XXI INTERNATIONAL SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '24
October 10-11, 2024; Niš, Serbia

Original scientific paper DOI: 10.5937/Railcon24091D

RAILWAY TRANSPORTATION AS A CAUSE OF CADMIUM POLLUTION

Jelena DIMITRIJEVIĆ [1] [0009-0006-7158-0737]
Elefterija ZLATANOVIĆ [2] [0000-0001-6783-1325]
Zoran BONIĆ [3] [0000-0002-7452-6756]
Dragan M. DJORDJEVIĆ [4] [0000-0001-9797-663X]
Zlatko ZAFIROVSKI [5] [0000-0003-2099-0710]

Abstract *– A number of current studies have revealed that during regular railway operations, different kinds of heavy metals accumulate on the track and in the railway body. Cadmium stands out among pollutants, both in terms of the amount of excess and in terms of the severe harm it causes to human life and health. In the first place, the study discusses existing methodologies for detecting the presence of heavy metals in soil on the railway body or in the surrounding areas. Following current procedures, the results of individual study were discussed and compared to those of other researchers. The individual study was done considering a section along a railway in service, which verified that cadmium was present on the railroad. In addition, various sources and origins of cadmium were analyzed considering the railway transportation. All the presented researches imposed an urgent need to establish effective remediation measures against the harmful impact of cadmium.*

Keywords - railway pollution, environment, heavy metals, cadmium.

1. INTRODUCTION

The significance of railway traffic in terms of transporting people and goods is enormous. It was expected that, in order to reduce the emission of gases with the greenhouse effect, this mode of transportation could take the lead, particularly in the promotion of passenger transport considering the rise in the number of people who travel for work.

The increased use of railways does not necessarily imply that harmful substance emissions into the environment could be avoided. Studies upon the impact of railway traffic on the quality of soil and water in nearby areas of railway routes, have discovered the presence of heavy metals, with cadmium (Cd) standing out as an extremely dangerous metal for human life and health [1, 2]. Cadmium may enter the human food chain in a variety of ways, including through contaminated agricultural land or drinking water sources [3].

In the case of railway transport, the release of pollutants into the environment was simplified since, as the rainwater was transported away from the railway structure, all pollutants flowed into the channels and were delivered to the recipient. During runoff, infiltration into the soil is inevitable. In this way, by gradual infiltration of Cd into the surrounding soil, which is often agricultural, it easily reaches the groundwater [4].

In order to test the soil near the railway track and find out if any hazardous heavy metals were present, this paper gave an outline of the methods that were actually employed [2], [5-7]. Additional details were provided on the findings of the analysis of Cd concentration in the railway embankment using two widely recognized techniques, XRF and ICP-OES [8]. The significance of choosing an appropriate testing method, focusing on the findings of evaluating the concentration of Cd in the railway line's body

[1] University of Niš, Faculty of Civil engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia, jelena.dimitrijevic@gaf.ni.ac.rs
[2] University of Niš, Faculty of Civil engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia, elefterija.zlatanovic@gaf.ni.ac.rs
[3] University of Niš, Faculty of Civil engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia, bonic@gaf.ni.ac.rs
[4] University of Niš, Faculty of Science and Mathematics, Višegradska 33, 18000 Niš, Serbia, dragance73@yahoo.com
[5] University "Ss. Cyril and Methodius" of Skopje, Faculty of Civil engineering, Blvd. Partizanski odredi 24, 1000 Skopje, Republic of North Macedonia, zafirovski@gf.ukim.edu.mk

paper, was highlighted. Values and positions of Cd spreading over the railway body's cross section were highly consistent throughout its depth.

Several particular findings on the origins of Cd were discussed below [7, 9, 10]. Examining the origins of Cd is crucial since obtaining this information may make it possible to reduce the excessive amount of the heavy metal released into the environment.

2. CADMIUM TOXYCITY AND HEALTH RISK

The International Agency for Research on Cancer (IARC) has classified cadmium and cadmium compounds as carcinogenic to humans [11]. Among the health issues they might cause, the kidney failure (tubular dysfunction and nephropathy), disturbances in calcium metabolism (osteomalacia and osteoporosis), lung changes (lung cancer and chronic obstructive pulmonary disease) and liver function are particularly noteworthy [4, 12].

Although the heart and brain tissues are not the first to be affected by Cd, they suffer immediate effects and might result in intoxication and death [13]. Human intoxication with Cd causes vascular tissue damages, atherosclerosis, hypertension, but also leads to Peripheral Arterial Disease and Conorary Hearth Diesase. During some initial examinations into the influence of cadmium on human health, several occurrences were identified, such as tremors, sweating, dermographia, increased-knee joint reflexes, altered neuromuscular conduction and optic and sensory disorders. Compared to impacts on the cardiovascular system, neurotoxicity can cause a larger range of symptoms, including headache, visual problems, slowed vasomotor functioning, peripheral neuropathy, disturbed balance and difficulty concentrating. In addition to the above-mentioned consequences, there is a detrimental influence on human's reproductive health [14].

The aforementioned disorders are often induced by consumption of contaminated food and water, where cadmium has entered the human food chain through recognized or undiscovered ways [3].

3. METHODS FOR CADMIUM DETECTION IN RAILWAY BODY TRACK

For the purposes of determining the concentration of Cd in the railway body, several methods were considered. All available test results, specifically related to the concentration of heavy metals in the soil near the railway track, were searched. It was about testing of soil in the railway body and the surrounding area.

According to the searched methods, the X-ray fluorescence spectrometry (XRF) stood out. Besides being the most commonly used technique, operator training takes little effort and it is simple to understand. It is recommended that the recording should be done on processed, ie. dried and crushed, sample in order to obtain the most homogeneous sample possible [8]. Furthermore, the recording might be done "in city". In that instance, it is crucial that the recording site is free of any obstacles so that access to the content being inspected is guaranteed. The area must be clean of vegetation or garbage so the device has direct contact with the material being tested. Based on existing research, concerning railway traffic influence on environment, XRF identified a wider range of heavy metals, including Cd [7].

The microwave plasma-atomic emission spectroscopy (MP-AES) was also employed in the published experiments for heavy metal detection in the soil along the railroad line. Microwave plasma-atomic emission spectroscopy has shown to be successful and widely used technique, for heavy metals identification in a variety of materials [7].

A couple of cases of inductively coupled plasma-optical emission spectrometry (ICP-OES) were observed in the investigation of the concentration of heavy metals in the railway area [5]. Identical to MP-AES, this approach is more reliable as it, with a wide range of applications. The ICP-OES method is similar to MP-AES, with the difference that ICP-OES uses argon plasma instead of nitrogen plasma (MP-AES) [6]. Along with ICP-OES and MP-AES, inductively coupled plasma-mass spectrometry (ICP-MS) was applied to evaluate the impact of rail traffic on heavy metal pollution [2]. In addition to material sampling, special preparation of the same is required before testing in spectometer. The preparation of the material should be done with the help of a professional associate who operates the spectrometer.

In this particular case, discussed in the paper, two techniques were run simultaneously to determine the presence of cadmium in the railway body: XRF and ICP-OES [8]. The examination of the concentration of heavy metals in the railway body was carried out using the ICP-OES spectrometer (iCAP 6000 series, manufactured by Thermo scientific company) with the operating parameters listed in Table 1. The preparation of the samples was done in compliance with the ICP-OES test protocol. As indicated in Table 2, sampling was conducted on two cross-sections and particular locations.

Significant observations were made regarding the results. According to the results, Cd was singled out due to multiple exceedances. The measured value ranged from 4,2 ppm to 7,1 ppm (Table 2). The maximum allowed value according to Maximum allowable concetration (MAC) prescribed for the Republic of Serbia was exceeded 5,5 to 8,9 times, since maximum allowed value was 0.8 ppm [15].

According to EU Directive document, permited value of 1.0 ppm was exeeded 4,4 to 7,1 times [16].

Tab. 1. Operating parameters for ICP-OES spectrometer

RF power (W)	1150
Analysis pump rate (rmp)	50
Flusc pump rate (rmp)	100
Nebulazer gas flow rate (L/m)	0.7
Coolant gas flow rate (L/m)	12
Auxilliary gas flow rate (L/m)	0.5
Observation mode	axial
Rinse time (s)	30

Tab. 2. Values of Cd in the sampled position of cross-section 1 and cross-section 2 obtained by ICP-OES

	Sample location	**Cd** [ppm]
cross-section 1	Track axis	5.1
	Track axis (1.3m depth)	5.1
	Foot of the ballast (left)	5.6
	Foot of the balast (right)	4.6
	Foot of the ballast (left, 1.3m depth)	4.4
	Foot of the ballast (right, 1.3m depth)	5.0
	Channel (left)	5.3
	Channel (right)	4.2
cross-section 2	Track axis	5.8
	Track axis (1.3m depth)	6.0
	Foot of the ballast (left)	5.4
	Foot of the balast (right)	7.1
	Foot of the ballast (left, 1.3m depth)	5.6
	Foot of the ballast (right, 1.3m depth)	5.3
	Channel (left)	5.4
	Channel (right)	5.8

Samples scanning was performed using the hand held analyzer made by LANScientific, model RTU-XRF7460. According to specification, the device was provided for detection of heavy metals in the soil on samples in the solid state, as dust, powder, soil clods or even thin layers of soil, with the Mg-U detection range [17].

The same samples were utilized for both technique, ICP-OES and XRF. It was detected 35 kinds of metal and among them a lot of hazardous heavy metals. Namely, the presence of Cd was not detected by the XRF procedure. Comparing the results of this testing with the results published by Samarska (2020), the most of main-filter and high-filter elements coincided, except Cd.

For unknown reasons, none of the 16 samples had cadmium found in them by the XRF instrument, indicated above. Whether in this case the characteristics and range of the device were not adequate for detecting cadmium in the material or there are other reasons, was impossible to debate. The presence of cadmium in the aforementioned samples was confirmed by the ICP-OES analysis. It is evident that, even with a widely used technology like XRF, study should never be limited to a single approach in the case of such delicate studies, especially when it comes to a particularly poisonous metal.

4. POSSIBLE SOURCES OF CADMIUM ON RAILWAY LINE

Considering the possible sources of cadmium, two obvious options arise. Cadmium in its natural state originates in volcanic stones [9]. This kind of stones are recommended for use in the construction of ballast to provide a stable support for the railway, maintain track geometry and adjust elasticity and stiffness of the track structure [10, 18]. The possibility that the ballast itself is one of the causes cannot be excluded. Ballast is a layer exposed to great static and dynamic influences and its crushing occurs. It is the element of the track that is most exposed to washing by stormwater, where crushed particles can easily reach the lower layers of the track body and drainage channels.

Generally speaking, excessive traffic is another potential cause of cadmium contamination [9]. This covers a variety of issues, including applying herbicides, lubricating machinery during usage and galvanizing metal components [7].

Upon examination of the aforementioned potential sources of cadmium, it is evident that they are wholly associated with components and procedures related to railway exploatation. It is impossible to envision railway traffic without any of these components, which makes the issue even more concerning because there is no way to eradicate Cd by removing the source.

5. CONCLUSION

Research on environmental contamination caused by train activity is becoming increasingly common and diversified. The paper mentions a couple of techniques able to detect and measure the amount of cadmium specifically in the body of the railway track, but also in the soil surrounding it. Each of the methods is distinguished by certain characteristics and in this connection, some more or less require the training of the researcher. The XRF scanning procedure is certainly most simple to use and does not require any specific knowledge of chemical bonding or principles. A completely different kind of techniques are methods such as ICP-OES, MS-AES and ICP-MS. In particular, the ICP-OES spectrometer, although it belongs to the group of more demanding techniques, proved to be more reliable in detecting Cd in the case when XRF failed to determine the presence of Cd, no mention to measure the amount.

The reasons for this result were not clear after testing nor after comparing with the results of other researchers who properly determined the presence of Cd using XRF devices. Due to the easier applicability and speed of obtaining results using XRF, it is necessary to determine factors affecting whether cadmium will be registered. This is not about the accuracy of measuring the amount, but about not detecting it at all.

The general conclusion, drawn on the basis of the above-mentioned research results, would certainly be that with sensitive substances, such as cadmium, the investigation should never be reduced to one method. Also, considering information about Cd origins, the construction of railways may be approached differently in an effort to reduce the discharge of heavy metals, particularly cadmium, into the environment.

REFERENCES

[1] Vaiškūnaitė, R., Jasiūnienė, V., *The analysis of heavy metal pollutants emitted by railway transport*, Transport, 35(2), 2020. https://doi.org/10.3846/transport.2020.12751

[2] Wang, Z., Zhang, J., Watanabe, I., *Source apportionment and risk assessment of soil heavy metals due to railroad activity using a positive matrix factorization approach*, Sustainability, 15,75, 2023. https://doi.org/10.3390/su15010075

[3] Motta, C.M., Rosati, L., Creti, P., Montinari, M.R., Denre, P., Simoniello, P., Fogliano, C., Scudiero, R., Avallone, B., *Histopathological effects of long-term exposure to realistic concetration of cadmium in the hepatopancreas of Sparus aurata juveniles*, Aquatic Toxicology, 268, 106858, 2024. https://doi.org/10.1016/j.aquatox.2024.106858

[4] Khan, Z., Elahi, A., Bukhari, D.A., Rehman, A., *Cadmium sources, toxicity, resistance and removal by microorganism- A potential strategy for cadmium eradication*, Journal of Saudi Chemical Society, 26, 101569, 2022. https://doi.org/10.1016/j.jscs.2022.101569

[5] Stojić, N., Štrbac, S., Ćurčić, Lj., Pucarević, M., Prokić, D., Stepanov, J., Stojić, G., *Exploring the impact of transportation on heavy metal pollution: A comparative study of trains and cars*, Transportation Research Part D, 125, 2023. https://doi.org/10.1016/j.trd.2023.103966

[6] Hou, X., Jones, B.T., Inductively coupled plasma/optical emission spectrometry, Tomic Spectroscopy, Encyclopedia of Analytical Chemistry, John Wiley & Sons, Ltd., pp.9468-9485, 2008.

[7] Samarska, A., Zelenko, Y., kovrov, O., *Investigation of heavy metal sources on railways: Ballast layer and herbicides*, Journal of Ecological Engineering, 21(8), pp.32-46, 2020. https://doi.org/10.12911/22998993/127393

[8] Dimitrijević, J., Bonić, Z., Zafirovski, Z., Milićević, D., Djordjević, D.M., Zlatanović, E., Mrmošanin, J., Marinković, N., *LID approach to railway track drainage: Determination of heavy metal content in the embankment of railway*, 68(3), pp.872-882, 2024. https://doi.org/10.3311/PPci.23433

[9] Bouida, L., Rafatullah, M., Kerrouche, A., Qutob, M., Alosaimi, A.M., Alorfi, H.S., Hussein, M.A., *A review of cadmium and lead contamination: Sources, fate, mechanism, health effects and remediation methods*, Water, 14, 3432, 2022. https://doi.org/10.3390/w14213432

[10] Guo, Y., Xie, J., Fan, Z., Markine, V., Connoly, D.P., Jing, G., *Railway ballast material selection and evaluation: A review*, Construction and Building Materials, 344, 128218, 2022. https://doi.org/10.1016/j.conbuildmat.2022.128218

[11] WHO-CED-PHE-EPE-19-4-3, Exposure to cadmium: a major public halth concern, World Health Organization, 2019. https://www.who.int/publications/i/item/WHO-CED-PHE-EPE-19-4-3

[12] Qu, F., Zheng, W., *Cadmium exposure: Mechanism and pathways of Toxicity and implications for Human Health*, Toxics, 12, 288, 2024. https://doi.org/10.3390/toxics12060388

[13] Naiija, A., Yalcin, H.C., *Evaluation of cadmium and mercury on cardiovascular and neurological systems: Effects on humans and fish*, Toxicology Reports, 10, pp.498-508, 2023. https://doi.org/10.1016/j.toxrep.2023.04.009

[14] Charkiewicz, A.E., Omeljaniuk, W.J., Nowak, K.,Garley, M.,Nikliński, J., *Cadmium toxicity and health effects- A brief summary*, Molecules, 28, 6620, 2023. https://doi.org/10.3390/molecules28186620

[15] Government of Republic of Serbia, "Uredba o graničnim vrednostima zagađujućih, štetnih i opasnih materija u zemljištu, Sl. Glasnik RS, broj 30/2018 i 64/19" (Regulation on the maximum concentrations of polluting, harmful and hazardous substances in soil Official Gazette of the Republic of Serbia, No. 30/2018 and 64/19), Belgrade, Serbia, 2019. (in [Serbian]). [online] Available at: https://www.paragraf.rs/propisi/uredba-granicnim-vrednostima-zagadjujucih-stetnih-opasnih-materija-zemljistu.html [Accessed: 21 January 2023]

[16] The Council of the European Communities, Directive, 01986L0278-20220101, COUNCIL DIRECTIVE (86/278/EEC) on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture, 1986.

[17] https://en.lanscientific.com/products-and-solutions/43.html

[18] SRPS EN 13450:2007 Agregati za zastor železničkih pruga

[19] Jiasheng, C., Tingting, L., Lin, W., *Soil heavy metal pollution in the soil of railway traffic: A mini review*, Academic Journal of Agriculture and Life Sciences, 1(1), 2020. https://doi.org/10.25236/AJALS.2020.010101