojuma noteikšanas metodes un šo metožu aprobācija, un pilnveide (III, IX, X Publikācija) ir neizbēgama darba sastāvdaļa.

3.1.1. Ilglaicīgā gaisa piesārņojuma noteikšanas metožu aprobācija

Pastāv dažādas metodes ilgtermiņa piesārņojuma novērtēšanai, kuras var iedalīt gan ķīmiskajās, gan bioloģiskajās metodēs. Viena no ilglaicīgā gaisa piesārņojuma noteikšanas metodēm, kas pieder bioloģisko metožu sadaļai, ir gaisa tīrības indeksa *(Index of Atmospheric Purity)* aprēķināšana. Ķērpji labi atspoguļo vietas, kuras ietekmē sēra dioksīds (Orlova et al. 2015), slāpekļa oksīdi (Mateos un González 2016) un smagie metāli (Kularatne un De Freitas 2013; Parzych et al., 2016).Toksisko elementu uzkrāšanās ķērpjos korelē ar attālumu no piesārņotāja (Attanayaka un Wijeyaratne 2013). Jelgavas pilsētas ilglaicīgā gaisa kvalitātes noteikšanai arī ir izmantota Dzeltenā sienas ķērpja *(Xanthoria parietina)* ievākšanas un analīzes metode (Pilecka et. al., 2017), kas ir otrā ilglaicīgā piesārņojuma noteikšanas metode, kas pieder dažādu ķīmisko vielu analīzei organismos un šūnās.

Jelgavas pilsētas teritorijā gaisa kvalitāti novērtēja, izmantojot datus no 125 parauglaukumiem, un identificēja trīs gaisa piesārņojuma zonas. Augsta piesārņojuma zona (1. grupa) bija teritorija ar minimālu ķērpju skaitu vai izdzīvošanu (IAP no 0-110). Vidēja piesārņojuma zona (2. grupa) bija ierobežota ķērpju populācijas jeb pārejas zona (IAP = 111 – 200). Zema piesārņojuma zona (3. grupa) ietilpa teritorijās, kur ķērpju klātbūtne bija bagāta vai kurās valdīja dabiska vides zona (IAP> virs 200). Saskaņā ar Grinfelde u.c., 2017. gada pētījumu, augsta gaisa piesārņojuma zona Jelgavā 2016. gadā aizņēma 1,66 km^2 jeb 2,75% no visām pilsētas teritorijām. Šī zona tika konstatēta 4 parauglaukumos: trīs Jelgavas centrā (teritorijā, kur ir Jelgavas notekūdeņu attīrīšanas iekārtas; Meiju ceļa un Kazarmes ielu krustojumā, Palīdzības ielas rajonā) un vienā ārpus centra (pie Langervaldes meža). Vidēja gaisa piesārņojuma zona Jelgavā 2016. gadā aizņēma 26,54 km^2 jeb 44,0% no kopējās platības. Salīdzinot ar iepriekšējiem rezultātiem no 1996. gada, vidējā gaisa piesārņojuma platība nedaudz palielinājās no 25,76 km^2 līdz 26,54 km^2, bet salīdzinot ar 2006. gada rezultātiem, tā samazinājās no 29,26 km^2 jeb 48,51% līdz 26,54 km^2 jeb 44,0%. Zema gaisa piesārņojuma jeb tīra gaisa zona Jelgavā 2016. gadā aizņēma vairāk nekā pusi no pilsētas teritorijas – 32,12 km^2 jeb 53,25%.



3.1. att. **Gaisa kvalitātes zonas pēc IAP indeksa**

3.1.2. Īslaicīgā gaisa piesārņojuma noteikšanas metožu aprobācija

Īslaicīgā gaisa piesārņojuma noteikšanai var izmantot gan ķērpju transplantu metodi, gan sniega paraugu ievākšanas metodi. Jelgavas pilsētas īslaicīgā gaisa piesārņojuma noteikšanai ir izmantotas abas metodes, ķērpja Pūslīšu hipogimnija *(Hypogymnia physodes)* transplantu metode izmantota Jelgavas pilsētas gaisa kvalitātes monitoringam kopš 1996. gada (Grinfelde et al., 2017).

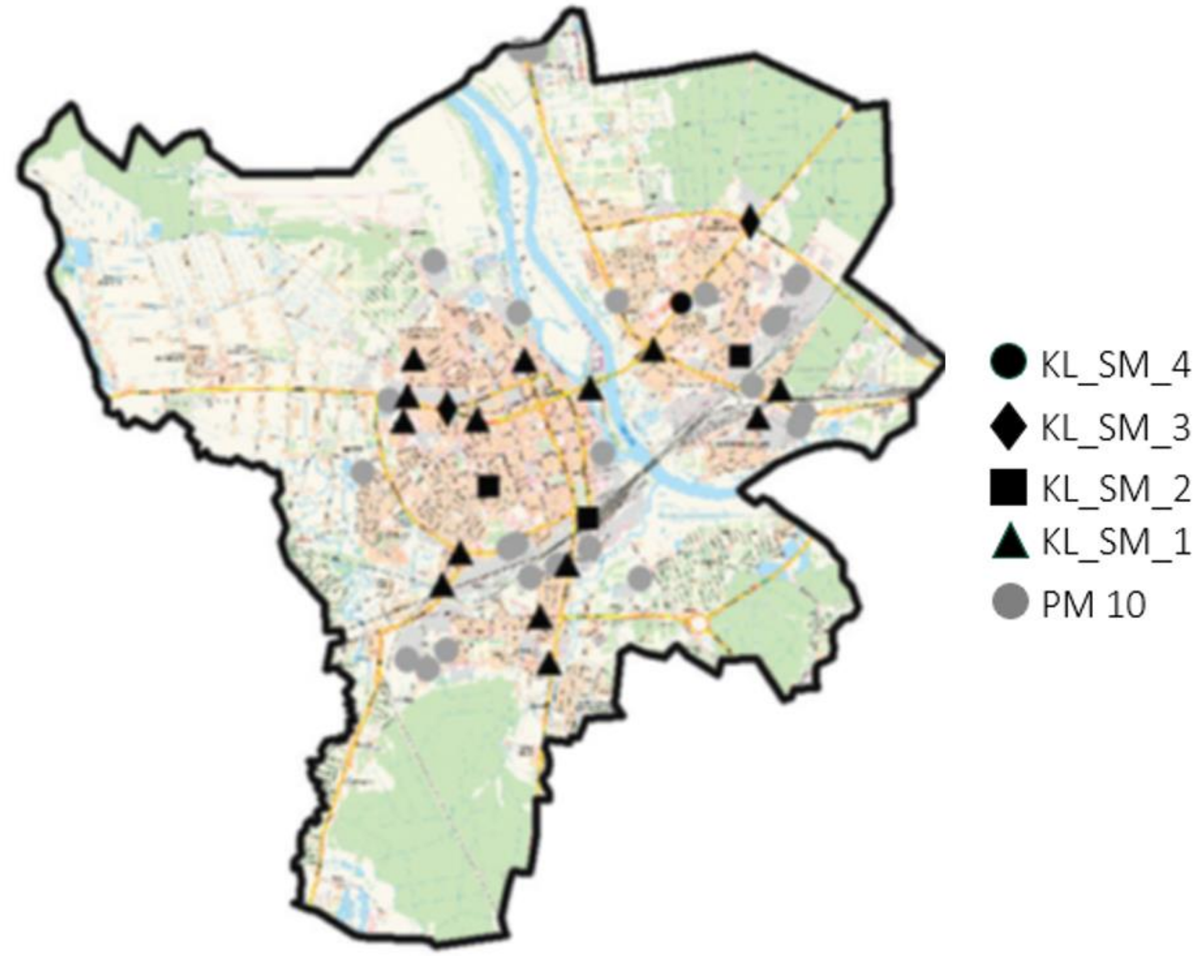
Monitorings, kas veikts 2016. gadā, liecina, ka Jelgavas pilsētas teritorijā Pūslīšu hipogimnija (*Hypogimnia physodes*) vitalitāte atšķiras. Divās monitoringu vietās - Prohorova iela/Neretas iela un Langervaldes mežs (Rubeņu ceļš) - ķērpju nekrozes un lapoņa nolobīšanās konstatētas jau pēc 2 mēnešiem (jūlija, augusta), tāpēc šajās vietās veikti atkārtoti pētījumi - atjaunoti ķērpju paraugi, kam nekrozes un lapoņa pilnīga nolobīšanās konstatēta attiecīgi pēc 31 un 90 dienām. Šīs atšķirības perioda ilgumā varētu būt skaidrojamas ar ķērpju lielāku fizioloģisko aktivitāti vasaras periodā, salīdzinot ar rudens/ziemas periodu. Trīs monitoringu vietās - Viskaļu iela/Lāču iela, Lietuvas šoseja/Savienības iela un Ausekļa iela/Blaumaņa iela - ķērpju nekrozes konstatētas pēc 3 mēnešiem (92 dienām). Autotransporta radītais piesārņojums ietekmējis gaisa kvalitāti šajās vietās, it īpaši Lietuvas šosejas tuvums.

Nedaudz labāka situācija ir piecās monitoringu vietās - Lietuvas šoseja/Platones iela, Tērvetes ielas pārbrauktuve, Satiksmes iela/Ganību iela, Rīgas iela un Dobeles šoseja/Satiksmes iela - ķērpju nekrozes konstatētas pēc 5 mēnešiem jeb 153 dienām, bet Dobeles šosejā pēc 6 mēnešiem jeb 184 dienām. Autotransporta radītais piesārņojums arī šajās vietās ir galvenais faktors. Savukārt trīs monitoringu vietās - Tērvetes iela/Pavasara iela, Lielā iela/Ozola skvērs un Aspazijas iela/Asteru iela - ķērpju nekrozes konstatētas pēc 7 mēnešiem jeb 215 dienām. Labvēlīga ietekme šajās pēdējās vietās ir klajumiem ar apstādījumiem, kas nodrošina piesārņojuma izkliedi. Ķērpjiem pēc 8 mēnešiem (243 dienas) tikai lapoņu krāsas izmaiņas konstatētas monitoringu vietās - Lielā iela/Driksas tilts, Rīgas iela/Brīvības bulvāris, Aviācijas iela un TC Valdeka/Rīgas iela. Ļoti labu vitalitāti (8 mēnešus jeb 243 dienas) saglabā ķērpji monitoringu vietās – Jelgavas dzelzsceļa stacija un Lielā iela/Dobeles iela. Abām šīm vietām ir salīdzinoši lielas atklātas telpas, kā arī abās vietās koki, pie kuriem piestiprināti paraugi, ir ābeles.

3.2.att. **Ķērpju transplants, kas izvietots Jelgavas dzelzceļa stacijā, 2016. gads**

Aprobējot, īslaicīgā gaisa piesārņojuma noteikšanas metodes izmantojot sniega paraugus aprakstītas (III Publikācija).

Klastera KL_SM_4 kopu raksturo ārkārtīgi augsts piesārņojums, kur primārais avots ir transporta radītais piesārņojums. Klasterim KL_SM_3 raksturīgs augsts transporta izplūdes gāzu radītais piesārņojums. Klasterim KL_SM_2 raksturīgs augsts piesārņojums, kas rodas rūpniecisko procesu rezultātā, bet klasterim KL_SM_1 raksturīgs samērā tīrs gaiss, ar nelielu transporta radīto piesārņojumu (Pilecka et al., 2018). Sniega klasteru analīzes rezultāti attēloti 3.3.attēlā.



3.3. att. **Īslaicīgā gaisa piesārņojuma klasteru analīzes rezultāti pēc sniega paraugu ķīmiskā sastāva, paraugi ievākti 14.02.2017**

3.1.3. Ilglaicīgā un īslaicīgā gaisa piesārņojuma noteikšanas metožu pilnveide

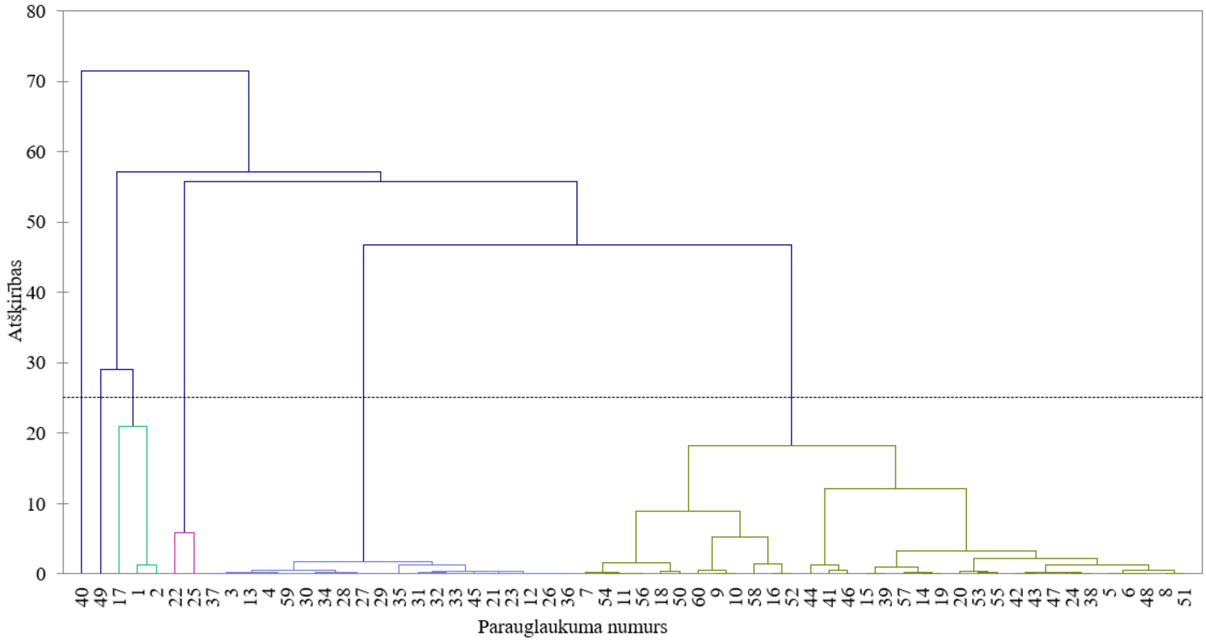
Apskatot dažādas metodes, ar kurām iespējams noteikt gan ilglaicīgā, gan īslaicīgā gaisa piesārņojuma noteikšanas iespējas pilsētvidē ir iespēja izvēlēties labāko no metodēm. Darba gaitā ir veikta metožu pilnveide - no 20 sniega parauglaukumiem pilsētas centrālajā daļā, parauglaukumu skaits pieaudzis līdz 60 parauglaukumiem visā pilsētas teritorijā, uz katru pilsētas 1km^2 vidēji ir viens parauglaukums.

Tika izvērtētas un salīdzinātas divas paraugu sagatavošanas metodes (III Publikācija): 1 grupa kur izkusušais sniegs tiek filtrēts un pēc tam skābināts un 2. grupa kur izkusušais sniegs tiek skābināts un pēc tam filtrēts. Aprakstošā statistika par svinu (Pb), cinku (Zn), niķeli (Ni), vanādiju (V), varu (Cu), mangānu (Mn) pa analītiskajām grupām ir parādīta 3.1. tabulā, kur atšķirības starp analītiskajām grupām ir būtiskas. Piemēram, Zn, Cu un V maksimālā koncentrācija otrajā grupā atšķiras vairāk nekā 10 reižu.

3.1. tabula. **Smago metālu aprakstošā statistika pa analītiskajām grupām**

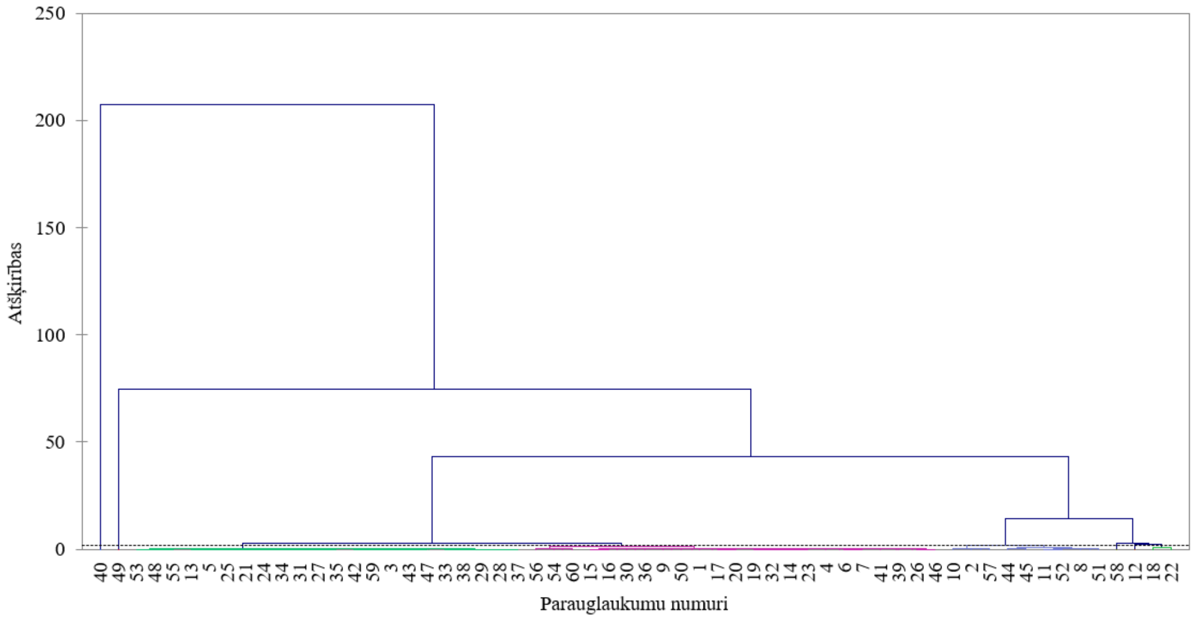
Statistika	**Minimums, µg/l**	**Maksimums, µg/l**	**Pirmā kvartile, µg/l**	**Mediāna, µg/l**	**Trešā kvartile, µg/l**	**Vidējā vērtība, µg/l**	**Standartnovirze, µg/l**
Pb | 1.grupa	1,00	1,34	1,00	1,00	1,00	1,01	0,05
Pb | 2.grupa	0,68	51,18	2,16	3,59	6,81	6,31	8,42
Zn | 1.grupa	0,48	11,91	2,10	3,88	6,63	4,63	3,05
Zn | 2.grupa	9,22	1002,05	22,32	45,91	81,51	79,62	135,32
Ni | 1.grupa	0,55	0,71	0,60	0,60	0,60	0,60	0,02
Ni | 2.grupa	0,40	40,75	1,00	1,59	2,85	2,80	5,24
V | 1.grupa	0,60	0,60	0,60	0,60	0,60	0,60	0,00
V | 2.grupa	0,55	64,16	0,60	0,67	2,21	2,92	8,31
Cu | 1.grupa	0,86	6,28	0,90	1,17	1,71	1,44	0,82
Cu | 2.grupa	2,82	829,49	5,78	8,93	23,34	28,66	105,24
Mn | 1.grupa	0,47	9,36	0,93	2,08	3,09	2,29	1,62
Mn | 2.grupa	5,89	1357,01	25,37	46,93	171,68	150,57	239,90

Pirmās grupas aglomeratīvās hierarhiskās klasterēšanas rezultāti ir parādīti 3.4 attēlā, tika noteiktas 6 klases, un atšķirība klases ietvaros ir 29%, bet starp klasēm 71%.



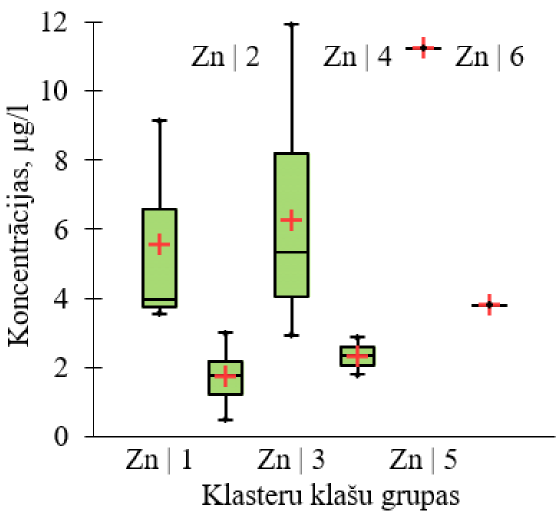
3.4. att. **1. grupas aglomeratīvās hierarhiskās klasterēšanas rezultāti**

Otrās grupas aglomeratīvās hierarhiskās klasterēšanas rezultāti ir parādīti 3.5. attēlā, tika definētas 8 klases, un novirze klases ietvaros ir 2% un starp klasēm tā ir 98%.

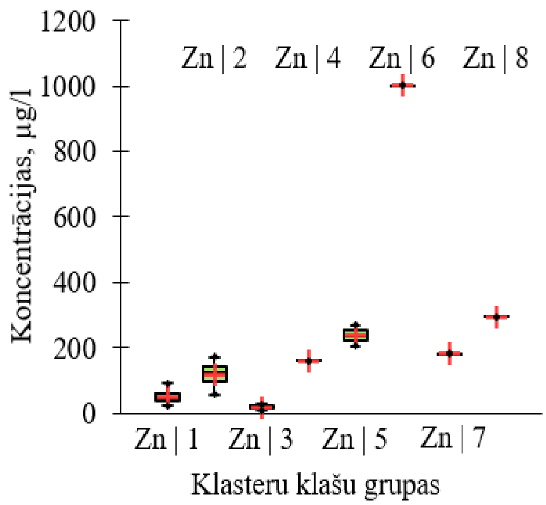


3.5. att. **Otrās grupas aglomeratīvās hierarhiskās klasterēšanas rezultāti**

Pirmās paraugu grupas 6 klašu cinka koncentrācijas ir parādītas 3.6. attēlā, kur ir pārklājums starp klasēm. Cinka (Zn) koncentrācija 8 grupās un otrajā paraugu grupā ir parādīta 3.7. attēlā, kur cinka koncentrācija klases robežās ir viendabīga un starp klasēm nav pārklājuma.

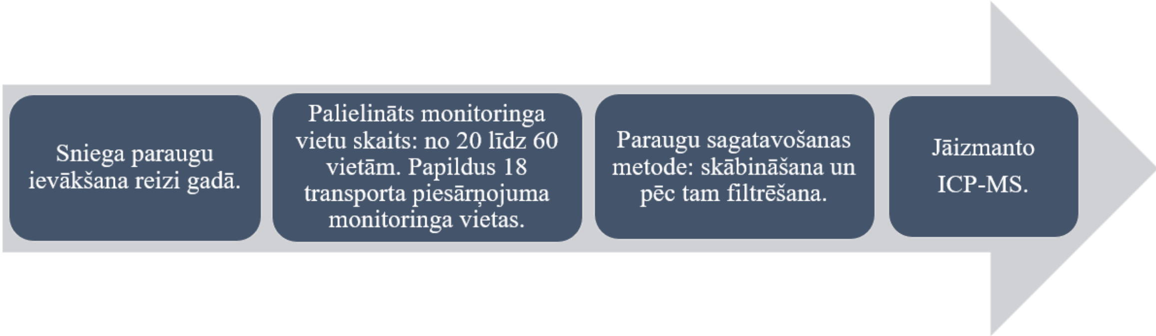


3.6. att. **Pirmās paraugu grupas 6 klašu Zn koncentrācijas (µg/l)**



3.7. att. **Otrās paraugu grupas 8 klašu Zn koncentrācijas (µg/l)**

Ilglaicīgā un īslaicīgā gaisa piesārņojuma noteikšanas metodes ir aprobētas un pilnveidotas. Dzeltenā sienas ķērpja *(Xanthoria parietina)* analīžu rezultāti ir integrēti darbā, apvienojot ilglaicīgā un īslaicīgā piesārņojuma noteikšanas metodes. Izvēlētā sniega paraugu analizēšanas metode ir publicēta IX Publikācijā. Tika secināts, ka sniega paraugu analizēšanai nepieciešams izmantot induktīvi saistītās plazmas masspektometrs (ICP-MS), jo tam ir augstāka izšķirtspēja (skat. 3.8.att.).



3.8. attēls. **Gaisa piesārņojuma noteikšanas metodes uzlabojumi un to posmi**

3.2. Gaisa piesārņojuma ar smagajiem metāliem un citu ķīmisku elementu koncentrāciju noteikšana

Šajā apakšnodaļā sniegti rezultāti vienkāršotai gaisa piesārņojuma ar smagajiem metāliem koncentrāciju noteikšanai izmantojot sniega paraugu analizēšanu aprakstošās statistikas līmenī. Koncentrāciju noteikšanai izmantotas divas iekārtas induktīvi savienotas plazmas optiskās emisijas spektroskops (ICP-OES) un induktīvi saistītās plazmas masspektometrs (ICP-MS). Induktīvi savienotā plazmas atomu emisijas spektroskopija (ICP-AES), ko dēvē arī par induktīvi saistītās plazmas optiskās emisijas spektroskopiju (ICP-OES) abas analītiskas metodes ir minētas rakstos.

Apkopojot 2019. gada vara (Cu) rezultātus, var secināt, ka tikai divos paraugos Nr.18 un Nr.39 vara koncentrācija bija augstāka nekā pārējiem paraugiem. Vara koncentrācija paraugā Nr.18 ir 12,5 µg/l, kas ir augstākais rezultāts. Šajā paraugā vara koncentrācija varētu būt tik augsta, jo gaisa kvalitāti varētu ietekmēt satiksmes plūsma, dzīvojamo ēku apbūve, blakus esošā dzelzceļa līnija un atkritumu nepareiza apstrāde vai nelikumīga dedzināšana privātajās teritorijās. Satiksme pilsētu teritorijās rada gan gaisa piesārņojumu, gan troksni. Parauga Nr.39 vara koncentrācija ir 11,7 µg/l. Vara koncentrāciju arī šajā paraugā varētu ietekmēt satiksme. Niķeļa (Ni) rezultāti liecina, ka tikai vienam paraugam ir augstāka niķeļa koncentrācija nekā citiem paraugiem. Niķeļa koncentrācija lielākajā daļā paraugu ir mazāka par 0,6 µg/l. Vislielākā niķeļa koncentrācija ir paraugā Nr.2., kur tā ir 4,4 µg/l. Paraugā Nr.2 niķeļa koncentrācija varētu būt tik augsta, jo gaisa kvalitāti varētu ietekmēt privātmāju apbūve, kas ziemas periodā izmanto nepiemērotu kurināmo materiālu ēku apkurei. Arī transporta koridors atrodas netālu no šīs parauga zonas, kas ietekmē gaisa kvalitāti intensīvās satiksmes dēļ. Svina koncentrācija paraugā Nr.13 ir 11.1 µg/l. Šajā paraugā svina koncentrācija varētu būt tik augsta, jo gaisa kvalitāti varētu ietekmēt satiksme pa tuvējo Lietuvas šoseju. Tādi piesārņotāji kā svins (Pb) un varš (Cu) nonāk gaisā no transportlīdzekļu izplūdes gāzēm (Pilecka et al., 2018).

Visaugstākā svina koncentrācija ir paraugā Nr.48. Svina koncentrācija šajā paraugā ir 72,3 µg/l. Salīdzinot ar svina koncentrāciju Viskaļu ielas paraugā, šis paraugs satur aptuveni septiņas reizes vairāk svina. Svina koncentrāciju var ietekmēt atkritumu sadedzināšana privātmājās (Pilecka et al., 2018). Vanādija (V) daudzums lielākajā daļā paraugu ir mazāks par 0,7 µg/l, bet citos paraugos tas nav lielāks par 1 µg/l. Blakus ir intensīva satiksme un dzelzceļa līnija, tur vanādija koncentrācija ir lielāka par 0,7 µg/l.

Cinka (Zn) rezultāti liecina, ka cinka koncentrācija trijos paraugos ir lielāka par 50 µg/l. Paraugiem Nr.39, Nr.46 un Nr.48 ir visaugstākie cinka rezultāti. Cinka koncentrācijas paraugā Nr.39 ir 53,7 µg/l un paraugā Nr.46 73,2 µg/l ietekmē satiksme. Augstākais cinka rezultāts parādās parauga Nr.48 rezultātos. Cinka koncentrācija šajā vietā ir 204,5 µg/l. Gaisa kvalitāti varētu ietekmēt satiksme un ēku apkure, izmantojot nepiemērotu kurināmo, piemēram, atkritumus.

Apskatot arī citu ķīmisku elementu koncentrāciju noteikšanu, šajā gadījumā alumīnija izplatību un koncentrācijas Jelgavas pilsētā datu apstrādei izmantoti 60 alumīnija mērījumu rezultāti no dažādām paraugu ievākšanas vietām Jelgavā laika periodā no 2018. gada līdz 2021. gadam. Lielākā daļa no paraugu ievākšanas vietām atrodas aptuveni 5 m attālumā no ceļu braucamās daļas vai gājēju ietvēm, kas varētu parādīt augstākas Al koncentrācijas.

Kā iespējams redzēt 3.2.tabulā, tad caur gadiem alumīnija vidējās aritmētiskās vērtības būtiski atšķiras mazākajai vērtībai 2019. gadā esot 0,08 µg/l, bet 2020. gadā 91,68 µg/l. Vismazākā standartkļūda ir 2019. gadā, tikai 0.01 µg/l, bet lielākā ir 2020. gadā sasniedzot 22,56 µg/l. Tāpat kā vidējās aritmētiskās vērtības arī mediānas pa gadiem būtiski atšķiras, 2019. gadā esot tikai 0,06 µg/l, bet 2020. gadā tā sasniedz – 38,59 µg/l. Pēc tabulas ir vērojams, ka lielākā standartnovirze ir vērojama 2020. gadā 173,30 µg/l, un 2019. gadā tā ir ievērojami mazāka 0,06 µg/l. Mazākā minimālā mērījumu vērtība konstatēta 2019. gadā esot 0,02 µg/l, bet lielākā minimālā vērtība konstatēta 2021. gadā – 4,43 µg/l. Mazākā maksimālā alumīnija vērtība konstatēta 2019. gadā – 0,36 µg/l, bet lielākā maksimālā alumīnija vērtība 2020. gadā sasniedzot 1183,66 µg/l. Kuoppamäki et al., (2014) savā pētījumā uzsver, ka satiksmes intensitātes un attāluma no ceļiem mijiedarbība bija statistiski nozīmīgs rādītājs.

3.2. tabula. **Alumīnija (Al) mērījumi sniegā no 2018. līdz 2021. gadam.**

Mainīgie lielumi		**Al, µg/l**			
		2018	**2019**	**2020**	**2021**
Skaits	**Derīgs**	60	60	60	60
	Nederīgs	0	0	0	0
Vidējā vērtība		1,13	0,08	91,68	32,58
Vidējās vērtības standartkļūda		0,48	0,01	22,56	6,67
Mediāna		0,25	0,06	38,59	12,20
Standartnovirze		3,68	0,06	173,30	51,23
Dispersija		13,53	0,004	30032,99	2624,48
Minimums		0,04	0,02	4,32	4,43
Maksimums		28,00	0,36	1183,66	315,17
Procentile	**25**	0,11	0,04	19,84	7,36
	50	0,25	0,06	38,59	12,20
	75	0,83	0,09	71,32	35,34

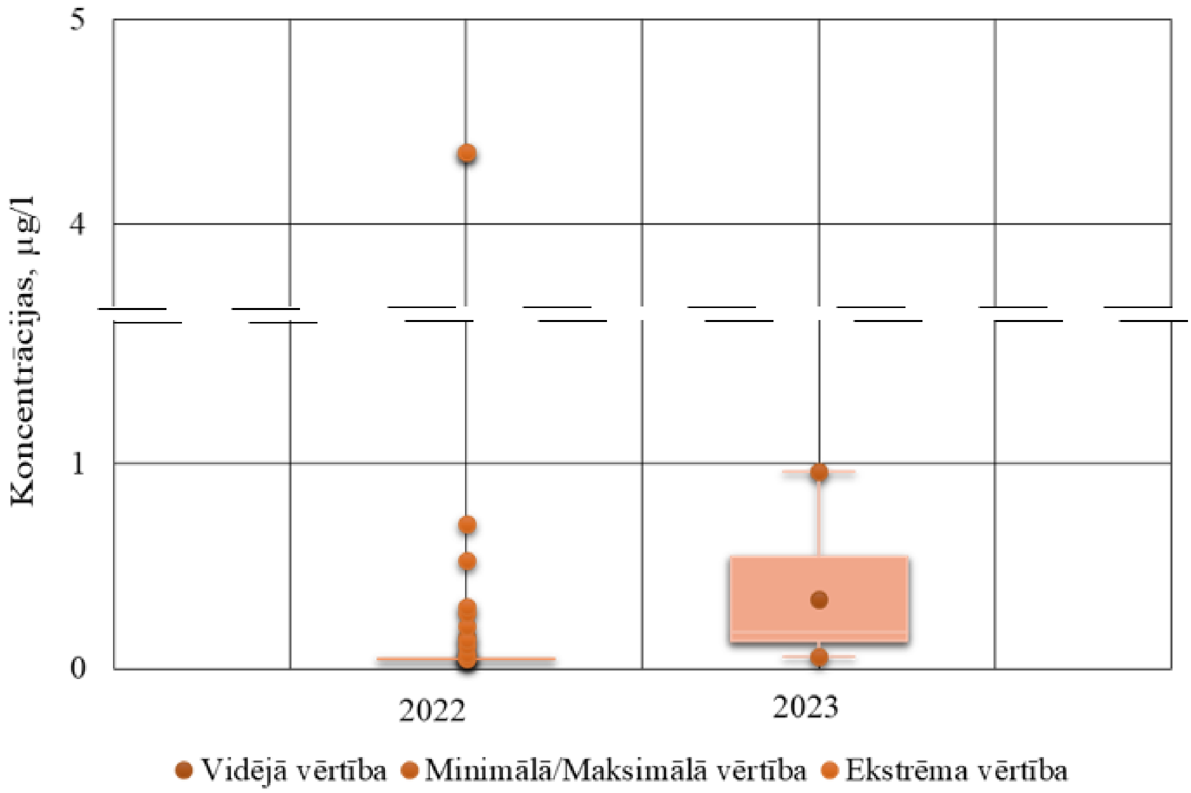
Satiksmes intensitātes ietekme uz izšķīdušajiem smagajiem metāliem bija dažāda, taču koncentrācija parasti bija augstāka blakus vai tuvu ceļiem, kā attālākās vietās pilsētā vai nostāk ceļam, īpaši attiecībā uz alumīniju, šādas tendences vērojamas arī Jelgavā veiktajā pētījumā izvērtējot alumīnija koncentrācijas pilsētvidē.

Jelgavas pilsētas alumīnija maksimālo vērtību esamība ir izteikti gar galvenajiem transporta koridoriem, kas spilgti tos iezīmē. Kuoppamäki et al., (2014) nonāca pie rezultāta, ka alumīnija koncentrācijas bija augstākas arī uz augstas intensitātes ceļiem salīdzinājumā ar zemas intensitātes ceļiem (Kuoppamäki et al., 2014), arī šajā pētījumā redzamas šādas tendences, īpaši uzsverot augstās koncentrācijas Lietuvas šosejas tuvumā. Paraugi, kas ievākti 2018. gadā un 2020. gadā iezīmē Dobeles šoseju un Rīgas ielu, kas ir galvenais ceļš, kas savieno Dobeles pilsētu, Jelgavas pilsētu ar Latvijas galvaspilsētu Rīgu. Jāpiemin, ka Jelgavas pilsētai ir tikai viens apvedceļš līdz, kuram ved Garozas iela, kur 2019. gadā konstatētas augstas alumīnija koncentrācijas 0,26 µg/l.

Nākotnē būtu jāanalizē vietējais mikroklimats un vēja virziens, jo apskatot parauglaukumos atrasto maksimālo vērtību izplatību pilsētā, ir redzamas kopīgas tendences pa gadiem, piemēram, 2021. gada visas maksimālās alumīnija vērtības ir grupējušās virzienā uz pilsētas dienvidiem.

Izvērtējot volframa koncentrāciju izmaiņas pa gadiem, minimālā vērtība 2022. gadā volframam Jelgavas teritorijā ir 0,05 µg/l, maksimālā vērtība 4,35 µg/l, bet mediāna ir 0,05 µg/l. Minimālā vērtība 2023. gadā volframam Jelgavas teritorijā ir 0,06 µg/l, maksimālā vērtība 0,96 µg/l, bet mediāna ir 0,18 µg/l (skat.3.9.att).

Izmantojot dažādas datu vizuālās interpretācijas metodes, tika secināts, ka koncentrāciju izplatību aprakstīšanai nepieciešams izmantot GIS rīkus. Apskatot smago metālu un citu ķīmisku elementu koncentrācijas, ir secināts, ka nepieciešams regulāri uzkrāt un publicēt datus atvērtas pieejas zinātniskajās datubāzēs. Dati par Jelgavas gaisa piesārņojuma ar smagajiem metāliem un citu ķīmisku elementu koncentrācijām ir publicēti - *Data in brief* (IX Publikācija), datu aktualizēšana plānota reizi 3 gados papildinot datubāzē jau pieejamo informāciju.

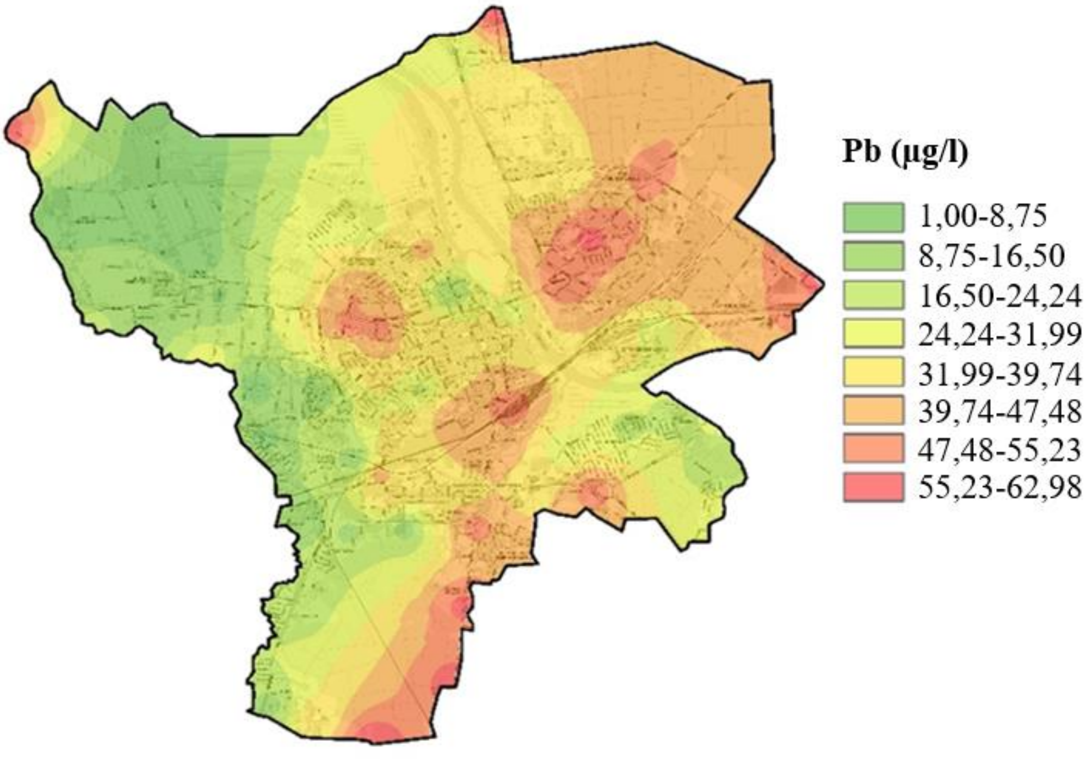


3.9. att. **Volframa izmaiņas pa gadiem**

3.3. Gaisa piesārņojuma ar smagajiem metāliem izplatības telpiskā analīze

Šajā apakšnodaļā aprakstīta gaisa piesārņojuma ar smagajiem metāliem izplatības telpiskā analīze. Telpiskās analīzes rezultātus labi var atspoguļot, izmantojot ArcGIS programmatūru, lietojot IDW *(Inverse-Distance Weighting)* metodi (Garcia et al., 2016; Chen et al., 2018) (V, II, II un XI Publikācijas). Pētījuma rezultāti no 2019. gada apliecina, ka lielākais piesārņojums ir lielāko ielu un krustojumu vietās. Viena no augstākajām vara (Cu) koncentrācijām ir Jelgavas pilsētas centra daļā - Lielās ielas un Dambja ielas krustojumā un pilsētas dienvidaustrumos, kur tās sasniedz 10,9-12,5 µg/l. Paaugstināta vara koncentrācija pilsētas centrā varētu būt skaidrojama ar ļoti intensīvu satiksmi starp Rīgu - Dobeli, Dobeli - Jelgavu, kā arī šajā krustojumā atrodas degvielas uzpildes stacija, dažādi autoservisi, kur ikdienā cirkulē daudz automašīnu. Naftas un fosilo materiālu sadedzināšana ir saistīta ar vara izdalīšanos. Vara koncentrācija dažādās pilsētas ielās var atšķirties atkarībā no vara klātbūtnes automašīnu bremzēs un vietās, kur vara koncentrācijas izdalās bremzēšanas rezultātā (Engelhard et al., 2007). Piesārņojums dienvidaustrumos varētu būt skaidrojams ar neatļautu atkritumu dedzināšanu privātmāju apkures sistēmās, kas ir viens no lielākajiem Cu emisiju radītājiem pilsētvidē (Rodella et al., 2017). Paaugstināta vara (Cu) koncentrācija Aviācijas ielā svārstās no 7,8-9,4 µg/l, kur atrodas viens no lielākajiem industriālajiem parkiem Latvijā ar kopējo platību 23 ha.

Šī parka teritorijā ietilpst gumijas ražošana un pārstrāde, metālapstrāde, PET pudeļu apstrāde, pulvermetalurģija un citi ražošanas procesi. Ievērojami paaugstināta niķeļa koncentrācija Jelgavas ziemeļrietumu daļā skaidrojama ar mežizstrādes darbiem, kas intensīvi tika veikta 2018. gada beigās un 2019. gada pirmajā ceturksnī. Piesārņojumu šajā teritorijā varētu ietekmēt tuvumā esošās auto darbnīcas aktivitātes. Lai precīzāk noskaidrotu niķeļa (Ni) avotus, nepieciešams veikt papildu pētījumu, kur vietējā līmenī tiek noteikts niķeļa piesārņojuma avots.



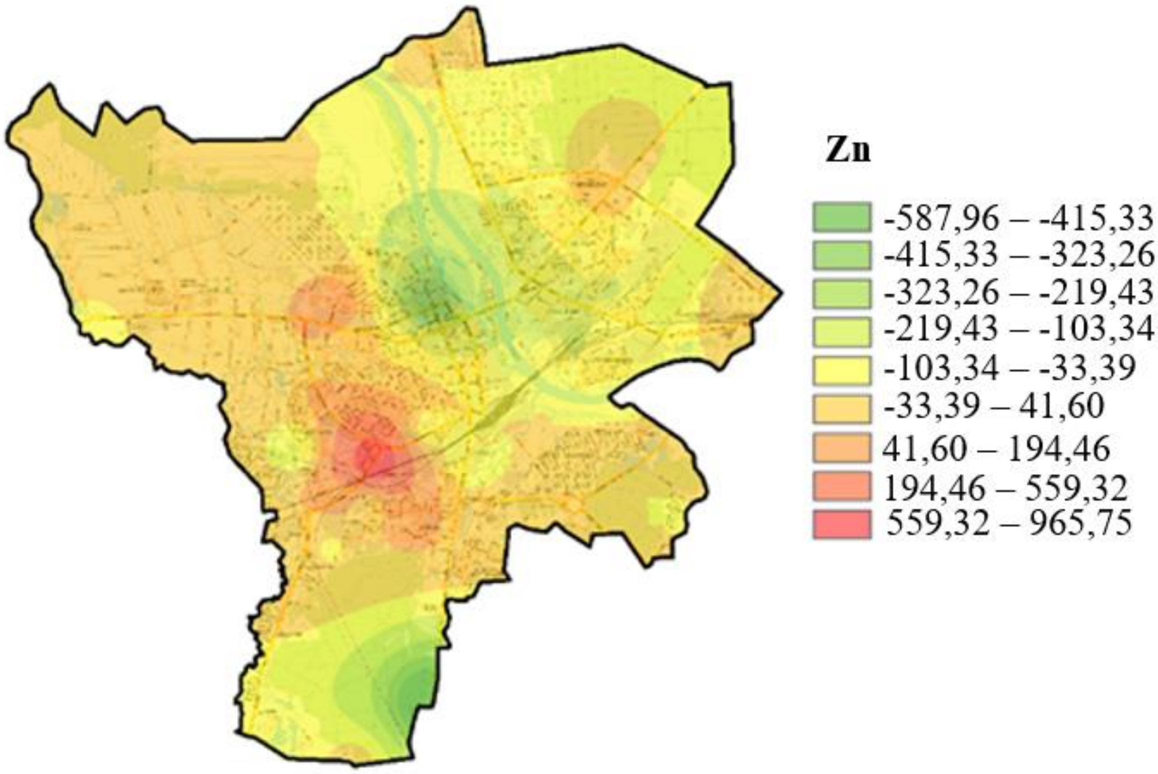
3.10. att. **Svina (Pb) izplatība Jelgavā 2019. gadā**

Svins (Pb) attiecas uz antropogēno piesārņojumu no automašīnu emisijām, bremžu nodilumu (Xue et al., 2020). Jelgavas pilsētā veiktās sniega analīzes skaidri norāda uz vietām ar intensīvu satiksmi, biežiem sastrēgumiem un krustojumiem ar intensīvu automašīnu satiksmes plūsmu (skat. 3.10.att.).

Visaugstākā mangāna (Mn) koncentrācija ir vietējos svarīgos krustojumos, kas liecina par intensīvas satiksmes un sastrēgumu ietekmi uz pilsētas gaisa kvalitāti. Teritorijās ar piesārņojumu no 27 līdz 54 µg/l varētu norādīt uz antropogēno piesārņojumu no privātmāju apkures sistēmām, jo ir zināms, ka Mn izdalās atkritumu un citu kurināmo sadedzināšanas laikā. Rūpnieciskajā zonā cinka līmenis parasti ir augstāks nekā citviet pilsētās, piemēram, Jelgavas pilsētā lielākās Zn koncentrācijas ir Aviācijas ielas parauglaukumos, kur tā svārstās robežās no 153,2 līdz 204,3 µg/l. Šajā teritorijā atrodas viens no lielākajiem industriālajiem parkiem Latvijā, kur notiek dažāda veida rūpnieciskā darbība. Atsevišķi apskatot relatīvo koncentrāciju izmaiņas 2017. gada februāra un 2018. gada februāra datiem ir redzams, ka Jelgavā niķeļa (Ni) relatīvo koncentrāciju izmaiņas nav īpaši lielas taču koncentrācijas ir vienmērīgi sadalītas pa visu pilsētu. Niķeļa relatīvo koncentrāciju izmaiņu relatīvās maksimālās vērtības ir blakus Tērvetes ielas dzelzceļa pārvadam un Rūpniecības un Tērvetes ielas krustojumā. Lielas niķeļa (Ni) relatīvās koncentrācijas izmaiņas parasti rada siltumenerģijas ražotāji, kā arī privātmāju apkures sistēmas.

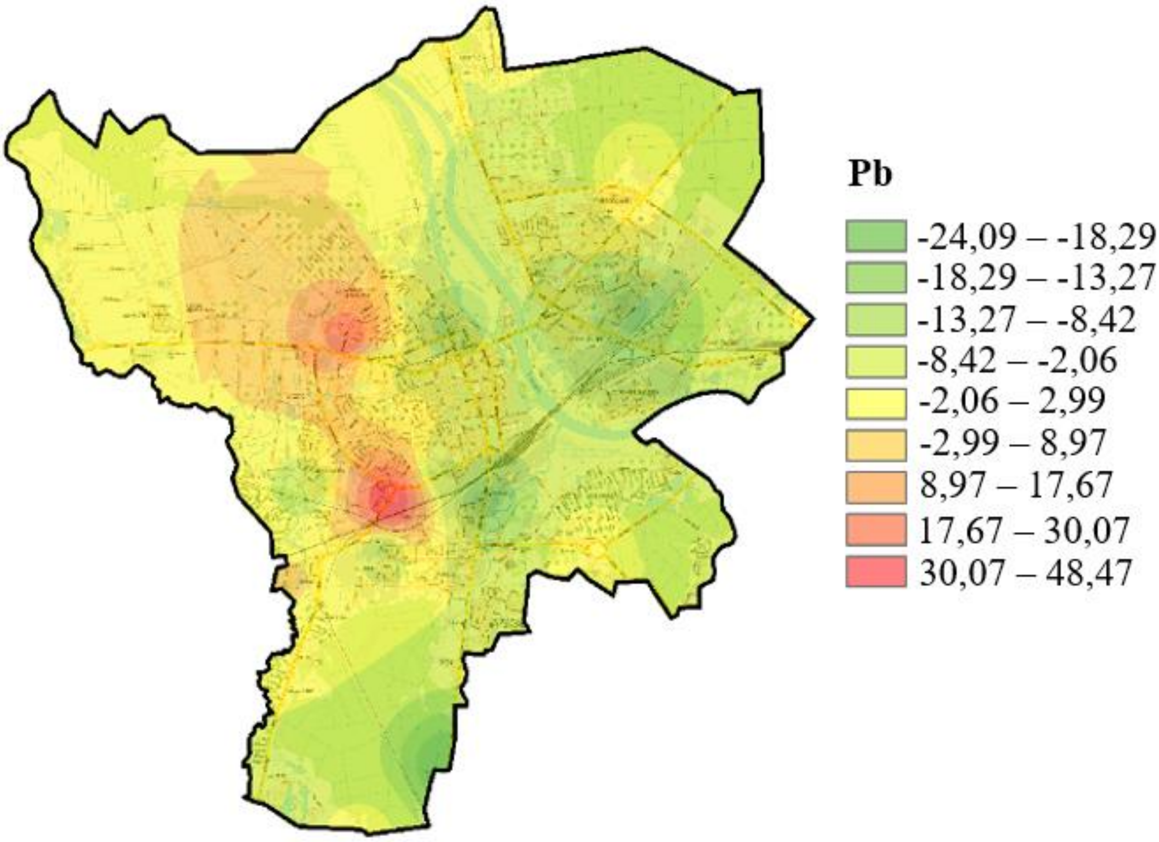
Vislielākais vara (Cu) koncentrācijas pieaugums ir Satiksmes ielas rajonā, kur atrodas sabiedriskā transporta stāvvietas. Vara (Cu) piesārņojums saistīts ar satiksmes intensitāti, privātmāju apkures sistēmām, fosilo kurināmo, uguņošanu un metālrūpniecību.

Cinks (Zn) tiek uzskatīts par toksisku metālu, tas rodas rūpnieciskās darbības procesā ogļu sadedzināšanas rezultātā, kā arī tas ir saistīts ar satiksmes intensitāti. Jelgavā cinka (Zn) relatīvo koncentrāciju izmaiņas nav lielas (skat.3.11. att.), taču koncentrācijas nav vienmērīgi sadalītas pa pilsētu. Cinka (Zn) relatīvo koncentrāciju izmaiņu relatīvās maksimālās vērtības ir pie Tērvetes ielas dzelzceļa pārvada, Rūpniecības un Tērvetes ielas krustojumā, un Satiksmes ielas rajonā, kur atrodas sabiedriskā transporta stāvvietas.



3.11. att. **Cinka (Zn) µg/l relatīvo koncentrāciju izmaiņas (2017. gada februāris un 2018. gada februāris) Jelgavas pilsētā**

Svina (Pb) relatīvo koncentrāciju izmaiņas Jelgavas pilsētā parādītas 3.12. attēlā. Svina (Pb) relatīvo koncentrāciju izmaiņu relatīvās maksimālās vērtības ir blakus Tērvetes ielas dzelzceļa pārvadam, Rūpniecības un Tērvetes ielas krustojumā un Satiksmes ielas teritorijā, kurā atrodas sabiedriskā transporta stāvvieta. Svina (Pb) klātbūtne Jelgavas pilsētā ir saistīta ar dedzināšanu, naftas un fosilo materiālu dedzināšanu un transportu.

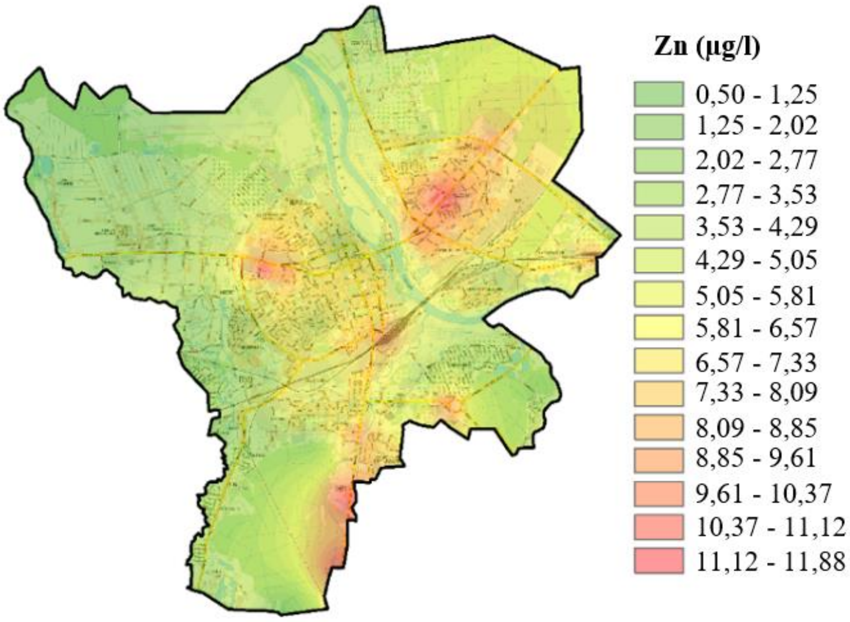


3.12. att. **Svina (Pb) µg/l relatīvo koncentrāciju izmaiņas Jelgavas pilsētā**

Vanādijs (V) tiek uzskatīts par tipisku eļļas sadegšanas procesa indikatoru, Jelgavā vanādija (V) relatīvo koncentrāciju izmaiņas nav īpaši lielas taču koncentrācijas nav vienmērīgi sadalītas pa pilsētu. Vanādija (V) relatīvo koncentrāciju izmaiņu relatīvās maksimālās vērtības ir blakus Tērvetes ielas dzelzceļa pārvadam. Dzelzs (Fe) parasti rodas fosilā kurināmā sadegšanas rezultātā. Dzelzs daļiņu avots ir dzinēja un automašīnas virsbūves materiāla nodilums. Jelgavā dzelzs (Fe) relatīvo koncentrāciju izmaiņas nav īpaši lielas, taču koncentrācijas ir diezgan vienmērīgi sadalītas visā pilsētā.

Arsēna (As) un hroma (Cr) koncentrāciju relatīvais pieaugums ir koncentrēts Tērvetes ielas pārvada rajonā un Satiksmes ielā. Arsēnu (As) rodas fosilā kurināmā sadegšanas rezultātā, arī hroms (Cr) ir tieši saistīts ar satiksmes intensitāti un atkritumu sadedzināšanu.

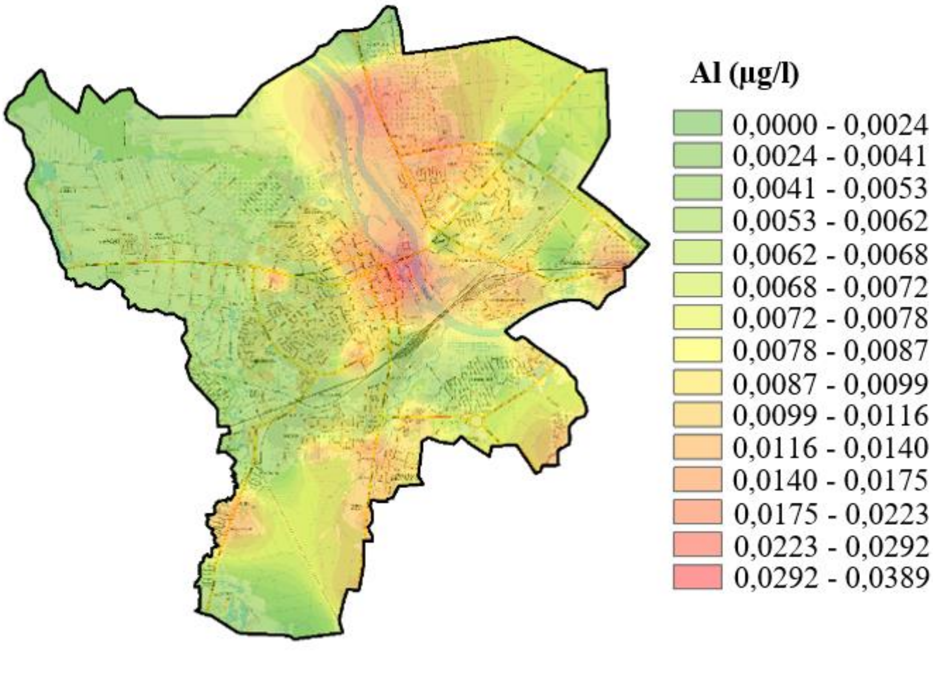
Apskatot dažādus veidus, kā veikt telpisko analīzi, piemēram, cinkam (Zn), alumīnijam (Al), varam (Cu) un dzelzim (Fe), tie tika grupēti pēc koncentrācijām, izmantojot hierarhisku klasteru analīzi ar Eiklida attāluma algoritmu. Salīdzinoši tīras, viegli piesārņotas un piesārņotas teritorijas tika sadalītas, izmantojot ArcGIS programmatūru. Cinka (Zn) sadalījums pēc relatīvās koncentrācijas parādīts 3.13. attēlā. Klasteru analīze iedala 15 relatīvo koncentrāciju grupas. Pirmās piecas grupas ar cinka (Zn) koncentrāciju no 0,50 līdz 4,29 µg/l definējām, kā salīdzinoši tīru teritoriju. Otrās piecas grupas ar cinka (Zn) koncentrāciju no 4,29 līdz 8,09 µg/l definējām, kā salīdzinoši viegli piesārņotu teritoriju. Pēdējās piecas grupas ar cinka (Zn) koncentrāciju no 8,09 līdz 11,88 µg/l definējām kā relatīvi piesārņotas teritorijas ar augstu antropogēno ietekmi. Galvenie cinka (Zn) avoti pilsētu teritorijās ir rūpniecība, ogļu dedzināšana un transports. Tādi transporta koridori kā Rīgas iela, Lielā iela un Lietuvas šoseja, kā arī dzelzceļš un apļveida krustojuma zona ir galvenie antropogēnie cinka (Zn) avoti Jelgavas pilsētā (skat. 3.13. att.).



3.13. att. **Cinka (Zn) µg/l izplatība Jelgavas pilsētā**

Alumīnijs (Al) ir viens no galvenajiem atkritumu sadedzināšanas un uguņošanas indikatoriem. Alumīnija (Al) sadalījums pēc relatīvās koncentrācijas parādīts 3.14. attēlā. Klasteru analīze iedala 15 relatīvo koncentrāciju grupas.

Pirmās piecas grupas ar alumīnija (Al) koncentrāciju no 0 līdz 0,007 µg/l definējām, kā salīdzinoši tīru laukumu. Otrās piecas grupas ar alumīnija (Al) koncentrāciju no 0,007 līdz 0,012 µg/l definējām, kā salīdzinoši viegli piesārņotu teritoriju. Pēdējās piecas grupas ar alumīnija (Al) koncentrāciju no 0,012 līdz 0,039 µg/l definējām kā relatīvi piesārņotas teritorijas ar augstu antropogēno ietekmi. Salīdzinoši augsta alumīnija (Al) koncentrācija ir teritorijās ar privātiem mājokļiem. Alumīnija (Al) piesārņojums virzās ziemeļu, ziemeļaustrumu virzienos no pilsētas centra zonas dominējošā vēja dēļ. Kalnciema ceļa privātmāju rajons un to apkures sistēmas varētu būt galvenais alumīnija (Al) avots šajā rajonā.



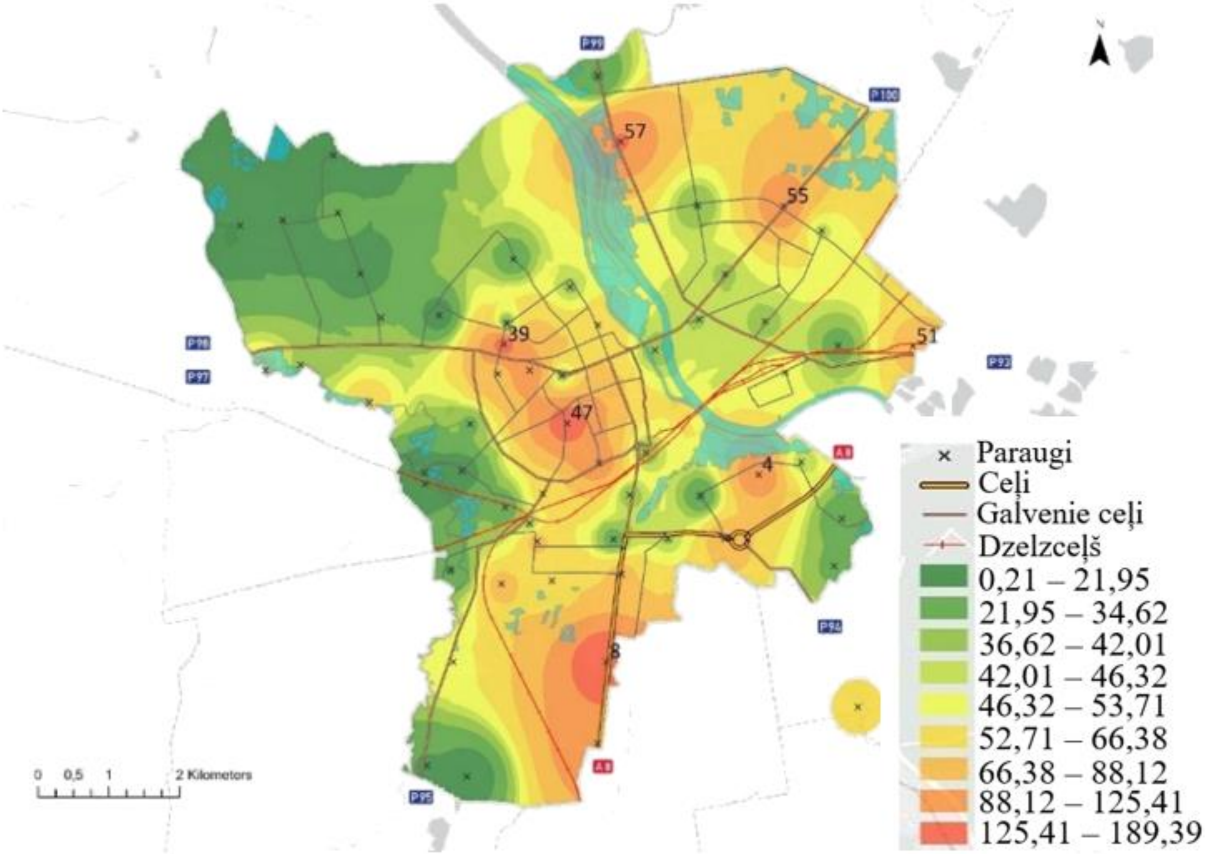
3.14. att. **Alumīnija (Al) µg/l izplatība Jelgavas pilsētā**

Varš galvenokārt rodas iekšdedzes dzinējos, sadegot naftas produktiem un atkritumiem. Klasteru analīze iedala 15 relatīvo koncentrāciju grupas. Pirmās piecas grupas ar vara (Cu) koncentrāciju no 0 līdz 2,01 µg/l definējām, kā salīdzinoši tīru laukumu. Otrās piecas grupas ar vara (Cu) koncentrāciju no 2,01 līdz 4,20 µg/l definējām, kā salīdzinoši viegli piesārņotu teritoriju. Pēdējās piecas grupas ar vara (Cu) koncentrāciju no 4,20 līdz 6,30 µg/l definējām kā relatīvi piesārņotas teritorijas ar augstu antropogēno ietekmi. Lielākā vara (Cu) koncentrācija Jelgavas pilsētā ir Lielā ielā un Rīgas ielā, kas savieno Jelgavu ar Rīgu. Katru dienu galveno ielu izmanto aptuveni 36000 automašīnu. Vara (Cu) koncentrācija rodas arī no nekontrolētas atkritumu dedzināšanas privātmāju rajonos.

Apskatot dzelzs (Fe) izplatību sniegūdenī, klasteru analīze iedala 13 relatīvo koncentrāciju grupas. Pirmās četras grupas ar dzelzs (Fe) koncentrāciju no 0 līdz 0,007 mg/l definējām, kā salīdzinoši tīru teritoriju. Otrās piecas grupas ar dzelzs (Fe) koncentrāciju no 0,007 līdz 0,017 mg/l definējām, kā salīdzinoši viegli piesārņotu teritoriju. Pēdējās četras grupas ar dzelzs (Fe) koncentrāciju no 0,017 līdz 0,024 mg/l definējām kā relatīvi piesārņotas teritorijas ar augstu antropogēno ietekmi. Paaugstināta dzelzs daļiņu koncentrēja bija galvenajos ceļu posmos, piemēram, Lielā ielā, Rīgas iela un Lietuvas šoseja. Dzelzs koncentrācijas aptver visu Jelgavas pilsētu, kas liecina, ka nav viens dzelzs (Fe) piesārņojuma avota, taču antropogēnās aktivitātes, piemēram, satiksme, apkures sistēmas, rūpniecība piesārņo gaisu, un paaugstina dzelzs (Fe) koncentrāciju pilsētās.

Pētot gaisa piesārņojuma izplatību pilsētvidē četru gadu periodā un apskatot aprakstošās statistikas rezultātus, redzams, ka 2018. gadā iegūts visaugstākais vidējais cinka mērījums – 79,62 µg/l, kas ir gandrīz 9 reizes lielāki par 2020. gadā iegūto vidējo mērījumu 8,88 µg/l. 2018. gadā iegūts vislielākais cinka mērījums 1002,05 µg/l un 2020. gadā iegūts vismazākais mērījums 0,99 µg/l. Apskatot vērtību procentiles sadalījumu redzams, ka 2018. gadā Jelgavas teritorijā iegūti ievērojami augstāki mērījumu rezultāti nekā 2019.-2021 gadā. 2019.-2021. gada mērījumu vērtības ir diez gan līdzīgas. Normalizēto cinka mērījumu telpisko reprezentāciju 2018. gadā. Visaugstākā cinka daļiņu koncentrācija konstatēta Dobeles un Satiksmes ielas krustojumā (39. punkts). Otra augstākā vērtība konstatēta netālu no reģionālā ceļa P99 (57. punkts), kā arī uz reģionālā ceļa P95 (17. un 21. punkts). Vēl ievērojami augstas koncentrācijas novērojamas uz valsts nozīmes autoceļa A8 (9. punkts). Īpaši augstas cinka koncentrācijas 2018. gadā var izskaidrot ar uguņošanu uz Pasta salas (48. punkts), kas kalpo kā pulcēšanās vieta dažādiem pasākumiem. Pārējos gadus paaugstināts cinka daļiņu piesārņojums 48. punktā nav konstatēts.

Ar vislielāko cinka piesārņojumu 2019. gadā izceļas tieši pilsētas cents, kur iegūts vairums augstākie cinka daļiņu mērījumi. Visaugstākās vērtības novērotas tieši pilsētas centrā (45. un 47. punkts) un pie pilsētas centra ārējās robežas (38. un 43. punkts). 2020. gadā augstākās vērtības novērotas uz valsts nozīmes autoceļu A8. 3 mērījumi uz šī ceļa norādīja uz paaugstinātu cinka koncentrāciju (6.;8. un 9. punkts). Netālu no Dobeles šoseja, kā arī reģionālas nozīmes ceļam P100 (55. punkts) ir novērojama paaugstināta cinka daļiņu koncentrācija. Visi paaugstinātās koncentrācijas punkti norāda uz satiksmes kustību Rīgas virzienā. 2021. gadā centrā uz kopējo pilsētas fonu ir mazāks cinka daļiņu piesārņojums nekā citus gadus. Šajā gadā ievērojami cinka daļiņu mērījumi novēroti uz reģionālajiem ceļiem P99, P100 un P93, kā arī uz valsts nozīmes ceļa A8. Pirmo reizi 4 gadu laikā, paaugstinātas cinka koncentrācijas novērota 4. punktā. Šis punkts atrodas privātmāju rajonā. Iespējamo piesārņojumu varētu izskaidrot ar neatļautu atkritumu dedzināšanu privātmāju apkures sistēmās.



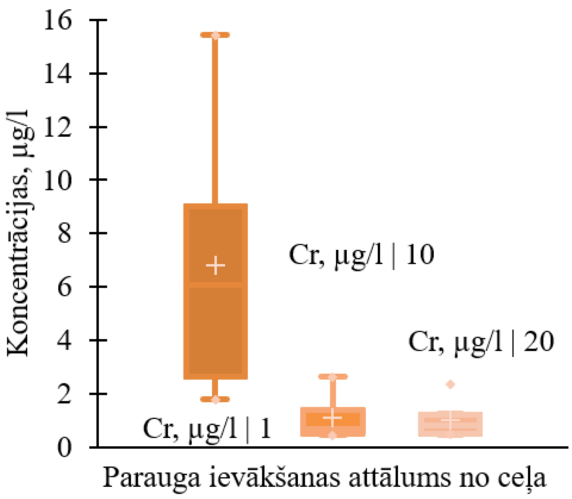
3.15. att. **Cinka daļiņu izplatība Jelgavā 2018.-2021. gads**

Apkopojot iegūtos rezultātus (skat. 3.15. att.) vēl vairāk izceļas jau gūtais priekšstats, pilsētas centrs un maģistrālie ceļi ir ar ievērojami lielāku cinka daļiņu piesārņojumu nekā pārējā Jelgava. Vislielākais cinka daļiņu piesārņojums novērojams uz valsts nozīmes ceļu A8 (8. punkts) un reģionālo ceļu P99 (57. punkts). Pilsētas centrā 4 gadu periodā vislielākais cinka daļiņu piesārņojums konstatēts Dobeles un Satiksmes ielas krustojumā (39. punkts) un Tērvetes un Pavasara ielas krustojumā (47. punkts). Ir vērts pieminēt, ka īpaši aizsargājamai dabas teritorijai Lielupes palienu pļavas paralēli iet reģionālais ceļš P99, kuram konstatēts paaugstināts cinka daļiņu piesārņojums un cinka daļiņu piesārņojums varētu nonākt aizsargājamā teritorijā.

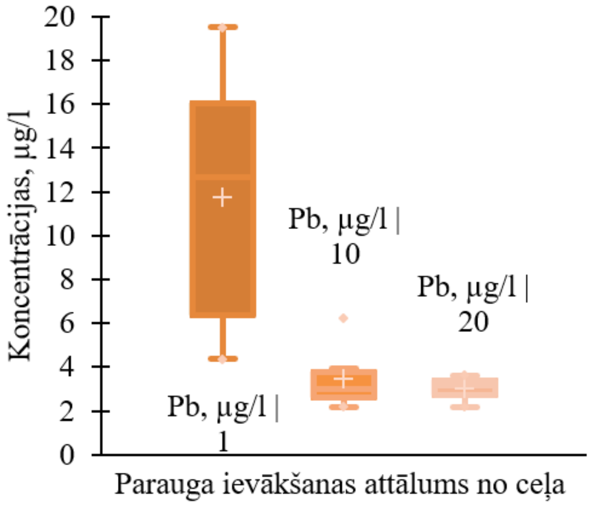
Jelgavas pilsētā piesārņojums ir homogēns, tādēļ nepieciešamas identificēt piesārņojuma izcelsmes avotus.

3.4. Gaisa piesārņojuma ar smagajiem metāliem avotu identifikācija

Svarīgs aspekts, pētot gaisa piesārņojumu ar smagajiem metāliem, ir identificēt avotus. Apskatot, rezultātus par piesārņojošo vielu koncentrācijām gar brauktuvēm var redzēt, ka augstākas piesārņojošo vielu koncentrācijas tiek novērotas 1 m attālumā no brauktuves, salīdzinot ar paraugiem, kas ņemti no tālākām paraugu ņemšanas vietām. 3.16. un 3.17. attēlā parādīta tieša satiksmes ietekme uz Cr un Pb koncentrācijām, cieša satiksmes ietekme bija redzama arī uz tādiem ķīmiskajiem elementiem kā Mn un V. Piesārņojošo vielu koncentrācijas samazinās 10 m attālumā. Iegūtie rezultāti uzrādīja, ka Cu un Zn koncentrāciju 20 m attālumā ietekmē arī citi avoti. Salīdzinot Pb, Zn un V koncentrācijas 1 m attālumā no brauktuves un 10 m attālumā no brauktuves, piesārņojošo vielu koncentrācijas samazinās 6 līdz 11 reizes.

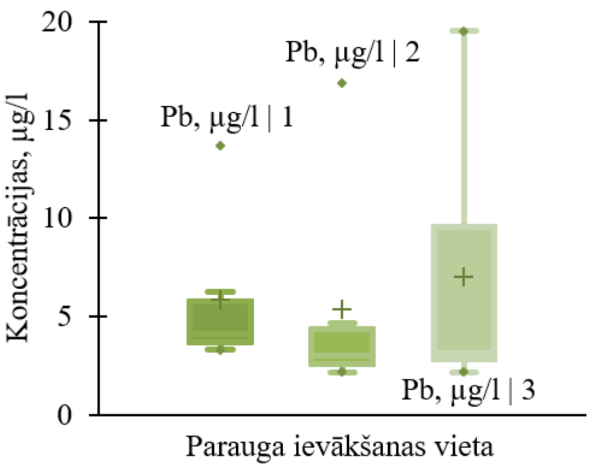


3.16. att. **Cr koncentrācijas atkarībā no attāluma no ceļa**

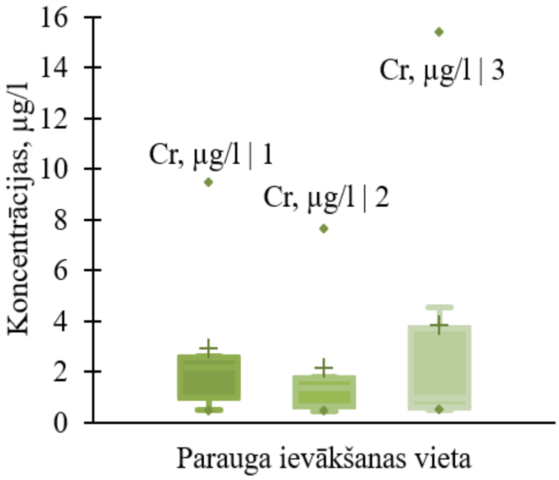


3.17. att. **Pb koncentrācijas atkarībā no attāluma no ceļa**

Lielākās Pb un Cr koncentrācijas atrodas uz autoceļa Jelgava-Rīga aptuveni 4 km no Jelgavas pilsētas centra (skat.3.18. att. un 3.19. att.). Šajā ceļa posmā arī tika konstatētas lielākās koncentrācijas Cu, Mn, V un Zn. Jelgavas pilsētas ziemeļu un austrumu daļā Mn koncentrācijas būtiski neatšķiras. V koncentrācija mainās no zemākas koncentrācijas pilsētas rietumu daļā uz augstāku pilsētas austrumu daļā. Cr un Pb koncentrācijas ir zemākas Jelgavas pilsētas ziemeļu daļā, salīdzinot ar citām vietām (skat.3.18. att. un 3.19. att.). Arī Cu koncentrācijas ir zemākas Jelgavas pilsētas ziemeļu daļā, salīdzinot ar citām vietām.



3.18. att. **Pb koncentrācijas atkarībā no atrašanās vietas**



3.19. att. **Cr koncentrācijas atkarībā no atrašanās vietas**

Apskatot 2018. gada datus, lai identificētu piesārņojuma avotus rezultāti, uzrāda augstas vara (Cu) 826,7 µg/l, niķeļa (Ni) 40,4 µg/l, svina (Pb) 50,5 µg/l, mangāna (Mn) 1351,1 µg/l un cinka (Zn) 992,8 µg/l, koncentrācijas dažādos pilsētas virzienos. Aprakstošā statistika par vara (Cu), niķeļa (Ni), svina (Pb), mangāna (Mn) un cinka (Zn) koncentrācijām izkusušā sniega paraugos sniegta 3.3. tabulā.

3.3.tabula. **Statistika par vara (Cu), niķeļa (Ni), svina (Pb), mangāna (Mn) un cinka (Zn) koncentrācijām**

Metāli / Statistika	Cu, µg/l	Ni, µg/l	Pb, µg/l	Mn, µg/l	Zn, µg/l
Novērojumu skaits	114	114	114	114	114
Iztrūkstošie novērojumi	0	0	0	0	0
Minimums	2,8	0,4	0,7	5,9	9,2
Maksimums	829,5	40,8	51,2	1357,0	1002,1
Diapazons	826,7	40,4	50,5	1351,1	992,8
Mediāna	11,2	2,0	3,6	46,9	34,7
Vidējais	24,5	3,4	6,2	151,6	86,6
Distance (n)	5957,7	20,1	50,7	52613,0	16154,6
Standartnovirze (n)	77,2	4,5	7,1	229,4	127,1

Sniega paraugos vara (Cu), niķeļa (Ni), svina (Pb), mangāna (Mn) un cinka (Zn) koncentrācijas tika analizētas pa atrašanās vietu grupām. Ceļa virzieni ir austrumu (A), ziemeļu (Z) rietumu (R) un pilsētas centrs (C). Kruskal-Wallis tests tika izmantots, lai noteiktu atšķirības starp grupām. Vara (Cu) un niķeļa (Ni) koncentrācijas uzrādīja statistiski nozīmīgas atšķirības starp atrašanās vietām Cu p-vērtība bija 0,028, Ni p-vērtība bija 0,001, bet Pb, Mn un Zn statistiski nozīmīgas atšķirības pēc atrašanās vietas neuzrādīja.

Tika izmantoti vairāki pāru salīdzinājumi, izmantojot *Steel-Dwass-Critchlow-Fligner* procedūru (Spurrier, 2007), lai noteiktu atšķirības starp Cu un Ni koncentrācijām pēc atrašanās vietas grupām (Rietumi (R); Ziemeļi (Z); Austrumi (A); Pilsētas centrs (C) Wij un grupa *Steel-Dwass-Critchlow-Fligner* procedūra pēc atrašanās vietu grupām ir parādīta 3.4. tabulā.

3.4. tabula. **Cu un Ni koncentrācijas *Wij statistics* un grupa pēc atrašanās vietu grupām, izmantojot *Steel-Dwass-Critchlow-Fligner* procedūru**

Cu, µg/l						
-	**R**	**Z**	**A**	**C**	**Groups**	
Cu, µg/l | **R**	-	2,46	1,48	**3,87***	A	-
Cu, µg/l | **Z**	-2,46	-	-0,27	1,85	A	B
Cu, µg/l | **A**	-1,48	0,27	-	2,11	A	B
Cu, µg/l | **C**	**-3,87***	-1,85	-2,11	-	-	B
**p-value*	*<0,05*					
Ni, µg/l						
-	**R**	**Z**	**A**	**C**	**Grupas**	
Ni, µg/l | **R**	-	2,37	1,52	**5,17***	A	-
Ni, µg/l | **Z**	-2,37	-	-0,56	2,50	A	B
Ni, µg/l | **A**	-1,52	0,52	-	2,89	A	B
Ni, µg/l | **C**	**-5,17***	-2,50	-2,89	-	-	B
**p-value*	*<0,001*					

3.5. tabula. **Cu, Ni, Pb, Mn, Zn koncentrācijas *Wij statistics* un grupa pēc attāluma grupām, izmantojot *Steel-Dwass-Critchlow-Fligner* procedūru**

Cu, µg/l							
-	**| 1**	**| 50**	**| 100**	**| 5**	**Groups**		
Cu, µg/l | 1	-	7,25*	6,40*	6,44*	A	-	
Cu, µg/l | 50	-7,25*	-	-0,63	0,35	A	-	
Cu, µg/l | 100	-6,40*	0,63	-	1,04	A	-	
Cu, µg/l | 5	-6,44*	-0,35	-1,04	-	-	B	
*p-value	<0,0001						
Ni, µg/l							
-	**| 1**	**| 50**	**| 100**	**| 5**	**Groups**		
Ni, µg/l | 1	-	7,25*	6,76*	7,85*	A	-	
Ni, µg/l | 50	-7,25*	-	-0,11	1,06	A	-	
Ni, µg/l | 100	-6,76*	0,11	-	1,65	A	-	
Ni, µg/l | 5	-7,85*	-1,06	-1,64	-	-	B	
*p-value	<0,0001						
Pb, µg/l							
-	**| 1**	**| 50**	**| 100**	**| 5**	**Groups**		
Pb, µg/l | 1	-	6,35*	7,23*	5,79*	A	-	
Pb, µg/l | 50	-6,35*	-	0,29	-1,31	A	-	
Pb, µg/l | 100	-7,23*	-0,29	-	-1,98	A	-	
Pb, µg/l | 5	-5,79*	1,31	1,98	-	-	B	
*p-value	<0,0001						
Mn, µg/l							
-	**| 1**	**| 50**	**| 100**	**| 5**	**Groups**		
Mn, µg/l | 1	-	6,80*	7,11*	6,00*	A	-	-
Mn, µg/l | 50	-6,80*	-	0,67	-2,72	A	B	-
Mn, µg/l | 100	-7,11*	-0,67	-	-3,84**	-	B	-
Mn, µg/l | 5	-6,00*	2,72	3,84**	-	-	-	C
*p-value	<0,0001	**p-value	<0,034				
Zn, µg/l							
-	**| 1**	**| 50**	**| 100**	**| 5**	**Groups**		
Zn, µg/l | 1	-	7,11	7,25	6,84	A	-	
Zn, µg/l | 50	-7,11	-	-0,98	-2,03	A	-	
Zn, µg/l | 100	-7,25	0,98	-	-2,13	A	-	
Zn, µg/l | 5	-6,84	2,03	2,13	-	-	B	

Vara (Cu), niķeļa (Ni) svina (Pb) cinka (Zn) koncentrācijas pēc attāluma no ceļa, izmantojot *Steel-Dwass-Critchlow-Fligner* procedūru, ir klasificētas divās grupās, kur 1 m 50 m un 100 m distance ir vienā grupā un 5 m otrajā grupā skatīt 3.5. tabulu.

Mangāna (Mn) koncentrācijas pēc attāluma no ceļa, izmantojot *Steel-Dwass-Critchlow-Fligner* procedūru, ir klasificētas trīs grupās, kur 1m un 50 m distance ir vienā grupā 50 m un 100 m otrajā grupā un 5 m trešajā grupā (skat. 3.5. tab.).

Rezultāti, kas parādās Jelgavas pilsētas izpētes datos par smagajiem metāliem parāda ļoti līdzīgus rezultātus ar citiem līdzīgiem pētījumiem, meklējot korelācijas starp transporta intensitāti un smago metālu piesārņojumu sniega kušanas ūdeņos (Engelhard et al., 2007). Vara (Cu), niķeļa (Ni), svina (Pb), mangāna (Mn) un cinka (Zn) koncentrācija pētījumā uzrāda lielu amplitūdu ar ļoti zemām vērtībām un ārkārtīgi augstām vērtībām. Jāatzīmē, ka grupās pēc paraugu ņemšanas vietas bija dažādas atšķirības. Pilsētas centrālajā daļā (C), ziemeļos (Z) un austrumos (A) bija atšķirības tikai Cu un Ni koncentrācijās, savukārt Mn, Pb un Zn neuzrādīja būtiskas atšķirības starp vietām. Šajā pētījumā sadalītās grupas parāda paraugu ņemšanas attāluma no ceļa nozīmi.

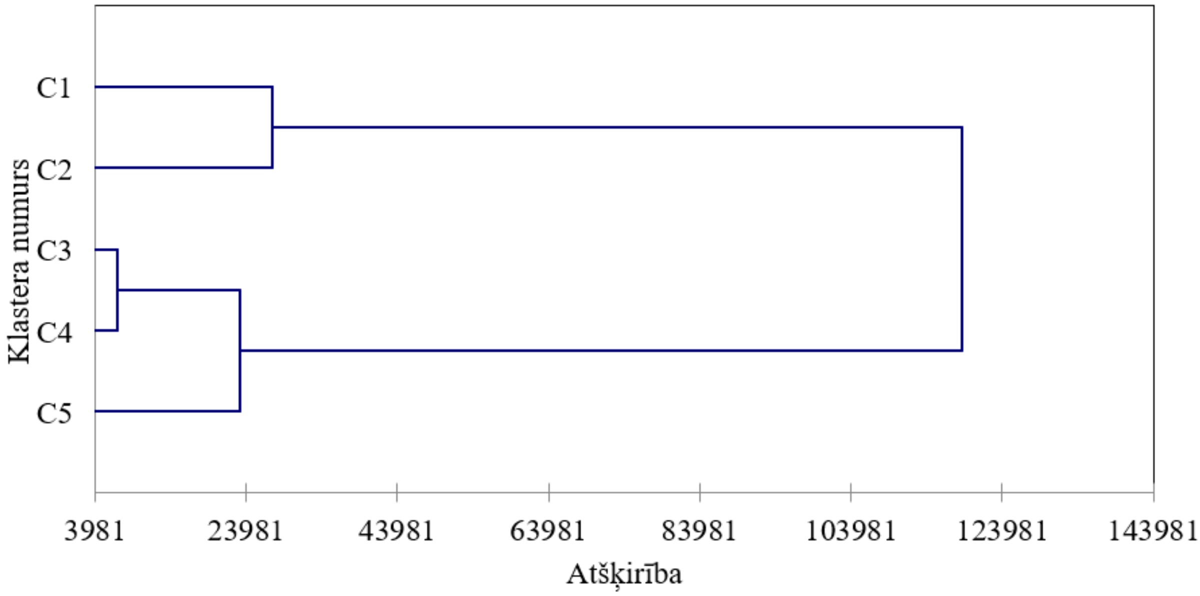
Darbā tika apskatītas iespējas identificēt gaisa piesārņojuma ar smagajiem metāliem avotus, izmantojot hierarhisko klasteru metodi. Kopumā tika apskatīti 19 ķīmiskie elementi, no kuriem tālāk tika veikta monitoringa punktu klasifikācija, izmantojot hierarhisko klasteru metodi. Klastera centroīda koordinātas ir norādītas 3.6. tabulā.

3.6. tabula. **Klasteru centroīdu koordinātas**

Ķīmiskais elements	**Klastera centroīda koordinātas**			
	1	**2**	**3**	**4**
Al (µg/l)	-0,57	1,11	1,06	1,16
Ca (µg/l)	-0,44	0,35	1,76	0,25
Fe (µg/l)	-0,58	0,41	1,11	0,45
K (µg/l)	-0,44	-0,17	0,55	-0,11
Mg (µg/l)	-0,40	0,31	2,24	0,51
Na (µg/l)	-0,50	0,61	3,84	-0,15
P (µg/l)	-0,34	-0,38	1,11	5,32
S (µg/l)	-0,70	0,21	2,54	2,38
As (µg/l)	-0,13	-0,13	-0,13	-0,13
Ba (µg/l)	-0,37	0,28	0,11	7,15
Cd (µg/l)	0,00	0,00	0,00	0,00
Co (µg/l)	-0,25	-0,26	2,36	0,43
Cr (µg/l)	-0,23	-0,23	-0,23	6,08
Cu (µg/l)	-0,85	0,46	0,22	1,80
Mn (µg/l)	-0,45	0,35	1,59	0,86
Mo (µg/l)	-0,30	-0,30	-0,30	-0,30
Ni (µg/l)	-0,23	-0,23	-0,23	-0,23
Pb (µg/l)	-0,06	-0,18	-0,20	7,52
Si (µg/l)	-0,53	0,67	1,02	0,70
Sr (µg/l)	-0,66	0,47	2,05	1,46
V (µg/l)	-0,32	-0,32	1,08	3,56
Zn (µg/l)	-0,45	0,01	-0,03	6,73

Lielākajā daļā paraugu ķīmisko elementu koncentrācijas bija zemākas par instrumenta kļūdas vērtību, bet atsevišķiem paraugiem koncentrācija bija pietiekami augsta, lai to noteiktu. Šajā pētījuma daļā tika izdalīti vairāki klasteri. Pirmajā klasterī ir apvienotas teritorijas ar salīdzinoši zemu gaisa piesārņojumu, kur visas metālu vērtības ir zem vidējās vērtības un klasterī ir iekļauts kontroles monitoringa punkts. Otrajā klasterī ir aprakstīti monitoringa punkti, kuros ķīmisko elementu sastāvs ir raksturīgs satiksmes izraisītam piesārņojumam (Engelhard et al., 2007; Vasić et al., 2012). Trešais klasteris apvieno monitoringa punktus, kuros papildus satiksmes piesārņojumam ir identificēts atkritumiem un fosilā kurināmā sadegšanai raksturīgo ķīmisko elementu saturs (Pacyna et al., 2001; Veysseyre et al., 2001; Rodella et al., 2017; Gao et al., 2017). Ceturto klasteru veido viens monitoringa punkts, kurā papildus transporta piesārņojumam ir konstatētas paaugstinātas cinka un svina vērtības. Šie metāli izteikti norāda uz atkritumu dedzināšanu (Rodella et al., 2017), ko varētu skaidrot ar blīvu privātmāju apbūvi, kur veidojas izteikts ielas kanjons, kas apgrūtina gaisa cirkulāciju un veicina piesārņojuma uzkrāšanos.

Apskatot tikai viena metāla klasteru analīzes rezultātus, uzrādījās līdzīgas tendences, kā apskatot vairāku metālu kopu. Klasteru analīzes rezultātā izdalījās piecas volframa piesārņojuma riska grupas (skat. 3.20.att.). Pirmais klasteris ir ar vidējo vērtību 0,12 µg/l un mediāna ar 0,10 µg/l. Otrā klastera vidējā vērtība ir 2,31 µg/l un mediāna 2,31 µg/l. Trešā klastera vidējā vērtība ir 0,25 µg/l un mediāna 0,25 µg/l. Ceturtajā klasterī vidējā vērtība ir 0,35 µg/l un mediāna 0,36 µg/l. Piektajā klasterī vidējā vērtība ir 0,44 µg/l un mediāna 0,45 µg/l.



3.20. att. **Volframa hierarhiskā klasteru analīze**

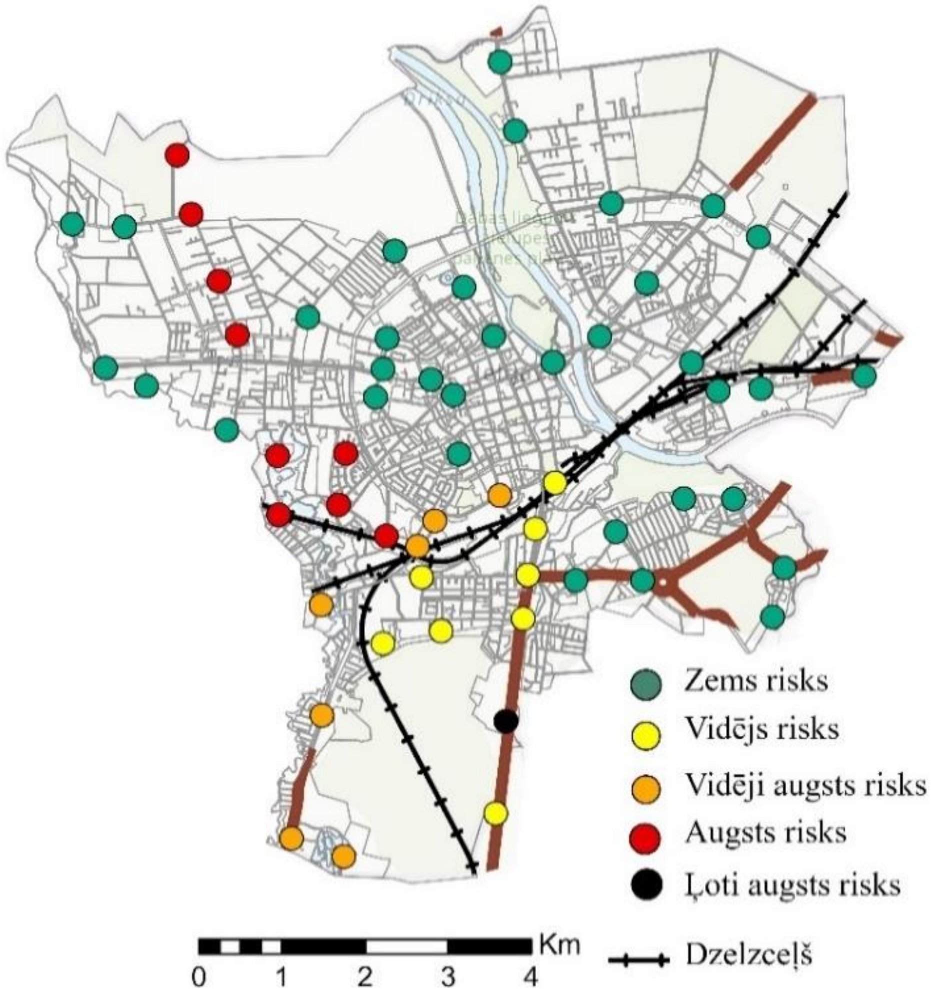
Volframa minimālās, maksimālās, vidējās un mediānas vērtības apkopotas 3.7.tabulā. Rezultāti iegūti pēc klasteru analīzes Jelgavas pilsētai 2022. un 2023. gadam.

3.7. tabula. **Volframa aprakstošā statistika pa kopām**

Klasteris	**Minimums (µg/l)**	**Maksimums (µg/l)**	**Vidējais (µg/l)**	**Mediāna (µg/l)**	**Riska līmenis**
2022 | 1	0,05	1,01	0,09	0,05	Zems risks
2022 | 2	4,17	4,48	4,35	4,41	Ļoti augsts risks
2022 | 3	0,05	0,31	0,09	0,05	Vidējs risks
2022 | 4	0,05	0,29	0,07	0,05	Vidēji augsts risks
2022 | 5	0,05	0,05	0,05	0,05	Augsts risks
2023 | 1	0,05	0,25	0,14	0,14	Zems risks
2023 | 2	0,26	0,28	0,27	0,27	Ļoti augsts risks
2023 | 3	0,29	0,52	0,41	0,41	Vidējs risks
2023 | 4	0,53	0,74	0,64	0,64	Vidēji augsts risks
2023 | 5	0,75	0,99	0,87	0,87	Augsts risks

Pētījumā, kas veikts Zviedrijā, volframa koncentrācija ziemā pieauga, bet vasarā bija daudz zemāka. Volframa vidējās vērtības notecē no ceļiem ziemā bija 9,18 µg/l, vasarā 1,06 µg/l Svaneberg pilsētā, Norsholm pilsētā vasarā tās bija 0,58 µg/l, bet ziemā 5,77 µg/l. Volframs bieži tiek atstāts novārtā ceļu noteces pētījumos, lai gan to bieži izmanto riepu radzēs

(Bäckström et al., 2003). Jelgavas pētījums parāda transporta koridoru būtisko ietekmi, īpaši augsts piesārņojuma risks ar volframu parādās galvenajā tranzīta virzienā uz Lietuvu, kur pie apdzīvotas vietas robežas, straujas bremzēšanas un uzsākšanas parādās visaugstākās volframa koncentrācijas, kur mediānas vērtība 2022. gadā bija 4,41 µg/l (skat. 3.21.att.).



3.21.att. **Volframa izplatība Jelgavā apskatot riska līmeņus**

Bourcier et al. 1980 pētījumā lietusūdeņu paraugos no ceļiem, kas ietver, ielu putekļus volframs bija 15000 µg/l (Bourcier et al., 1980). Jelgavas pilsētā regulāri tiek savākti putekļi no asfaltētajām ielām. Pētījums parāda, ka ielās bez asfalta seguma ir augsts volframa piesārņojuma risks. Volframa koncentrācijas izkusušos sniega paraugos, kas ievākti Polijā, dažādās vietās bija 1,70 µg/l lidlaukā, pie šosejas 2,59 µg/l un 1,5 m attālumā no iebrauktuves autostāvvietā 1,93 µg/l (Adamiec et al., 2013). Pētījumā, kas veikts Jelgavas pilsētā, 2022. un 2023. gadā vidējās volframa koncentrācijas svārstījās robežas no 0,07 µg/l līdz 4,35 µg/l.

4. SECINĀJUMI UN PRIEKŠLIKUMI

1. Pasaulē vairākas zinātnieku grupas veic pētījumus smago metālu un gaisā suspendēto cieto daļiņu (PM) gaisa piesārņojuma noteikšanai, tomēr jāmin, ka šie pētījumi ir fragmentāri, vērsti uz specifisku piesārņojuma veidu un neatspoguļo urbāno vidi kā sarežģītu un kompleksu gaisa piesārņojuma avotu.
2. Jelgavas pilsētā ir aprobēts un izveidots ilglaicīgā un īslaicīgā piesārņojuma monitoringa tīkls, kas ļauj novērtēt gaisa piesārņojuma dinamiku laikā un telpā. Ir izveidota datubāze, kas satur ķīmisko elementu koncentrācijas sniegā 60 parauglaukumos no 2018.-2024.gadam.
3. Jelgavas pilsētā ir ļoti plašs gaisa piesārņojuma ar smagajiem metāliem diapazons, cinka (Zn) koncentrācijas svārstās no 0,01-1002,10 µg/l, vara (Cu) koncentrācijas svārstās no 0-829,50 µg/l, niķeļa (Ni) koncentrācijas svārstās no 0,001-40,40 µg/l, svina (Pb) koncentrācijas svārstās no 0,70-62,97 µg/l, mangāna (Mn) koncentrācijas svārstās no 5,90-1357,0 µg/l, alumīnija koncentrācijas svārstās no 0,01-1183,66 µg/l.
4. Gaisa piesārņojuma ar ķīmiskajiem elementiem izplatības telpiskā analīze parāda, ka transporta koridori ir vieni no galvenajiem faktoriem, kas nosaka piesārņojuma telpisko izplatību pilsētā.
5. Gaisa piesārņojumu avotu identifikācijai nepieciešamas izmantot vairākas statistikas metodes kombinācijā ar telpisko analīzi izmantojot GIS. Saskaņā ar Kruskal-Wallis testu varš (Cu), niķelis (Ni), svins (Pb), mangāns (Mn) un cinks (Zn) radīja būtiskas atšķirības starp attāluma grupām ar p vērtību $< 0,0001$.
6. Promocijas darbā ir veikts pirmais posms, Pasaules Veselības organizācijas noteiktajā gaisa piesārņojuma riska izvērtējuma procedūrā, kas saistīts ar piesārņojuma koncentrācijām un to telpiskā izplatības risku. Nākamos posmus var veikt medicīnas zinātnēs nozares speciālisti.
7. Pētījumu nepieciešams turpināt un analizēt paaugstinātu ķīmisko vielu koncentrāciju avotus, kas ir ļoti sarežģīts un komplekss uzdevums, jo pilsētvidē ir vesela virkne punktveida un difūzie piesārņojuma avoti, kuri ir mainīgi laikā un telpā, un kuru radītā piesārņojuma telpisko izplatību ietekmē, gan pilsētas struktūras, gan globālais un lokālais klimats.

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THE TEMPORAL AND SPATIAL ANALYSIS OF TRANSPORT IMPACT ON TRACE ELEMENTS IN SNOW SAMPLES

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ABSTRACT

More than half of the world population lives in cities. In 2030, 80% of the world population will live in urban areas, according to United Nations migration forecasts. People who are living in cities are exposed to air pollution. The concentration of air pollution is increased by traffic intensity. Increasing traffic intensity increases the number of automobile congestion in large cities. Therefore, there is a need to implement the measures for reducing air pollution in surroundings. Scientific studies show that emissions from vehicle establish more than 90% of air pollution in the urban environment. Air pollution is associated with many premature deaths every year.

The snow samples from the entire depth of snow show the pollution rate during the period of the permanent snow blanket and the sampling time. In this study, snow blanket pollution was investigated in Jelgava in February 2017 and 2018 after exposition of 7 days. The 20 sampling plots were created in the city and one plot in the natural area of the southern side of Jelgava. In each sampling area, 1.0-1.5 kg of snow was collected and in each plot 3 samples were taken for testing. In 2017, the average snow depth was 6-10 cm, but in 2018 the snow depth was 7-12 cm.

The chemical elements were detected in 63 snow samples from February 2017 and 63 in snow samples from February 2018. 126 snow samples in total were analysed. The concentrations of the chemical elements were calculated in the melting snow water and in the HNO3 solution.

Concentrations were determined by using an inductively connected plasma atomic emission spectroscopy (ICP-AES) method.

The results of the chemical elements in snow show a similar level of pollution. However, there are minor differences in the spatial distribution of pollution due to differences in transport flow and climate conditions.

Keywords: Traffic; Pollution; Chemical elements; ICP-AES.

INTRODUCTION

70% of the world's population is living in cities now; and it is estimated that this amount will be 80% by 2030 [1]. Worldwide, more than half of 1.3 million people living in developing countries die every year from air pollution in cities. Air pollution in cities is a major environmental problem, what is affecting people in both developed and developing countries [2].

People worldwide are encountered with increased soil, surface and groundwater pollutions and also with air pollution. The increase of the pollution goes hand to hand with economic activities, which promotes intensive use of natural resources. The use of chemicals in agriculture and in households, the extraction of mineral resources and their industrial exploitation cause tremendous air pollution by various chemical elements [3]. Human activities, such as industry and agriculture, are the main sources of heavy metals in the environment [4].

Several studies use snow as an indicator to detect air pollution in cities [5] and is the world-renowned method for determining air pollution. Snow samples are collected at different exposition periods, and then analyzed by determining the chemical elements from the melted snow. The presence of chemical elements in the snow water indicates one or more specific pollutants. For instance, iron (Fe), copper (Cu), chromium (Cr), vanadium (V), and arsenic (As) are produced by combustion of fossil fuel [8], [9]. Zinc (Zn), nickel (Ni) and lead (Pb) are produced by waste burning [10], [11].
The aim of research is to evaluate temporal and spatial changes of trace elements concentrations in snow samples in Jelgava city.

MATERIALS AND METHODS

Jelgava is located in the central part of Latvia (Figure 1), which is part of Zemgale Plain. Jelgava is located next to the Lielupe River and the river Driksa is situated on its territory. Jelgava is one of the largest cities in Latvia. It has a dense building and there are about 61,160 inhabitants living there.

Figure 1. The geographical location of Jelgava.

Jelgava is located in area of the temperate continental climate. In the winter months, the average temperature is -5.5 °C, and in the summer months +17.1 °C. The average temperature amplitude is 22.1 °C. On average per year, there are 150-155 cloudy days and atmospheric precipitation is observed in 170 - 180 days. The amount of precipitation is 550 - 560 mm per year. The highest absolute humidity is in June, but minimum is in February. The no frost period lasts from 135 to 145 days [6], [7].

Figure 2. Collection of snow samples

Snow samples were collected both in February 2017 and in February 2018. In 2017, the average snow depth was 6-10 cm, but in 2018 the snow depth was 7-12 cm. Snow was collected within 5 m from the road [6]. The chemical elements were detected in 63 snow samples from February 2017 and in 63 snow samples from February 2018. 126 snow samples were analysed in total.

The chemical elements were determined by an inductively coupled plasma atomic emission spectroscope (ICP-AES). This equipment is intended for analysis of liquid samples. Samples were analysed only when the snow was melted to allow the sample to be liquid. First, the samples were acidified to 1% HNO_3, secondly, they were acidified for 3 days, and, thirdly, was filtered through a paper filter [7].

RESULTS AND DISCUSSIONS

In Jelgava, the changes of relative concentrations of nickel (Ni) are not very high (Figure 3), but the concentrations are evenly distributed throughout the city. The relative maximum values of Ni change of relative concentrations are next to the railroad overpass of Tervete Street and Fortum Jelgava boiler house. High change of relative concentrations of Ni usually arises from heat producers, as well as private house heating systems.

The change of relative concentrations of copper (Cu) in Jelgava city is presented in figure 4. The highest rise of concentrations is in Satiksmes street area where is located public transport parking area. The pollution of copper (Cu) is related to traffic intensity, private housing heating systems, burned down fossil fuels, fireworks, metal industry.

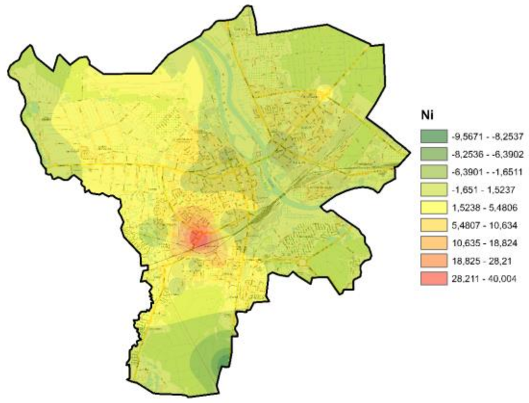

Figure 3. The change of relative concentrations of nickel (Ni) µg l^{-1} in Jelgava city.

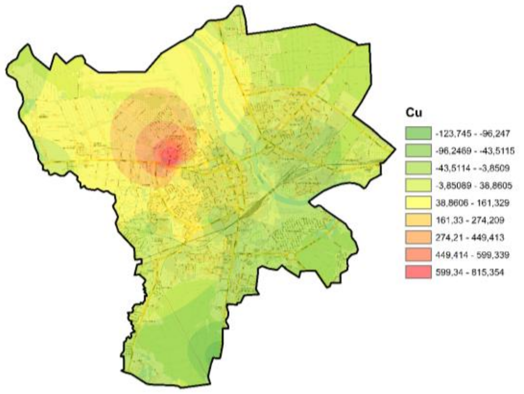

Figure 4. The change of relative concentrations of copper (Cu) µg l^{-1} in Jelgava city.

Zinc (Zn) is considered as a toxic metal and it is hazardous to living organisms in high concentrations. It occurs in the process of industrial activities as a result of combustion of coal, as well as it is related to traffic intensity and pollution. In Jelgava, the changes of relative concentrations of zinc (Zn) are not very high (Figure 5), but the concentrations are not evenly distributed throughout the city. The relative maximum values of zinc (Zn) change of relative concentrations are next to the railroad overpass of Tervete Street and Fortum Jelgava boiler housen and in Satiksmes street area where is located public transport parking area.

The change of relative concentrations of lead (Pb) in Jelgava city is presented in figure 6. The relative maximum values of lead (Pb) change of relative concentrations are next to the railroad overpass of Tervete Street and Fortum Jelgava boiler housen and in Satiksmes street area where is located public transport parking area. The presence of lead (Pb) in the Jelgava city is associated with incineration, burning of oil and fossil materials, and transport.

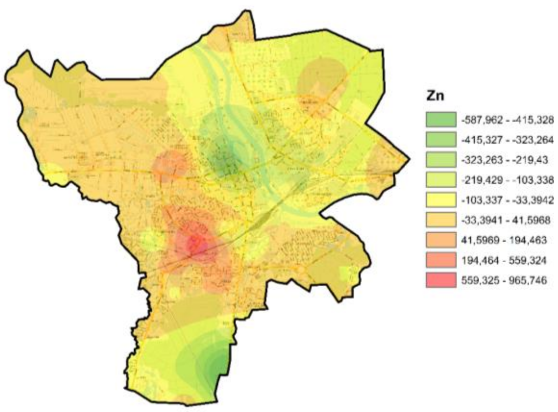

Figure 5. The change of relative concentrations of zinc (Zn) µg l^{-1} in Jelgava city.

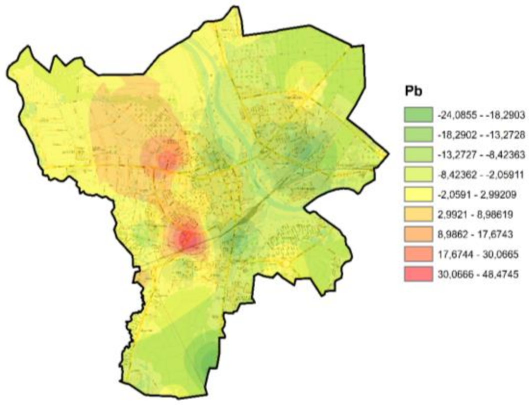

Figure 6. The change of relative concentrations of lead (Pb) µg l^{-1} in Jelgava city.

Vanadium (V) is considered to be typical oil combustion process indicator, as well as it arise from heating producers in large quantities. In Jelgava, the changes of relative concentrations of vanadium (V) are not very high (Figure 7), but the concentrations are not evenly distributed throughout the city. The relative maximum values of vanadium (V) change of relative concentrations are next to the railroad overpass of Tervete Street and Fortum Jelgava boiler housen.

Iron (Fe) usually arises from combustion of fossil fuels as a result of incineration. The source of iron particles is wear of the engine and car body material. In Jelgava, the changes of relative concentrations of iron (Fe) are not very high (Figure 8), but the concentrations are quite evenly distributed throughout the city. The relative maximum values of zinc (Zn) change of relative concentrations are next to the railroad overpass of Tervete Street and Fortum Jelgava boiler housen.

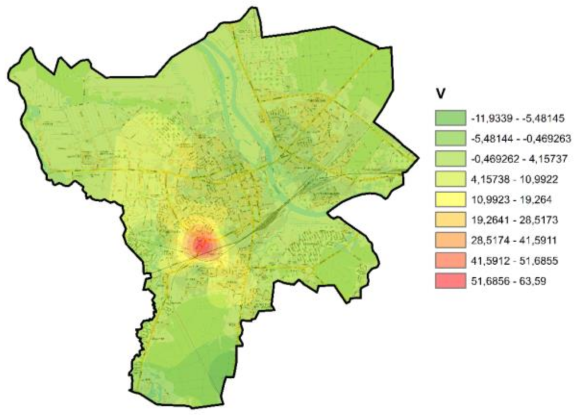

Figure 7. The change of relative concentrations of vanadium (V) μg l^{-1} in Jelgava city.

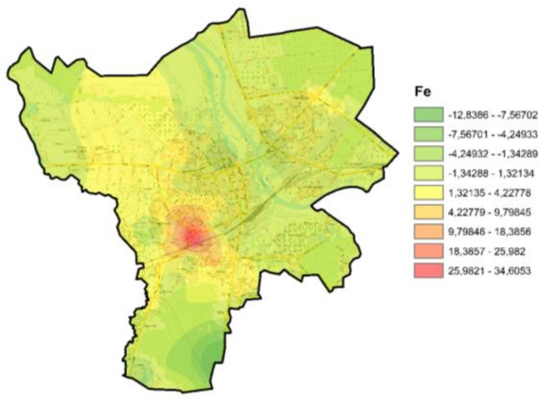

Figure 8. The change of relative concentrations of iron (Fe) mg l^{-1} in Jelgava city.

Chromium (Cr) is directly related to traffic intensity, and incineration of waste. The change of relative concentrations of Chromium (Cr) in Jelgava city is presented in figure 9. The relative maximum values of Chromium (Cr) change of relative concentrations are next to the railroad overpass of Tervete Street and Fortum Jelgava boiler housen and in Satiksmes street area where is located public transport parking area.

The relative increase of concentrations of arsenic (As) is concentrated in the district of the overpass of Tervete Street (Figure 10). Arsenic (As) is widely used in production of pesticides and fertilizers, as well as in production of wood protection products. Also, As occurs as a result of combustion of fossil fuels.

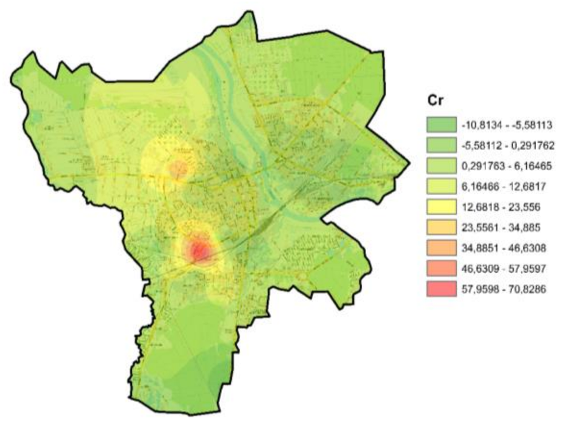

Figure 9. The change of relative concentrations of chromium (Cr) µg l^{-1} in Jelgava city.

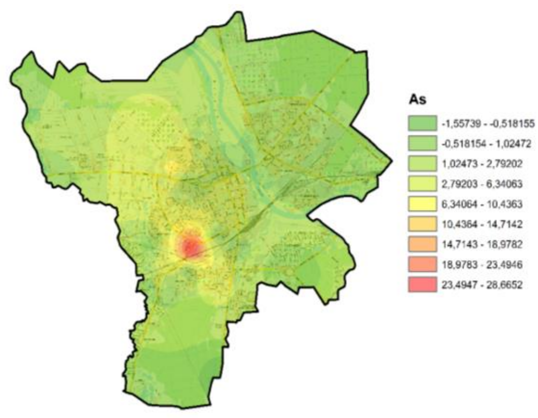

Figure 10. The change of relative concentrations of arsenic (As) µg l^{-1} in Jelgava city.

CONCLUSION

The relative increase of concentration of zinc (Zn), lead (Pb), nickel (Ni), copper (Cu) vanadium (V) iron (Fe) chromium (Cr) arsenic (As) in snow is recognized in all area of Jelgava. Relatively higher increase of concentrations of trace elements are in west part of Jelgava. It can be explained by location of source pint pollutants and transport corridor’s as well as wind direction.

The results of the comparison of relative concentrations of zinc (Zn), lead (Pb), nickel (Ni), copper (Cu), vanadium (V), iron (Fe), chromium (Cr), arsenic (As) in snow show a rapid rise of concentration in Tervete Street and Fortum Jelgava boiler housen area. The relative changes can be related with railroad flow and increasing transport intensity, as well as wood chips combustion in Fortum Jelgava boiler housen.

The aditional increase of concentrations is in Satiksmes street area where results of the comparison of relative concentrations of zinc (Zn), lead (Pb), nickel (Ni), copper (Cu), chromium (Cr) in snow show a rapid rise of concentration.

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THE SPATIAL ANALYSIS OF AIR POLLUTION WITH TRACE ELEMENTS USING SNOW SAMPLING

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ABSTRACT

Air pollution is one of the main factors that affects human health. It may affect our health in many ways both long and short term. Exposure time of air pollution increases the risk of respiratory diseases, such as pneumonia, lung cancer, and causes cardiovascular diseases. Air pollution affects different groups of individuals in various ways.

An objective of this study was to investigate the level of pollution in snow blanket in Jelgava city after exposition of 7 days and to determine the cause of pollution in different parts of Jelgava city. In Jelgava city, 60 sampling plots were established, which cover the whole city area and describe the main streets, industrial districts and areas with private houses. In each sampling plot in February 2018, 1.0-1.5 kg of snow was collected and the depth of snow in sampling time was 7-12 cm. The snow samples were taken from entire snow depth, because it represents the level of air pollution between the period of permanent snow blanket and time when sample was taken. The chemical elements were analysed in 180 snow samples from city and in 3 samples from natural forest. The concentration of chemical elements was calculated in melting snow water and HNO3 solution. The concentrations were determined by using an inductively connected plasma atomic emission spectroscopy (ICP-AES) method.

The pollutant groups were distributed by using data of chemical elements and cluster analysis. The relatively clean, medium polluted and polluted areas were distributed by using ArcGIS software depending on the chemical elements characteristic of the sources of pollution.

The results show the negative impact of transport corridors and private building on air quality.

Keywords: ArcGIS; Chemical elements; Pollution; ICP-AES.

INTRODUCTION

More than 70% of Europeans live in cities [7], and recent researches show that air pollution will be a premature cause of death in the coming decades [1]. When people come across with the surrounding air pollution, chronic respiratory diseases, namely lung cancer, pneumonia, and cardiovascular diseases, are increasing [4]. Air pollution affects the most vulnerable groups of individuals such as children, elderly people, people with limited income and limited access to doctors. People who are already sick are particularly affected; these people experience more severe health problems [5].

Traffic is the main source of pollution in cities [3]. The growth rate of cars and traffic is very fast, but investment in infrastructure is low [2]. For instance, in Spain transport emissions are responsible of 90% of total air pollution [4].

In recent years, there has been an increasing amount of researches on studying pollution loads in snow in the northern climatic conditions [2], [8]. Snow is a very good material for determination of air pollution for a number of reasons:

1) Snow samples can be easily collected and analyzed;

2) The deposition time is determined by meteorological data;

3) Large surface area and slow snowfall allow absorbing both organic and inorganic contaminants from the atmosphere [3].

The presence of chemical elements in the snow water indicates one or more specific pollutants, for instance, the presence of iron (Fe) in the snow indicates conflagration of fossil fuels, car engine, and vehicle bodywork wear. The presence of copper (Cu) in snow is more related to vehicle breaks and their wear, not to exhaust emission [9]. Zinc (Zn) indicates coal combustion and traffic-based emissions [10]. Aluminum (Al), copper (Cu), zinc (Zn), and iron (Fe) results from waste incineration [11], [12]. In Latvia, there are no strict rules what can or should not be used as fuel material in private house heating systems. The aim of the study is to determine the cause of pollution in different parts of Jelgava city.

MATERIALS AND METHODS

Jelgava is located in the central part of Latvia (Figure 1), Eastern Europe part of the Western plain. The Northern part lies on the lowland sandy plain of the Seaside, Southern part – Zemgales plain. The climate is temperate continental. The no frost period is 135 - 145 days long. The average precipitation amount is 550-560 mm per year. Usually a permanent snow cover forms at the end of December. The snow cover thickness is very variable, ranging from 10 to 25 cm [13].

The Westward winds are dominated in the territory (Southwest, West, Northwest). The paramount relief is characterized by the fact that different air masses are flowing from different sides of the sky. The influx of air masses results in rapid changes in weather conditions.

Jelgava is a city of the Republic of Latvia and there are 61,162 residents living there after January 1, 2018 [6].

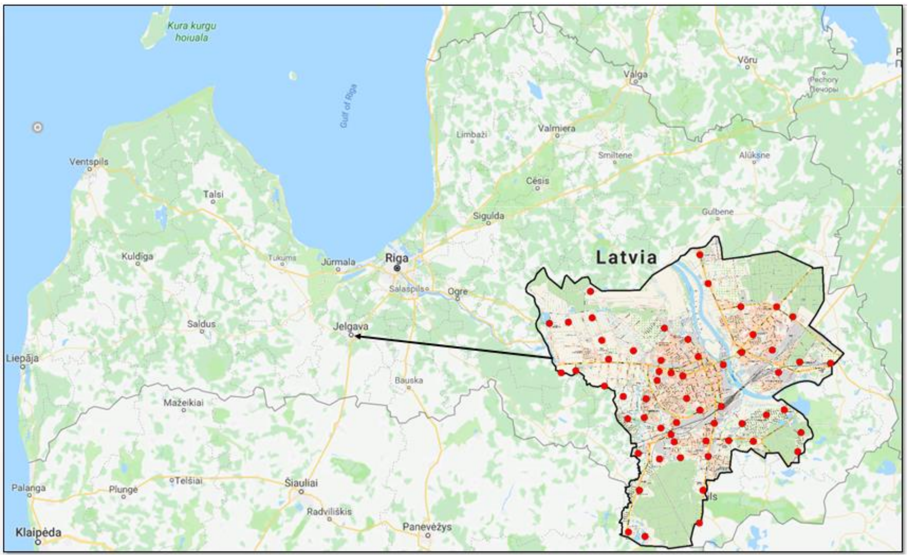

Figure 1. The geographical location of Jelgava.

Snow samples were collected on February 12, 2018. The snow exposure period was 7 days [8]. Samples were gathered at a distance of 5 m from the road's ride (Figure 2), grass stalks or leaves were not collected with snow, and rubber gloves were used in gathering.

Figure 2. Snow samples collection in Jelgava.

The analysis of snow sample is one of the short-term pollution detection methods for monitoring air pollution by chemical elements in urban areas. In total, 183 snow samples were collected in Jelgava city in 63 plots. 180 samples were collected from the city territory and 3 from the territory outside Jelgava, located in Mezciems. Three replicate snow samples were collected at each site. The chemical elements were determined by an inductively coupled plasma atomic emission spectroscope (ICP-AES).

The samples were analyzed in melted snow water samples. Samples were filtered through a paper filter and then acidified to 1% HNO3 and then were analyzed.

RESULTS AND DISCUSSIONS

The snow sampling with an exposition period of seven days is one of the short-term air pollution monitoring methods for quantifying anthropogenic air pollution. The key sources of air pollution in urban areas are transport sector, household heating systems, and industry. The pollutants, such as zinc (Zn), aluminium (Al), copper (Cu), and iron (Fe), were grouped by concentrations using hierarchical cluster analysis by Euclidian distance algorithm. The relatively clean, medium polluted, and polluted areas were distributed by using ArcGIS software depending on the chemical elements characteristic of the sources of pollution.

Zinc (Zn) is one of the air pollutants related with anthropogenic sources; it can be toxic for human health and environment in high concentrations. The distribution of zinc (Zn) by relative concentration is presented in Figure 3. The cluster analysis divides 15 groups of relative concentrations. The first five groups with concentration of zinc (Zn) from 0.50 till 4.29 µg l^{-1} we defined as relatively clean area. The second five groups with concentration of zinc (Zn) from 4.29 till 8.09 µg l^{-1} we defined as relatively light polluted area. The last five groups with concentration of zinc (Zn) from 8.09 till 11.88 µg l^{-1} we defined as relatively polluted areas with high anthropogenic impact. The key sources of zinc (Zn) in urban areas are industry, coal burning, and transport. The mine transport corridors such as Rigas street, Liela street and Lietuva road as well as the railway and the roundabout area is the main anthropogenic sources of zinc (Zn) in Jelgava city (Figure 3).

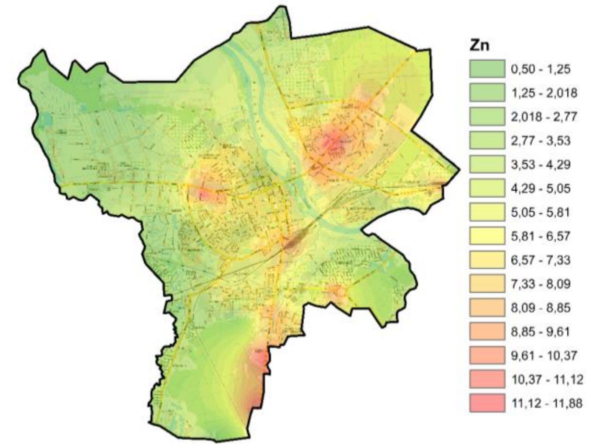

Figure 3. The distribution of zinc (Zn) µg l^{-1} in Jelgava city.

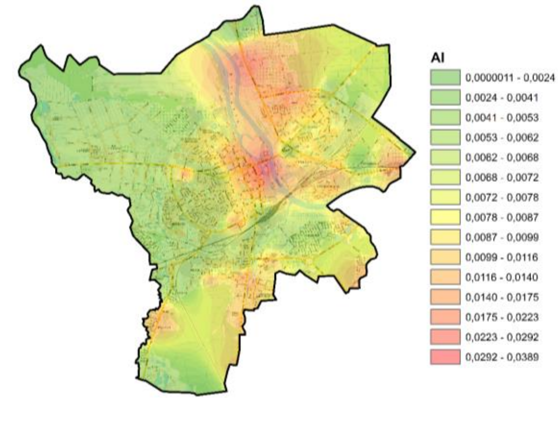

Figure 4. The distribution of aluminium (Al) µg l^{-1} in Jelgava city.

The aluminium (Al) is one of the main indicators of waste burning and fireworks. The distribution of aluminium (Al) by relative concentration is presented in Figure 4. The cluster analysis divides 15 groups of relative concentrations. The first five groups with concentration of aluminium (Al) from 0.000 till 0.0068 µg l^{-1} we defined as relatively clean area. The second five groups with concentration of aluminium (Al) from 0.0068 till 0.0116 µg l^{-1} we defined as relatively light polluted area. The last five groups with concentration of aluminium (Al) from 0.0116 till 0.0389 µg l^{-1} we defined as relatively polluted areas with high anthropogenic impact. The relatively high concentrations of aluminium (Al) is in areas with private housing. Pollution of aluminium (Al) moves in North, North-east directions from the city centre area due to the dominant wind. Kalnciema road private housing area and their heating systems could be the key source of aluminium (Al) in this area.

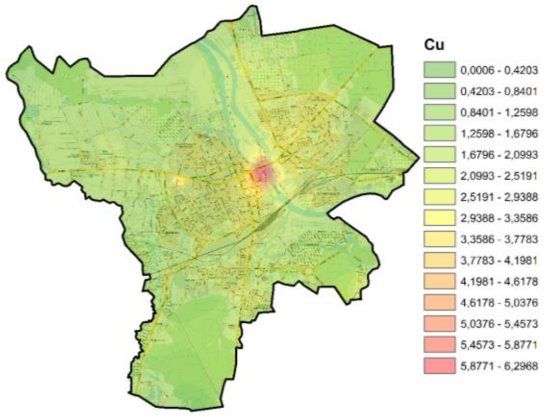

Figure 5. The distribution of copper (Cu) µg l^{-1} in Jelgava city.

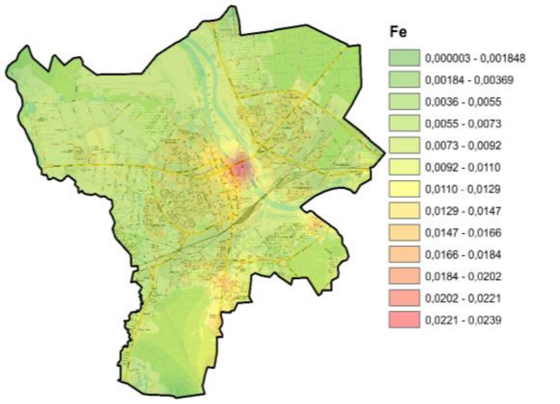

Figure 6. The distribution of iron (Fe) mg l^{-1} in Jelgava city.

The dusts of copper (Cu) are hazardous for human health and environment. Copper is mainly produced by combustion of oil products and waste as well as internal combustion engines. The distribution of copper (Cu) by relative concentration is presented in Figure 5. The cluster analysis divides 15 groups of relative concentrations. The first five groups with concentration of copper (Cu) from 0.0006 till 2.0993 µg l^{-1} we defined as relatively clean area. The second five groups with concentration of copper (Cu) from 2.0993 till 4.1981 µg l^{-1} we defined as relatively light polluted area. The last five groups with concentration of copper (Cu) from 4.1981 till 6.2968 µg l^{-1} we defined as relatively polluted areas with high anthropogenic impact. The largest concentration of copper (Cu) in the city of Jelgava is on the main street of the city, Liela street and Riga street, which connects Jelgava with the capital of Latvia, Riga. Each day approximately 36,000 cars use the main street. Copper (Cu) concentrations also arise from uncontrolled burning of waste at private housing areas.

The distribution of iron (Fe) by relative concentration is presented in Figure 6. The cluster analysis divides 13 groups of relative concentrations. The first four groups with concentration of iron (Fe) from 0.0 till 0.0073 mg l^{-1} we defined as relatively clean area. The second five groups with concentration of iron (Fe) from 0.0073 till 0.0166 mg l^{-1} we defined as relatively light polluted area. The last four groups with concentration of iron (Fe) from 0.0166 till 0.0239 mg l^{-1} we defined as relatively polluted areas with high anthropogenic impact. The particles of iron concentrated on the main road sections such as Liela Street, Riga Street, and Lithuanian highway. Iron concentrations cover the entire city of Jelgava, which indicates that there is no single source of iron (Fe) pollution, but the anthropogenic activities such as traffic, heating systems, industry pollute air and rise iron (Fe) concentration in urban areas.

CONCLUSION

The level of pollution in snow blanket in Jelgava city after exposition of 7 days was investigated to determine the cause of pollution in different parts of Jelgava city. 180 samples of snow were collected and analysed. The key sources of air pollution in Jelgava is transport corridors, railway, and private housing with individual heating systems. Industry, coal burning, and transport are the main sources of zinc (Zn) pollution, private housing is the main cause of aluminium (Al) pollution, the main street and the uncontrolled burning of waste at private housing areas are the main sources of copper (Cu) pollution, traffic, heating systems, and industry are the main sources of iron (Fe) pollution.

For further research more precise evaluation of air quality in Jelgava city is required. There is a necessity to make a sampling for evaluation of long-term air pollution to compare the results with short-term air pollution sampling results.

The development of Jelgava city has to be planned with respect to main wind directions.

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ANALYZING DIFFERENTLY PREPARED SNOW SAMPLES TO DETERMINE AIR QUALITY IN THE CITY

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ABSTRACT

Air pollution has a negative impact on human health and the ecosystem as a whole. It causes a variety of diseases, such as asthma, various lung diseases, cardiovascular diseases, which particularly affect children and the elderly. The aim of the study is to determine how the preparation of melted snow samples for analysis influences concentrations of lead (Pb), zinc (Zn), nickel (Ni), vanadium (V), copper (Cu), manganese (Mn) in snow samples. For snow samples analysis ICP-OES spectrometer "iCAP 7000" is used. In study, 180 snow samples are collected in 60 different locations in Jelgava city. Two different sample preparation methods are used to determine Pb, Zn, Ni, V, Cu, Mn in concentration in snow samples. In the first sample preparation method, the snow samples are filtered through a paper filter and acidified to 1% HNO_3, while in the second preparation method snow samples are acidified to 1% HNO_3, aged for 3 days and then filtered through a paper filter. The results shows that samples that are filtered and then acidified have lower concentrations of contamination than samples acidified with dust. Concentrations of Pb, Zn, Ni, V, Cu, Mn in snow samples between both sample preparation methods differ significantly. The results show that contamination accumulates in dust, and therefore they are the most dangerous to human health.

Keywords: urban environment, contamination, snow, ICP-OES method, dusts

INTRODUCTION

Air pollution has a negative significant impact on human health and on the overall ecosystem [1], [2]. Pollution causes different diseases, such as asthma, lung disease, heart and blood vessel disease, etc. that especially heavily affect children and elderly [3], [4], [5]. Snow cover is used as an indicator of air pollutants because of its capability to accrue the absorbed pollutants on the surface of snow crystals during snowfall. Accretion of pollutants in snow cover has an impact on groundwater, overland environment and human health. Many of these pollutants, e.g., heavy metals, are hazardous. Accretion of pollutants is influenced also by different processes in atmosphere. Natural processes and industrial production are biggest cause of trace metal and metalloid disposal in atmosphere. Natural processes are associated with rock weathering, mineralization, dust storm, volcanic eruption, etc. Fossil and oil ignition, vehicle emission, smelting, metal manufacturing, waste incineration and building material production are referred to as industrial processes. The atmospheric cycle of these pollutants rely on different obstacles, such as, physical-chemical characteristics of material, meteorological factors, relief and the size of particles. Pollution in snow cover appears in two ways: 1) throughout snowflake crystallization process in the clouds; 2) dry accreting of pollutants from already fallen snow or surrounding soils and rocks. After snowmelt these substances will be transposed further to the environment. Energy flow to snow cover affects its melt rate. Accordingly studies of local weather conditions, chemical processes and local polluting sources are essential to understanding of interaction between snow cover and air pollutants [6], [7], [8]. Trace metals are present in all kinds of water as salt waters, fresh waters, in precipitation, also in drinking water. Precise measuring of these particles has always been a complicated task. Measuring low mass density of trace metal particles together with matrix impacted disturbance of measurements is a challenge even for the highest sensitivity instruments [9]. The aim of the study is to determine how the preparation of melted snow samples for analysis influences concentrations of lead (Pb), zinc (Zn), nickel (Ni), vanadium (V), copper (Cu), manganese (Mn) in snow samples.

MATERIALS AND METHODS

Jelgava is located in central Semigalia Plain south of Riga whereas most of the territory is cultivable. The average temperature in winter months is -5.5°C in summer months +17.1°C. Frost-free period lasts 135 to 145 days. Absolute humidity maximum is observed in June, but minimum – in February. Yearly 150 to 155 days are overcast and 170 to 180 days are with atmospheric precipitation. Average precipitation is 550-560 mm/year. Prevailing winds are from the West (South-West, West, North -West). Wind direction can change rapidly due to continuous cyclone and anticyclone action [10].

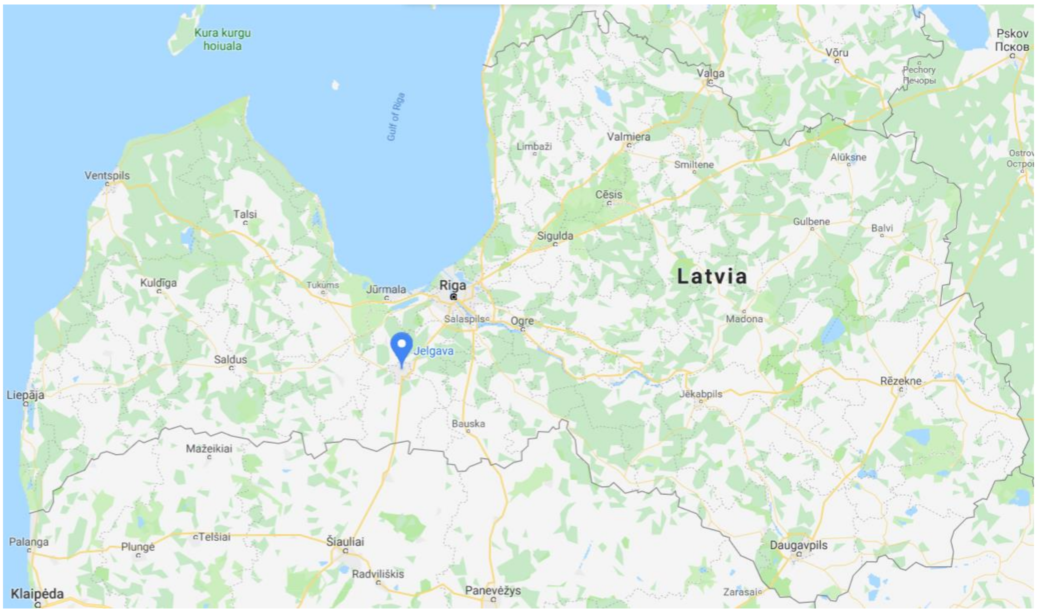

Figure 1. Location and area of Jelgava city

However, mainly prevailing wind direction remains from the West. Permanent snow cover is created at the end of December and its thickness varies from 10 to 25 cm. Soil freezing depth ranges from couple of centimetres to 50 cm and is dependent on air temperature, snow cover thickness and humidity. Soil freezes at the end of December and thaws in April [10].

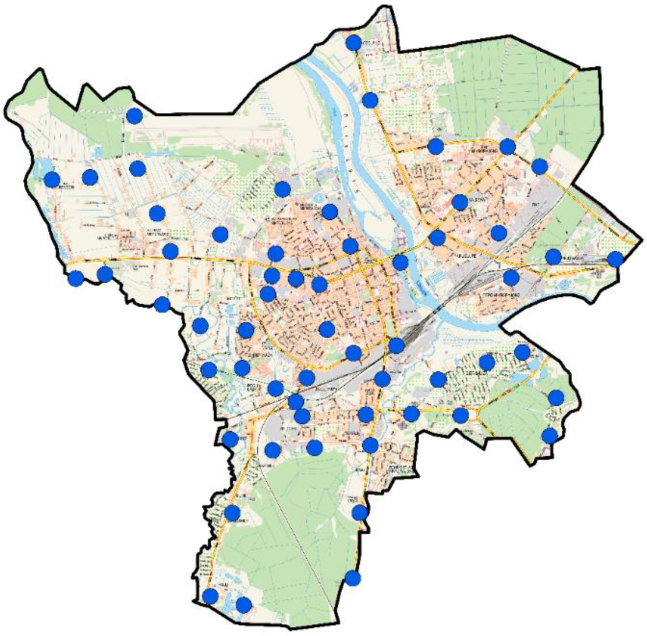

Figure 2. Snow sample collection sites in Jelgava city

Snow samples were collected at locations marked in Figure 2. The exact coordinates of the sample are given in Table 2. In each location six snow samples was collected according to the methodology described in the Pilecka et al. article [11].

Table 1. Snow samples plots description and location.

Nr.	Monitoring point description	X (LKS92)	Y(UTM(WGS84))
1	Mežciems (control)	486351,478	6277232,428
2	Lediņu ceļš/Atpūtas iela	486147,068	6279179,694
3	lediņu ceļš/Kārniņu ceļš	486257,120	6279825,219
4	Kārniņu ceļš/Staļģenes iela	485683,757	6280597,263
5	Sieramuižas iela/Nomales iela	485079,955	6280423,303
6	Bauskas iela/ Staļģenes iela	484255,4074	6280132,615
7	Bauskas iela/Miera iela	484637,1495	6279526,587
8	Miera iela/Zemeņu iela	483798,1614	6279554,088
9	Lietuvas šoseja	482829,4865	6276660,263
10	Lietuvas šoseja	483081,1892	6278496,735
11	Lietuvas šoseja/Viskaļu iela	483106,3332	6279021,035
12	Viskaļu iela/Liepājas iela	482159,3857	6278979,051
13	Viskaļu iela	481446,2437	6278935,840
14	Salnas iela/Ruļļu iela	481947,6343	6279514,414
15	Platonesiela /Viktorijas iela	483029,4143	6279542,321
16	Savienības iela/ Lietuvas šoseja	483308,1454	6280141,941
17	Dzelzceļš	483544,6837	6280710,124
18	Pulkveža Oskara Kalpaka iela	482820,1910	6280583,767
19	Tērvetes iela (Astarte)	482027,4497	6280165,585

Nr.	Monitoring point description	X (LKS92)	Y(UTM(WGS84))
20	Tērvetes iela (Dzelzceļa pārbrauktuve)	481841,5864	6279758,815
21	Baložu iela/Būriņu ceļš	480726,9148	6279121,970
22	Tērvetes iela/ Krastmalas iela	480763,0299	6277873,761
23	Tērvetes iela/Aku ceļš	480390,7456	6276464,039
24	Aku ceļš	480954,7790	6276315,310
25	Putnu iela/Kārklu iela	481496,4250	6279980,108
26	Dambja iela/Kāklu iela	480929,5161	6280330,078
27	Būriņu ceļš (pie 1.tilta)	480364,9560	6280297,590
28	Būriņu ceļs (pie 2.tilta)	480218,3077	6281046,991
29	Laipu iela 8	480994,3310	6280970,978
30	3.līnija/Nameja iela	479717,1219	6282304,974
31	3.līnija/Riekstu ceļš	479488,7439	6282946,924
32	3.līnija/Meža ceļš	479157,5985	6283708,002
33	Šūmaņu ceļš	479103,0951	6284601,909
34	Meža ceļš/ 5.līnija	478350,7880	6283558,680
35	Meža ceļš/6.līnija	477706,2328	6283519,515
36	6.līnija/Dobeles šoseja	478108,5339	6281847,674
37	Zanderu ceļš	478610,4272	6281656,276
38	Malkas ceļš	479571,3007	6281135,210
39	Asteru iela/Aspazijas iela	481367,4727	6281586,622
40	Satiksmes iela/Dobeles iela	481435,3560	6281893,985
41	Satiksmes iela/Ganību iela	481499,5898	6282269,832
42	1.līnija/Ganību iela	480563,0806	6282595,106
43	Meiju ceļš/Slokas iela	481613,8071	6283357,423
44	Liepkalnu iela/Zvejnieku iela	482415,5612	6282978,073
45	Blaumaņa iela/Ausekļa iela	482763,0244	6282397,202
46	Dobeles šoseja/Lielā iela	481842,7202	6281844,251
47	Jāņa Asara iela/Lielā iela	482240,4474	6281743,817
48	Pavasara iela/Tērvetes iela	482368,9400	6280983,419
49	Pasta sala	483614,7500	6282118,504
50	Brīvības bulvāris/Rīgas iela	484241,1919	6282536,054
51	Prohorova iela/Neretas iela	485491,6409	6281862,247
52	Garozas iela	487261,8930	6282173,412
53	Rubeņu ceļš (Langervaldes mežs)	486210,1641	6282215,231
54	Aviācijas iela/Lāču iela	485280,8937	6282618,029
55	Aviācijas iela/Loka maģistrāle	485974,1826	6283742,655
56	Rīgas iela/Loka maģistrāle	485429,9327	6284080,320
57	Loka maģistrāle/Bērzu ceļš	484213,7378	6284085,268
58	Rogu ceļš/Kalnciema ceļš	483101,5694	6284866,343
59	Kalnciema ceļš	482820,8032	6285841,073
60	Rīgas iela/Institūta ieta	484626,2862	6283139,93

The melted snow samples were prepared to analysis using two different approaches. The first set of three samples from each location were filtered using paper filter and then acidified till 1% using HNO_3 (1st group). The second set of three samples from each location were acidified till 1% using HNO_3 and after three days were filtered using paper filter (2nd group).

Samples were analyzed with the ICP. First introduced in mid 1960s, the inductively coupled plasma (ICP) method has become widely used not only as a great ion source for optical emission spectrometry (OES) but also for inductively coupled plasma mass spectrometry (ICPMS). The first ICP/OES device was implemented in 1974 and since then its ability of detection has improved significantly [12]. Electrical discharge, which is generated at radio frequencies, is the inductively coupled plasm (ICP). Argon is the most commonly used gas for the method. Within the quartz torch plasma is maintained at atmospheric pressure [13]. Temperature gradient inside ICP accordingly to height above the load coil. In induction region, where is the highest temperature, occurs energy transfer. Upwards towards to the tail plume the temperature decreases. Before entering the plasma, drops of sample go through three processes. In the first step or undergoing the process of desolvation, the solvent from sample drops are removed which results as microscopic solid particles or dry aerosol. The second step is vaporization when the particles are transferred to gaseous state of molecules. In the last third step – atomization -, newly formed gaseous molecules are broken down to atoms.

Primarily the liquid undergoes these processes already in the preheating zone. In the initial radiation zone and in the normal analytical zone, after excitation and ionization of the atoms has occurred, the analytical emission of sample is collected. At the end of the process a very bright, brilliant white, teardrop shaped, high-temperature plasma is formed [12]. At this moment spectrometer measures the emission spectrum of an element. And because each element has its own emission spectrum, the concentration in the sample can be calculated using the measured calibrated light intensity on the wavelength [14].

The concentration of lead (Pb), zinc (Zn), nickel (Ni), vanadium (V), copper (Cu), manganese (Mn) in snow samples were calculated average of three samples for each analytical group by location. The two groups of data were analyzed using agglomerative hierarchical clustering (ACH) of standardized concentrations, to group samples and compare clusters of each sample group.

RESULTS AND DISCUSSION

The descriptive statistics of (Pb), zinc (Zn), nickel (Ni), vanadium (V), copper (Cu), manganese (Mn) by analytical groups is presented in table 2. Where differences between analytical groups are significant. For example the maximum concentration of Zn, Cu and V in second group differ more than 10 times.

Table 2. The descriptive statistics of heavy metals by analytical groups

Statistic	Nbr. of observations	Minimum, µg l^{-1}	Maximum, µg l^{-1}	Range, µg l^{-1}	1st Quartile, µg l^{-1}	Median, µg l^{-1}	3rd Quartile, µg l^{-1}	Mean, µg l^{-1}	Standard deviation (n), µg l^{-1}
Pb | 1^{st} group	60	1.00	1.34	0.34	1.00	1.00	1.00	1.01	0.05
Pb | 2^{nd} group	60	0.68	51.18	50.50	2.16	3.59	6.81	6.31	8.42
Zn | 1^{st} group	60	0.48	11.91	11.43	2.10	3.88	6.63	4.63	3.05
Zn | 2^{nd} group	60	9.22	1002.05	992.83	22.32	45.91	81.51	79.62	135.32
Ni | 1^{st} group	60	0.55	0.71	0.16	0.60	0.60	0.60	0.60	0.02
Ni | 2^{nd} group	60	0.40	40.75	40.35	1.00	1.59	2.85	2.80	5.24
V | 1^{st} group	60	0.60	0.60	0.00	0.60	0.60	0.60	0.60	0.00
V | 2^{nd} group	60	0.55	64.16	63.61	0.60	0.67	2.21	2.92	8.31
Cu | 1^{st} group	60	0.86	6.28	5.42	0.90	1.17	1.71	1.44	0.82
Cu | 2^{nd} group	60	2.82	829.49	826.66	5.78	8.93	23.34	28.66	105.24
Mn | 1^{st} group	60	0.47	9.36	8.90	0.93	2.08	3.09	2.29	1.62
Mn | 2^{nd} group	60	5.89	1357.01	1351.13	25.37	46.93	171.68	150.57	239.90

The agglomerative hierarchical clustering results of 1st group is presented in figure 3 were 6 classes was defined and variance within class is 29% and between classes is 71%. The agglomerative hierarchical clustering results of 2nd group is presented in figure 4 were 8 classes was defined and were variance within class is 2% and between classes is 98%.

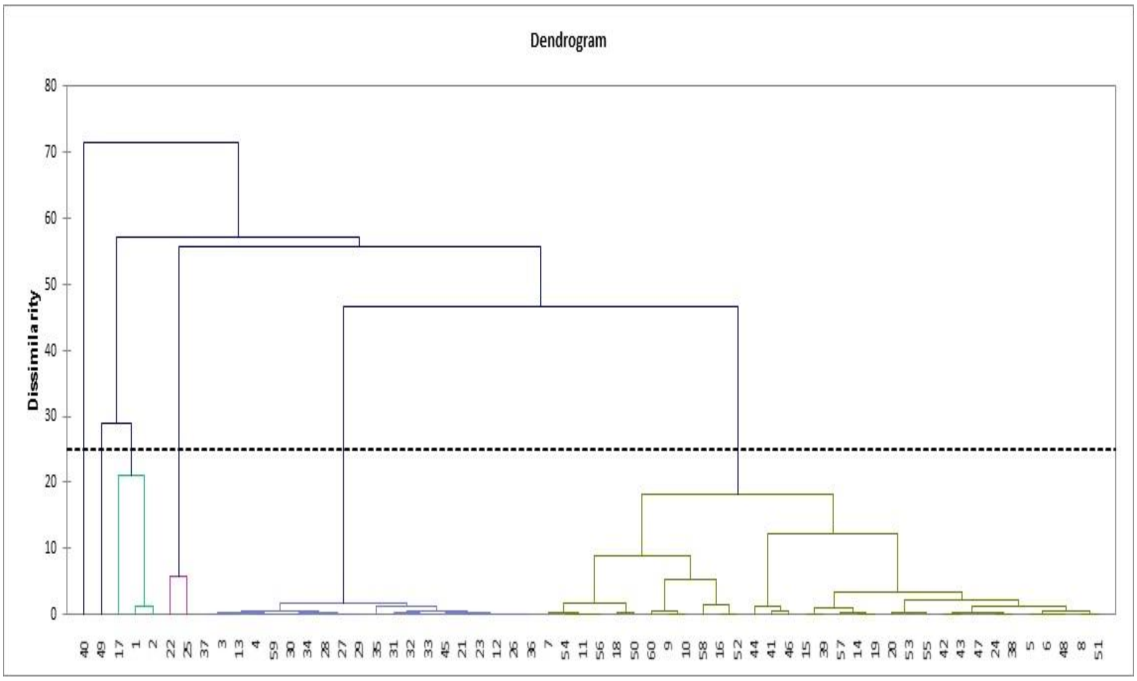

Figure 3. The agglomerative hierarchical clustering results of 1st group

The boxplot of Zn concentrations of 6 classes of 1st sample group is presented in figure 5 where is overlay between classes. The boxplot of Zn concentrations of 8 classes of and 2nd sample group is presented in figure 6 where is clear homogeneity of Zn concentrations within class and there is no overlay between classes.

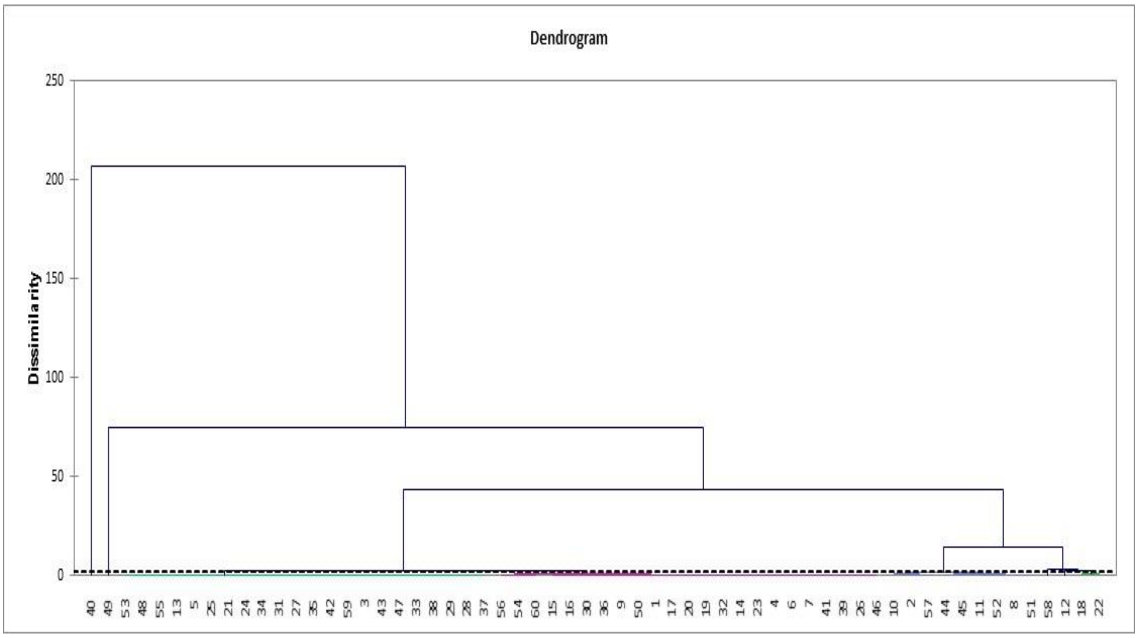

Figure 4. The agglomerative hierarchical clustering results of 2nd group

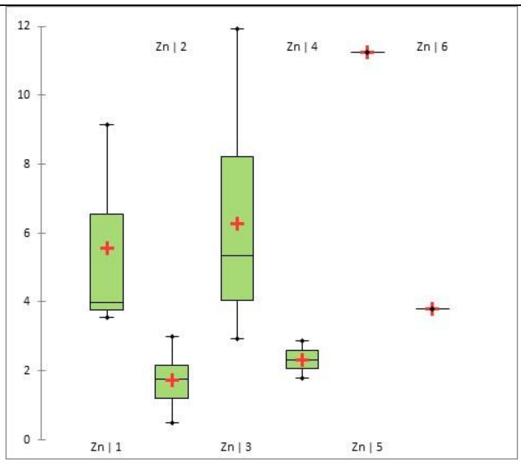

Figure 5. The boxplot of Zn concentrations (μg l^{-1}) of 6 classes of 1st sample group

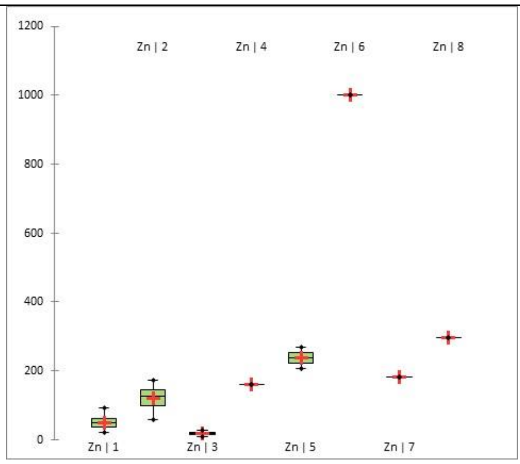

Figure 6. The boxplot of Zn concentrations (μg l^{-1}) of 8 classes of 2nd sample group

CONCLUSIONS

The results shows that the samples that are filtered using the paper filter and then acidified till 1% using HNO_3 have lower concentrations of lead (Pb), zinc (Zn), nickel (Ni), vanadium (V), copper (Cu), manganese (Mn) than the samples that are acidified till 1% using HNO_3 and after three days are filtered using paper filter.

Concentrations of lead (Pb), zinc (Zn), nickel (Ni), vanadium (V), copper (Cu), manganese (Mn) in snow samples between both sample preparation methods differ more than 10 times and there is no clear relationship between 1st and 2nd group of samples.

The air quality in urban areas is related not only with different gas concentrations in air but also with solid particles concentration in air where is different sources of particles. The results show that lead (Pb), zinc (Zn), nickel (Ni), vanadium (V), copper (Cu), manganese (Mn) accumulates in solid particles, and therefore they are the most dangerous to human health.

The methodology of melted snow sample analysis with aim to evaluate air quality is very sensitive to acidification and according to this research there is recommendation before analysis using ICP to acidify samples till 1% using HNO3 and filter after after three days.

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SNOW IN THE CITIES AS AN INDICATOR OF AIR POLLUTION CAUSED BY TRAFFIC

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ABSTRACT

Air pollution in cities caused by traffic is an important environmental and health issue worldwide. Air pollution caused by traffic exceeds air pollution from other anthropogenic sources, such as industrial, various heat supply and residential areas. This study analyzes a wide range of pollutants in snowpacks at different intensity roads in one of the largest cities in Latvia in Jelgava. Snow samples are taken from three sampling points at distance of 1 m, 10 m, and 20 m from the roadway. In the study, various metals, namely lead (Pb), zinc (Zn), silicon (Si), manganese (Mn), copper (Cu), nickel (Ni), vanadium (V), chromium (Cr) are analyzed in the study. Samples are acidified to 1% HNO_3, then left for 3 days and filtered through a paper filter. ICP-OES spectroscopy „iCAP 7000" is used for analysis. Most pollutants show similar trends; higher concentrations of pollutants are observed at a distance of 1 m from the roadway compared to samples taken from further sampling points. Concentrations of pollutants decrease significantly at distance of 10 m. Comparing the concentrations of Pb, Zn, and V at a distance of 1m from the roadway and at a distance of 10 m from the roadway, the concentrations of pollutants decrease by 6 to 11 times. The highest concentrations of Cu, Cr, Mn, Pb, V, Zn are located on roadway Jelgava-Riga about 4 km from city center of Jelgava.

Keywords: ICP-OES spectroscope, heavy metal, snow, roadway.

INTRODUCTION

Various polluting elements such as nutrients, metals and organic pollutants have been reported to accumulate in air, soil, both surface and ground waters near roadways of different intensity in urbanized areas [1]. The outcome of air pollution, consumption of polluted water, contamination of soils caused by traffic results in more than hundred known diseases and important environmental and health issues [2]. Studies reveal that pollution coming from roadways by traffic exceeds to be greater than other anthropogenic sources, such as industrial and residential activities, power and heat supplying plants, metallurgy, mining etc. [3]. There are identified two categories of environmental factors that has an important effect on the dispersion and concentration of air polluting elements after emission. The first category encompass various abiotic factors, such as ambient temperature, relative humidity, speed and direction of wind, and intensity of sunlight. The second category submits interaction with environmental surfaces of the ground, soil, waterbodies, rain, snow, vegetation and human created objects in the site [2]. When the snow melts, snow-trapped pollutants relocate to environment in different ways, such as transferring to the soil in sites, where snow settled down during cold period, also adding up to meltdown runoff, and some parts of pollutants are released back into the atmosphere by evaporation [3]. Snow is known to efficiently accumulate various contaminants from the atmosphere to snowpacks near roadways. In urbanized areas, it risk of hazardous influence not only on the local environment near roadways, but also to surface and groundwater supplies during snow melting in spring by expected stormwater [4], [5]. In studies revealed in Engelhard et al. (2007), snowflake can accumulate more polluting contaminants from the air than raindrops, because of snowflake's characteristics and structure – it has a larger surface area and considerably slower fall velocity compared to raindrops. In cold climatic conditions, snow surveying done in various researches has come to the fact that snow acts as a natural filter. It can filter various chemical elements, particles, organic and inorganic pollutants and also heavy metals that derive from traffic pollution from roadways [3], [6].

This study analyses various pollutants in samples of snowpacks taken alongside different intensity roads in Jelgava city to determine locally developed traffic contamination. Also the study aims to determine whether and how the concentrations and accumulation of different polluting contaminants in snowpacks varies depending on the traffic intensity and distance from the roadway.

MATERIALS AND METHODS

City Jelgava is the fourth largest city in Latvia by population and fifth by territory. The total area of Jelgava is 60.3 km^2, of which 2.72 km^2 are water areas, 1.62 km^2 are parks, green areas and 12.64 km^2 are forests [7]. Population of Jelgava in 2018 was 56 383 regular inhabitants. Due to geographical location of Jelgava city, intensive cargo transportation takes place in the city, services are well developed and easily accessible, both by local and international companies. Jelgava is also located 42 km from the capital of Latvia – Riga, this link is important both for freight and passenger traffic, as most of Latvia business, transport and logistics companies, administrative businesses are concentrated in Riga's area. This business environment provides stable and continuous traffic flow on roadways every day which is one of the determining factor for increasing polluting element emission near roadways [8].

The samples of the snow were taken on 9 January 2019, the air temperature on sampling day was - 4.7 ^{0}C, the relative humidity was 82.5 %, but the precipitation was 0.1 mm. In the previous days in January (01.01. - 08.01.) before the sampling day (09.01.) there was an average air temperature of -2.95 ^{0}C, total precipitation in these days was 16 mm and air humidity was an average of 88.5 %. The average air temperature in winter 2018/2019 in Latvia was - 1.4 ^{0}C, which is 1.6 ^{0}C above the seasonal norm, becoming the 23rd warmest winter in observation history since 1924. Total amount of precipitation in Latvia winter 2018/2019 was 116.0 mm which is 19 % below the seasonal norm (142.8 mm), becoming the 36th driest winter in observation history and the 4th driest in the 21st century. In January 2019, the average air temperature in Latvia was - 4 ^{0}C, which is 0.8

^{0}C below the monthly rate becoming the first month which is colder since last March. The total amount of precipitation in Latvia in January was 46.5 mm, which is 8 % below the decade norm (50.6 mm). In the first decade of January, the average air temperature in Latvia was - 3.6 ^{0}C, which is 0.7 ^{0}C below the decade norm. Maximum decade air temperature was + 6.4 ^{0}C. The total amount of precipitation in Latvia in the first decade of January was 17.2 mm which is 3 % above the decade norm (16.7 mm). On snowpacks sampling day January 9, the average snow layer thickness was 9.6 cm, but in the previous days in January there was an average snow layer thickness of 5.6 cm [11].

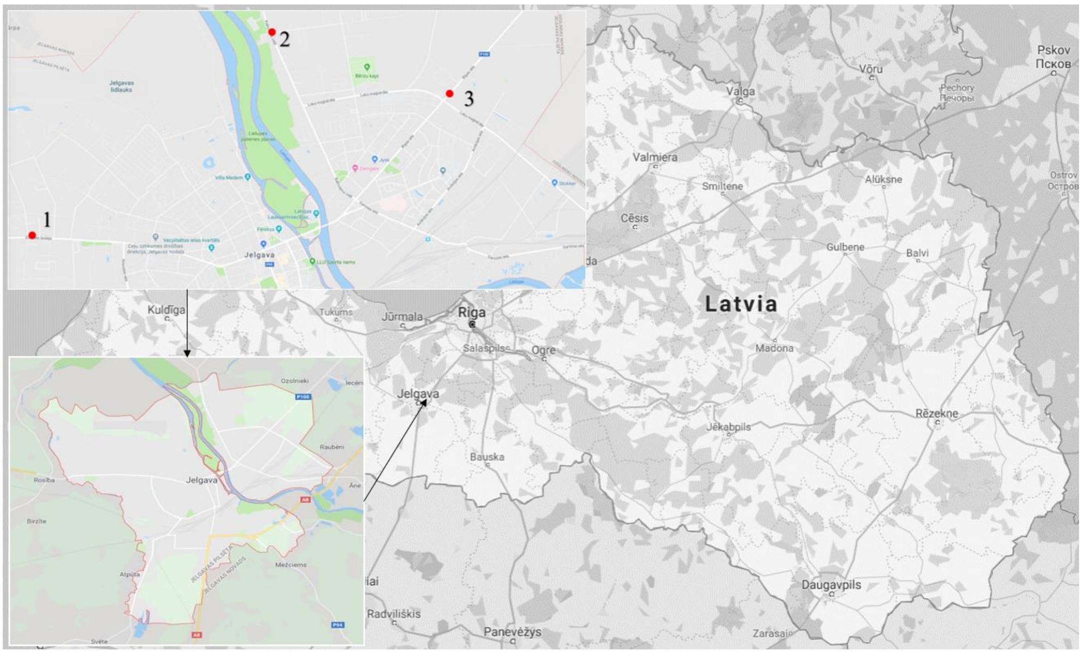

Figure 1. Location and area of Jelgava city

Snow samples were taken near different intensity roads in Jelgava city. Location of Jelgava city is shown in Figure 1. Samples were collected from sampling points in three different locations in Jelgava city and were taken at three different distances from the roadway of 1 m, 10 m and 20 m. Arrangement of sampling points in each location is shown in Figure 2, Figure 3, and Figure 4. To reveal the contamination of pollutants in snowpacks, various metals were analysed in the study, such as lead (Pb), zinc (Zn), silicon (Si), and manganese (Mn), copper (Cu), nickel (Ni), vanadium (V), and chromium (Cr) using ICP-OES spectroscopy method.

Figure 2. Arrangement of samples taken from sampling point 1.

Figure 3. Arrangement of samples taken from. sampling point 2.

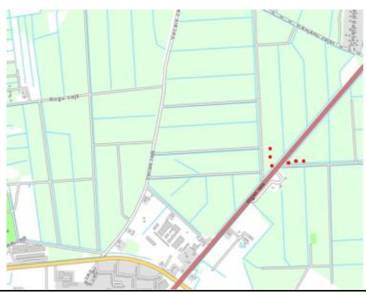

Figure 4. Arrangement of samples taken from sampling point 3.

To identify various metals in analyzed snowpacks, ICP-OES spectroscopy device “iCap 7000” is used. Inductively Coupled Plasma is one of the methods of optical emission spectrometry. Inductively Coupled Plasma Optical – Emission Spectrometry is an elemental analysis technique that provides its analytical data from the emission spectra of elements by exciting them with a high – temperature plasma [9]. The technology is based on the fact that in the device plasma energy is given to an analysis sample from outside and it moves the component elements (atoms are excited). After that, when excited atoms get back to low energy position, emission or spectrum rays are released. Then the device measures the emission rays that fit to the photon wavelength. Device determines each element type by the position of the photon rays and also the content of each element by the rays’ intensity. First, there is need to generate plasma in the device, it is done by supplying argon gas to torch coil, then high frequency electric current is applied to the work coil at the end of the torch tube. Argon gas is ionized and plasma is generated by using the electromagnetic field that was developed in the torch tube by the high frequency current. Created plasma has very high electron density and temperature (10000 K). The given energy is used to excite the atoms of the solution samples that are introduced into the plasma through a narrow tube in the centre of the torch tube in an atomized state [10]. ICP optical emission spectrometry device consists of a light source, a spectrophotometer, a detector and a data processing unit as shown in Figure 5 [10].

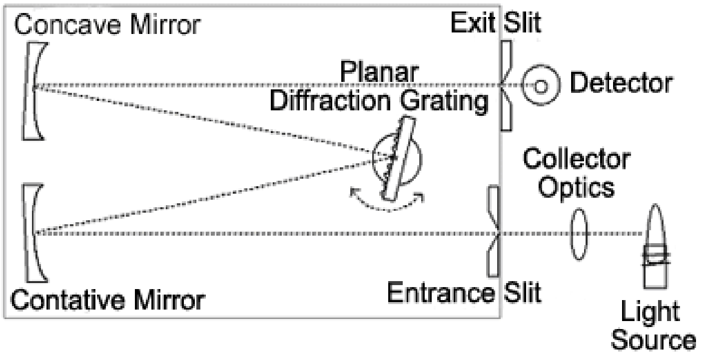

Figure 5. Sequential Type ICP-OES

ICP-OES method provides stable simultaneous, sequential analyses of various elements, a wide linear region of analytical curve, high sensitivity (the lowest limit of detection – 10 ppb or lower), a large number of measurable elements – analyzes also elements that are complicated to analyze in atomic absorption spectrometry, for example, zirconium (Zr), tantalum (Ta), rare earth, P and B elements. The given features are depending on the characteristics and structure of the initiated light source plasma [10].

RESULTS AND DISCUSSION

Most pollutants show similar trends. Higher concentrations of pollutants are observed at a distance of 1 m from the roadway compared to samples taken from further sampling points. Figures 7, 8, 9, and 10 show direct traffic impact to Cr, Mn, Pb, and V concentrations. Concentrations of pollutants decrease at distance of 10 m. Figures 6 and 11 show that concentration of Cu at the 20 m distance is also affected by other sources. Comparing the concentrations of Pb, Zn, and V at a distance of 1m from the roadway and at a distance of 10 m from the roadway, the concentrations of pollutants decrease by 6 to 11 times.

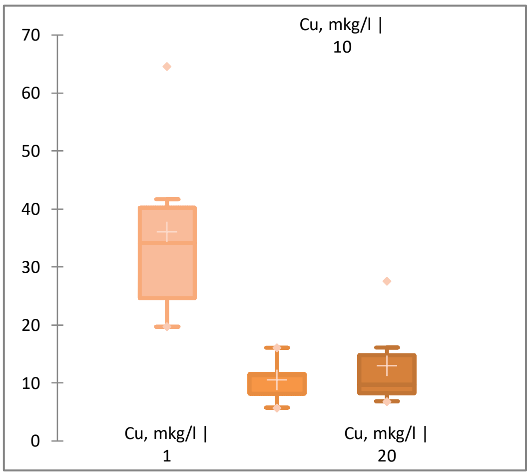

Figure 6. Boxplot of Cu concentrations depending on distance from road.

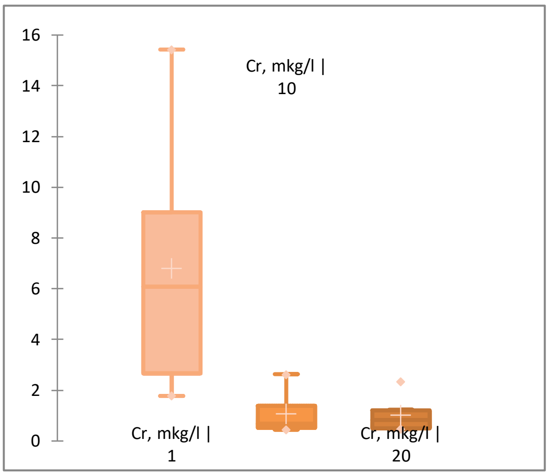

Figure 7. Boxplot of Cr concentrations depending on distance from road.

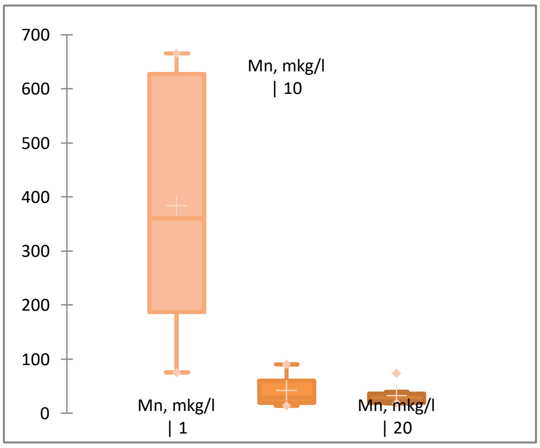

Figure 8. Boxplot of Mn concentrations depending on distance from road.

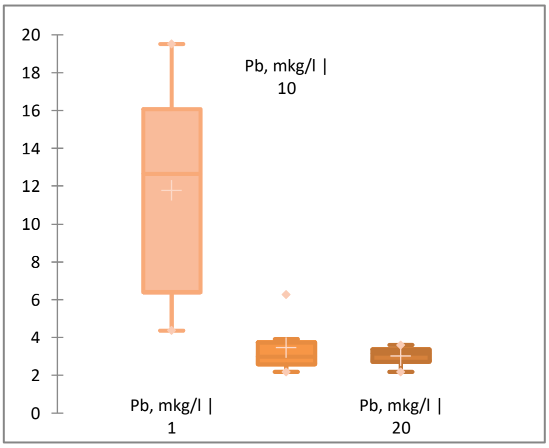

Figure 9. Boxplot of Pb concentrations depending on distance from road.

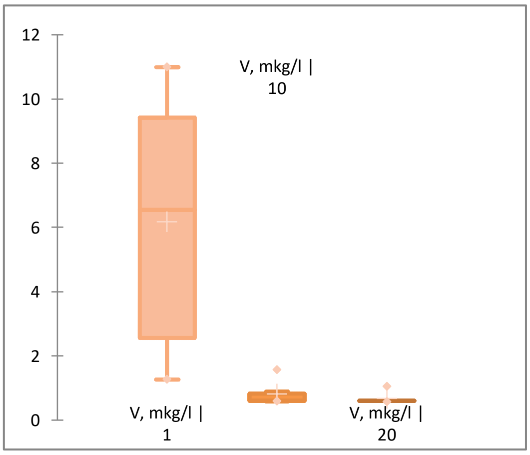

Figure 10. Boxplot of V concentrations depending on distance from road.

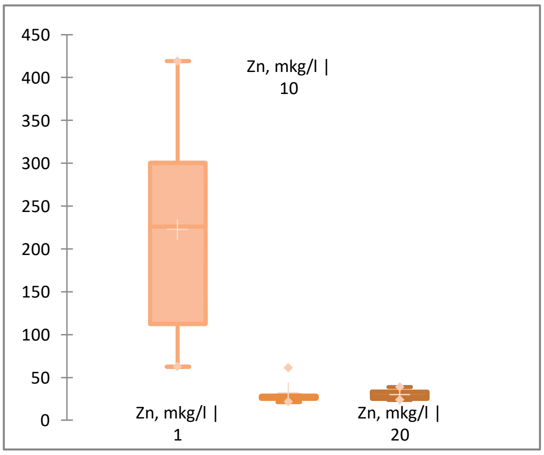

Figure 11. Boxplot of Zn concentrations depending on distance from road.

Figures 12, 13, 15 and 17 show that the highest concentrations of Cu, Cr, Mn, Pb, V, Zn are located on roadway Jelgava-Riga about 4 km from city center of Jelgava (location 3). Figure 14 shows that Mn concentration at locations 2 and 3 does not differ noticeably. The concentration of V is changing from lower at location 1 to higher at location 3 (Figure 16). The concentrations of Cu, Cr, and Pb are lower at location 2 comparing to other locations (Figures 12, 13, and 15).

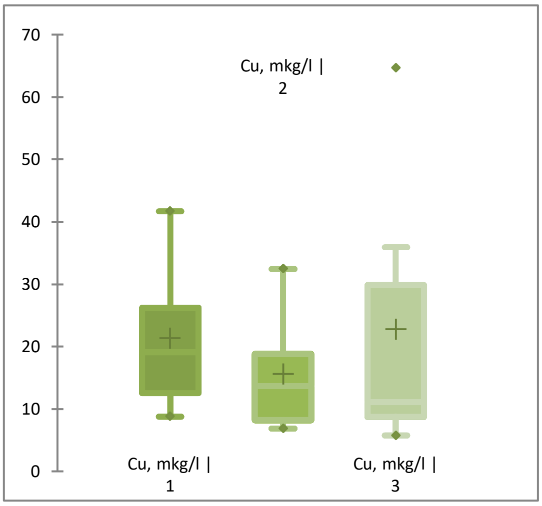

Figure 12. Boxplot of Cu concentrations depending on location.

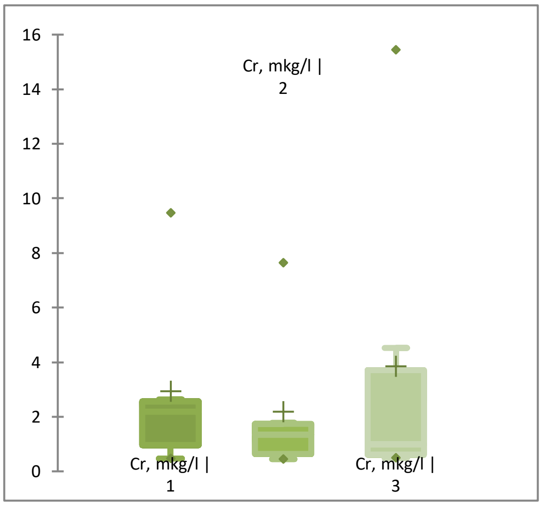

Figure 13. Boxplot of Cr concentrations depending on location.

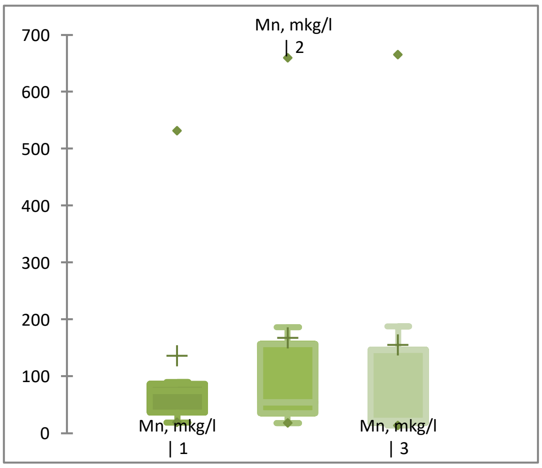

Figure 14. Boxplot of Cu concentrations depending on location.

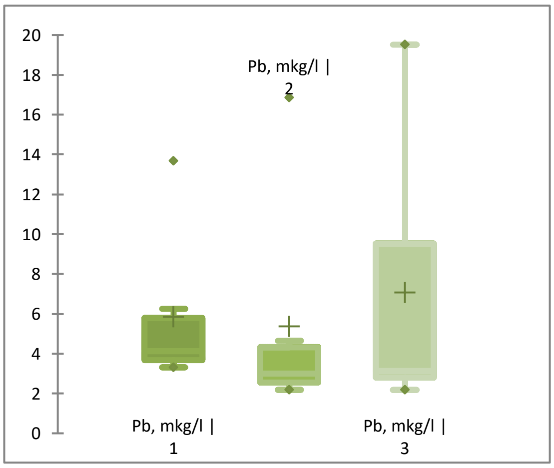

Figure 15. Boxplot of Cr concentrations depending on location.

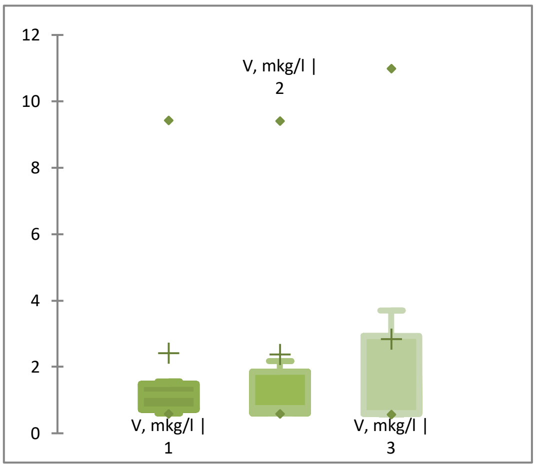

Figure 16. Boxplot of V concentrations depending on location.

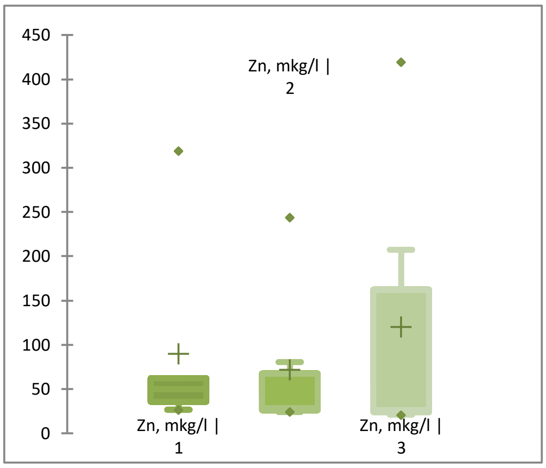

Figure 17. Boxplot of V concentrations depending on location.

CONCLUSION

Air pollution in cities caused by traffic is an important environmental and health issue worldwide. Analysed various pollutants in samples of snowpacks taken alongside different intensity roads in Jelgava city to determine locally developed traffic contamination show strong evidence of traffic negative impact on environment. Snow samples were taken from different locations at 1 m, 10 m and 20 m distances from the road and show negative relationship between concentrations and distance from road.

Most pollutants showed similar trends. The higher concentrations of pollutants were observed at a distance of 1 m from the roadway compared to samples taken from further 10 m and 20 m sampling points.

The highest concentrations of Cu, Cr, Mn, Pb, V, Zn are located on roadway Jelgava-Riga about 4 km from city center of Jelgava, were traffic is more intensive

Understanding the distribution of pollution in Jelgava city caused by traffic can help to prevent future health problems caused by air pollution, if air pollution reduction measures are included in the city planning. There is need for future research of transit corridor impact on air quality as well as development of mitigation measures to reduce air pollution in residential areas.

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THE HEAVY METAL DEPOSITION IN SNOW: CASE STUDY OF JELGAVA CITY

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ABSTRACT

Majority of world inhabitants are living in cities as well as many inhabitants in Latvia choose to move to cities to look for wellfare. Living in a city with a high density of buildings, cars, and factories, the risk of air pollution increases. Air pollution from the transport, industry, and energy sectors affect the health of the urban population. In cities, air is often contaminated with dust containing various chemical elements, including heavy metals, which, even in low concentrations, can be hazardous to human health. The aim of the study is to determine the distribution of heavy metals in the urban air as well as the relation of heavy metal concentration to anthropogenic point and nonpoint pollution sources. In winter 2019, 183 snow samples were collected in 61 different locations in the city of Jelgava to determine concentrations of various heavy metals in the city and to cover all possible urban areas: residential, industrial, high-rise, and more. In study, distribution of copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) are analyzed in the urban environment. ICP-OES spectrometer "iCAP 7000" is used for the analysis of snow samples. In the first analysis step, samples are acidified with 1% HNO_3. In the second step, the sample is hold for three days. In the third step, the sample is filtered through a paper filter and further analyzed with the "iCAP 7000". The spatial interpolation and the mapping methods were performed using ArcGIS 10.3. The IDW spatial interpolation method build in ArcGIS 10.3 based on relationship between sampling sites and concentrations was used in the study. The spatial results show that Jelgava has inhomogeneous distribution of heavy metals in the air, where the highest concentrations were found near the source of anthropogenic pollution. The highest observed concentrations of heavy metals are: Cu 12.5 (µg/l), Ni 4.4 (µg/l), Pb 72.3 (µg/l), Mn 73.0 (µg/l), Zn 204.5 (µg/l).

Keywords: heavy metals, air quality, air pollution, ICP-OES, contamination

INTRODUCTION

More than half, about 55% of the world's population lives in cities. This number is predicted to increase to 68% by 2050 [14]. In 2018, 68% of the population lived in cities in Latvia. Dust in urban air consists of particles from the soil, building materials, soot and smoke released from the transport. Street dust is the most appropriate indicator of urban quality compared to water and soil control indicators, it reflects a comprehensive picture of pollution [3]. The distribution of pollution in a city can be very different, it depends on the specifics of the city. Urban dust reflects various industries, such as transport, etc. [3]. Over the years, the bioaccumulation of toxic substances such as heavy metals (eg cadmium (Cd), mercury (Hg) and lead (Pb)) in food chains has raised concerns about its risks to human and wildlife health [10], as they can be harmful even at low concentrations [11; 12]. Heavy metals usually originate from anthropogenic sources during important fireworks festivals [15], from cars, factories, etc. Being in the environment, they sooner or later end up in terrestrial and aquatic ecosystems. Due to the persistence and toxicity of heavy metals, even at relatively low levels, heavy metals, including Pb, Cd, Hg, As and Cr, are considered hazardous to the environment in the latest air quality standards. Concerns about the deposition of heavy metals in the atmosphere have been increased, as they can have a direct and indirect impact on ecosystems and human health [1]. Pollutants are present in particulate and gaseous forms. Most heavy metals enter the atmosphere as aerosol particles. Sedimentation in the atmosphere occurs in both wet and dry processes, collectively referred to as mass deposition. During wet deposition, particles and gases are deposited by precipitation, i.e. rain, snow, hail, fog and fog [2]. Snow is an ideal material for monitoring the deposition of pollution from the atmosphere. Compared to other materials, atmospheric particles in snow are diluted with pure water rather than other materials, so atmospheric deposition can be accurately measured up to very low concentrations [8]. Snowflakes accumulate more pollutants from the atmosphere than water droplets (raindrops) because they have a larger surface area and a slower rate of fall [9]. Chemical elements accumulate on various surfaces and can spread to large areas in the form of dust. It is the dust that is the most dangerous that can enter the human respiratory tract [8]. The aim of the research is to determine the distribution of heavy metals in urban air, as well as the relationship of heavy metal concentrations with anthropogenic point and diffuse sources of pollution.

MATERIALS AND METHODS

Jelgava is the fourth largest city in Latvia in terms of population. The city has a population of 55972 [4]. One of Latvia's largest rivers, the Lielupe, flows through the city and it is located about 46 km from the Latvian capital, Riga. The climate is characterized by temperate climate conditions. In Jelgava, the wind direction is mostly from the west (northwest, west, southwest. The average air temperature in January was about -4.5 ºC. The air temperature on the day before sampling was -1.9 ºC, but on the day of sampling the air temperature was -8.14 ºC. For 13 days before sampling, the air temperature was at least below -0.7 ºC both day and night [6]. Snow samples were collected on 31 January 2019. Samples were collected during the cold and dry seasons, when a total of 60 samples were collected at sites. At the time of sampling, the weather was sunny and windless. Sampling sites were roughly distributed throughout the city areas. First, for five heavy metals (Cu, Ni, Pb, Mn, Zn) the concentrations in the samples were determined when they were in liquid form. Second, the samples were acidified to 1% HNO3, then aged for 3 days. Third, they were filtered through a paper filter. Snow samples were analyzed with an Optical Emission Spectrometry (ICP Optical Emission Spectrometry (*ICP-OES*)) [7]. There are more than 100 objects in the city of Jelgava that cause more or less air pollution (see Fig. 1). To the southeast and to the east there is a railway station with several companies and warehouses engaged in the transportation and storage of oil products, fertilizers, liquefied oil gas, ammonia, acrylic nitrile, chlorine, sulfur dioxide, various acids and others. The method of geographical statistical analysis involves GIS mapping to assess the quantitative distribution of spatial heavy metals in urban snow melting water. Spatial interpolation and mapping techniques were performed using ArcGIS 10.3. The spatial interpolation method used in this study was (IDW) based on the relationship between sampling sites and concentrations. Concentrations of copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), zinc (Zn) in snow were calculated on average from three samples.

Figure 1. Sampling sites in the city of Jelgava.

The snow samples used in the research were acidified along with the dust in it to fully understand the amount of substances in the snow. Only before sample analysis ICP-OES melted snow samples were filtered. In total, 183 snow samples were collected in Jelgava city and five microelements were analyzed (e.g., Cu, Ni, Pb, Mn, Zn).

RESULTS AND DISCUSSION

The research results section consists of maps created in ArcGIS software using the IDW method, collecting and analyzing the obtained snow melting water analysis data. The results of the research confirm that the greatest pollution is in the places of major streets and intersections, as well as the density of companies in certain parts of the city affecting the air quality in the city.

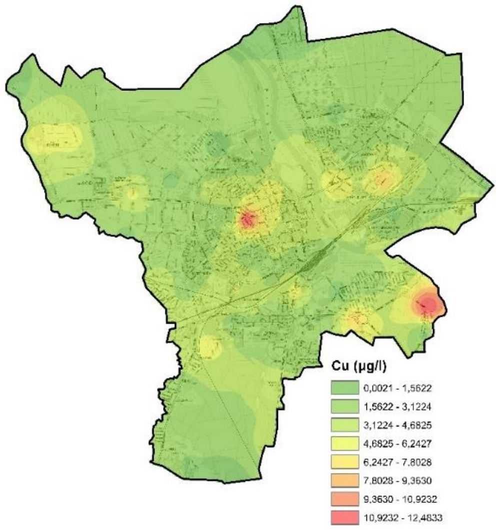

Figure 2. Distribution of copper (Cu) in Jelgava.

One of the highest concentrations of copper (Cu) is in the part of Jelgava city center - at the intersection of Lielas Street and Dambja Street and in the south-east of the city, where they reach 10.9-12.5 µg / l. Increased copper concentrations in the city center could be explained by very intensive traffic between Riga - Dobele, Dobele - Jelgava, as well as at this intersection there is a gas station, various car services, where many cars circulate every day. Combustion of oil and fossil materials is associated with the release of Cu. Copper concentrations in different city streets can vary due to the presence of copper in the car brakes and in places where copper concentrations are higher for braking [13]. Pollution in the southeast could be explained by the unauthorized incineration of waste in heating systems in private homes, which is one of the largest emitters of Cu in the urban environment [5]. Elevated Copper (Cu) concentrations, ranging from 7.8-9.4 µg / l, are in Aviacijas Street, where it is one of the largest industrial parks in Latvia, with a total area of 23 ha. The territory of this park includes rubber production and processing, metal processing, PET bottle processing, powder metallurgy and other types of production processes.

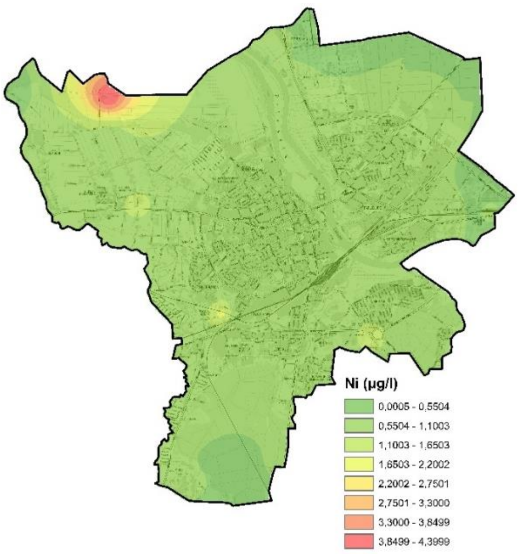

Figure 3. Distribution of nickel (Ni) in Jelgava.

Significantly elevated nickel concentrations at the north-western end of Jelgava can be explained by a landfill 1.5 km from the city border, logging operations that were carried out intensively during the winter, as well as car mechanics workshop activities in the vicinity. In order to find out the source of Ni more precisely, it is necessary to perform an additional study, where the source of Ni pollution is identified at the local level.

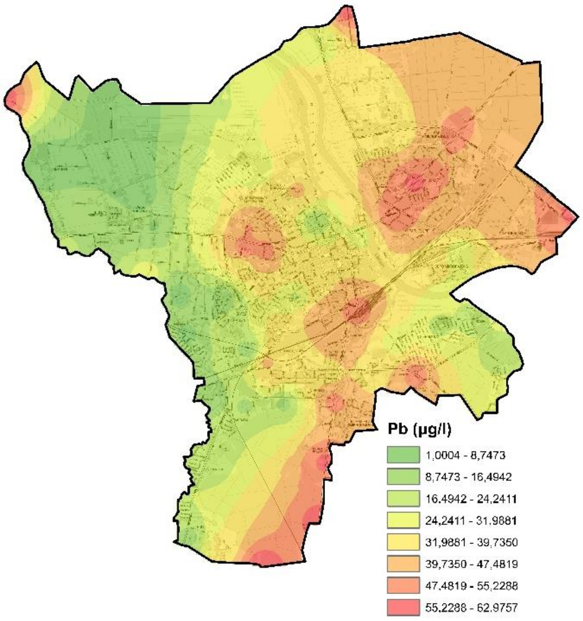

Figure 4. Distribution of lead (Pb) in Jelgava.

Pb refers to anthropogenic pollution from car emissions, brake wear [12]. Snow analyzes taken in the city of Jelgava clearly indicate areas with heavy traffic, frequent congestion and intersections with heavy car traffic.

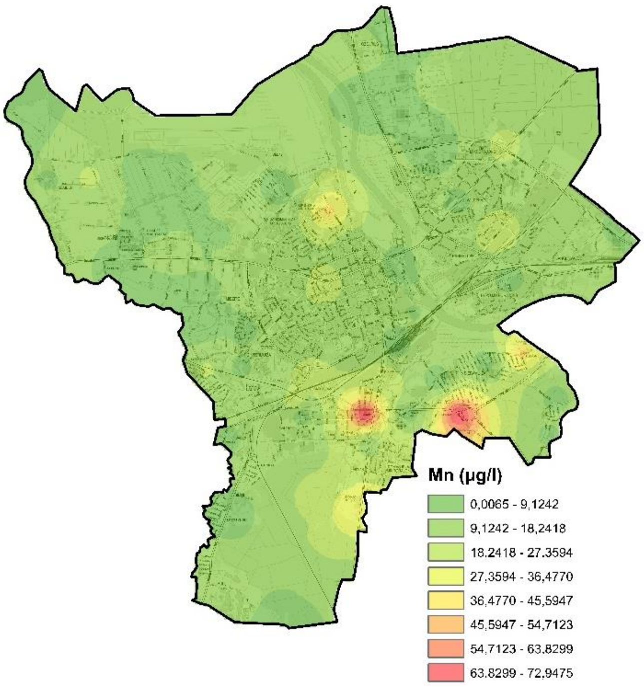

Figure 5. Distribution of manganese (Mn) in Jelgava.

The highest concentrations of Mn are at local important intersections, which indicates the impact of heavy traffic and congestion on urban air quality. In areas with pollution between 27 and 54 µg/l, there could be evidence of anthropogenic pollution from domestic heating systems, as Mn is known to be released during the incineration of waste and other fuels. High concentrations of Mn are also observed in areas where there are fireworks events, however, in the city of Jelgava, very high concentrations of Mn were not found in the vicinity of the main fireworks display.

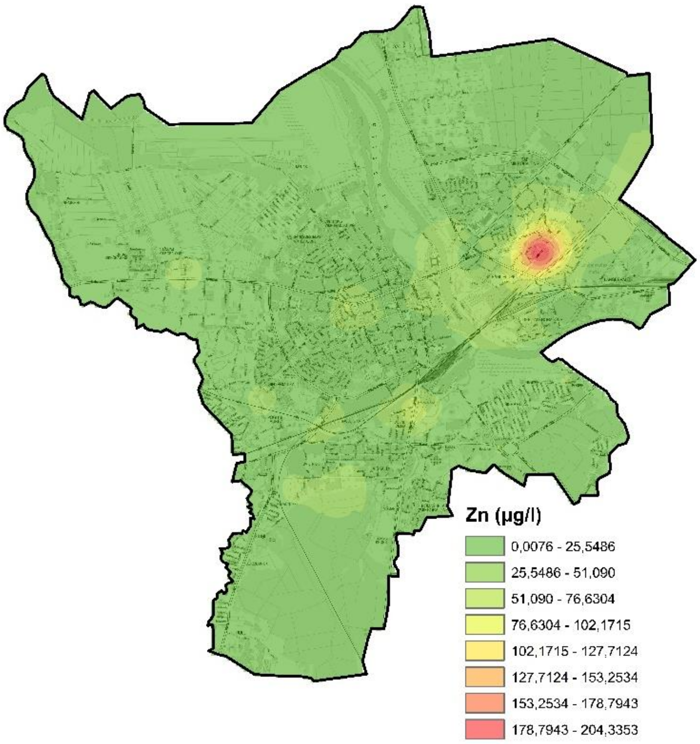

Figure 6. Zinc (Zn) distribution in Jelgava.

In the industrial area, zinc levels are generally higher than elsewhere in cities. In the city of Jelgava, the highest concentrations of Zn are in the sample plots of Aviacijas Street, where one of the largest industrial parks in Latvia is located, where various types of industrial activity take place. Zn concentrations in the aviation street sample plots range from 153.2 to 204.3 µg/l.

CONCLUSION

The effect of traffic flow intensity on the distribution of heavy metals in the urban environment is clearly seen in the analysis of lead concentrations in snow melting water, where Pb concentrations in snow melting water around heavy transport corridors ranged from 39 to 63 µg / l, indicating not only air quality but risks of lead accumulation in soil and infiltratation groundwater.

Special attention should be paid to the distribution of Ni, Zn, Mn and Cu in the urban environment, because in some areas of the city increased concentration of these metals in snow water indicates not only heavy traffic, but also economic activity, which is not always carried out in accordance with regulations.

This research shows that there is a large amount of heavy metals on the sides of streets and roads.

In order to pinpoint the sources of pollution, the research should be repeated with much more and more frequent snow sampling.

The research should also be extended to include a method for detecting long-term pollution in order to conclude what and how much pollution accumulates in the urban environment.

Additional risks include snow melting water that directly flushes heavy metal-containing PM particles into rainwater drainage systems that enter watercourses directly and pose a direct threat to surface water pollution. The study should be extended to health research, where, depending on the urban region, human health would be tested to determine whether or not existing air pollution affects human health. However, such research is in the field of medical science and involves the protection of personal data, which makes it difficult to carry out such research. As well as human health is affected not only by air but also by other environmental factors, food quality and living standards.

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Car transport intensity impact on heavy metal distribution in urban environment

To cite this article: Jovita Pilecka *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **578** 012032

IOP Conf. Series: Earth and Environmental Science **578** (2020) 012032 doi:10.1088/1755-1315/578/1/012032

Car transport intensity impact on heavy metal distribution in urban environment

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Abstract. Air pollution is one of the main environmental problems and the cause of various diseases around the world. Intensive traffic is one of the main sources of air pollution in an urban environment. In cold and temperate climate regions snow on roads and its surroundings can accumulate significant amounts of pollutants which can affect human health and the environment in both the short and long term. Various urban snow pollution studies were made in many parts of the world, but in Latvia, Jelgava city such an experience is something new. In this article, we studied the relationship between air pollution on different road sections depending on the snow sample sampling distance from the road. In the city of Jelgava near the roads with high traffic there were collected 54 snow samples, in 18 places on 3 road sections in 3 different distances from road 1 m, 50 m and 100 m. Snow samples were collected in January 2018, seven days after snowfall. We analyzed copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) concentrations in snow melting water samples. Mostly Cu concentrations at a distance of 1 m from the road were up to eight times higher than 50 or 100 m distance. The highest concentrations of Mn, Ni, Pb and Zn are 1 m away from the road. For snow samples at a distance of 50 m and 100 m from road differences are minimal. To better understand pollution spread near road, different intensity roads and streets of Jelgava should be covered. Sample plots should be located all over the city territory, excluding as much as possible other pollutants object impact on performed study.

1 Introduction

Air pollution caused by traffic is an important environmental and health issue worldwide. Every day a person puts himself under the influence of dust particles caused by cars [10]. A versatile mixture of metals from tyres, braking parts wear and exhaust gas comes from cars [5, 7, 9]. Road dust can directly pose a risk to human health by swallowing, inhaling and coming into contact with the skin [6]. Road traffic with particulate matter and gaseous

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emissions is the main cause of air pollution in most urban areas [1]. Zinc (Zn) [5, 10], copper (Cu), nickel (Ni), lead (Pb) [10] and manganese (Mn) are related to traffic dust [9]. Various epidemiological studies worldwide have increasingly shown the impact of traffic on respiratory diseases. This trend is observed in both developed and less developed countries [1, 10].

Snowflakes accumulate more atmospheric pollution than rain drops because their surface areas are larger than rains and fall speeds slow. Thanks to this, in countries in the cold region, collect snow is a good method for determining air quality [2, 3]. Vehicles both cause and transfer pollution by lifting dust in the air during dry weather, contributing to urban pollution levels [10-12].

Street dust and air quality studies are very important. They are needed to determine the origin, distribution and level of heavy metals in urban environment, near streets and roads. The focus should be on concentrations of trace elements that accumulate in the long term and may accumulate in the urban environment [10, 12].
In this article, we studied the relationship between air pollution on different road sections depending on the snow sample sampling distance from the road.

2 Materials and Methods

Jelgava is the fourth largest city in Latvia, both by population and territory. City area is 60.3 km^2. Around 56000 inhabitants live in the city [4]. Due to Jelgava's geographical location, intensive freight transport is taking place in the city. The services are well developed and easily accessible to both local and international companies. Jelgava is located 42 km from the capital of Latvia – Riga.

In the city of Jelgava near the roads with high traffic there were collected 54 snow samples, in 18 places (Fig.1, Fig.2, Fig.3) on 3 road sections in 3 different distances from road 1 m, 50 m and 100 m as well as 60 samples in Jelgava city (code in data analysis C) according to methodology distances from road 5 m [16]. Snow samples were collected in January 2018, seven days after snowfall. The average thickness of the snow layer during sampling was 9 cm. January average air temperature was -4 º C [4].

Fig. 1. Arrangement of samples taken from sampling point West (W).

Fig. 2. Arrangement of samples taken from. sampling point North (N).

Fig. 3. Arrangement of samples taken from sampling point Esat (E).

We analyzed copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) concentrations melted in snow samples. The ICP-OES spectroscopy device “iCap 7000” is used to identify various metals [7-8].

3 Results

The results show a high concentration range of copper (Cu) 826.7 mkg/l, nickel (Ni) 40.4 mkg/l, lead (Pb) 50.5 mkg/l, manganese (Mn) 1351.1 mkg/l, and zinc (Zn) 992.8

mkg/l. The descriptive statistics of copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) concentrations melted in snow samples are presented in table 1.

Table 1. Simple ststistics of copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) concentrations.

Metal / Statistics	Cu, mkg/l	Ni, mkg/l	Pb, mkg/l	Mn, mkg/l	Zn, mkg/l
Nbr. of observations	114	114	114	114	114
Nbr. of missing values	0	0	0	0	0
Minimum	2.8	0.4	0.7	5.9	9.2
Maximum	829.5	40.8	51.2	1357.0	1002.1
Range	826.7	40.4	50.5	1351.1	992.8
Median	11.2	2.0	3.6	46.9	34.7
Mean	24.5	3.4	6.2	151.6	86.6
Variance (n)	5957.7	20.1	50.7	52613.0	16154.6
Standard deviation (n)	77.2	4.5	7.1	229.4	127.1

The copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) concentrations melted in snow samples were analysed by location groups. The road directions east (E), north (N) west (W) and city (C). The Kruskal-Wallis test were used to identify differences between groups. Copper (Cu) and nickel (Ni) concentrations showed statistically significant differences in location Cu p-value was 0.028 and Ni p-values were 0.001, but Pb, Mn and Zn did not show statistically significant differences by location.

Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner [13] procedure was used to identify differences between Cu and Ni concentrations by location groups (West (W); Nord (N); East (E); City center (C). The Wij and group of Steel-Dwass-Critchlow-Fligner procedure by location groups is presented in tables 2 and 3.

Table 2. The Cu concentration Wij statistics and group of Steel-Dwass-Critchlow-Fligner procedure by location groups.

	Cu, mkg/l | W	**Cu, mkg/l | N**	**Cu, mkg/l | E**	**Cu, mkg/l | C**	**Groups**	
Cu, mkg/l | W		2.462	1.477	**3.874***	A	
Cu, mkg/l | N	-2.462		-0.268	1.845	A	B
Cu, mkg/l | E	-1.477	0.268		2.113	A	B
Cu, mkg/l | C	**-3.874***	-1.845	-2.113			B
***p-value**	*<0.05*					

Table 3. The Ni concentration Wij statistics and group of Steel-Dwass-Critchlow-Fligner procedure by location groups.

	Ni, mkg/l | W	**Ni, mkg/l | N**	**Ni, mkg/l | E**	**Ni, mkg/l | C**	**Groups**	
Ni, mkg/l | W		2.371	1.521	**5.166***	A	
Ni, mkg/l | N	-2.371		-0.515	2.499	A	B
Ni, mkg/l | E	-1.521	0.515		2.885	A	B
Ni, mkg/l | C	**-5.166***	-2.499	-2.885			B
**p-value*	*<0.001*					

The copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) concentrations melted in snow samples were analyzed by distance from road. The distance from road 1 meter (1), 5 meter (5), 50 meter (50) and 100 meter (100). The Kruskal-Wallis test were used to identify differences between groups. Copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) shoved significant differences between distance groups with p-value < 0.0001.

The copper (Cu), nickel (Ni) lead (Pb) zinc (Zn) concentrations by distance from road by Steel-Dwass-Critchlow-Fligner procedure are classified in two groups where 1m; 50m and 100m distance is in one group and 5m in second group see Table 4, 5, 6, 8.

Table 4. The Cu concentration Wij statistics and group of Steel-Dwass-Critchlow-Fligner procedure by distance groups.

	Cu, mkg/l | 1	**Cu, mkg/l | 50**	**Cu, mkg/l | 100**	**Cu, mkg/l | 5**	**Groups**	
Cu, mkg/l | 1		7.248*	6.398*	6.440*	A	
Cu, mkg/l | 50	-7.248*		-0.627	0.352	A	
Cu, mkg/l | 100	-6.398*	0.627		1.040	A	
Cu, mkg/l | 5	-6.440*	-0.352	-1.040			B
***p-value**	<0.0001					

Table 5. The Ni concentration Wij statistics and group of Steel-Dwass-Critchlow-Fligner procedure by distance groups.

	Ni, mkg/l | 1	**Ni, mkg/l | 50**	**Ni, mkg/l | 100**	**Ni, mkg/l | 5**	**Groups**	
Ni, mkg/l | 1		7.248*	6.756*	7.849*	A	
Ni, mkg/l | 50	-7.248*		-0.112	1.057	A	
Ni, mkg/l | 100	-6.756*	0.112		1.644	A	
Ni, mkg/l | 5	-7.849*	-1.057	-1.644			B
***p-value**	<0.0001					

Table 6. The Pb concentration Wij statistics and group of Steel-Dwass-Critchlow-Fligner procedure by distance groups.

	Pb, mkg/l | 1	**Pb, mkg/l | 50**	**Pb, mkg/l | 100**	**Pb, mkg/l | 5**	**Groups**	
Pb, mkg/l | 1		6.354*	7.227*	5.786*	A	
Pb, mkg/l | 50	-6.354*		0.291	-1.308	A	
Pb, mkg/l | 100	-7.227*	-0.291		-1.979	A	
Pb, mkg/l | 5	-5.786*	1.308	1.979			B
***p-value**	<0.0001					

The manganese (Mn) concentrations by distance from road by Steel-Dwass-Critchlow-Fligner procedure are classified in three groups where 1m; and 50m distance is in one group 50m and 100m in second group and 5m in third group see Table 7.

Table 7. The Mn concentration Wij statistics and group of Steel-Dwass-Critchlow-Fligner procedure by distance groups.

	Mn, mkg/l | 1	**Mn, mkg/l | 50**	**Mn, mkg/l | 100**	**Mn, mkg/l | 5**	**Groups**		
Mn, mkg/l | 1		6.801*	7.114*	6.004*	A		
Mn, mkg/l | 50	-6.801*		0.671	-2.717	A	B	
Mn, mkg/l | 100	-7.114*	-0.671		-3.841**		B	
Mn, mkg/l | 5	-6.004*	2.717	3.841**				C
***p-value**	<0.0001	**p-value	<0.034				

Table 8. The Zn concentration Wij statistics and group of Steel-Dwass-Critchlow-Fligner procedure by distance groups.

	Zn, mkg/l | 1	Zn, mkg/l | 50	Zn, mkg/l | 100	Zn, mkg/l | 5	Groups	
Zn, mkg/l | 1		7.114	7.248	6.843	A	
Zn, mkg/l | 50	-7.114		-0.984	-2.029	A	
Zn, mkg/l | 100	-7.248	0.984		-2.130	A	
Zn, mkg/l | 5	-6.843	2.029	2.130			B

4 Discussion

Heavy metal concentration data show absolute concentration values as in similar studies looking for correlations between transport intensity and heavy metal pollution in snowmelt waters [2]. The concentrations of copper (Cu), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn) in the study show a large amplitude, with very low values and extremely high values. Air quality studies have been carried out in Jelgava City for several years [7, 8, 14-17]. In all these studies, heavy metal concentrations show a high amplitude, which is not always due to the presence of transport corridors. It should be noted that groups showed mixed differences after the sampling site. The central part of the City center (C), North (N) and East (E), showed differences in concentrations of only Cu and Ni, while Mn, Pb and Zn did not show any significant differences between locations. This phenomenon can be explained by potential climate impacts on pollution concentrations, where it would be necessary to analyse climate records during the snow decomposition period. The groups distributed in this study demonstrate the importance of sampling distance from the road. Further studies would need to find out what the trend in heavy metals pollution intensity is.

5 Conclusions

Most concentrations of heavy metals had similar trends. Higher concentrations of pollution were observed within 1 m of the road compared to samples taken from additional sampling points of 5 m, 50 m and 100 m. Spatial analysis of heavy metal distribution shows the difference between the western part and the central part, which could be explained by the prevailing wind direction and point sources of pollution in the central part of the city.

The study would need to be continued in several directions, where it would be necessary to reduce the sampling step from 50m to 5m or even 1m in order to identify trends in pollution deposition intensity. It is necessary to carry out repeated studies analysing the impact of climate on the volume of heavy metals precipitated by the deposit period.

Studies should be initiated identifying and quantifying the impact of contamination accumulated in snow melting waters on surface and underground waters where spatial analysis and runoff modelling tools would be used.

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HEAVY METALS AIR POLLUTION IN JELGAVA CITY LATVIA

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ABSTRACT

Air pollution is a problem today, and it is essential to know how high it is. By increasing people's standard of living, increasing the number of factories, cars and citizens, it is helpful to know how much pollution is distributed and whether it does not exceed the standards allowed for pollution. It is necessary to investigate air pollution with heavy metals in Jelgava by identifying data from areas. In preparing the analysis, it is possible to assess whether air quality is adequate and does not exceed pollution standards. So far, Jelgava has not collected data and air quality problems, so it cannot be concluded whether air quality complies with norms. The aim of the work is to prepare an analysis of the pollution and distribution of heavy metals in the Jelgava urban environment, using the results of the study of the 2019 snow samples. Snow samples were harvested on 31 January 2019. On the day of sampling, the snow had sustained more than seven days after the first snowfall. Sampling sites were roughly distributed across all areas of the city. Three samples of snow, which are control samples, were harvested in the rural area. Samples were analyzed with induction-coupled plasma spectroscopy (ICP-OES). An analysis of pollution data shows that air pollution with heavy metals is higher in densely populated areas but less in open spaces. Air quality is significantly affected by the use of unsuitable or low-quality fuels in residential heating buildings. The highest zinc, copper, and calcium concentrations are observed in a snow sample taken in the residential area.

Keywords: urban air pollution, ICP-OES, trace elements

INTRODUCTION

Sources of air pollution can be both anthropogenic (artificial) and natural. The primary anthropogenic sources of air pollution are fossil fuels in electricity generation, the transport sector, industry and households, industrial processes and solvent use, agriculture and others.

The population of cities is growing every year. Data from 2017 show that 4.1 billion or more than half (55%) of the world's population lives in cities. In Latvia, 68.5% of the people live in cities, and 604,791 or 31.5% live in rural areas. Data from the Central Statistical Bureau show that at the beginning of 2019, the town of Jelgava had a population of 55.972, which is 2.92% of the total population of Latvia.

Methods for identifying contamination of chemical elements can be divided into the determination of long-term pollution and determination of short-term pollution. Long-term pollution is determined by analysing the chemical composition of the lichens and using the lichen index to determine the air purity index (I.A.P.). Temporary pollution is determined by placing lichen transplants in an urban environment or analysing snow samples.

Many heavy metals can be essential trace elements in plants, animals or humans nutrition, while others have no known beneficial effects. For example, zinc (Zn), copper (Cu), manganese (Mn), chromium (Cr), nickel (Ni), vanadium (V) are essential in plants, animals and human consumption. At the same time, lead (Pb), cadmium (Cd), mercury (Hg) has no positive effects on plants, animals and humans. These elements can cause toxic effects (some at deficient levels) if they occur in excessive amounts. Pollution of heavy metals largely depends on their chemical form, concentration, residence time, etc. [1].

The aim of the study is to prepare an analysis of the pollution and distribution of heavy metals in the Jelgava urban environment, using the results of the study of the 2019 snow samples.

MATERIALS AND METHODS

Description of the geographical and climatic conditions of the research object

Jelgava is the largest city in the Zemgale planning region in terms of population and area. The total area of Jelgava is 60.3 km2. The city is located in the centre of the Zemgale plain, on the banks of the second largest river in Latvia – Lielupe.

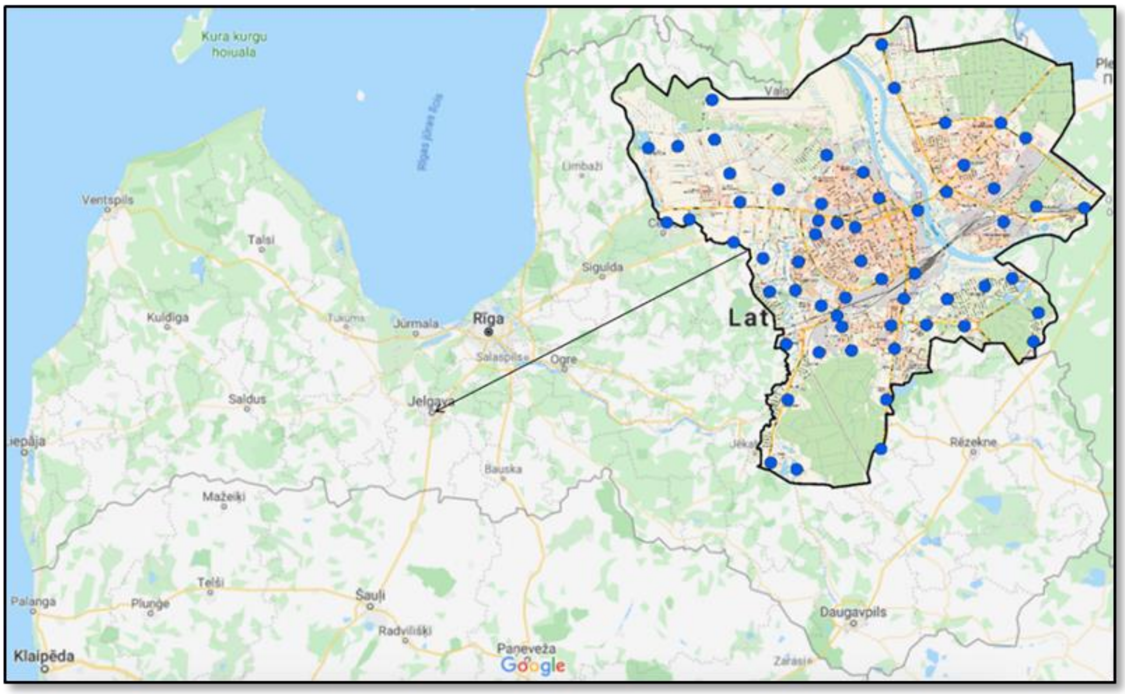

Figure 1. The geographical location of Jelgava city. Author: M.Stankevica

Jelgava region is characterized by a flat relief, which allows different air masses to flow in from all sides of the sky, which causes rapid changes in weather conditions. Jelgava region has an extensive and branched network of rivers (Jelgava, 2010). Jelgava county is crossed by the Lielupe, and the county is located in the central part of Latvia. Jelgava region has a moderately continental climate. The average annual temperature in Jelgava

in 2019 was + 8.5 degrees. In the winter months, the average temperature was -5 degrees, but the average temperature was +17 degrees in the summer months. The average yearly precipitation in 2019 was 603 mm.
Permanent snow cover usually forms at the end of December, and its thickness varies from 10 to 25 cm. The soil freezes in late December but thaws entirely in April. Soil can freeze up to a depth of 50 cm, and its freezing is affected by air temperature, snow cover thickness, humidity conditions.

Method for the determination of transient pollution
Snow samples were collected on 31 January 2019. Samples were collected during the cold and dry seasons when a total of 180 snow samples were collected.
Three snow samples, which are control samples, were collected in Mezciems and 59 city locations, a total of 177 snow samples (3 snow samples are collected in each city location) (see Fig.1). At the time of sampling, the weather was sunny and windless.
The snow cover had lasted no more than seven days after the first snow on the day of sampling. Sampling sites were roughly distributed across all urban areas.

Method of analysis of snow samples

Samples were analysed by inductively coupled plasma spectroscopy (ICP-OES). Inductively coupled plasma (ICP) spectrometers were first used in 1960 and have since become widely used [1]. The electrical discharge at radio frequencies is inductively coupled plasma (ICP). The most commonly used gas for this method is argon gas. Plasma atmospheric pressure is maintained by a quartz lamp [2]. In the first (separation) process, the solvent is removed from the sample droplets to form microscopic solids. The second process is evaporation, where the particles are converted into gaseous molecules. In the third process - atomization - the newly formed gaseous molecules are broken down into atoms.
Mostly the liquid is already subjected to these processes in the preheating zone. In the initial radiation zone and the normal analytical area, after ionization of the atoms, the sample's emission is taken. At the end of the process, very high temperature, bright white, drop-shaped plasma is formed [1]. At this point, the spectrometer measures the emission spectrum of the element. As each component has its emission spectrum, the concentration in the sample can be calculated using the measured calibrated light intensity at the wavelength.

RESULT AND DISCUSSION

When collecting snow samples, the temporary air quality of cities, rural areas or other areas can be determined. Snow samples collected and analyzed indicate contamination from snow exposure (during snowfall, accumulation) and are therefore considered a method for detecting transient contamination. The snow-water samples are reliable data on the degree of air pollution, and the results can be used as practical and straightforward indicators of urban air pollution [3]. The graphs summarize the calcium, copper, nickel, lead, vanadium and zinc results from 60 samples.
Calcium results determine the concentrations in the urban environment when looking at non-toxic metals.
Summarising the calcium (Ca) results, it can be seen that the calcium results are higher in the three samples (see Fig.2.).

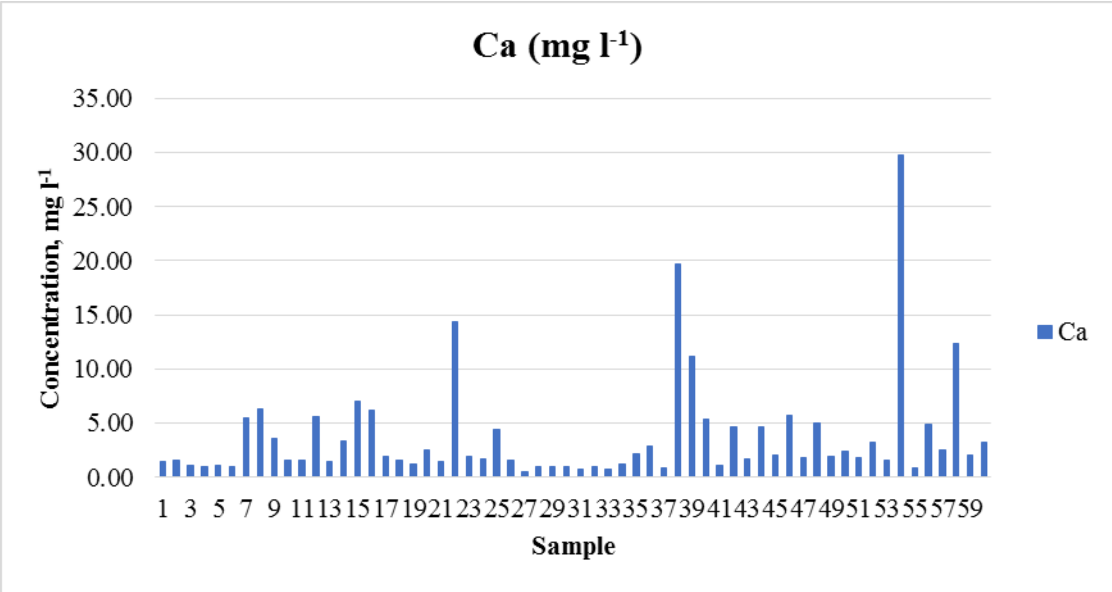

Figure 2. Calcium (Ca) concentrations in the city of Jelgava in 2019

The sample No. 22 the calcium results are higher than the other samples. The calcium concentration in this place is 14.60 mg l^{-1}. There are no factories or railways in the vicinity of this sample, nor is there increased traffic. The higher amount of calcium in this sample could be because the airflow could be affected by the flow of traffic and the construction of private houses, which not only burn firewood but also burn waste during the winter. Incinerated ash contains high levels of free heavy metals and other harmful toxic substances that can lead to ecosystem degradation, soil degradation and risks to human's health and safety [4]. A sample No.38 has a higher calcium concentration. The calcium concentration at this site is 19.65 mg l^{-1}. Air quality in this area could also be affected by the construction of private houses, which heat buildings and traffic through area during the winter. In the sample No.54 the highest calcium concentration was detected 29.74 mg l^{-1}. This sample's high concentration of calcium could be since there is an asphalt concrete plant and a railway line near the sampling site.

Summarizing the copper (Cu) results, it can be concluded that only two samples No.18 and No.39 had higher copper concentrations than the other samples (see Fig.3). The copper concentration in the sample No. 18 is 12.5 µg l^{-1}. Of all the copper results, this is the highest result. In this sample, the concentration of copper could be so high because air quality could be affected by the flow of traffic, the construction of residential buildings, the nearby railway line and the improper treatment or illegal burning of waste materials in private areas. Road traffic in urban areas causes both air pollution and noise. It contributes significantly to air pollution in Europe [5]. The copper concentration of the sample No.39 is 11.7 µg l^{-1}. The concentration of copper in this sample could be affected by traffic.

The nickel (Ni) results show that only one sample has a higher nickel concentration than the other samples. The nickel concentration in most samples is less than 0.6 µg l^{-1} (see Figure 4). The highest nickel concentration is in the sample No.2. The nickel concentration in this sample is 4.4 µg l^{-1}. In the sampleNo.2., the nickel concentration could be so high because the air quality could be affected by the construction of private houses, which use unsuitable fuels to heat the buildings during the winter.

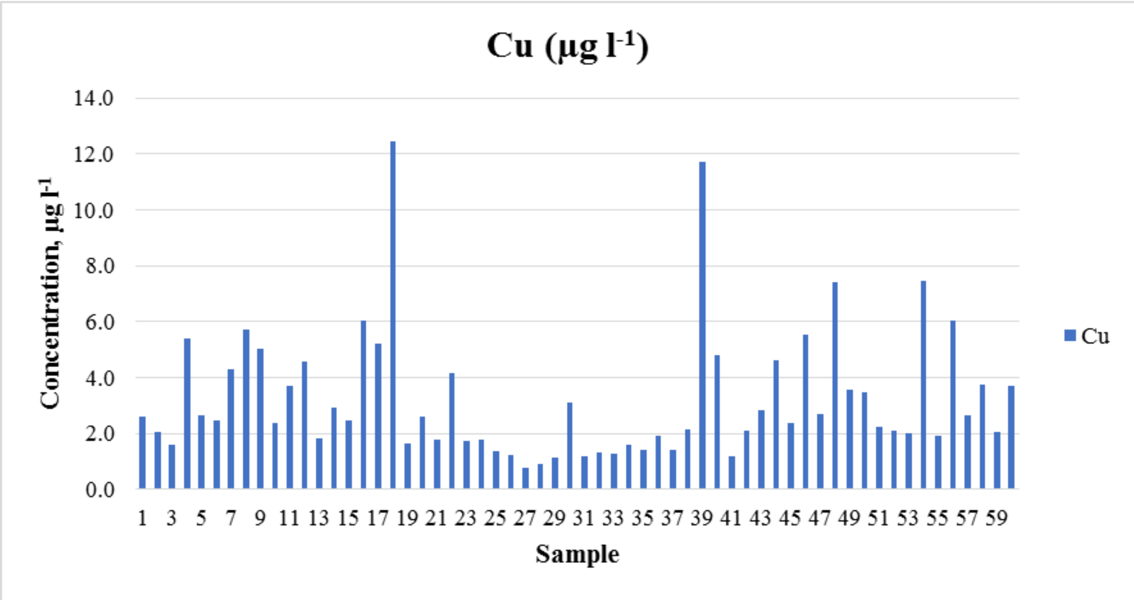

Figure 3. Copper (Cu) concentrations in Jelgava city in 2019

Transport corridor is also close to this sample area, affecting air quality due to heavy traffic. Sewage contains heavy metals such as nickel, zinc, lead Pb, copper Cu, chromium Cr, cadmium Cd and mercury Hg [6], so it is possible that at the sampling point, there has been a sewage leak.

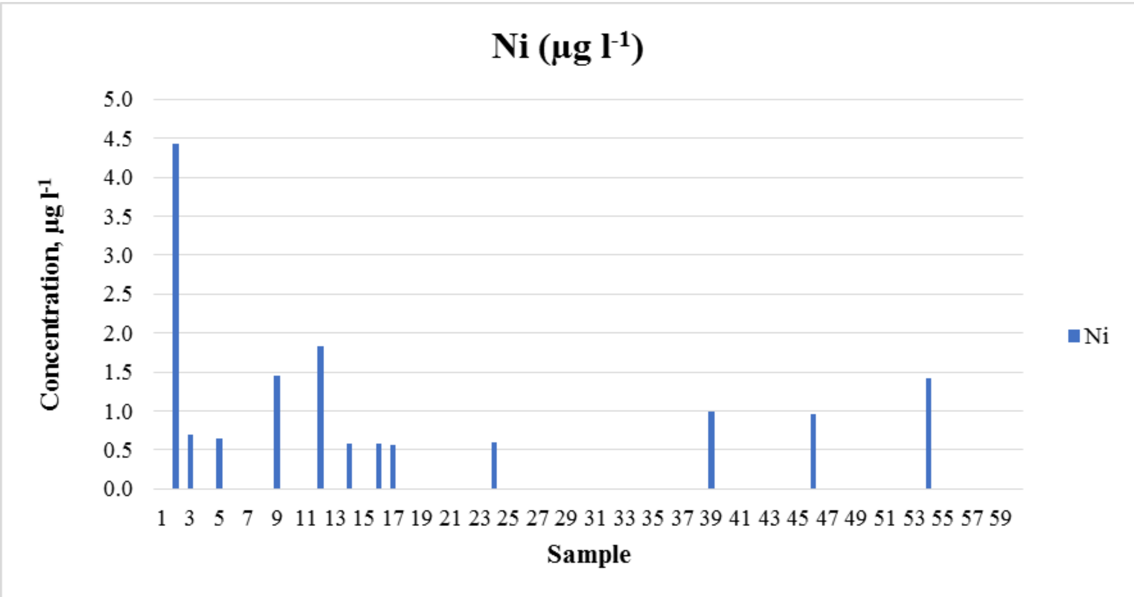

Figure 4. Nickel (Ni) concentrations in the city of Jelgava in 2019

The lead concentration in the sample No.13 is µg l^{-1}. In this sample, the concentration of lead could be so high because air quality could be affected by traffic through the nearby Lithuanian highway and the use of wrong fuel in winter, heating buildings in private areas. Contaminants such as lead (Pb), copper (Cu), chromium (Cr), tin (Sn) and antimony (Sb) are released into the air from vehicle exhaust [7].

The highest concentration of lead is in the sample No.48. The lead concentration in this sample is 72.3 µg l^{-1} (see Fig. 5). Compared to the lead concentration in the Viskaļu Street sample, this sample contains about seven times more lead. Lead concentrations could be affected by waste incineration in private homes [7].

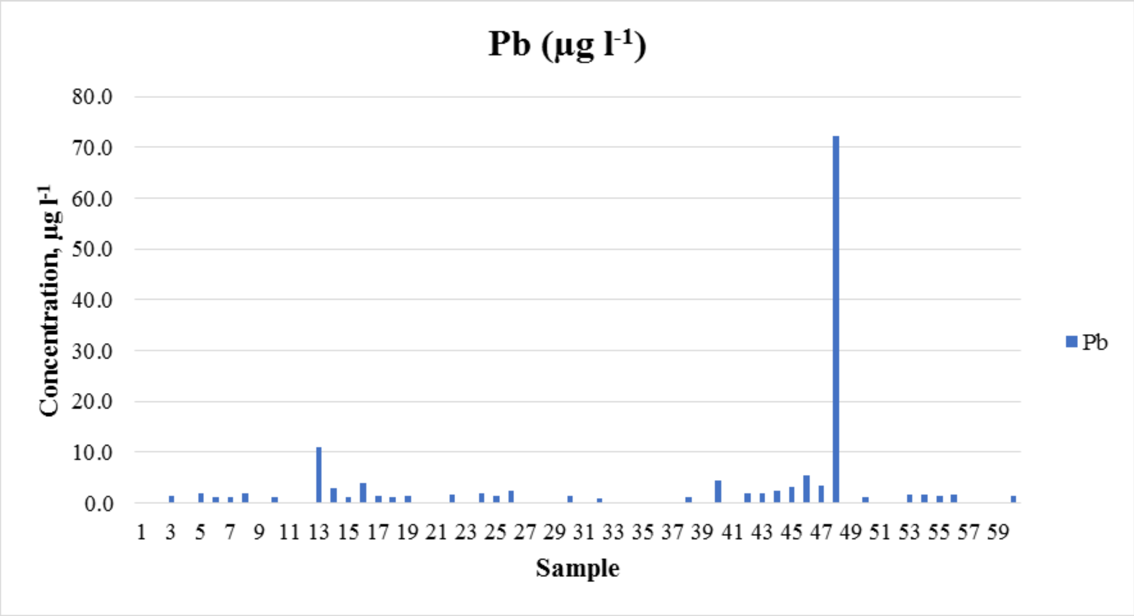

Figure 5. Lead (Pb) concentrations in the city of Jelgava in 2019

The amount of vanadium (V) in most samples is less than 0.7 µg l^{-1}, but in other samples, it is not more than 1 µg l^{-1} (see Fig. 6).

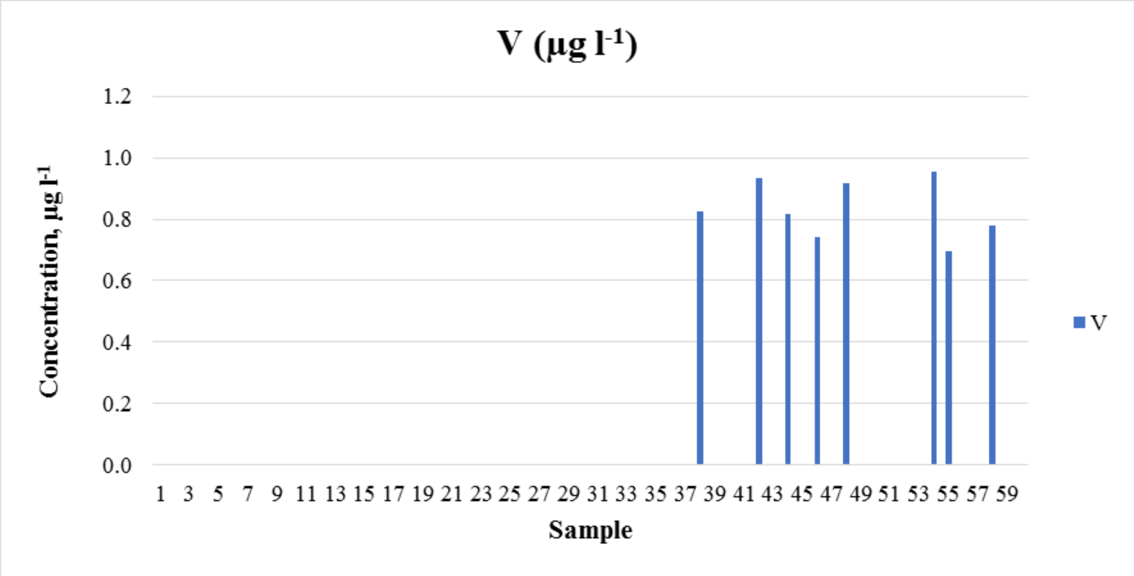

Figure 6. Vanadium (V) concentrations in the city of Jelgava in 2019

There is heavy traffic and a railway line nearby for samples with a vanadium concentration higher than 0.7 µg l^{-1}.
The zinc (Zn) results show that the zinc concentration in the three samples is higher than 50 µg l^{-1}. Samples No.39, No.46 and No.48 have the highest zinc results (see Figure 7).

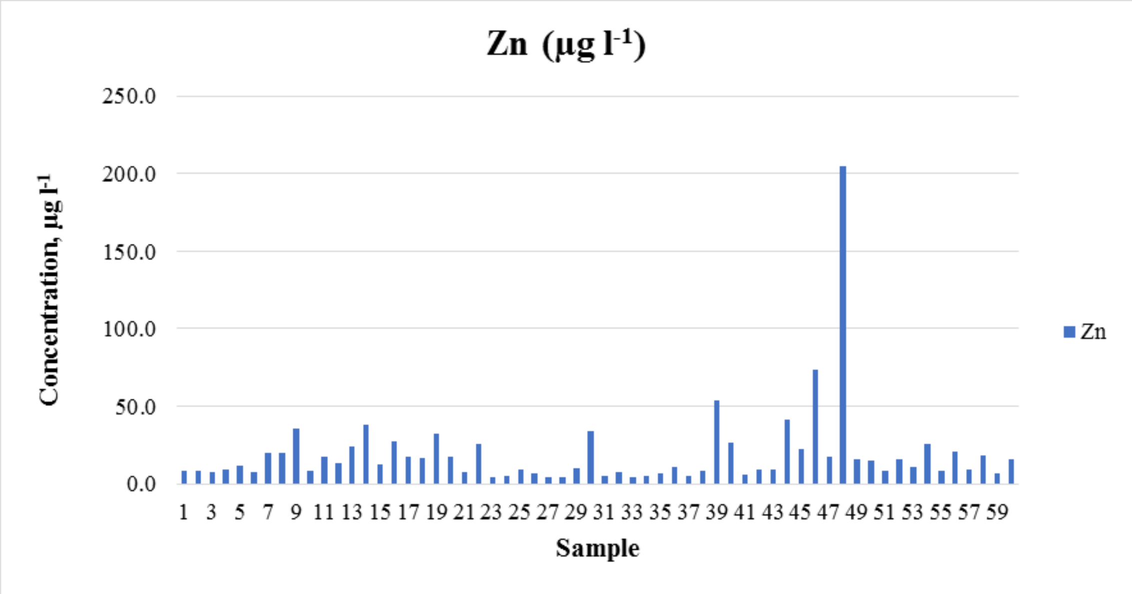

Figure 7. Zinc (Zn) concentrations in the city of Jelgava in 2019. Source: Compiled by the author.

The zinc concentration in sample No.39 is 53.7 µg l^{-1}. Zinc concentrations in this area are affected by traffic. For the sample No.46 the zinc concentration in the results is 73.2 µg l^{-1}. In this sample, air quality could be affected by traffic.
The highest zinc result appears in the results of the sample No.48. The zinc concentration at this location is 204.5 µg l^{-1}. In the sample, air quality could be affected by traffic and heating of buildings using unsuitable fuels, such as waste.

CONCLUSION

In densely populated areas, air pollution with heavy metals is higher, but in open spaces, it is lower. Air quality is significantly affected by the use of unsuitable or poor quality fuels for residential heating buildings.

The most significant air pollution with heavy metals is observed in the sample No. 39. The highest zinc, copper, and calcium concentrations appear in the snow-water sample of No. 39.

Air pollution is lower in open areas where trees and shrubs grow. Parks with traffic through major streets nearby have significantly better air quality than densely populated areas.

The study used only one method to detect contamination: snow sampling, which is a costly and not universally available method, but in the future, to rule out errors, several contamination methods should be continued and selected, such as lichen or other urban placement of bioindicators, urban lichen harvesting or other methods.

To reduce air pollution with heavy metals, several activities should be done - people should use more public transport, green the city, and reduce traffic in the city centre by building a bypass, encouraging inhabitants not to burn waste and cleaning flue gases more effectively.

An analysis of pollution data shows that air pollution with heavy metals is higher in densely populated areas but less in open spaces. Air quality is significantly affected by the use of unsuitable or low-quality fuels in residential heating buildings. The highest zinc, copper, and calcium concentrations are observed in a snow sample taken in the residential area.

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DISTRIBUTION AND POLLUTION OF CHEMICAL ELEMENTS IN JELGAVA URBAN ENVIRONMENT

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ABSTRACT

Increasing the number of cars in urban areas and the development of a variety of production technologies involving the use of fossil fuels in the urban environment are leading to a significant increase in air pollution. As air pollution with heavy metals and other chemical elements increases, air quality is deteriorating. Poor air quality, in turn, causes a number of different problems for human health, causes poor feeling and reduces life quality in total. The method of analysis of snow samples is one of the methods for monitoring air pollution. Using this method, it is possible to detect air pollution with a variety of chemical elements, including heavy metals. The aim of this research is to identify of air pollution distribution intensity for 2019 in Jelgava city urban area. The study collected 180 samples, 60 different sites. Three samples were collected in each of the sites selected. Fifty nine sampling sites were located in Jelgava and 1 outside it in Mezciems (representing a natural environment without pollution sources) so that the data can be compared. The volume of each sample collected reaches 1.0 to 1.5 kilograms of snow. To determine the degree of contamination of heavy metals, 180 samples of molten snow were acidified along with dust, then filtered out. In conclusion, the concentration of chemical elements in snow water was determined using an induction coupled plasma spectrometer (ICP-OES). The following metals were analysed at work: aluminium (Al), calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), silicon (Si), strontium (Sr), vanadium (V), zinc (Zn). The study used a hierarchical cluster analysis method for data processing to analyse the concentrations of heavy metals identified in the samples and their relationships. In the Jelgava city urban area are identified four air pollution groups.

Keywords: air quality, heavy metals, snow cover, environmental risk

INTRODUCTION

A rapid increase in the use of fossil fuels has been observed since 1950. Comparing 2019 data with 1980 data, fossil fuel consumption to meet the needs of the world's population has doubled and continues to grow, reaching 136.761 TWh in 2019 [1]. As the number of cars in cities increases, the proportion of heavy metals and other harmful elements in the air increases, which significantly reduces air quality in cities. Living in cities with polluted air has a negative effect on human health. In 2020, 56.2% of the world's population will live in cities. This number is higher than ever, and the United Nations predicts that this percentage will only increase [2]. As a result, more and more people will be exposed to polluted air in cities [2]. Combustion of fossil fuels (including fuel) releases a number of elements into the air that cause damage to human health at elevated doses. Chemical elements such as: As, Cu, Co, Cr, V, Ni, Sb, Fe, Mn, Zn, Sn, Mn, Pb, Fe, Ni are released into the air. For example, increased intake of lead (Pb) can affect and promote the development of various diseases, such as haematopoietic and lymphatic tumors, damage to the kidneys, reproductive system and central nervous system. These systems are vulnerable to the dangers of exposure to high levels of lead in the body [3]. Zinc (Zn) - although this heavy metal is considered to be relatively non-toxic, symptoms such as nausea, vomiting, abdominal pain, lethargy and general fatigue occur when the human body is exposed to high doses [4]. Heavy metals are very common in large cities around the world. The source of these toxic elements in urban areas is mainly due to the increase in fossil fuel consumption in recent decades. Pollution with heavy metals also occurs from biological sources such as sewage treatment plants, which produce lead (Pb) and zinc (Zn) [5], [6].

Snow geochemistry has become a topical research topic since 1996. Research is carried out in different countries of the world and in different conditions. Sampling points can be urban, rural, mountainous, etc. This type of test method is adaptable to almost all situations where the snow layer is large enough to collect the amount of snow required for the sample. Snow geochemistry has been used in studies related to the assessment and testing of anthropogenic impacts and their distribution [7]. Many studies have been performed to characterize the pollution of heavy metals in the urban environment using this method [8], [9], [10].

The aim of this research is to identify of air pollution distribution intensity for 2019 in Jelgava city urban area.

MATERIALS AND METHODS

Object of research: The city of Jelgava is located in the middle of Latvia, in the Zemgale lowland, see Figure 1. Its area reaches 60.3 km^2, and the population at the end of 2019 reached 56062 people, which ranks Jelgava 4th in Latvia in terms of population. In the city of Jelgava, the average annual temperature is 6.5 ° C, with an average annual rainfall of about 642 mm. Snow cover in the city is usually observed from November to March [11].

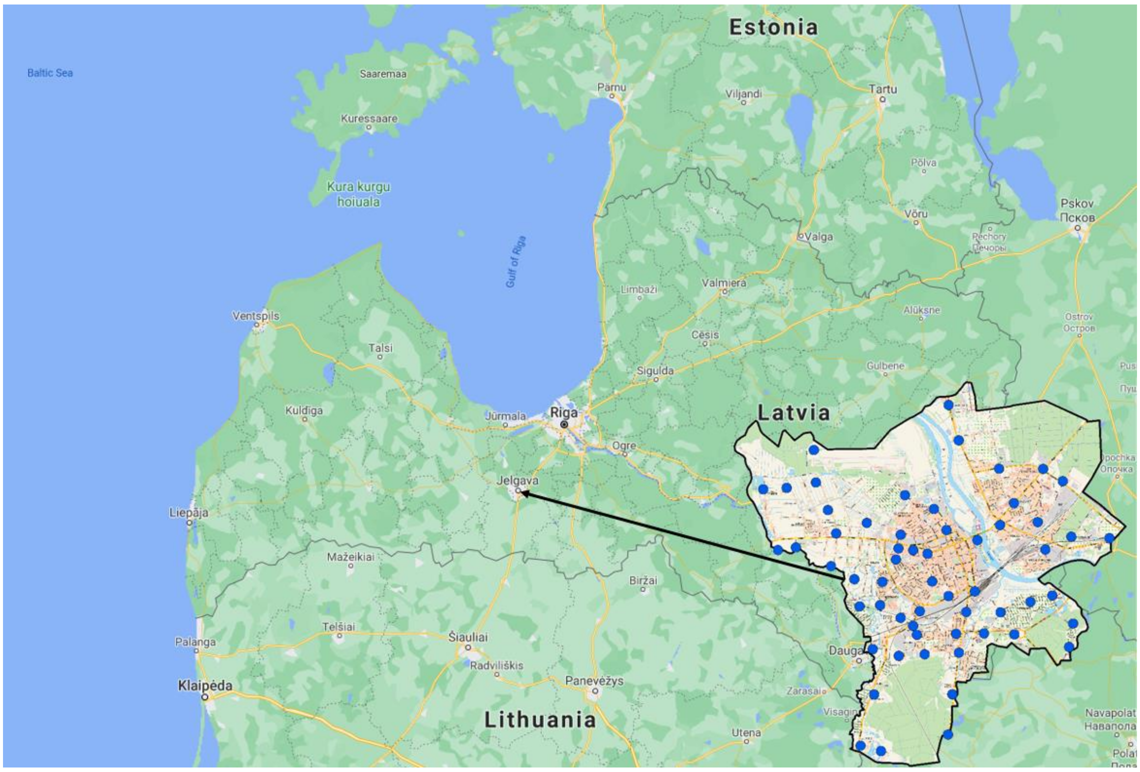

Figure 1. The geographical location of Jelgava.

The sampling sites selected in the study are selected on the basis of the following principles: a general variety of building effort between sampling sites, a short distance to transport corridors, including both residential and industrial zones. In addition, another sampling site with different conditions was selected in the study, a natural, forest environment in Mezciems. The site is located south-east of the city centre of Jelgava, and the basic idea of the sample is to check the difference between the amount of chemical elements in and outside the city. Table 1 summarises all 60 sampling locations and geographical coordinates.

1. Table. Sampling points.

No.	Sampling points	N	E
1	Ledinu road	56º 37’ 33’’	23º 46’ 27’’
2	Kalmju street/Karninu road	56º 37’ 52’’	23º 46’ 35’’
3	Karninu road/Stalgenes street	56º 38’ 19’’	23º 45’ 59’’
4	Sieramuizas street/Nomales street	56º 38’ 19’’	23º 45’ 24’’
5	Bauskas street /Stalgenes street	56º 38’ 6’’	23º 44’ 36’’
6	Miera street /Bauskas street	56º 37’ 47’’	23º 44’ 55’’
7	Miera street /Zemenu street	56º 37’ 47’’	23º 44’ 8’’
8	Lietuvas highway/Romas krogs	56º 36’ 52’’	23º 43’ 19’’
9	Lietuvas highway /Platkaji	56º 36’ 16’’	23º 43’ 12’’
10	Viskalu street/Lietuvas highway	56º 37’ 32’’	23º 43’ 31’’
11	Viskalu street/Liepajas street	56º 37’ 27’’	23º 42’ 33’’

No.	Sampling points	N	E
12	Viskalu street	56º 37’ 22’’	23º 41’ 52’’
13	Salnu street/Rullu street	56º 37’ 48’’	23º 42’ 19’’
14	Platones street /Lietuvas highway	56º 37’ 49’’	23º 43’ 34’’
15	Savienibas street /Lietuvas highway	56º 38’ 7’’	23º 43’ 39’’
16	Railway station	56º 38’ 25’’	23º 43’ 53’’
17	Pulkveza O. Kalpaka street /Rupniecibas street	56º 38’ 20’’	23º 43’ 14’’
18	Rupniecibas street / Tervetes street	56º 38’ 10’’	23º 42’ 28’’
19	Tervetes street /railway	56º 38’ 0’’	23º 42’ 16’’
20	Balozu street /Burinu road	56º 37’ 37’’	23º 41’ 8’’
21	Tervetes street /Krastmalas street	56º 36’ 54’’	23º 41’ 9’’
22	Tervetes street /Aku street	56º 36’ 6’’	23º 40’ 48’’
23	Aku street 4	56º 35’ 59’’	23º 41’ 25’’
24	Putnu street /Karklu street	56º 38’ 4’’	23º 41’ 54’’
25	Dambja street/Karklu street	56º 38’ 16’’	23º 41’ 20’’
26	Burinu road 8	56º 38’ 35’’	23º 40’ 37’’
27	Burinu street (Kalna Burini)	56º 38’ 12’’	23º 40’ 38’’
28	Laipu street 8	56º 38’ 36’’	23º 41’ 25’’
29	3.line/Nameja street	56º 39’ 22’’	23º 40’ 8’’
30	3.line/Riekstu road	56º 39’ 43’’	23º 39’ 55’’
31	3.line/Meza road	56º 40’ 9’’	23º 39’ 35’’
32	Sumanu street	56º 40’ 32’’	23º 39’ 25’’
33	Meza road /5.line	56º 40’ 4’’	23º 38’ 48’’
34	Meza road /6.line	56º 40’ 5’’	23º 38’ 11’’
35	Dobeles highway/ 6.line	56º 39’ 9’’	23º 38’ 35’’
36	Zanderu road	56º 39’ 2’’	23º 39’ 4’’
37	Malkas road	56º 38’ 45’’	23º 40’ 1’’
38	Aspazijas boulevard/ Asteru street	56º 38’ 0’’	23º 42’ 16’’
39	Dobeles highway/ Satiksmes street	56º 39’ 9’’	23º 41’ 51’’
40	Satiksmes street / Ganibu street	56º 39’ 21’’	23º 41’ 54’’
41	1.line/Ganibu street	56º 39’ 29’’	23º 40’ 58’’
42	Meiju road/Slokas street	56º 39’ 55’’	23º 41’ 59’’
43	Liepkalnu street /Zvejnieku street	56º 39’ 41’’	23º 42’ 48’’
44	Ausekla street / Blaumana street	56º 39’ 22’’	23º 43’ 9’’
45	Liela street /Dobeles highway	56º 39’ 5’’	23º 42’ 25’’
46	Lielas street /J.Asara street	56º 38’ 59’’	23º 42’ 41’’
47	Tervetes street / Pavasara street	56º 38’ 36’’	23º 42’ 45’’
48	Pasta island	56º 39’ 12’’	23º 43’ 51’’
49	Rigas street / Brivibas street	56º 39’ 22’’	23º 44’ 24’’
50	Prohorova street /Neretas street	56º 39’ 1’’	23º 45’ 48’’

No.	Sampling points	N	E
51	Garozas street 112	56º 39’ 7’’	23º 47’ 31’’
52	Garozas street/ Rubenu road	56º 39’ 2’’	23º 46’ 18’’
53	Aviacijas street/ Lacplesa street	56º 39’ 12’’	23º 45’ 29’’
54	Aviacijas street/Loka street	56º 40’ 1’’	23º 46’ 16’’
55	Rigas street/Loka street	56º 40’ 13’’	23º 45’ 44’’
56	Loka street/Berzu road	56º 40’ 14’’	23º 44’ 32’’
57	Rogu road/Kalnciema street	56º 40’ 42’’	23º 43’ 24’’
58	Kalnciema street 132	56º 41’ 9’’	23º 43’ 13’’
59	Instituta street/ Rigas street	56º 39’ 43’’	23º 44’ 57’’
60	Mezciems (control)	56º 36’ 33’’	23º 46’ 48’’

Samples were collected in 60 different locations in Jelgava city on January 11, 2019. 3 samples were collected at each sampling point, for a total of 180 samples. Sampling was performed 7 days after fresh snow, which allowed time for the contamination to accumulate in the snow. Each sample was collected carefully. It was placed in a plastic box. Rubber gloves were used for the snow sampling. The sample is removed with a round plate, which is cleaned before each subsequent sample to exclude the possibility of contamination entering the new sample from the previous sampling point. Contaminant concentrations were determined in all 180 molten snow samples. Inductively coupled plasma spectroscopy (ICP-OES) was used to analyze the samples. The concentration of chemical elements present was analyzed for all 180 samples separately. After analysis, data processing was performed using clustering.

The goal of cluster analysis is to group observational data based on their properties. The basic principle of cluster analysis is the grouping of observation data into subgroups (clusters). Each of the clusters combines the most closely related observations. Such clusters help to understand how similar or different the observational data are.

RStudio for data processing: RStudio is a free, open source software that offers features such as: data processing and retrieval for science, scientific research and technical communication between researchers. The program allows anyone with access to a computer to work freely with data and information that improves the acquisition and application of knowledge, and promotes collaboration and research in science. RStudio is an integrated development environment for R, statistics and graphical programming languages. The software also offers a hierarchical cluster analysis tool in its data processing range, which is the main data processing tool in the study. Using this tool, it groups the collected data and forms clusters, which are displayed in a dendrogram and are clear and easy to interpret.

RESULTS AND DISCUSSION

As a result of the analysis of the snow samples collected in the study, 19 chemical elements were identified, from which the classification of monitoring points was further performed using the hierarchical cluster method (Ward’s Method). The clusters of analyzed snow samples are shown in Figure 2. The coordinates of the cluster centroid are given in Table 2.

Table 2. Coordinates of cluster centroids

Chemical element	Coordinates of class central monitoring points			
	1	2	3	4
Al	-0.568	1.107	1.062	1.156
Ca	-0.443	0.354	1.763	0.249
Fe	-0.578	0.405	1.112	0.454
K	-0.440	-0.173	0.553	-0.109
Mg	-0.395	0.306	2.243	0.507
Na	-0.502	0.611	3.837	-0.153
P	-0.342	-0.381	1.109	5.323
S	-0.695	0.210	2.543	2.382
As	-0.129	-0.129	-0.129	-0.129
Ba	-0.371	0.282	0.110	7.150
Cd	0.000	0.000	0.000	0.000
Co	-0.252	-0.252	2.355	0.427
Cr	-0.225	-0.225	-0.225	6.078
Cu	-0.854	0.461	0.219	1.797
Mn	-0.450	0.350	1.591	0.861
Mo	-0.296	-0.296	-0.296	-0.296
Ni	-0.234	-0.234	-0.234	-0.234
Pb	-0.062	-0.180	-0.199	7.515
Si	-0.530	0.669	1.022	0.701
Sr	-0.659	0.469	2.049	1.459
V	-0.317	-0.317	1.084	3.562
Zn	-0.449	0.012	-0.025	6.731

In most of the samples, the concentrations of the chemical elements were lower than the error value of the instrument, but in the case of some samples the concentration was high enough to determine it.

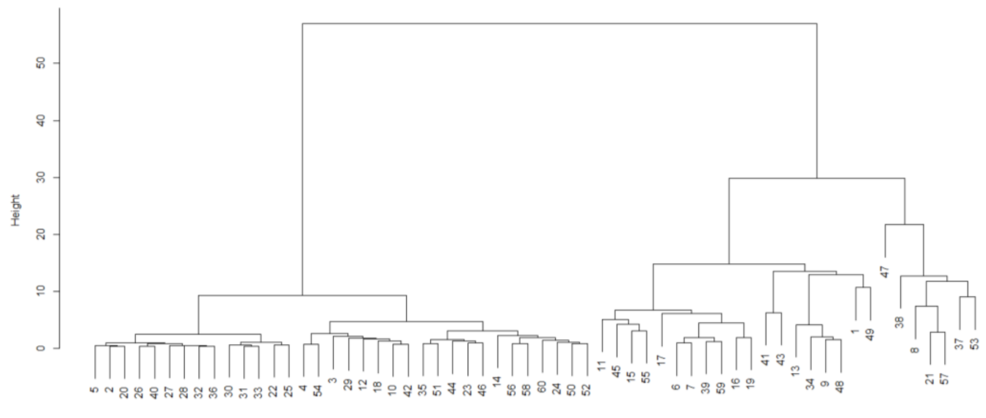

Figure 2. Cluster dendogram.

The first cluster combines areas with relatively low air pollution, where all metal values are below average and the cluster includes a control monitoring point. The second cluster describes monitoring points where the composition of chemical elements is characteristic of traffic-based pollution [9], [10]. The third cluster combines monitoring points where, in addition to traffic pollution, the content of chemical elements characteristic of waste and fossil fuel combustion has been identified [5], [12], [13], [14]. The fourth cluster consists of one monitoring point, where in addition to transport pollution, elevated zinc and lead values have been detected. These metals are a pronounced sign of waste incineration, which could be explained by the construction of dense private houses, where a pronounced street canyon is formed, which impedes air circulation and promotes the accumulation of pollution.

CONCLUSION

Cluster analysis showed that the city is divided into 4 zones, where each zone has a different proportion of chemical elements. The first zone include areas with relatively low air pollution, where all metal values are below average and the cluster includes a control monitoring point. The second zone associate areas where the composition of chemical elements is characteristic of traffic-based pollution. The third zone combines areas where, in addition to traffic pollution, the content of chemical elements characteristic of waste and fossil fuel combustion has been identified. The fourth zone consists of one monitoring point, where in addition to transport pollution, elevated zinc and lead values have been detected.

Most of the city of Jelgava has good air quality, where the values of chemical element concentrations were below the average value of monitoring points and the composition of chemical elements corresponds to the level of background pollution in rural areas.

The results of the clusters showed the main groups of pollution sources, which are wear and tear of transport running gear, fossil fuel incineration and unauthorized waste incineration, which is especially relevant in private areas and is related to public ignorance about the harmful effects of waste incineration on the environment and human health.

In the future, research should focus on the identification of point and diffuse sources of pollution and research on limiting the spread of pollution and potential methods (through greenery, barriers, other types of structures).

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Data in Brief 38 (2021) 107300

Contents lists available at ScienceDirect

Data in Brief

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Data Article

Dataset of trace elements concentrations in snow samples collected in Jelgava City (Latvia) in December 2020

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ARTICLE INFO

Article history:
Received 21 April 2021
Revised 13 August 2021
Accepted 13 August 2021
Available online 4 September 2021

Keywords:
Air pollution
Atmospheric deposition
Contaminants
Environmental monitoring
Heavy metals
Urban air quality
Snow composition

ABSTRACT

The data set provided in this article consist of two repeated data sets of chemical elements concentrations in snow samples. The snow samples were collected in Jelgava city at December 15th with 5 day exposition time. Snow samples were collected in 59 monitoring points in Jelgava city and in one sample in rural area monitoring point as control. The collected snow samples were melted, acidified with HNO_3 and analysed with ICP-MS. The samples were analysed Aluminium (Al), Silicon (Si), Chrome (Cr), Manganese (Mn), Iron (Fe), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Molybdenum (Mo), Cadmium (Cd), Barium (Ba), Tungsten (W), Lead (Pb). The collected data are with fundamental scientific value and can be applied only for local data analysis. Data set is useful for local city air quality research work and for evaluation not only local urban impact but in future evaluate city green infrastructure impact on air quality and evaluation of air pollution mitigation measures efficiency.

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https://doi.org/10.1016/j.dib.2021.107300

Specifications Table

Subject	Atmospheric Science
Specific subject area	The urban air quality
Type of data	Table
How data were acquired	Inductively coupled plasma mass spectrometer (ICP-MS). „ Agilent ICP-MS 8900 QQQ" was used for analysis of snow samples.
Data format	Raw; Analyzed
Parameters for data collection	All samples were collected in plastic containers and transported to laboratory.
Description of data collection	One set of chemical elements Al, Si, Cr, Mn, Fe, Ni, Cu, Zn, As, Mo, Cd, Ba, W, Pb in snow samples.
Data source location	Institution: Latvia University of Life Sciences and Technologies City: Jelgava Country: Latvia Latitude and longitude (and GPS coordinates, if possible) for monitoring points are presented in Table S.
Data accessibility	With the article

Value of the Data

- The urban air pollution is related with increasing human health risks. The knowledge about chemical elements distribution in urban areas helps to develop and improve city infrastructure.
- The data could be very useful for local authorities as well as can be used for fundamental research where urban air pollution issues are investigated.
- The information of air pollution is very useful with temporal distance where by repeating of experiment it is possible to evaluate mitigation measures.
- The collected data can be used to evaluate point-source and nonpoint-source, pollution impact on air quality.
- The multidisciplinary research of dust and chemical elements long distance transport in future will be possible if data in this article are included in models with point source pollution [1] and distribution of chemical elements in catchment areas [2].

1. Data Description

The raw data of chemical elements concentrations Al, Si, Cr, Mn, Fe, Ni, Cu, Zn, As, Mo, Cd, Ba, W, Pb in snow samples collected December 2020 are presented in Table S. The unit of concentrations measurement is microgram per liter (µg/l). In Table S first column is ID number of monitoring points. Second and third column represents coordinates of monitoring point. The fourth column represents snow sample number for each monitoring point.

2. Experimental Design, Materials and Methods

The location of data collection area is presented in Fig. 1. The Jelgava city with ∼ 57 000 inhabitants is located in central part of Latvia. The sampling areas were selected with aim to monitor transport corridors in Jelgava city. The 59 sampling points were in Jelgava city and one reference point was in rural area at SW from Jelgava city.

The first snow event in Jelgava was at 11^{th} of December 2020. The snow samples were collected at 15^{th} of December 2020. Snow deposition period was 5 days [4]. This period represent normal city life where transport flow is more active during week days end, less intensive during weekends. The air temperature, precipitations wind direction and wind speed [5] during deposition period is presented in Fig. 2.

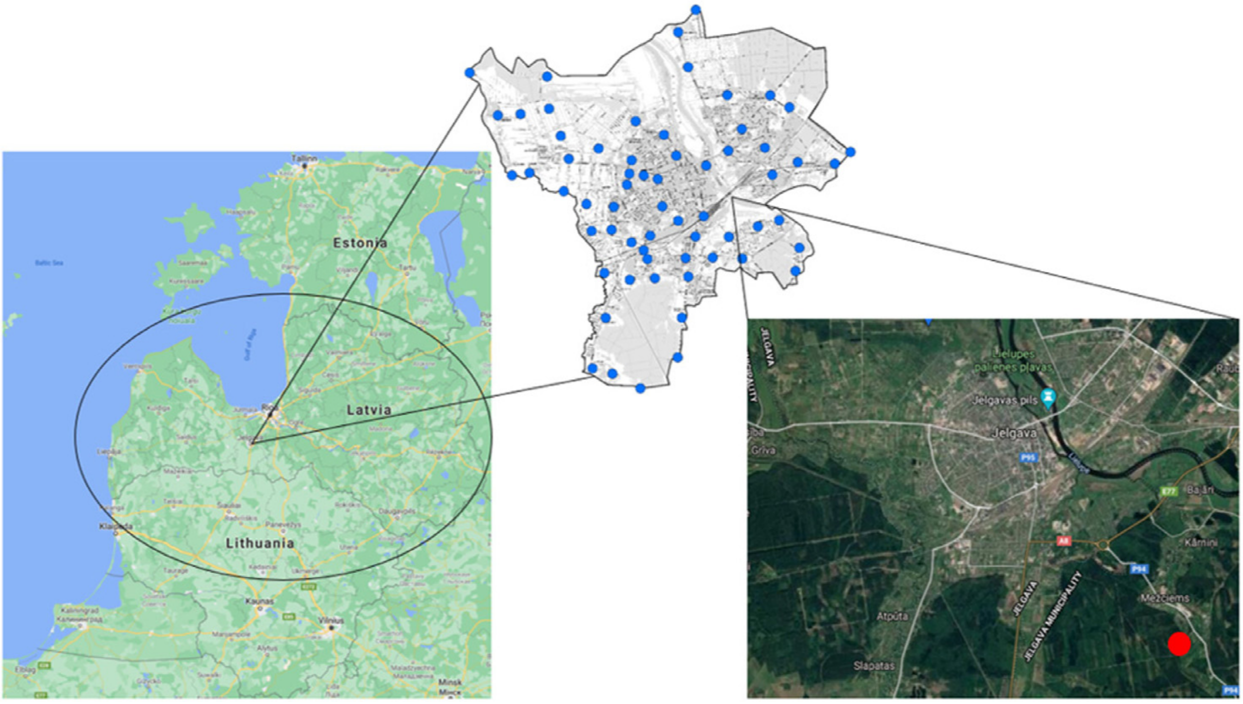

Fig. 1. The location of snow sample collection area, the coverage of monitoring points in Jelgava administrative area (blue) and location of rural monitoring point (red).

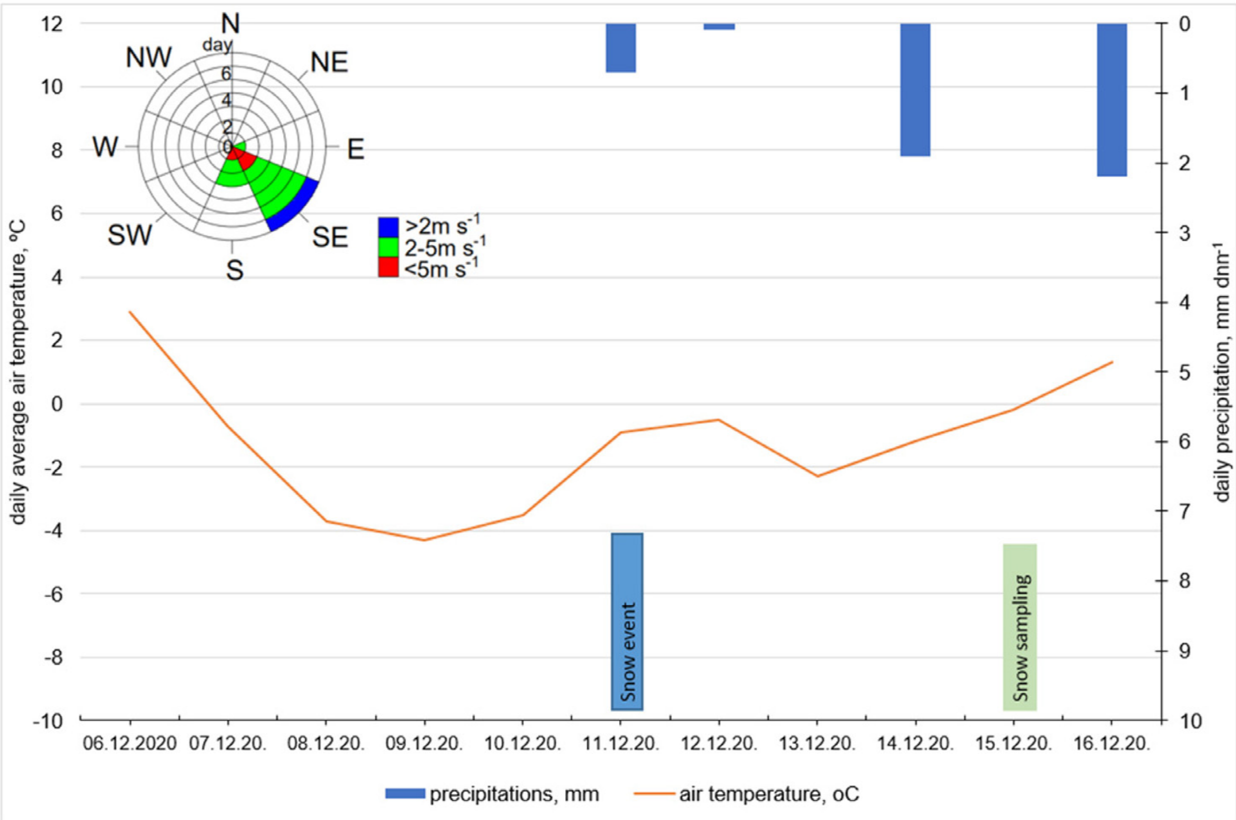

Fig. 2. The precipitation and air temperature before sampling period and wind direction and wind speed.

The three snow samples in each monitoring point were collected 5 meters from road [6] edge using measuring tape and 25 cm diameter steel ring covered with teflon Fig. 3. The snow depth was from 7 cm to 19 cm. The snow from ring were collected using disposable dust free nitrile gloves. All snow cover profile from sampling ring were collected in plastic containers and immediately transported to laboratory. The melted snow water was from 378 ml till 436 ml.

Fig. 3. Snow sampling method.

In Laboratory snow samples were melted and acidified up to 1% (m/m) HNO_3 final concentration in solution (1 mL of concentrated HNO_3, Fischer, TraceMetalGrade 69%, per 150 mL of sample). After 72 h samples were filtered through prewashed (1% (m/m) HNO_3 water solution) ashless paper filters (Whatman 541) [3,7–10]. The Inductively Coupled Plasma Mass Spectrometer "ICP-MS, Agilent 8900 ICP-QQQ" equipped with Micro-mist nebulizer and He collision/reaction cell was used for analysis of chemical elements in snow samples [7–10]. ICP-MS standard stock solution (10 mg/L, High Purity Standards, ICP-MS-68 A, NIST SRM 3100) was used for the calibration of equipment. Method of external calibration graph with blank correction was used. Deionised water (Millipore, EC $< 0.055\ \mu S/cm$) was used as blank solution. Calibration graph was constructed in concentration diapason from 0.1 $\mu g/L$ to 100 $\mu g/L$. 10 $\mu g/L$ internal standard mix solution of Bi, Ge, In, Sc, Tb, Y and Li was used as internal standard for system stability control. One standard solution was introduced into system after every ten samples to verify stability of measurements. Measurements were made in MS/MS configuration using He as collision gas (He flow – 5 mL/min). The instrumental parameters of ICPMS were set as follows: RF power - 1550 W, sampling depth - 8 mm, auxiliary gas flow - 0.90 mL/min, plasma gas flow – 15 L/min.

CRediT Author Statement

Inga Grinfelde: Term, Investigation, Writing - Original Draft; **Jovita Pilecka-Ulcugaceva:** Investigation, Validation, Methodology, Data curation, Writing - Reviewing and Editing; **Maris Bertins:** Formal analysis, Writing-Reviewing and Editing; **Arturs Viksna:** Methodology; **Vita Rudovica:** Writing - Review and Editing; **Sindija Liepa:** Visualisation, Data Curation; **Juris Burlakovs:** Writing - Review and Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have or could be perceived to have influenced the work reported in this article.

Acknowledgments

The snow sampling were funded by Latvia University of Life Sciences and Tecnologies and analysis of chemical elements in samples were funded by University of Latvia.

Supplementary Materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.dib.2021.107300.

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 DOI: 10.22616/rrd.28.2022.041

PREVALENCE OF LONG-TERM AND SHORT-TERM POLLUTION OF CHEMICAL ELEMENTS IN THE CITY OF JELGAVA

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Abstract
Air pollution is a global environmental problem. More than 92% of the world's population lives in areas where air pollution exceeds limit values. The aim of the research is to analyse the pollution of chemical elements and their distribution in the environment of Jelgava city, using long-term and short-term pollution detection methods. City air quality is a critical factor in ensuring the quality of life in the city.
Methods for the identification of contamination of chemical elements can be divided into two broad groups: 1. for the determination of short-term pollution and 2. for the determination of long-term pollution. Temporary pollution is determined using two methods: the analysis of snow samples and the placement of lichen transplants in the city. Long-term pollution is determined by analysing the chemical composition of lichen (*Xanthoria parietina*) and determining the air purity index I.A.P.
During the work, snow samples were collected on 10 January and 14 February 2017 to detect temporary contamination; samples were collected in 20 sampling areas of the urban area and one sampling area of the natural site with three repetitions. Chemical elements were identified in 120 snow samples and 60 lichen samples (*Xanthoria parietina*) from the city and six snow samples and three lichen samples (*Xanthoria parietina*) from the forest, which is on the southwest side of the city and represents background pollution with chemical elements.
Preliminary results vividly reflect the effect of transport corridors on the chemical composition of snow samples. Snow analyses indicate pollution from heat supply and road transport.
Key words: environment, pollution, heavy metals in the city, snow.

Introduction

Air pollution is one of the most significant environmental problems, as well as it is the biggest environmental threat to health (She *et al.*, 2017). People living in cities, especially large cities, face serious health threats from urban air pollution (Shi, Ka-Lun Lau, & Ng, 2017). Industrial development and urbanisation worldwide have led to chemical pollution of the environment. About 92% of the world's population lives in places where the level of air pollution does not meet the permissible limits (Battista & de Letto Vollare, 2017). Pollution in the air causes various diseases or even death in many parts of the world. The number of premature deaths due to air pollution in the world has risen from 0.22 million in 2010 to 3.7 million in 2012, highlighting the high health risk. For example, air pollution has become the fourth most significant risk factor for deaths in China (She *et al.*, 2017).

Economic activity increases every year, and it promotes the intensive use of natural resources. The use of chemicals in agriculture, households, mineral extraction and industrial use cause significant air pollution with various chemical elements (Tchounwou, Yedjou, Patlolla, & Sutton, 2014). Several studies use snow as an indicator of urban air pollution (Dossi *et al.*, 2007; Engelhard *et al.*, 2007).

The idea that lichen is affected by air pollution was first expressed in 1790 by studying lichen at metal foundries in North Wales (Nimis, Scheidegger, & Wolseley, 2002). The environmental monitoring method, based on the viability of lichen, is based on various environments. The development phase of lichen indication developed most rapidly in the 20th century. In the 1960s and 1970s, when the theoretical bases for lichen indications were formed, essential methods of lichenoindiation were developed, such as the Index of Atmospheric Purity – I.A.P. (LeBlanc & DeSloover, 1970). The benefits of lihenoindication are the low cost and ability to characterise long-term pollution. The objective of the research is to analyse the pollution and distribution of chemical elements in Jelgava city's environment using long-term and short-term pollution detection methods.

Tasks of the research are:

1. To get acquainted with the experience of previous research to identify chemical element pollution in the urban environment;
2. To develop a methodology for chemical element pollution identification and to select a pilot site for conducting a study;
3. To carry out sampling and sample analysis;
4. Analyse the prevalence of pollution of chemical elements and provide proposals to limit pollution.

Materials and Methods

Jelgava has more than 59,000 inhabitants (Office of Citizenship and Migration Affairs Republic of Latvia) and it is located in the middle of Latvia next to the Lielupe (Figure 1). It is located in the temperate climate zone. The average annual rainfall is 180 mm in autumn, 117 mm in winter, 124 mm in spring and 217 mm in summer. The snow typically ranges from November to March, and the length of the snow

Figure 1. The geographical location of Jelgava city (created by the author).

exposure period is affected by local meteorological conditions, such as the effects of urban heat islands. The region is dominated by westerly and south-westerly winds (LEGMC).

The territory of Jelgava city (60.32 km^2) for air quality mapping depending on the building density, location of highways and production companies is divided into 104 plots (green dots in Figure 2) – centre 500 m x 500 m (52 plots) and the rest area – 1 km x 1 km (52 plots). The sample plots were established in 1996, where repeated research was carried out according to a standard methodology also in 2006 and 2016. Considering the intensity of construction and the development trends of the city of Jelgava, 21 additional sample plots (read dots in Figure 2) have been created in this study (Figure 2).

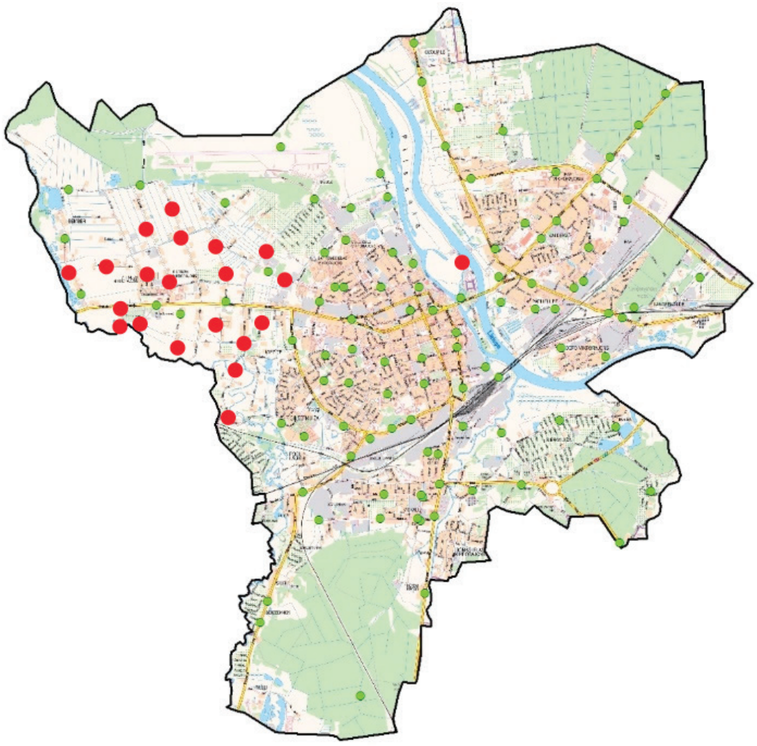

Figure 2. Location of lichen indication plots in Jelgava city, added plots in read (created by the author).

Quantitative assessment of lichen diversity is one of the simplest and most effective methods for lichen indication. Air purity index I.A.P. (Index of Atmospheric Purity) method (LeBlanc & De Sloover, 1970) is considered the most popular bioindication solution globally for air quality assessment obtained data reflect the long-term level of pollution. An inventory of all lichen species was made on ten tree trunks at the height of 30 cm to 2 m in each plot. The percentage of lichens by species is estimated on the side of the trunk where the most lichens are found.

The air purity index or I.A.P. is determined for each plot and consists of the sum of the product of the toxicological tolerance factor Q for all lichen species and the values for the degree of coverage f.

It is calculated by the following equation:

$$IAP = \sum_{l}^{n} \frac{(Q \times f)}{10} \quad (1)$$

where: I.A.P. – air purity index; n – number of lichen species in the study area; Q – toxic tolerance factor (constant for each lichen species) (1).

$$Q = {}^{n_1}/_{n_2} \quad (2)$$

where: n_1 – the total number of all lichen species in all plots containing the species of interest; n_2 – the sum of the sample plots in which the species of interest is found; f – degree of cover occurrence, which is determined by the combination of the percentage cover of the lichen species and the frequency of occurrence of the lichen species in each plot (2).

f values:

1 – species rare, with little cover; 2 – species rare or with 1-5% coverage; 3 – species not common or with 5-10% coverage; 4 – species often or with 10-20% coverage; 5 – species widespread with a coverage of more than 20%.

The study selected 1250 deciduous trees, possibly with similar ages, crown shapes and exposures, and similar growing sites, mainly on the side of streets and roads.

Analysis of snow samples is one of the methods for monitoring pollution with chemical elements in urban areas. As part of the work, snow samples were collected on 10 January and 14 February 2017 to determine transient chemical contamination. Samples were collected at 20 urban sampling sites and one natural site sampling site with three replicates, averaging from 1.0-1.5 kg of snow. The average snow depth was 6-10 cm. Inductively coupled plasma-optical emission spectroscopy (ICP-OES) method was used to determine chemical elements in melting snow water.

In order to determine the long-term pollution in the city area, lichen samples were collected. They were harvested from deciduous trees, about 1.3-1.5 m above the ground. Preparation of the samples to determine the chemical elements: (a) The lichens are dried and then weighed in a 50 ml glass beaker with an analytical balance of 0.3000 ± 0.0002 g. (b) Add 10 ml of concentrated HNO_3 and 5 ml of concentrated H_2O_2 (analytical reagents); (c) after 12 hours, the solutions were extracted by heating in a block at 160 °C; (d) After cooling the extract (7.5 ml), filter the sample solutions and makeup to 20 ml with ultrapure deionised water in polypropylene tubes. Metal concentrations and chemical elements were measured with an ICP-OES spectrometer. Chemical elements were determined in 120 snow samples and 60 lichen samples (*Xanthoria parietina*) from the city, six snow samples, and three lichen samples (*Xanthoria parietina*) from the forest outside the city.

Results and Discussion

The air purity index in the territory of Jelgava was calculated using data from 104 plots, and air pollution zones were divided into three groups:

I High pollution zone: With a minimal lichen population or lichen survival zones (I.A.P. from 0-110); II Medium pollution zone: With limited lichen population or transition zone (I.A.P. = 111 – 200); III Low Pollution Zone: Lichen-rich or natural environment zone (I.A.P.> over 200).

The high air pollution zone in Jelgava in 2016 occupied 1.66 km^2 or 2.75% of the entire city territory: it was found in 4 sample plots: in the centre of Jelgava – in 3 sample plots (part of wastewater treatment plants; the territory of LTD. Larelini, Palīdzības street) and outside the centre - in one sample plot (near Langervalde park).

The average air pollution zone in Jelgava in 2016 occupied 26.54 km^2, or 44.0% of the total area. Compared to the previous results in 1996, its area had slightly increased – from 25.76 km^2 or 44.0% to 26.54 km^2 or 44.0%, respectively, but compared to the results of 2006, it had decreased from 29, respectively, 26 km^2 or 48.51%, 26.54 km^2 or 44.0%.

In 2016, the low air pollution or clean air zone in the city of Jelgava occupied more than half of the city territory – 32.12 km^2 or 53.25%. Compared to the previous results in 1996 and 2006, in general, it had slightly increased in Jelgava: in 1996 – 32.11 km^2 or 53.23% and 2006 – 29.56 km^2 or 49.01%. However, compared to the previous results in the city centre, the clean air area now occupies only 3 km^2 or 23.08% of the area; moreover, it tends to decrease (5.75 km^2 or 44.25% and 5 km^2 or 38.46% respectively in 1996 and 2006).

The KL_SM_4 cluster is characterised by extremely high pollution, where the primary source is transport exhaust. The KL_SM_3 cluster is characterised by

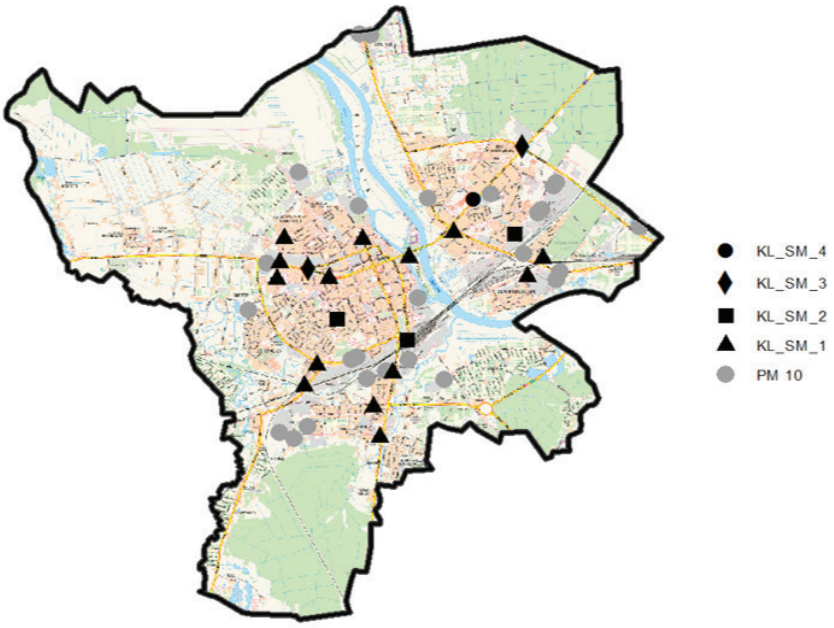

Figure 3. Cluster analysis results of short term air pollution by chemical composition of snow samples collected 14.02.2017 (created by the author).

high levels of pollution from transport exhaust. The KL_SM_2 cluster is characterised by high pollution resulting from industrial processes. The KL_SM_1 cluster is characterised by relatively clean air, with little pollution from transport (Figure 3).

Conclusions

According to the long-term air pollution monitoring data, there is 2.75% high pollution zone, 44.0% medium pollution zone and 53.25% low pollution zone in the territory of Jelgava city. According to the long-term air pollution monitoring data, there is 2.75% high pollution zone, 44.0% medium pollution zone and 53.25% low pollution zone in the territory of Jelgava city. According to short-term air pollution monitoring data, 2 points have very high transport pollution, but surprisingly high air pollution, the primary source of transport exhaust, is at one point.

For further research, it is recommended to establish a more uniform sampling network to obtain more detailed information on the spatial variability of chemical element concentrations.

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THE SPATIAL AND TEMPORAL DISTRIBUTION OF ZINC IN SNOW: CASE STUDY OF JELGAVA CITY

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ABSTRACT

The harmful effects of various air pollutants on human health, living in a polluted air environment, are relatively well proven: the morbidity of the population is increasing, life expectancy is decreasing. Suspended particulates are one of the generally recognized air pollutants. The most dangerous solid particles are released during primary combustion processes, they contain heavy metals (zinc, copper, iron, lead). Heavy metals are known to be persistent in the human body and remain for decades. Heavy metals can enter the human body by inhaling dust particles, coming in contact with contaminated soil and water.

According to the National Atmospheric Emissions Inventory, the main causes of zinc suspended particulate matter pollution are emissions from industrial areas, fuel and diesel combustion processes. Even suspended particles from car tires and brake disc wear can account for up to 20% of zinc air pollution. As a result of all these activities, zinc enters the urban environment, where it accumulates as the snow melts.

In environmental monitoring snow is a valuable resource for information on air pollution sources and air pollution levels. Snow serves as an efficient accumulator for car exhaust gases, as well as an accumulator of other pollutants. It has a large surface area that can store as much pollutants as possible.

The aim of the work is to look at the zinc pollution in the snow cover in the city of Jelgava by using descriptive statistics, and to draw conclusions about the changes in air quality over the years. The results of 240 measurements obtained from 60 measurement sites in Jelgava in the period from 2018 to 2021 were used in the data processing. The compacted infrastructure and high-rise buildings in the city center form corridors where zinc pollution can accumulate. Preliminary results indicate high levels of zinc pollution at key traffic points.

Keywords: pollution, heavy metals, environment, ArcGIS, Inverse distance weighted (IDW)

INTRODUCTION

Emissions of air suspended particles remain one of the most pressing air quality problems in cities, both in the World, Europe and Latvia [1], [2]. In Latvia, the situation is worse than the average in the EU, directly in terms of the impact of particles $PM_{2.5}$, where Latvia has the 17th worst position among the 41 European countries assessed [3], [4].

Poor air quality has a negative impact on quality of life, particularly for urban residents. It can cause health problems such as asthma and cardiovascular diseases, reducing life expectancy [5]. Zinc, although this heavy metal is considered to be relatively non-toxic, symptoms such as nausea, vomiting, abdominal pain, lethargy and general fatigue are expected to occur when the human body is exposed to high doses [6], [7] However, a Canadian study found a close link between zinc pollution and mortality [7].

As well, heavy metals that come into the atmosphere with releases of different sources of pollution, with time in the form of wet and dry deposits, lie on the soil and accumulate in the surrounding environment, because they are not biodegradable, their chemical status may vary as well as their toxicity changes. It has been estimated that 500 g ha^{-1} of zinc is on soil in Europe during the year [7], [8].

Increases in concentrations of solid suspended particles are caused by combustion processes for fuel and diesel fuel, heat energy production processes in boiler houses, as well as various dust generating processes [7].

Transport is also a major source of air pollution, particularly in cities. Air pollutants such as fine particles (PM) and nitrogen dioxide (NO_2) are harmful to human health and the environment. Although air pollution caused by transport has decreased over the last decade due to the introduction of fuel quality standards, Euro emissions standards and the use of cleaner technologies, concentrations of air pollutants are still too high [9]. The number of vehicles in Jelgava City is increasing, with light cars dominating. At the beginning of 2020, 25 336 vehicles were registered in the city [10].

Diesel engines consume 25% less fuel compared to petrol engines. Diesel engines are also more durable, serve longer and their CO_2 emissions are lower than gasoline engines, but they have relatively higher emissions of volatile organic compounds and NO_X that contribute to air pollution. Diesel engines also cause significant air pollution with PM_{10} dust, which is considered to be carcinogenic. New vehicles with catalysts can significantly reduce these emissions [11]. However, it should be stressed that there is a trend towards a second-hand car market in Latvia, and it is cars that are already considered too polluting elsewhere in Europe that come to urban traffic.

MATERIALS AND METHODS

Jelgava is located in the central part of Latvia - in the north of the Zemgale plain, on both shores of the other major rivers of Latvia - Lielupas. It is the fourth largest city of Latvia, both in size and population. The city area is characterised by flat terrain. The absolute markings of the ground surface range from 2.5 to 4.5 m above sea level, with a high level of groundwater in the city. Jelgava has a total area of 60.3 km^2 of which 272 ha is open water, 1264 ha - forests, 162 ha - parks and square areas. The geographical location of the city and the intersection of transport lines have contributed to the development of Jelgava as one of the country's most important transit centres. Five railway lines and six motorways are crossed in Jelgava [12].

The snow samples surveyed were collected in 2018, 2019, 2020 and 2021. During the January and February period of each year, 59 snow samples and 1 control sample were collected in the city of Jelgava, from the point where urban pollution is not present. The sampling sites have been fixed and have not changed over a period of 4 years. Samples were collected in industrial areas, in multi-apartment and private house areas, in areas with high transport infrastructure, as well as in green areas.

Samples were harvested seven days after snowing, which gave time for air pollution to sink into a blanket of snow. To ensure the accuracy of the measurements, snow samples were collected using plastic gloves, dishes and stored in a pre-prepared organic glass box. Sampling was carried out at least five metres from the part of the road. Each sample of snow was taken from the full thickness of the snow and its mass ranges from 1 to 1.5 kg. All molten snow samples showed the presence of zinc. The heavy metals content was determined using inductive coupled plasma optical emission spectrometry (ICP-OES) [13].

The measurements were analysed with descriptive statistics and data transformations were carried out to make it possible to compare the changes and prevalence of zinc contamination over the years. After the transformation of the data, measurements for each year were included on a scale of 0 to 100, where 0 is the year's lowest zinc value, while 100 for that year's highest.

Maps were developed for each year using the ArcGIS Pro (IDW) function [14]. The "Planning Regions – 2021, Jelgava City" data layer was selected as the border. The sampling coordinates to which data transformations are linked. The map is supplemented with layers of interest "Oak, Specifically Protected Nature Areas", "Roads" and "Railways". In addition, a map including data from 2018 to 2021 was created to assess the 4-year overall trends in zinc contamination.

Figure 1. The location of snow sampling points.

The data processing uses a score of 240 measurements derived from 60 measurement sites in Jelgava during the period 2018-2021. 4 measurement results have been obtained for each of the measuring points, respectively.

RESULTS AND DISCUSSION

Looking at the results of the descriptive statistics (Table 1), it appears that in 2018 the highest average zinc measurement was 79.62 µg l^{-1}, which almost 9 times the average measurement of 8.88 µg l^{-1} is obtained in 2020.

The largest zinc measurement of 1002.05 µg l^{-1} was obtained in 2018 and the smallest measurement of 0.99 µg l^{-1} was obtained in 2020. Looking at the percentile distribution of values, it appears that in 2018 Jelgava produced significantly higher measurement results than in 2019-2021. The 2019-2021 measurement values are hardly similar.

Table 1. Descriptive statistics of zinc concentrations µg l^{-1} in snow samples (by author).

Variables		**2018**	**2019**	**2020**	**2021**
N	**Valid**	60	60	60	60
	Missing	0	0	0	0
Mean		79.62	19,17	8.88	10.02
Std. Error of Mean		17.62	3.56	1.05	0.87
Median		45.91	11.10	6.42	7.54
Std. Deviation		136.46	27.54	8.13	6.74
Variance		18311.48	745.86	65.01	44.67
Minimum		9.22	3.89	0.99	3.60
Maximum		1002.05	204.55	47.48	34.98
Percentiles	**25**	22.32	7.88	3.64	5.88
	50	45.91	11.10	6.42	7.54
	75	81.51	20.02	10.65	10.87

Looking at the spatial representation of normalized zinc measurements in 2018 (Figure 2). The highest concentration of zinc particles was found at the intersection of Dobele and Satiksmes Street (monitoring point 39). The second highest value was found near the regional road P99 (monitoring point 57) and on the regional road P95 (monitoring points 17 and 21). Further significant concentrations are observed on the path of national importance A8 (monitoring point 9).
The outspoken theory, which explains the particularly high zinc measurements in 2018 with fireworks, could confirm the relatively elevated zinc values on the Pasta island (monitoring point 48), which serves as a rallying ground for various measures. For the rest of the year, no increased contamination of zinc particles has been identified in monitoring point 48.

In 2019 (Figure 3), the largest zinc pollution stands out directly at the city dime, where most of the highest zinc particle measurements are obtained. The highest values were observed directly in the centre of town (monitoring points 45 and 47) and at the centre of town borders (monitoring points 38 and 43).

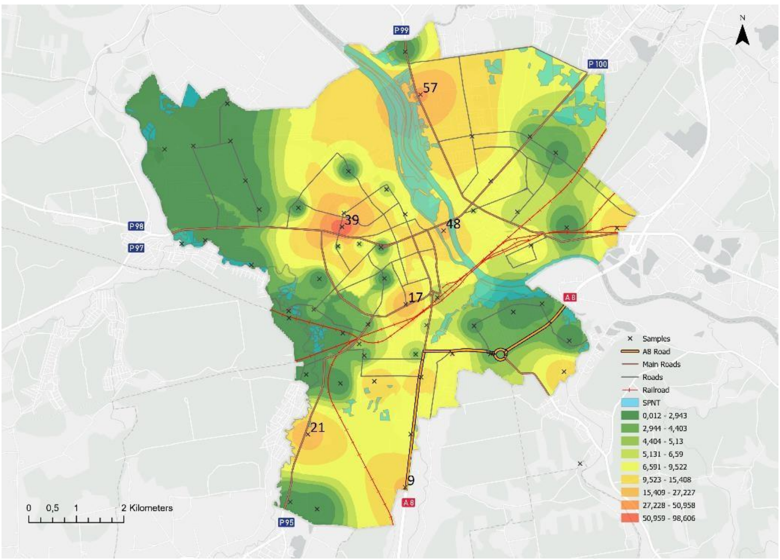

Figure 2. The distribution of zinc in snow samples in Jelgava at year 2018.

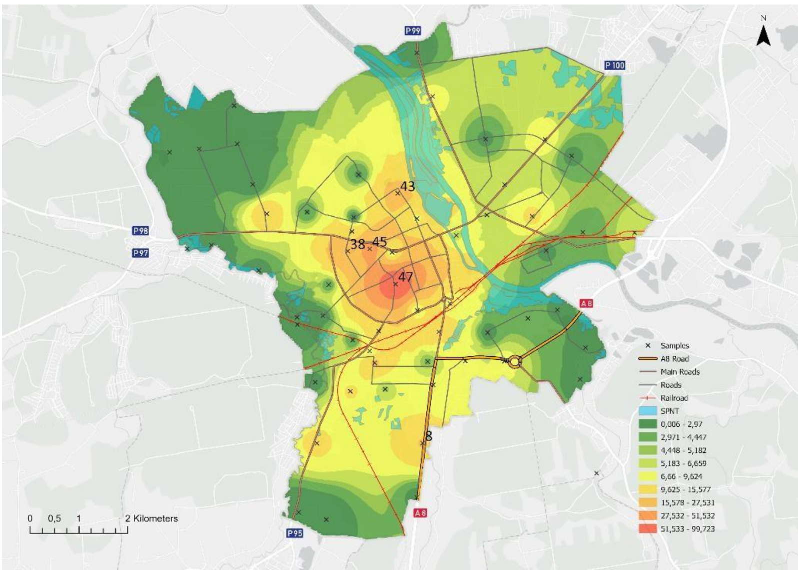

Figure 3. The distribution of zinc in snow samples in Jelgava at year 2019.

In 2020 (Figure 4), the highest values were observed on the national road A8. 3 measurements on this path indicated an increased zinc concentration (monitoring points 8 and 9). An increased concentration of zinc particles is observed near the Dobele Highway as well as the regional road P100 (monitoring point 55). All points of increased concentration point to the traffic movement in the direction of Riga. As well as the south, south-east winds.

In 2021 (Figure 5), downtown to a common urban background, there is less zinc particle pollution than other years. This year, significant measurements of zinc particles have been observed on regional roads P99, P100 and P93, as well as on the national road A8. For the first time in 4 years, elevated zinc particles have been observed in monitoring point 4. This point is located in the private housing area. The potential contamination could be explained by a individual heating systems or even polluting activities such as illegal waste burning in local heating systems and burning tires.

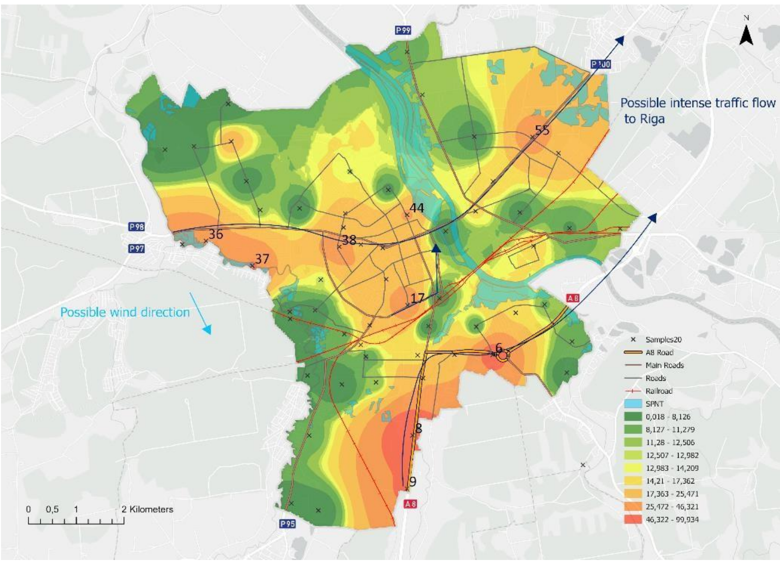

Figure 4. The distribution of zinc in snow samples in Jelgava at year 2020.

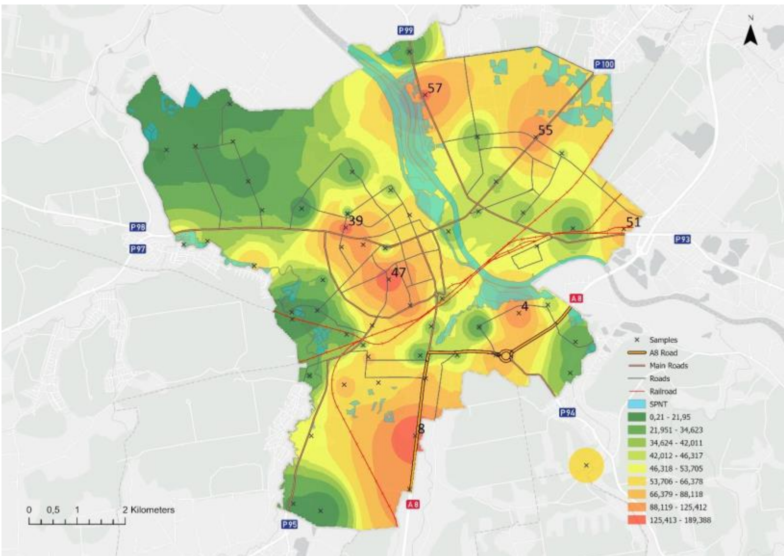

Figure 5. The distribution of zinc in snow samples in Jelgava at year 2021.

In compiling the results obtained (Figure 6), the outcome has already been achieved, the city centre and the main roads are significantly more polluted by zinc particles than the rest of Jelgava. The largest contamination of zinc particles occurs on the national road A8 (monitoring point 8) and on the regional road P99 (monitoring point 57).

In downtown over a 4-year period, the largest contamination of zinc particles was detected at the intersection of Dobele and Satikmes Street (monitoring point 39) and at the intersection of Tervetes and Pavasara Street (monitoring point 47). It is worth noting that for a specially protected nature area, Lielupe river slouch meadow is located in parallel on the regional road P99, which has been found to be contaminating zinc particles and that zinc particles are likely to come to the protected area.

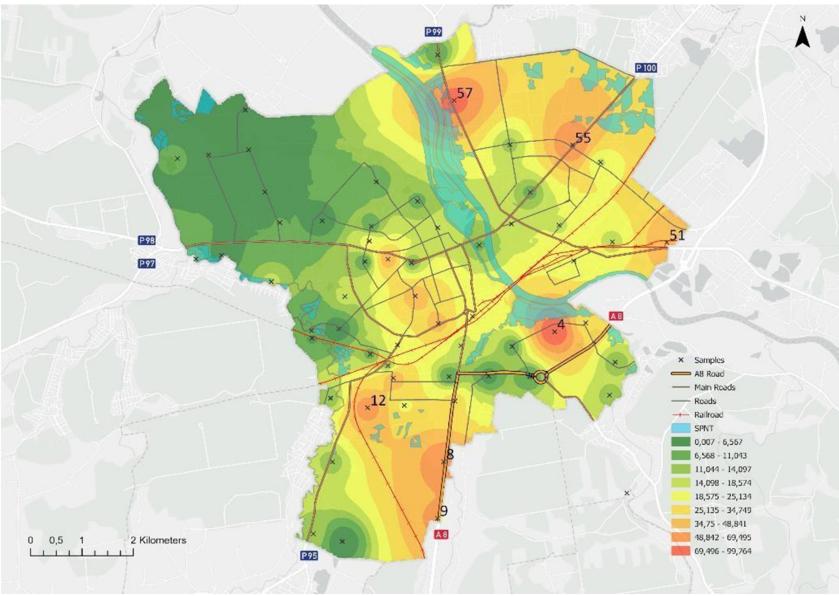

Figure. 6. The distribution of zinc in snow samples in Jelgava at years 2018 till 2021.

CONCLUSION

The study shows that the analysis of zinc contamination in the snow can lead to a perception of air quality. Urban zinc pollution goes to specially protected nature areas. The city center's compacted infrastructure and high-rise buildings create corridors to accumulate for zinc pollution.

The largest zinc measurement of 1002.05 μg l^{-1} was obtained in 2018 and the smallest measurement of 0.99 μg l^{-1} was obtained in 2020. Looking at the percentile distribution of values, it appears that in 2018 Jelgava produced significantly higher measurement results than in 2019-2021. The 2019-2021 measurement values are hardly similar.

Increased zinc pollution is a good indicator of intensive traffic, which reflects well the effects of traffic on air quality. One of the largest air pollutants is transport. The largest contamination of zinc particles occurs on the national road A8 (monitoring point 8) and on the regional road P99 (monitoring point 57).

Collecting data with site and time fixation makes it possible to further use data in other studies, such as air quality impact assessments.

Linking the data obtained to geographic information systems can give an increased understanding of the processes observed. In the context of the future, the most polluted urban areas can be predicted.

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THE SPATIAL AND TEMPORAL DISTRIBUTION OF ALUMINUM EMISSIONS IN AIR FROM TRANSPORT IN JELGAVA

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ABSTRACT

The number of transport units in cities is increasing every year. This trend contributes to air pollution problems in many rapidly urbanizing countries. Various heavy metals and other chemical elements, including aluminum, have been related to air quality degradation. Poor air quality affects people, especially young children, the elderly, and people with chronic illnesses, causing health problems and aggravating existing problems. The aim of the research is to find out which parts of the city of Jelgava have the highest risk of aluminum pollution in the air. In the research was used Jelgava city snow sampling spatial data of aluminum pollution in air collected over a period of four years. The concentrations of aluminum elements in snow water were determined using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS). The results show that the average arithmetic values of aluminum differ significantly when looking at the data from 2018-2021 and range from 0.076 µg/l to 91.68 µg/l. The collected data can be used in planning of the urban environment, in the selection of construction technologies, as well as in the implementation of air quality improvement solutions to reduce aluminum pollution in the air at residential areas.

Keywords: pollution, metals, ICP-MS, vehicles, snow

INTRODUCTION

Air pollution around us is every day. Air pollution, including dust containing various metals, has been identified as one of today's most critical problems for human health [1], [2]. Outdoor air abatement rates are determined not only by emissions sources but also by a variety of external factors-wind, emissions interaction, and cross-border air pollution [1]. Aluminum sources can be divided into two groups: natural (volcanic eruptions, weather conditions where aluminum is transferred in the form of soil particles to water, and air) and anthropogenic sources (automobiles, industry, waste incineration, coal incineration) [2], [3], [4], [5].

Aluminum is present in a variety of concentrations, both in the air and in water, and food, which is used daily [5] [6]. In atmospheric air, aluminum concentrations are very variable: above Antarctica, it is 0.0005 µg/m3, while in urban areas, the concentration can reach one µg/m3 [5], and aluminum is naturally present in food [6]. The health risks arising from exposure to aluminum depend on its physical and chemical forms, and how the response varies depending on the type of intake, extent, duration, and frequency [6]. Aluminum is commonly inhaled or eaten in the human body [7]. In particular, inhalation of aluminum particles in the air may be linked to the development of asthma [6]. However, no relevant evidence exists to identify it as a cause of disease [6], [8].

The city is an area that grows and develops every day and is at increasing risk of industrial and transport air pollution. The overall car park is aging in part of Europe, including Latvia. The impact of the city's air quality on health and the well-being of people is increasingly pressing. The aim of the research is to find out which parts of the city of Jelgava have the highest risk of aluminum pollution in the air.

MATERIALS AND METHODS

The study was carried out in the administrative area of Jelgava City. Jelgava is located in the central part of Latvia. Jelgava is the fourth largest city in Latvia by population and the fifth by area. Jelgava had a population of 56.383 in 2018, which decreased to 55.336 by the beginning of 2021 [9]. The total area of Jelgava is 60.56 km2. One of the largest rivers of Latvia – Lielupe, flows through Jelgava. The average annual temperature in Jelgava is 6.5 ^{0}C, and the average rainfall is 642 mm. Snow cover in the city is usually observed from November to March [10].

Snow samples were collected over four years, from 2018 to 2021, when snow accumulated for at least seven days.

Samples were collected at 59 monitoring points and one monitoring point located in a natural area 15 km south of Jelgava city center. A total of 180 snow samples were collected each year [11].

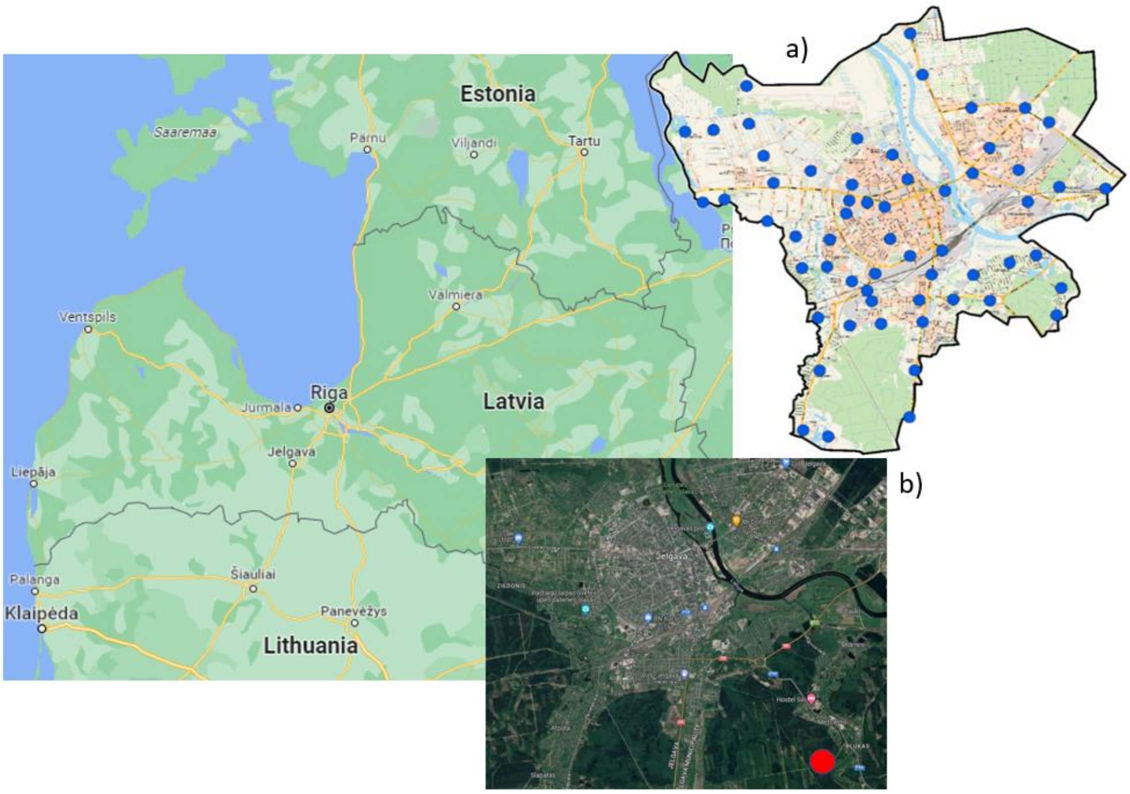

Figure 1. The geographical location of Jelgava, a) sampling sites in the city of Jelgava, b) Location of control (Mežciems)

Snow samples were collected in different places in the city of Jelgava: in the territories of private houses, in the territories of apartment buildings, in the territories of industrial buildings, in the territories of transport infrastructure, and in natural and green areas. Rubber gloves were used to collect snow samples. Samples were collected with a round ring that was cleaned between sample collections to avoid contamination of the collected samples from other collected samples. The sampling ring was placed approximately 5 m from the roadway or pedestrian sidewalk. Snow samples were collected in sterile plastic boxes (Container transparent PP) with a total volume of 1000 ml [4], [11]. After the samples were collected, they were immediately transported to the laboratory and refrigerated. Contaminant concentrations were determined in all collected snow samples. Aluminum was determined (among other elements) in melted snow water. Snow samples melted at refrigerator temperature were analyzed for chemical elements using an Inductively Coupled Plasma Mass Spectrometer (Agilent 8900 ICP-QQQ) equipped with a Micro-mist nebulizer and a He collision/reaction cell. Instrument calibration was performed using ICP-MS standard stock solutions.
The transformation of data was used to understand nobility in aluminum pollution over the years and to be able to determine the dynamics of pollution, where aluminum values were recalculated and scaled on a scale of 0 to 100 each year, where 0 is the lowest value, and 100 is the highest value. The data were analyzed using descriptive statistics and spatial analysis.

RESULTS

The results of 60 aluminum measurements from various sample collection locations in Jelgava over four years were used for data processing. All measurements were included in this paper - no significant deviations were found in any measurement—descriptive statistics for measurements carried out on aluminum over four years (2018-2021).

Table 1. Aluminium (Al) measurements in snow from 2018 to 2021.

Variables		**Al, µg/l | 2018**	**Al, µg /l | 2019**	**Al, µg /l | 2020**	**Al, µg /l | 2021**
N	**Valid**	60	60	60	60
	Missing	0	0	0	0
Mean		1.129	0.076	91.683	32.584
Std. Error of Mean		0.479	0.008	22.562	6.670
Median		0.252	0.057	38.593	12.204
Std. Deviation		3.678	0.062	173.300	51.230
Variance		13.527	0.004	30032.991	2624.479
Minimum		0.042	0.016	4.317	4.427
Maximum		28.000	0.359	1183.660	315.166
Percentiles	**25**	0.111	0.035	19.842	7.361
	50	0.252	0.057	38.593	12.204
	75	0.828	0.091	71.319	35.338

As shown in Table 1, the average values of aluminum vary significantly between years, with the smallest value in 2019 at 0.076 µg/l and 91.683 µg/l in 2020. The slightest standard error is in 2019, with only 0.008 µg/l and the largest reaching 22.562 µg/l in

2020. As with annual averages, the median values vary significantly through the years, with only 0.057 µg/l in 2019 and reaching 38.593 µg/l in 2020. The table shows that the highest standard deviation was observed in 2020 at 173.300 µg/l and significantly lower at 0.062 µg/l in 2019. The minimum measurement value was found at 0.016 µg/l in 2019, and the highest minimum value was found in 2021 at 4.427 µg/l. The smallest maximum aluminum value was found in 2019 at 0.359 µg/l; the maximum aluminum value reached 1183.660 µg/l in 2020.

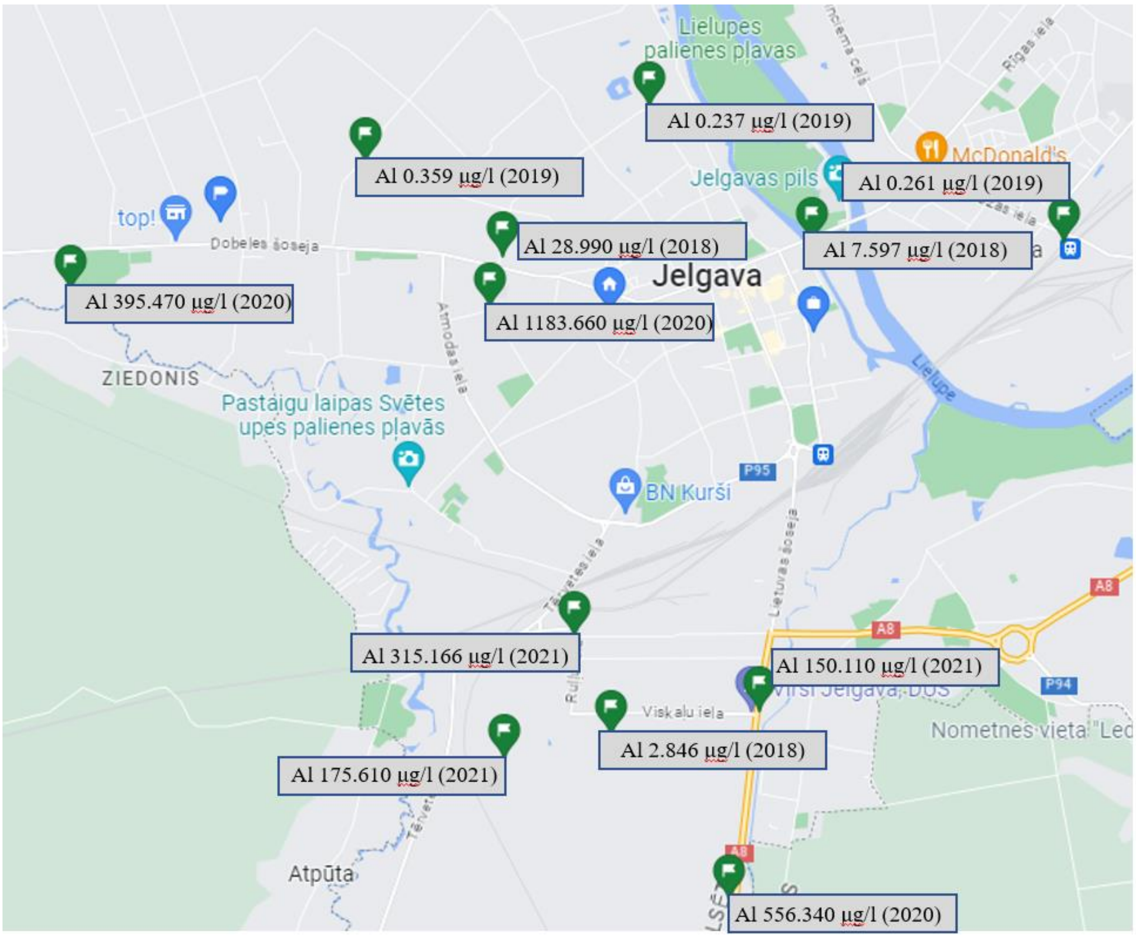

Figure 2. The highest aluminum concentrations in the city of Jelgava during 2018-2021.

DISCUSSION

Snow is a regular phenomenon in the study area. Snow is considered the perfect matrix for determining the deposition of pollution from the atmosphere, which is a sample that is easy and cheap to import [12]. Thanks to the excellent nature of the snow (the ability to accumulate pollution), it is used as an air pollution detection tool when determining the short-term air pollution of the city of Jelgava during winter.

In this study, most of the sampling sites are located approximately 5 m from the roadway or pedestrian sidewalks, which could show higher Al concentrations. Kuoppamäki et al. (2014) concluded that the interaction between traffic intensity and distance from roads was statistically significant. The effects of traffic intensity on dissolved heavy metals varied, but concentrations were generally higher near roads compared to 5 m away, especially for aluminum, cobalt, and chromium. Kuoppamäki et al. (2014) concluded that aluminum concentrations were also higher on high-intensity roads compared to low-intensity roads [13]. The existence of the maximum values of aluminum in the city of Jelgava is pronounced along the main transport corridors, which clearly mark them. The samples collected in 2018 and 2020 mark the Dobele highway and Rīgas Street, which is the main road connecting the city of Dobele, the city of Jelgava, with the capital of Latvia, Riga. It should be mentioned that the city of Jelgava has only one bypass road leading to Garozas Street, where high Al concentrations (0.261 µg/l) were found in 2019. Kuoppamäki et al. (2014) emphasize in their study that 5 m from the road, there are higher concentrations of Al than in more distant places. Also, in our study, high concentrations of Al were found on the Lithuanian highway that connects more remote villages of Jelgava county with the city of Jelgava. The Jelgava ring road leading to Riga, as well as the Lithuanian highway, is the main transport corridor for transport from Lithuania to Jelgava, as well as part of the cargo from Lithuania, is delivered to Riga through the Jelgava ring road, where Al concentrations are very high both in 2019 and 2020 and in 2021.

In the study by Akba et al. (2013), the concentration of aluminum in the wastewater sample is 0.048-0.056 mg/l [14], a relatively large indicator that further enters the surface water. In the Jelgava city study, the values range from a few µg/l to more than 1183 µg/l in the analyzed melted snow sample. In the study of Akba et al. (2013), the concentration of Al directly in the snow is 13.245 µg/kg [14]; compared to our study, this value is slightly higher than the maximum values found in the city of Jelgava.

The local microclimate and wind direction should be analyzed in the future, as the urban prevalence of the maximum values found in plots shows common trends over the years. For example, in 2021, all the maximum aluminum values have been grouped towards the south of town.

CONCLUSION

This study showed that snow analysis successfully reflects the amount of aluminum pollution in the city of Jelgava. Snow, as a natural short-term pollution accumulator, can be successfully used in Latvian conditions to identify the state of air quality.

The intensity of the distribution of chemical elements varies considerably from year to year. Nevertheless, it must be taken into account that various factors must be taken into account in the process of snow accumulation, such as wind, precipitation, melting conditions, a specific time, how long, and in what period the snow has accumulated.

Annually, the data are comparable, but when comparing between years, it is recommended to use normalized data.

The obtained data can be used in urban planning, in the selection of construction technologies, as well as in the implementation of air quality improvement solutions in various areas.

The amplitude of fluctuations is highly variable over the years. The maximum values differ significantly between years. For example, in 2018, the maximum value of aluminum was 28.0 µg/l. In 2019, 0.359 µg/l; in 2020 1183.660 µg/l. And in 2021, 315.166 µg/l.

In further studies, in order to obtain more accurate data and specific sources of pollution, it would be necessary to distinguish different groups of territories where samples are collected, as well as to identify in industrial territories which production sectors are represented, in the territories of private houses, which heating systems are used, and to conduct observations of traffic intensity for determination. Also, the collection of samples should be carried out in meteorologically similar conditions and during identical periods of snow accumulation.

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THE DISTRIBUTION OF TUNGSTEN IN JELGAVA CITY AT 2022 AND 2023

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ABSTRACT

Every year, cities are becoming more populated and urban traffic more intense. Urban air quality is deteriorating and causes for pollution are being sought and solutions to improve the quality of life in urban areas. Atmospheric deposits, vehicles, traffic and de-icing products are the main sources of snow pollution in cities. Snow, located near roads and streets with intense traffic, is a very useful tool for identifying the risks of traffic-related metals in the environment. In many countries, in winter, they use tires with studs made of tungsten-based material. The tires wear out to fine particles that disperse in the environment, particularly in the vicinity of roads and streets. In the environment, tungsten can also come from the incineration of waste and industry. Due to low concentrations of tungsten in the natural environment, this can be a potentially good identifier for traffic and other anthropogenic contamination. The aim of the study is to identify the risk of spreading tungsten in different areas in Jelgava. This study studied the harvested snow in 2022 and 2023. Snow was harvested at 59 monitoring points 5 m from the road or street section in Jelgava, Latvia. Tungsten concentrations were determined by ICP-MS. The average concentration of tungsten was 0.154 µg/L in 2022 and 0.342 µg/L in 2023. Five groups of tungsten distribution from low pollution risk to high pollution risk were divided using the hierarchical clustering method. The spatial distribution of divided risk groups in urban areas highlights the impact of the transport corridor and private buildings on the urban distribution of tungsten.

Keywords: tungsten, ICP-MS, air pollution, snow, traffic in the city

INTRODUCTION

In most cities, traffic is the largest contributor to particulate matter in the air, and traffic, as such, is considered one of the primary sources of environmental pollution in urban areas [6], [9]. In regions with cold climatic conditions, the study of snow becomes an essential topic of environmental research [6]. Snow can be used to monitor local air pollution caused by road traffic [6].

Snow is a good collector of organic and inorganic matter. Snow acts as a natural filter for various chemical elements, particles, and dust, especially those resulting from anthropogenic activities (for example, industry and road traffic) [1], [6], [9].

Snowflakes accumulate more atmospheric pollutants than raindrops because of their larger surface area and slower falling speed [6]. The snow also absorbs dust from the material spread on the road in winter. Using tires with studs causes additional wear on the driving part and the studs containing tungsten. This dust enters the snow and the surrounding environment, especially during winter [2], [4]. The concentration of tungsten decreases rapidly with the distance from the roadway, which indicates an indisputable source of pollution from the road [4]. In general, street dust consists of road wear material and sand that is spread, as well as tire and brake wear, engines (combustion and friction), and vehicle corrosion [1].

Due to the low concentration of tungsten in the natural environment, it can be a suitable identifier of road and traffic pollution [4]. Tungsten is released naturally into the atmosphere through wind-blown dust from the soil, or it can enter waters by leaching. Several studies have reported an increased content of tungsten in road dust rainwater runoff from the road and roadside soils, which is associated with wear of tire studs, wear and tear of cars, and intensive traffic flow [1], [6], [3]. In processes of anthropogenic origin, tungsten can still occur, for example, in ore processing processes, as a result of the production of hard metals, during the production and use of tungsten carbide, as well as as a result of the combustion of household waste, when tungsten escapes into the atmosphere [8].

The aim of the study is to identify the risk of spreading tungsten in different areas in Jelgava.

MATERIALS AND METHODS

The study was carried out in the administrative territory of Jelgava City. The total area of Jelgava is 60.56 km^2 see Figure 1. One of Latvia's largest rivers, Lielupe [10], flows through Jelgava. In early 2022, the city of Jelgava had a population of 54694 [12]. The exact location and location of the control monitoring point and snow sample collection can be found in Grinfelde et al., 2021.

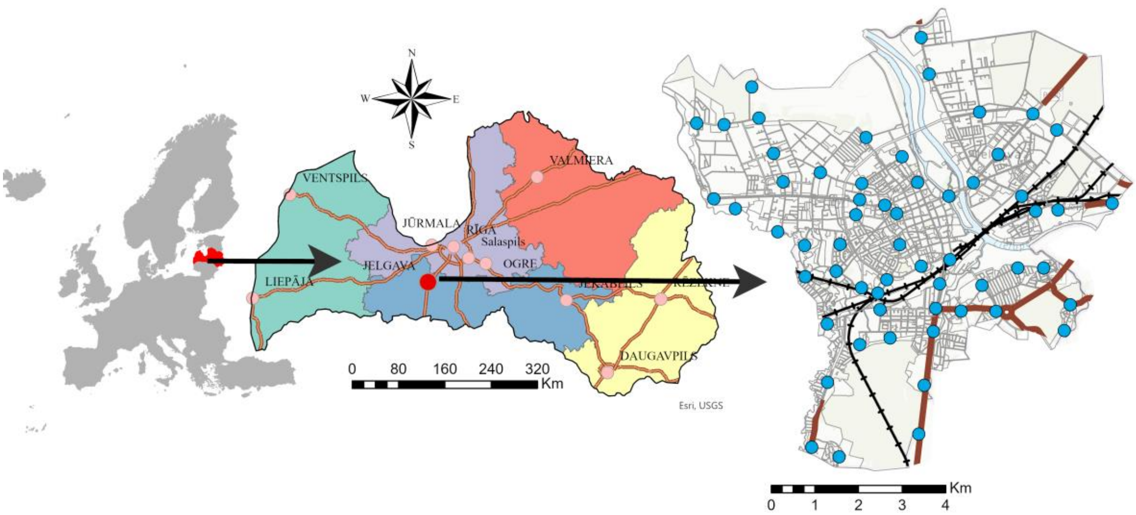

Figure 1. The geographical location of Jelgava.

Public weather data from the “Latvian Environment, Geology, and Meteorology Centre” meteorological observation station “Jelgava” (56 ° 33 ′ 24,954 ″ N and 23 ° 57 ′ 50,679 ″ E) were used to describe climatic conditions during sampling. Snow samples were collected on February 4, 2022. The average air temperature on the sampling day was -2.33 °C, snow cover was 5.8 cm, and rainfall was 1.4 mm. Snow samples were collected after an 8-day exposure period. Snow samples were collected on January 9, 2023. The average air temperature on the sampling day was -2.48 °C, the average snow cover was 4 cm, and the rainfall was 0 mm on the sampling day. Snow samples were collected after a 6-day exposure period.

Snow samples were collected about 5 m from the roadway. A steel ring with an inner diameter of 25 cm was used for sample collection. Snow was collected from the ring using disposable dust-free nitrile gloves. The entire snow cover was collected from the steel ring. The snow was collected in sterile plastic containers and immediately transported to the laboratory.

Samples were analyzed using an inductively coupled plasma mass spectrometer ICP-MS, Agilent 8900 ICP-QQQ. Snow samples were analyzed according to the method described by Grinfelde et al., 2021.

Cluster analysis was performed for normalized (0-100) 2022 and 2023 data series. Agglomerative hierarchical clustering (AHC) analysis using Euclidean distance calculation and Ward’s method.

RESULTS

In 2022, the minimum value for tungsten in the territory of Jelgava is 0.050 µg/L, the maximum value is 4.352 µg/L, and the median is 0.050 µg/L. the minimum value in 2023 for tungsten in the territory of Jelgava is 0.060 µg/L, the maximum value is 0.960 µg/L, and the median is 0.179 µg/L see Figure 2.

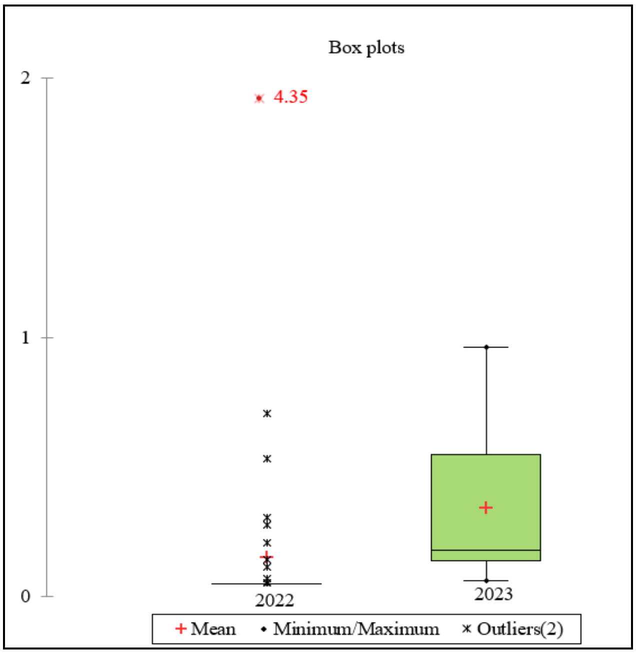

Figure 2. Variation of tungsten by year.

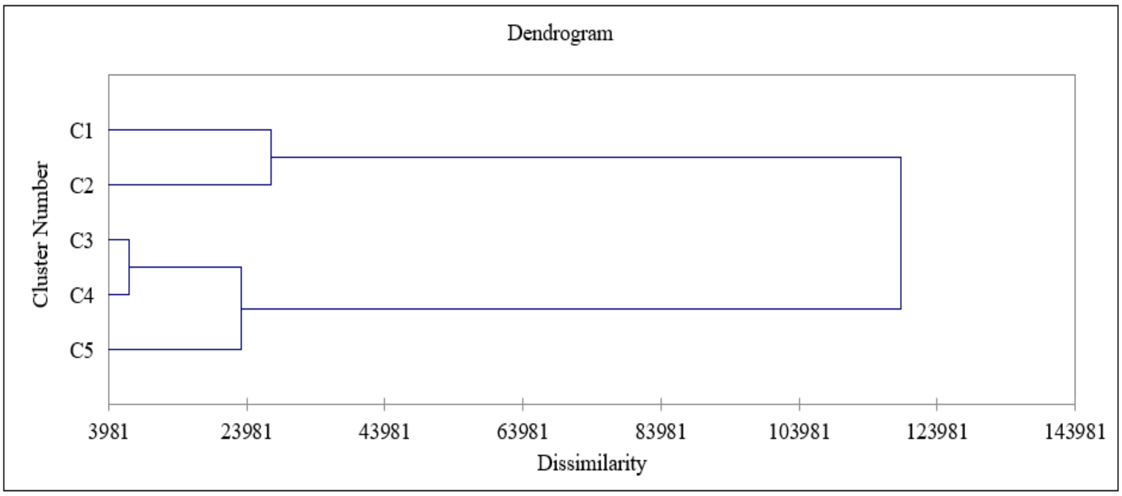

Figure 3. Hierarchical cluster analysis of tungsten.

Cluster analysis resulted in five vanadium contamination risk groups. The first cluster has a mean value of 0.119 µg/L and a median of 0.097 µg/L. The mean value of the second cluster is 2.311 µg/L, and the median is 2.311 µg/L. The mean value of the third cluster is 0.246 µg/L, and the median is 0.251 µg/L. In the fourth cluster, the mean value is 0.351 µg/L, and the median is 0.355 µg/L. In the fifth cluster, the mean value is 0.443 µg/L, and the median is 0.445 µg/L.

The minimum, maximum, average, and median values of tungsten are summarized in Table 1. The results were obtained after cluster analysis for the city of Jelgava for 2022 and 2023. See Table 1 for the breakdown by year.

Table 1. Descriptive statistics of tungsten by clusters.

Cluster by year	**Minimum (µg/L)**	**Maximum (µg/L)**	**Mean (µg/L)**	**Median (µg/L)**	**Risk level**
2022 | 1	0.050	1.009	0.093	0.050	Low risk
2022 | 2	4.165	4.483	4.352	4.406	Extremely high risk
2022 | 3	0.050	0.310	0.087	0.050	Medium risk
2022 | 4	0.050	0.288	0.072	0.050	Medium-high risk
2022 | 5	0.050	0.050	0.050	0.050	High risk
2023 | 1	0.050	0.250	0.144	0.143	Low risk
2023 | 2	0.260	0.280	0.270	0.270	Extremely high risk
2023 | 3	0.290	0.520	0.405	0.405	Medium risk
2023 | 4	0.530	0.740	0.635	0.635	Medium-high risk
2023 | 5	0.750	0.990	0.870	0.870	High risk

DISCUSSION

In a study conducted in Sweden, tungsten concentrations increased in winter but were much lower in summer. Average values of tungsten in road runoff in winter were 9.18 µg/L, in summer 1.06 µg/L in Svaneberg, in Norsholm they were 0.58 µg/L in summer, and 5.77 µg/L in winter. Tungsten is often neglected in road runoff studies, although it is often used in tire studs. [4]. Our research shows the significant impact of transport corridors. The exceptionally high risk of contamination with tungsten appears in the main transit direction to Lithuania, where the highest tungsten concentrations appear at the border of the settlement, where the median value in 2022 was 4.406 µg/L.

Bourcier et al. In a 1980 study, tungsten was 15,000 µg/L in rainwater samples from roads containing street dust [5]. In the city of Jelgava, dust is regularly collected from asphalted streets. The study shows that unpaved streets are at high risk of tungsten contamination. An analysis of pollution from incineration (MWI) plants in Barcelona, Spain, concluded that tungsten concentrations in fly ash from MWI plants ranged from 13 to 17 µg/g [14]. As a result of burning, tungsten probably enters the atmosphere from the city's heat energy producer and heating equipment of private houses in the southwestern part of the city. This is evidenced by complex studies in Jelgava [14]. Tungsten concentrations in melted snow samples collected in Poland were 1.70 µg/L at the airport, 2.59 µg/L near the highway, and 1.93 µg/L at a distance of 1.5 m from the entrance in the parking lot [9]. The study conducted in Jelgava in 2022 and 2023 showed that the average tungsten concentration ranged from 0.072 µg/L to 4.352 µg/L.

CONCLUSION

Tungsten concentration in snow during the observation period from 2022 to 2023 in the city of Jelgava ranges from 0.050 µg/L to 4.483 µg/L.

Tungsten concentrations in Jelgava city territory differ significantly, and the influence of transport corridors and heating systems is marked.

Tungsten concentration in snow during the observation period from 2022 to 2023 in the city of Jelgava ranges from 0.050 µg/L to 4.483 µg/L.

Tungsten concentrations in Jelgava city territory differ significantly, and the influence of transport corridors and heating systems is marked.

The study identified five levels of risk of tungsten contamination in the air. In low-risk areas, tungsten concentrations correspond to the natural background of tungsten pollution. The tungsten source can be transport and heating systems in medium and medium-high-risk areas.

The spatial distribution of tungsten in the city over the years requires the collection of more extended data series to be able to make accurate statements about the sources of vanadium pollution and their impact on air quality in urban areas.

Future work should be done on methods to help identify and differentiate between diffuse and point sources of tungsten air pollution.

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