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RAILWAY INFRASTRUCTURE OF UKRAINE AS A FACTOR OF SOIL CHEMICAL HAZARD (ANALYTICAL OVERVIEW)

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Abstract. To reach the aim in solving these tasks, the following theoretical methods of research were used, mainly analysis, experimental data, complex assessment of hazardous influence of railway infrastructure on the environment, mainly soil chemical pollution, which are an essential part of railway infrastructure. Considering the comparative characteristics, we can make a prognosis on any heavy metal impact with excessive content of acid and alkaline properties of polluted soils. A result of scientific research an analytical review of the issue of railway infrastructure in Ukraine as a factor of soil chemical hazard and determination of the main sources of pollution among the enterprises of rail transport.

Keywords: railway transport, soil, chemical hazard, environmental safety, heavy metals.

JEL Classification: Q53, R41.

Introduction

The activity of rail transport is connected with transportation process, loading and uploading operations and technical sustainment of rolling stock and railways. Railway enterprises in Ukraine comprise the territories in average from 2 to 50 ha, which are distinguished not only by the size, but by the level of pollution. They include locomotive and carriage depots, fuel stores, washing and steaming stations, impregnated sleeper factories, carriage maintenance points, railway stations and train stations. The type of technological processes which are carried out by the railway enterprises define type and concentration of pollutants, amount of wastes including toxic wastes.

Considering a wide range of chemical compounds polluting soils, it is appropriate to provide the classification of these substances. The classification of soils chemical pollutants can be carried out according to different criteria – chemical origin, degree of hazard, source, certain chemical or physical properties, etc.

Rail transport and railroad infrastructure cause less negative affect to the environment comparing to other kinds of transport. However, there is a considerable pollution of all the biosphere components: atmospheric air, water, soil (Bosak et al., 2022; Pylypchuk et al., 2021; Pylypchuk, 2020). Toxic components of impregnated sleeper materials, exhaust gases of locomotive diesel engines, gaseous emissions of heating stations, etc. The sources of water objects pollution are waste waters after tank washing of freight and passenger carriages. Soils are heavily contaminated with chemicals of different origin.

The research work (Kobylkin et al., 2020) represents processes of changes in management of infrastructure projects. Modified multi-criteria classification of infrastructure projects. To ground the choice and evaborate new efficient technologies of prevention of soil contamination by hazardous chemicals and methods of reduction of negative affect of railway infrastructure on the adjacent territories, it is necessary to obtain relevant data which includes complex assessment of causes and sources of pollution, classification and characteristics of pollutants – chemicals, indication of factors which influence condition of soil pollution, etc. similar complex approach is not observed in the modern literature. Therefore, the research includes analytical review of modern national

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and foreign literary sources in regards to negative influence of the infrastructure of the railway in Ukraine on soils, analysis and classification of the main pollutants of soils in the vicinity of railroad transport enterprises, distinguishment of most dangerous sources of pollution etc.

Thus, the aim of the research is to provide an analytical review of issue regarding railroad infrastructure in Ukraine as a factor of soil chemical hazard, definition of the main sources of pollution among railroad transport enterprises; determination of technological, exploitative, ecological and economic problems and perspectives regarding possibilities of prevention soil chemical pollution in the vicinity of railway; creation of classification of the main chemical pollutants of soils, which are produced by railway enterprises in Ukraine. To reach this aim it is necessary to solve the following tasks: to carry out analytical review of modern scientific literature and provide objective characteristics of the issue on railway infrastructure in Ukraine as a factor of soil chemical hazard; to define main groups of soil chemical pollutants in the vicinity of railway infrastructure; to provide an example of consideration of the described factors and prove the possibility of its practical application.

1. Analysis of literary sources and research results

Based on the sources of origin soil hazards are divided into three groups: natural; anthropogenic; combined (natural-anthropogenic). The second group comprises anthropogenic factors. Obviously, hazards from rail transport infrastructure belong to this group.

Generalization of current information in scientific literature allowed to classify anthropogenic hazards based on the type of influence on soil, which can be divided into further groups in the Table 1.

Table 1. Groups of hazards based on their influence on soil

No. of order	Group of hazards	Characteristics
1.	Mechanic	Compaction, inner destruction of array, terrain erosion
2.	Hydro mechanic	Terrain hydroaccumulation (dam embankment, mound embankment), hydroerosion of terrain (subsidential suffusional influence, fracking).
3.	Hydro-dynamic	Increase or reduce of water pressure (flooding, irrigation, drainage)
4.	Thermal	High temperature processes on soils (fires, campfires, scorching)
5.	Physical	Electrical current, electromagnetic elimination, noise, vibration
6.	Radiation	Soil contamination by radionuclides of short or long-term decay period
7.	Chemical	Soil contamination by hazardous chemical substances

Negative influence of railway infrastructure on soils can be characterized by at least four groups of anthropogenic hazards: mechanic, physical, chemical and biological. It is proved by results of research of soil in the vicinity of railways in different regions of Ukraine by national (Bosak et al., 2022; Karabyn et al., 2019; Lukyanchuk & Ruda, 2013; Menshov & Camps, 2017; Pylypchuk et al., 2021; Pylypchuk, 2020; Rybina, 2012; Zelenko et al., 2015) and foreign (Blake & Goulding, 2002; Šeda et al., 2017; Wierzbicka et al., 2015; Zhang et al., 2012; Vaiškūnaitė & Jasiūnienė, 2020) scientists.

It is stated in the research (Rybina, 2012) that rail transport negatively affects environmental condition of soil by the main ecosystems, substantially violating their functional characteristics, which eventually can lead not only to the reduction of soil cover fertility, but to degradation. Based on the analysis of railway activity, main factors causing soil pollution and degradation are defined by the author: lands pollution with production and municipal wastes of industria enterprises of rail transport; design, location, construction and start-up of rail transport objects which affect soils condition; violation of ecological requirements regarding disposal, accumulation and storage of industrial and municipal wastes, and also in case of dealing with radioactive, chemical and other toxic and hazardous substances.

The results of ecological research obtained through magnetization methods are described in the research (Menshov & Camps, 2017) in the case study of the city of Truskavets (the Lviv region, Ukraine). It was found that specific magnetic susceptibility of unpolluted gumbo soils is equal to $\chi = 8 - 10\times10^{-8}$ m^3/kg, and polluted soils sampled alongside the railway track are characterized as $\chi = 29 - 162\times10^{-8}$ m^3/kg. The obtained results are the indication of technogenic influence. They are evidence of pollution of adjacent to railway soils which contain other metals and pollutants.

The authors (Bobryk et al., 2016) found the regularities of reorganization of microbial communities in soils at five monitored plots located in the area of influence of the railway line Chop-Uzhhorod-Sambir (within the Trans-Carpathian region). Due to the high level of heavy metals, all types of the soils in the vicinity of railway tracks are characterized by the increased level of amonifacators and spore microbiota. The greatest number of medium and strong correlations is established between the number of microorganisms of ecological and trophic groups and content of acid-sululable forms of Pb at the level of 0.72-1.72 of maximum permitted concentration (MPC).

Analyzing the works of the scientists, it is clear that the greatest soil hazard is caused by rail transport through chemical pollution or chemical hazard. Based on the results of foreign and national scientists, it is proved that the concentration of hazardous chemical compounds in the soil in the vicinity of railway could be several times higher than on the clean control plots beyond the research. Pollutants accumulated in soil, especially heavy metals, can change its pH, simultaneously destroying its natural chemical, physical and biological balance. Physical and chemical changes of the environment can lead to redistribution of accumulated pollutants on soil surface. A part of them migrates to deeper soil horizons, and in case of their occurrence, pollutants tend to accumulate (Blake & Goulding, 2002; Šeda et al., 2017; Wierzbicka et al., 2015; Zhang et al., 2012).

According to the author (Rybina, 2012) soil chemical pollutants in the vicinity of railways are devided into three classes based on the hazard degree: class 1 (arsenic, cadmium, mercury, selenium, lead, zinc, fluorine, benzapyrene) – highly hazardous substances; class 2 (boron, cobalt, nickel, molybdenum, copper, antimony, chromium) – moderately hazardous substances; class 3 (barium, vanadium, tungsten, manganese, strontium) – slightly hazardous substances. Unfortunately, the classification neglects chemical pollutants of organic origin, for example, petroleum products, etc. The authors (Pylypchuk et al., 2021) assume that all soil chemical pollutants originating from rail transport are divided into two groups: petroleum products and heavy metals. The proposed division is rather limited, since it comprises a considerably wide range of substances, which are not always soil pollutants based on the data of numerous researches. Therefore, while making a classification of the above – mentioned chemical substances, it is important to consider not only chemical structure and the degree of hazard, but also properties (chemical and physical) and level and direction of hazardous impact of certain chemical substances on soil. Besides, transformation of pollutants in time under the influence of external factors, which results in creation of new compounds, which properties substantially differ from those which occurred in soil at the first stage of pollution. Obviously, approach to the classification require additional research, however the described classification can be applied in practice as the most convenient (Pylypchuk, 2020; Pylypchuk et al., 2021).

Negative influence of petroleum products in soils appears as following: structure dispersing appears; waterproofness reduces; oxygen is replaced violating microbiological and biochemical processes; ration of C:N increases; content of movable forms of F (fluorine) and K (potassium) reduces. As a result, water, air and nutrition regimes, root nutrition of plants deteriorates, growth and development are slowed down which eventually causes death (Kulahin, 2017; Kyrylchuk & Bonishko, 2011). Research (Zelenko et al., 2015) demonstrates results of research of perspectives of railway touristic transportation in the Trans-Carpathian region from the point of view of influence on potential ecological objects which are located within the railway infrastructure field.

According to the data of National center of the Institute of soil science and agricultural chemistry (Zaporozhets' et al., 2017), more than 25% of the territory of Ukraine is polluted by heavy metals (today, as a result of russian aggression against Ukraine, this percentage can be much higher). Soil pollution by heavy metals causes acidic or alkaline reaction of soil environment, reduction of metabolizable cationic capacity, loss of nutrients, change in density, porosity, reflectivity, development of erosion, deflation, decline of vegetation species composition, its depression or total death.

Soil cover pollution by rail transport is performed with dry and wet wastes of hazardous (toxic) chemicals. The work (Chayka et al., 2016) defines (Ti, Cr, Mn, Fe, Cu, Zn, Pb) in soils of Lviv in the vicinity of railway track. It was found that Ti content at the distance of 1 m from the railway track is 1.7 times greater than background concentration. Similar relationship is observed in regards to other metals (Cr, Mn, Fe, Cu, Zn). It is noted that further away from the track concentration of metals is different. Maximum concentration of metals Fe, Mn is detected at the distance of 5 m, and access based on background concentration of Fe was 2.8 times more, and for Mn is 1.8 times. The research showed that the concentration of Cr, Cu, Zn, Pb was the highest at 10 m distance and it exceeds the background content: for Cr – 2 times, Cu – 4.5 times, Zn – 3.7 times, Pb – 1.5 times. The attention is paid to the fact that migration of heavy metals of different chemical origin in the vicinity of the track happens through different mechanisms, which is determined by inequality of the terrain, amount of green plantations, soil density, surface waters and other factors.

The degree of pollution was studied (Hupal & Chornyavska, 2018) under the influence of technogenic environment of the railway and spread of movable forms of Pb, Cd, Zn, Cu, Ni, Co, Cr, Fe, Mn in the soils of protective forest plantations with the growing distance from the railway track. The relationship between heavy metals content and the distance from the railway is observed for Zn, Co and Mn in oak and maple protective forest belt in the Kharkiv region, and also Cr and Mn in the forest plantations of the Sumy region. Based on the research results, relationship between accumulated heavy metals and the distance from the railway is uneven for other elements. It can be explained by the fact that a part of heavy metals is absorbed by the protective forest belt, therefore the plantations perform their silvicultural and melioration functions. It can also be related to the winds which cause uneven transportation of chemicals and migration process of heavy metals in soils.

The authors (Samaraska & Zelenko, 2018a, b; Samaraska et al., 2020) extensively and gradually study the condition of soils by the railway tracks of Ukrainian railway and patterns of influence of different external factors on the content of heavy metals and the pollution degree of soils of the railway infrastructure.

The work (Samaraska & Zelenko, 2018a) analyses modern condition of heavy metals pollution, mainly Pb, Cd, Zn, Cu, Ni, Fe, Mn, in soils of railway infrastructure of three stations of Cisdnieper Railways:

Kamyanske – Pasazhyrske (KP), Zaporizhzhia – Kamyanske (ZK) and Trytuzna (T). Soil samples from inter-track space (gross amount of metals was defined) and the samples from two sides of the track at the distance of 15 m (content of movable forms of metal was defined). The obtained results indicate that the soils condition at the station "KP" represents low environmental risk and slight degree of pollution, since it is a passenger station and pollution occurs due to the friction of wheels and rails, pantograph and catenary, and also use of pesticides. Soils pollution at the station "ZK" differs with considerable potential environmental risk and high degree of pollution, since it is a freight and passenger station and such degree of pollution is usually a result of unloading and loading processes. The soils at the station "T" are characterized by medium potential environmental risk and medium level of pollution. Reformation of freight trains is performed at the station, however due to the transportation of considerable amounts of ore freights heavy metals occur in the soils at the station. Besides, the station is non-electrified.

The research (Samaraska & Zelenko, 2018b) studied the area of railway infrastructure between stations Vilnohirsk and Erastivka of the regional branch "Cisdnieper railways" of "Ukrzaliznytsia". The subject of the research was to determine gross content of heavy metals, mainly Cd, Pb, Zn, Ni, Cu, Mn, Fe. Sampling was carried out at the distance of 0, 5, 10, 15, 20, 30, 50 and 100 m from the railway track, on each side, at each 100 m. It was described that based on the soil pollution intensity rail transport can be classified as a moderate source of heavy metals intake; such conclusion can be made exclusively for transfers.

The objectives of the research in the work (Samaraska et al., 2020) were rail track ballast and herbicides. Ballast sampling spot was a passenger station which is characterized with high motion intensity. It was found that rail track ballast does not contain sufficient amount of Cd, Co, Mo, Pd, Sn, W, Pb, As to be identified, but there is a considerable amount of Fe, Mn, Cu, Cr and Ni. The metals are put in such an order based on total content in polluted ballast layer: Fe>Mn>Cu>Cr>Ni>Zn>Pb>As. Fe content in the polluted ballast stones substantially correlated with the content of Ni, Cr and Mn. These metals are included into rail steel, since the sources of abrasion are rails and wheels. All studied herbicides contained Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn. It is shown that in comparison to ballast stones, herbicides could be considered unsubstantial source of heavy metals.

Thus, Cd is characterized with considerable reduction in the content at the distance of 50 m from the railway track. The area from 0 to 10 m in comparison to the background concentration of cadmium (1 mg/kg) is the most polluted (Samaraska & Zelenko, 2018b). It is related to the processes of abrasion (cadmium can be used as a metal galvanic coating) and processes of freight transportation containing Cd, for example coal. It is mentioned that the role of rail transport in cadmium contribution into the soils is insignificant.

It is considered that the main source of Cu contribution at rail transport is the abrasion of catenary with pantograph and other junctions. Based on the studied line (Samaraska & Zelenko, 2018b) passengers and freight trains travel at considerable speed, that is why the increased level of Cu can be explained by these processes. The most polluted area is at the distance of 0–10 m.

Heavy metal Zn has the highest amount of sources of contribution, mainly during spilling and spraying of freight, is present in ballast materials, reinforced concrete sleepers and pesticides. It can also be contributed into soil during the use of rubber for strengthening of slopes and during running gear erasing. The most polluted area with zinc is located up to 20 m from the track. Other adjacent areas (from 20 m to 100 m) are characterized by moderate, minimal enrichment and its absence (Samaraska & Zelenko, 2018b).

Heavy metal Mn may occur in soil due to spilling and spraying of freights (iron and manganese ore), and also during the abrasion of junctions and elements of rolling stock, wheels with rails, brake pads. Soil pollution by iron and manganese could be regarded as natural and typical for the Ukrainian railways. Soil pollution by manganese in the vicinity of railway roads (Samaraska & Zelenko, 2018b) is considered to be minimal. Metal Ni occurs in soils of railway infrastructure due to freight loss and abrasion of the elements of rolling stock. Reduction in concentration of Ni to the background level is performed at the distance of 50 m from the track (Samaraska & Zelenko, 2018b).

Heavy metal Pb is typical for non-electrified railway stations, since it is present in exhaust gases of combustion engines of rolling stocks. Lead appears in soils due to freight loss; lead can migrate from fortified concrete sleepers. With the distance further away from the track lead distribution is characterized with reduction in concentration in the area of 0–10 m from the track (Samaraska & Zelenko, 2018b). A sharp increase in Pb content is observed at the distance of 15 m which is caused by high wind speed during transportation of freights containing considerable amount of lead. Though, at further points the analysis demonstrates gradual reduction in concentration to 5.09 mg/kg.

2. Results and discussion

The analytical review of national and foreign scientific literature allowed defining justice (Pylypchuk et al., 2020) and distinguishing two main groups of chemical pollutants in soil, which are petroleum products and heavy metals. Based on the conducted analysis of the issue of soil chemical pollution in the vicinity of railway infrastructure of Ukraine, we can formulate two main groups of factors in the table 2 which are necessary to consider during the complex analysis of the situation and elaboration of recommendations to prevent further soil pollution.

Table 2. Main factors which influence the assessment of soil chemical pollution in the vicinity of railway infrastructure

Factor	Features
Chemical	A factor which considers chemical nature and chemical properties of pollutants. It is important to distinguish nature and properties of chemical elements (in case of heavy metals) and compounds containing these elements. In this regard, the scientists define gross content of certain element and content of movable forms. Consideration of nature of chemical compounds is extremely important in the analysis of petroleum products group.
Special	A factor which characterizes soil space around the infrastructure of railway objects undergoing chemical pollution. For example, soil sampling spot (inter-track space, space on track sides, distance from railway object etc.). Geographical terrain peculiarities of the location of infrastructure objects are also vital to consider.
Technological	A factor considering peculiarities of technological processes and operations on a certain objects of railway infrastructure. Based on this feature objects are divided into stations, depots, railway track etc.). This factor also includes type of freights transported by railways and technogenic accidents which cause intake of chemical pollutants into soil.
Secondary	This factor could be related to the chemical, since it characterizes transformation of chemical pollutants in soils in time and secondary pollution with products of these transformations. Hence there are notions of "fresh" and "obsolete" pollution, which can be found in the scientific literature.

Relying on the proposed classification of factors which influence the assessment of soil chemical pollution in the vicinity of railway infrastructure and the conducted analytical review of the existing research, we can state that modern scientific research usually considers two factors – special and technological. Chemical and secondary factors are taken into account partially or superficially, which is unacceptable since it does not describe a complete picture and prevent from making complex assessment of soil chemical pollution in the vicinity of railway infrastructure.

To demonstrate importance of the above-mentioned factors, let us provide an example of consideration of chemical properties of heavy metals, which are one of the main groups of pollutants and provide direct influence on acidic and alkaline properties of polluted soils. For this purpose a comparative characteristics of acidic and alkaline properties of heavy metals is provided, which are characterized by such indicators: acidity degree, ionization energy and Pauling electronegativity (Danchenko, 2017, 2021; Danchenko et al., 2017, 2019). The results are showed in the Table 3.

Table 3. Comparative characteristics of heavy metals based on oxidation degree and ionization energy

Heavy metals	Oxidation degree	Ionization energy, kJ/mole
Ti	2, 3, 4	657.8
Mn	7, 6, 4, 3, 2, 0, –1	716.8
Zn	2	905.8
Cr	6, 3, 2, 0	652.4
W	6, 5, 4, 3, 2, 0	769.7
Pb	4, 2	715.2
Fe	6, 3, 2, 0	759.1
Co	3, 2, 0, –1	758.1
Cu	2, 1	745.0
Ni	3, 2, 0	736.2
Sn	4, 2	708.2
Mo	6, 5, 4, 3, 2, 0	684.8
As	5, 3, –3	946.2
Pd	4, 2, 0	803.5

The results a comparative characteristics of acidic and alkaline properties of heavy metals is provided, which are characterized by Pauling electronegativity are showed in the Figure 1.

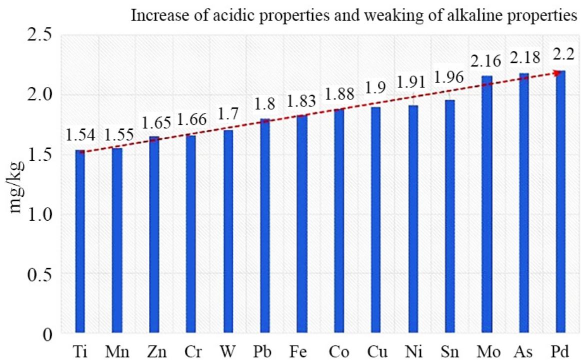

Figure 1. Comparative characteristics of heavy metals based on Pauling electronegativity

However, all heavy metals are amphoteric and, in most cases, they are the reason of increased acidity of polluted soils, but to compare, for example, the presence of Sn, Zn, As, Pd will increase the acidity more considerably than the presence of Ti, Mn, Pb, Cr. Thus, consideration of chemical properties will allow making a prognosis on pollutants impact on the properties of polluted soils and predicting the peculiarity of negative influence of chemical pollution on the external environment in general.

Most scientists pay attention to a range of factors which can affect the quality of soils in the vicinity of railway tracks, such as deterioration of their chemical and biological properties. If scientists do not pay enough attention, especially when we consider chemical pollution and contamination with other organic pollutants, it can lead to the pollution of biota and so-called delayed-action chemical bomb.

Conclusions

Technological, exploitative, ecological and economic problems and perspectives in regards to the possibilities of prevention of soils pollution by chemicals in the vicinity of railways were determined. The classification of the main soil chemical pollutants typical for the railway enterprises in Ukraine was elaborated. It was established that the existing classification of soil chemical pollutants in the vicinity of railways (two groups – petroleum products and heavy metals) can be used now, however it requires further improvement. The main four factors influencing the assessment of chemical pollution of soils in the vicinity of railway infrastructure were defined: chemical, special, technological and secondary. The example of consideration of chemical factor, mainly acid and alkaline properties of heavy metals, was described, and it was proved that consideration of this factor will allow making prognosis on any heavy metal (with prevailing content) impact on acid and alkaline properties of polluted soils.

Based on the analysis, railway infrastructure of Ukraine is a source of soil pollution by heavy metals of rather wide range. To assess the influence of each metal, it is vital to consider not only chemical properties, but to find out main sources of intake of each metal in soils, and also the patterns of distribution of metals in the vicinity of railway tracks and other objects. It will allow making prognosis in regards to soils pollution on certain infrastructure objects of the railway

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