Cemeteries as nodes of urban green infrastructure: assessing ecological risks in war-affected areas of "Yatsevo" necropolis, Chernihiv, Ukraine

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Received: 2 March 2026 / Accepted: 3 April 2026

Abstract. This study assesses the ecological transformation of the "Yatsevo" necropolis in Chernihiv, Ukraine, following intense combat operations. As a critical node of urban green infrastructure, this site represents a unique case of a memorial landscape subjected to both war-induced disturbances and anthropogenic pressure from ritual waste. We hypothesized that the combination of shell craters and unsustainable burial practices transforms the cemetery into a source of geochemical and biological risks, specifically due to contaminant migration toward the Desna River floodplain. Our multidisciplinary approach involved analyzing soil profiles from shell craters and grave walls, conducting 17 geobotanical relevés, and measuring mobile Pb and Cd via atomic absorption spectrophotometry. Results showed that 100% of samples from shell craters exceeded Pb maximum permissible concentrations (average 10.4 mg/kg). In ritual waste zones, Pb reached 28.1 mg/kg, while Cd peaked at 2.05 mg/kg, linked to polymer degradation. The flora (412 species) is highly synanthropized (59% adventive), dominated by *Solidago canadensis* L. (up to 98% cover). This research presents a pioneering assessment of a specific green infrastructure node–a necropolis–directly impacted by military actions in Ukraine. We conclude that post-conflict management must replace polymer ritual products with sustainable phytodesign using xerophilous perennials (*Sedum* L., *Thymus* L.) to mitigate toxicant migration.

Keywords: soil contamination, heavy metals, *Solidago canadensis*, phytoremediation, post-conflict restoration, green infrastructure, polymer ritual waste.

Abbreviations:
ANOVA – Analysis of variance
ATO – Anti-terrorist operation
GI – Green infrastructure
MPC – Maximum permissible concentrations
SD – Standard deviation

1. Introduction

The concept of urban green infrastructure (GI) has evolved from a simple planning tool into a fundamental framework for maintaining urban biodiversity and climate resilience. Cemeteries, often categorized as "silent" or "informal" GI nodes, play a crucial role in this network by providing essential ecosystem services, from carbon sequestration to urban heat island mitigation (Pauleit et al., 2020). In the context of contemporary urbanization, municipal cemeteries are increasingly recognized as vital components of the urban GI rather than merely isolated sites for interment (Sallay et al., 2023). These necropolises are transitioning into integrated multifunctional landscapes that provide essential ecosystem services, including microclimate regulation, carbon sequestration, and biodiversity support. Well-managed cemetery forests can mitigate the urban heat island effect, lowering ambient temperatures by 2–4°C through evapotranspiration (Sallay et al., 2023). Furthermore, these sites act as “biodiversity hotspots” and refugia for species sensitive to urban disturbances, serving as “stepping stones” in ecological corridors that maintain regional wildlife connectivity (Andersson et al., 2007; Itescu & Jeschke, 2024).

In line with United Nations (n. d.) Sustainable Development Goal 11, environmental management plans transform cemeteries into inclusive public spaces that support community mental health. These “therapeutic landscapes” offer restorative environments that reduce cortisol levels and provide quiet retreat areas in overcrowded cities (Quinton et al., 2019). Furthermore, cemeteries preserve the cultural and historical identity of a community. Effective management ensures that historical monuments are protected from environmental degradation (e.g., erosion or invasive species), thereby maintaining the social and symbolic continuity of the urban fabric (Rugg, 2013; Woodthorpe, 2011).

The ecological management of cemeteries has emerged as a critical global challenge, particularly within large metropolitan areas where land scarcity and high burial density intensify environmental pressures. Beyond their ritual significance, urban necropolises function as complex biogeochemical hotspots. As global urbanization continues, the transition of these sites from passive burial grounds to active nodes of urban GI requires addressing systemic risks of soil and groundwater contamination that are inherent to large-scale memorial landscapes worldwide.

The intensive operation of large-scale necropolises poses complex environmental and social challenges. The primary concern remains environmental protection and hydrogeological safety. The mineralization of organic remains, combined with anthropogenic pressure, leads to the potential contamination of soil and groundwater by necroleachate – a fluid characterized by high concentrations of ammonia, chlorides, and dissolved organic carbon (Spongberg & Becks, 2000). Additionally, traditional ritual practices introduce toxic substances, such as heavy metals (Pb, Cd, Zn) from casket corrosion and plastic artifacts, necessitating rigorous eco-toxicological oversight (Zhang et al., 2022; Lima et al., 2025).

However, the functional stability of these nodes is increasingly threatened by synergistic stressors. In Eastern Europe, the traditional challenge of chemical pressure from ritual activities is now compounded by the catastrophic environmental footprint of military conflicts (Pyrikov et al., 2022). Recent studies emphasize that warfare-induced landscape fragmentation not only introduces acute toxicological risks but also triggers the collapse of native plant communities, opening niches for aggressive biological invasions (Boukita et al., 2025). Assessing the resilience of such GI components in post-war conditions (Kowarik et al., 2016; Straka et al., 2022) is vital for developing integrated environmental management plans that move beyond simple reconstruction toward sustainable ecological restoration in Ukraine (Yurieva & Udovychenko, 2024).

For Ukrainian cities such as Chernihiv, the “Yatsevo” cemetery, which has been in operation since 1975, represents a salient example of an eco-technogenic node within the city’s GI. While its spatial integration is defined by proximity to natural forest tracts, the ecosystem’s stability is increasingly threatened by a disproportionate accumulation of ritual polymer waste, leading to significant geochemical and structural degradation. This creates a persistent source of pollution that mobilizes through the permeable sandy horizons of the Desna River terrace. Furthermore, the site’s environmental profile was dramatically altered by the military aggression of 2022, transforming the cemetery into a “landscape of resilience” that requires urgent post-conflict restoration and the protection of its cultural and historical identity. In 2022, during hostilities at the “Yatsevo” cemetery, capital buildings were destroyed, and equipment (trucks and tractors), a warehouse with finished products, and blanks for monuments were destroyed, and an administrative building was burned (Svoboda.fm, 2022).

The study aims to evaluate the ecological state of the “Yatsevo” necropolis under the combined pressure of military destruction and anthropogenic pollution. Furthermore, it seeks to justify sustainable management strategies to restore the site’s function as a resilient urban GI node.

We hypothesize that war-induced disturbances and unregulated ritual waste transform the necropolis into a source of significant geoecological risks. The mechanism of this transformation is driven by the specific lithological structure (sand over clay), which facilitates the rapid migration of contaminants toward the Desna River floodplain. Consequently, these factors degrade the necropolis from a functional GI node into a localized environmental threat.

2. Materials and methods

2.1. Study site, data sources, and infrastructure audit

The primary object of this research is the “Yatsevo” municipal cemetery (Chernihiv, northern Ukraine). Official quantitative data regarding the cemetery’s total area (120 ha), number of interments (>127,000), internal road infrastructure (140 km), technical fleet, and waste management facilities were provided by the Municipal Enterprise “Special Service Combine” of the Chernihiv City Council.

The infrastructure audit focused on the environmental footprint of the specialized vehicle fleet (MTZ excavators, CASE loaders, and a 10-unit funeral fleet), evaluated as a source of technogenic risk during transit between the cemetery blocks and “Yatsevo-1” and “Yatsevo-2” sites. The analysis of the waste management system was based on a quantitative assessment of existing facilities (collection points, wooden bins) and the calculation of anthropogenic pressure (1,100–1,200 graves per hectare). Spatial integration into the city's GI was performed using high-resolution satellite imagery and topographical maps.

The architectural and ritual landscape of the “Yatsevo” necropolis is characterized by a high degree of sealing, with over 60% of graves featuring granite monuments and being lined with granite slabs or tiles. While artificial flowers and wreaths remain the primary decorative elements, the seasonal influx of cut flowers is significant, particularly during the spring period preceding Easter and on Radonitsa (traditional memorial days).

Furthermore, the active planting of perennials in spring and autumn, along with the sowing of annuals in early spring, substantially intensifies local water consumption. This seasonal peak in irrigation demand is evidenced by a noticeable drop in water pressure within the cemetery’s supply network during the spring and summer months, as relatives maintain the vegetation on individual plots. This intensive watering regime likely acts as an additional factor in the mobilization and leaching of pollutants from the topsoil.

2.2. Field investigation of soil lithology and stratigraphy

The lithological structure and stratigraphy were investigated by examining freshly excavated anthropogenic profiles (walls of newly dug graves before burial) up to 2.2 m deep. This approach allowed for direct observation of vertical soil sections in their undisturbed state. Following the methodology for assessing the vulnerability of the vadose zone (Żychowski, 2012), the study focused on identifying risks of lateral contaminant migration. All field activities were conducted with official permission from the municipal authorities of Chernihiv, adhering to ethical standards for memorial sites and avoiding any interference with existing burial places.

2.3. Methods for assessing mechanical landscape and infrastructure damage

To quantify the consequences of combat operations, we used field mapping and morphometric analysis. The counting of shell craters was conducted through a systematic visual survey covering all 140 cemetery sectors to ensure a complete spatial record of the damage. Morphometric parameters (diameter and depth) were measured using a Leica Disto laser rangefinder and a 50 m geodetic tape. Infrastructure destruction, including monuments and buildings, was documented via high-resolution digital photography. These visual data were subsequently converted into quantitative metrics by calculating the ratio of damaged objects to the total number of monuments within each sector.

2.4. Flora inventory and geobotanical surveys

The vascular flora was inventoried through route surveys. The total number of species per plot was recorded through direct counting. To assess the invasive activity of *Solidago canadensis* L., we conducted 17 geobotanical relevés during the peak flowering period within 100 m² plots. The number of relevés was determined to ensure representativeness across the entire necropolis. One representative plot was selected for every 10 cemetery sectors. Three plots located on the western, northern, and eastern periphery of the cemetery, where no burials have yet occurred, were also selected. No invasion of *S. canadensis* were detected in the southern section (at the entrance to the cemetery). This spatial distribution ensured the representation of phytocoenoses with varying degrees of invasion across the site. Standard geobotanical methods (Yakubenko et al., 2018) were applied to determine the projective cover. The species coverage was estimated using a visual percentage scale (0–100%).

2.5. Quantitative assessment of ritual plastic

The accumulation of artificial flowers and wreaths was monitored between 2022 and 2025. To ensure data representativeness, ritual waste was weighed (accuracy 0.05 kg) from peripheral graves in each of the 140 cemetery sectors. The sampling followed a chronological stratification based on burial years: 1974–1993 (n=50), 1994–2013 (n=60), and 2014–2025 (n=50). This longitudinal approach was chosen to track the historical shift in polymer usage and its subsequent degradation stages in the soil.

2.6. Soil sampling and laboratory analysis

Soil samples were collected at 20 points near ritual waste collection sites and at 10 points in areas of shell craters resulting from combat operations that occurred in February – March 2022. To ensure a representative geochemical profile of the entire necropolis, these 30 sampling points were distributed evenly across the cemetery’s 140 sectors, covering both central and peripheral zones: 20 points were located at a distance of 0.5–1.0 m from the boundaries of temporary ritual waste collection sites, and 10 points were situated directly within the center of shell craters resulting from the 2022 combat operations. At each site, five sub-samples were collected using the "envelope" method (Kapanadze et al., 2019) from the 0–20 cm horizon. The priority monitoring of Pb and Cd is justified by their role as key markers: in ritual zones, these metals serve as stabilizers and pigments in polymer products, while in shell craters, they originate from detonators and munition fragments.

The content of mobile forms of lead (Pb) and cadmium (Cd) was determined via atomic absorption spectrophotometry using a Spectr AA 240Z Varian AA DUO (Agilent Technologies, USA) according to the methods of State Standard of Ukraine (Derzhspozhyvstandart Ukrainy, 2007a, 2007b). The results were compared against the ecological safety standards established by the Cabinet of Ministers of Ukraine (Kabinet Ministriv Ukrainy, 2021). The priority monitoring of Pb and Cd is essential because these metals are widely used as stabilizers and pigments in the production of synthetic ritual products. Their accumulation in the soil serves as a direct indicator of environmental pollution caused by the degradation of polymer waste (Spongberg & Becks, 2000; Turner & Filella, 2021). The priority monitoring of Pb and Cd at shell crater sites is critical, as these metals are key components of detonators (initiating explosives), shell casings, and anti-corrosion coatings of munitions. Due to high-temperature explosions, these elements are dispersed into fine particles and deposited within the craters, creating zones of persistent geochemical soil contamination (Certini et al., 2013).

2.7. Statistical data processing

All statistical analyses were performed using STATISTICA 13.3 (TIBCO Software Inc.). The results are expressed as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was applied to determine the statistical significance of differences in metal concentrations between the studied functional zones (craters vs. waste sites). Differences were considered significant at $p < 0.05$.

3. Results

3.1. General characteristics, hydrogeological setting, and spatial integration

The "Yatsevo" cemetery (Chernihiv, Ukraine), covers 120 hectares on the planar segment of the Desna River forest terrace. The site functions as a strategic node of the city's GI, providing ecological connectivity between urban areas and suburban forests.
The lithological profile is characterized by a distinct binary stratigraphic structure: the upper horizon consists of permeable anthropogenic and natural aeolian sands, overlying a substantial

impervious substrate of loams and clays. This composition presents significant hydrogeological challenges: while the sandy layer facilitates rapid infiltration of meteoric waters, the underlying clay strata act as aquitards, potentially leading to the lateral migration of necroleachate toward the Desna River floodplain.

The infrastructure includes approximately 140 km of asphalt-paved roads, creating a vast area of impervious surfaces that significantly alters the local hydrological cycle by increasing surface runoff. This runoff serves as a vector for pollutants, including petroleum hydrocarbons from the specialized vehicle fleet (CASE loaders, MTZ excavators, and 10 funeral vehicles) and heavy metals mobilized from ritual artifacts. This high-density necropolis (1,100–1,200 burials/ha) is buffered by natural forest stands to the south and southwest, which transition into the “Yatsevo” forest tract, acting as “urban lungs” and stabilizing the terrace slopes.

3.2. Physical and infrastructural degradation of the necropolis landscape due to combat operations

The military operations of 2022 caused catastrophic physical and geochemical degradation of the necropolis. According to field reports, approximately 3,000 graves were completely destroyed, with several thousand more partially damaged by shelling and shrapnel (Svoboda.fm, 2022; Fig. 1). The explosive impacts from large-caliber projectiles created a “shattering effect”, where granite monuments and ritual artifacts within a wide radius were pulverized into small fragments. This mechanical destruction acted as a catalyst for environmental risk, instantaneously fragmenting hundreds of kilograms of ritual polymers and stone cladding, significantly increasing the surface area for heavy metal leaching compared to the gradual degradation typical of peacetime.

Field surveys at the “Yatsevo” necropolis revealed significant mechanical and structural landscape damage resulting from combat operations in February – March 2022. A total of 59 shell craters were identified, with the largest measuring 5.6 m in diameter and 1.7 m in depth. The anthropogenic impact is further evidenced by extensive infrastructure destruction: approximately 3,000 monuments were documented as completely destroyed, with a significantly higher number partially damaged. Artillery strikes resulted in the destruction of St. Lawrence Church and the chapel located near the memorial sector for fallen Ukrainian soldiers (2014–2021). The second destruction is shown in Figure 2. Additionally, extensive tracks from heavy military vehicles were recorded, leading to soil compaction and degradation of the vegetation cover.

Figure 1. Aerial view of a war-affected sector at the “Yatsevo” necropolis (Chernihiv, Ukraine). The image demonstrates the extensive mechanical destruction of burial plots and monuments caused by shelling in 2022, leading to the fragmentation of ritual polymers and stone cladding (Source: Svoboda.fm, 2022; used with permission/reference)

Figure 2. Evidence of structural damage to the memorial infrastructure at “Yatsevo” cemetery resulting from shelling in February – March 2022. The ruins of the memorial chapel near the ATO participants’ burial sector (June 2022)

3.3. Quantitative analysis of polymer ritual artifact accumulation

Research conducted between 2022 and 2025 established a clear temporal trend in the accumulation of artificial flowers and wreaths (Fig. 3). Statistical analysis of measurements across 140 sectors revealed a significant progressive increase in plastic mass correlating with the burial period. For the earliest period (1974–1993), the mean plastic mass per grave was 0.7 ± 0.35 kg (range 0.00–2.30 kg). This value increased significantly in the 1994–2013 period, reaching a mean of 1.45 ± 0.62 kg (range 0.00–4.25 kg).

The 2014–2025 period showed a sharp peak, with a mean mass of 5.7 ± 1.84 kg per grave (range 0.15–8.50 kg), representing an 8-fold increase compared to the initial period. One-way ANOVA confirmed that the differences between all three burial periods are statistically significant ($p < 0.05$).

Furthermore, a spatial relationship was observed between physical degradation and war-affected areas: in sectors containing craters, the dispersal of plastic mass was more heterogeneous due to mechanical fragmentation by shelling. This trend indicates that military impacts act as a catalyst for the secondary distribution of polymer pollutants across the necropolis territory.

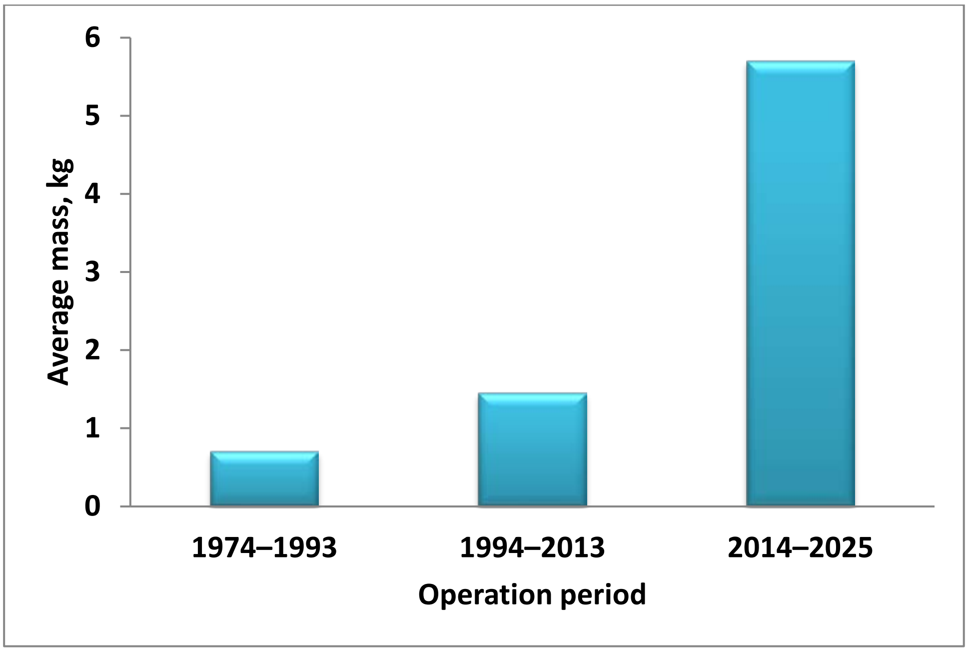

Figure 3. Longitudinal dynamics of the average mass of artificial flowers and wreaths per single grave plot (kg) across three operational periods (1974-2025)

3.4. Content of mobile forms of heavy metals (Pb, Cd) in soil

The study of mobile forms of heavy metals in the vicinity of ritual waste collection sites (near wooden containers) revealed significant heterogeneity in toxicant distribution, driven by the localized nature of synthetic product degradation.

The investigation into mobile Pb and Cd compounds at the “Yatsevo” necropolis reveals that both ritual waste accumulation sites and shell craters serve as intensive anthropogenic contamination hubs (Tables 1 and 2). To assess the significance of these findings, we compared the results with the national (Kabinet Ministriv Ukrainy, 2021) maximum permissible concentrations (MPC: Pb – 6.0 mg/kg, Cd – 0.7 mg/kg) and local background levels. Point 6 (for Pb: 2.602 ± 0.450 mg/kg) and Point 8 (for Cd: 0.528 ± 0.042 mg/kg) from Table 1 were utilized as background references, representing the least disturbed areas.

Table 1. Content of mobile Pb and Cd (mg/kg) in soils near ritualwaste collection points (mean ± SD, n=20)

Point	Pb	Cd
1	6.361 ± 0.234	0.813 ± 0.021
2	7.256 ± 0.313	0.910 ± 0.031
3	9.251 ± 0.211	0.604 ± 0.022
4	3.200 ± 0.341	1.008 ± 0.181
5	8.003 ± 0.987	0.905 ± 0.355
6	2.602 ± 0.450	2.054 ± 0.244
7	7.118 ± 0.311	0.815 ± 0.094
8	6.225 ± 0.229	0.528 ± 0.042
9	5.154 ± 0.253	0.534 ± 0.061
10	2.735 ± 0.081	0.542 ± 0.024
11	6.190 ± 0.143	1.024 ± 0.257
12	3.173 ± 0.262	0.915 ± 0.148
13	3.012 ± 0.086	0.531 ± 0.095
14	5.667 ± 0.125	0.719 ± 0.226
15	8.922 ± 1.078	0.717 ± 0.031
16	7.131 ± 0.875	0.545 ± 0.076
17	5.818 ± 0.150	1.152 ± 0.213
18	28.117 ± 4.762	0.721 ± 0.594
19	9.251± 0.310	1.114± 0.081
20	6.121± 0.094	1.113±0.244

In waste collection zones, Pb concentrations exceeded the MPC in 60% of samples, with an extreme anomaly at Point 18 (28.117 ± 4.762 mg/kg), which is 10.8 times the background level. In shell craters (Table 2), the impact was even more systemic: 100% of samples exceeded the MPC, with a mean value of 10.45 ± 3.42 mg/kg ($p < 0.05$, ANOVA). The highest concentrations (Points 6 and 9) were 2.5–3 times above the norm, suggesting that ammunition detonation facilitated the conversion of lead components into mobile forms through explosive destruction and thermal impact.

Table 2. Content of mobile forms of heavy metals (mg/kg) at shell crater points (mean ± SD, n=10)

Point	Pb	Cd
1	10.250 ± 1.334	0.614 ± 0.020
2	8.256 ± 0.213	0.562 ± 0.091
3	9.251 ± 0.211	0.463 ± 0.655
4	6.205 ± 2.341	0.638 ± 0.013
5	11.340 ± 1.405	0.905 ± 0.035
6	17.654 ± 3.324	1.723 ± 0.064
7	8.951 ± 0.367	0.984 ± 0.055
8	11.254 ± 0.985	0.690 ± 0.675
9	15.012 ± 2.884	0.762 ± 0.050
10	7.265 ± 0.510	0.812 ± 0.046

Cd contamination was more pronounced, with exceedances recorded in 75% of waste area samples and 70% of crater samples. In waste zones, Cd levels reached 2.054 ± 0.244 mg/kg (Point 6), correlating with the degradation of plastic pigments. In craters, the maximum reached 1.723 ± 0.064 mg/kg (crater Point 6), which is 2.4 times the MPC. One-way ANOVA confirmed that Cd levels in both impacted zones are significantly higher than the background ($p < 0.05$).

The risk of contaminant transport toward the Desna River is determined by the specific lithological profile of the “Yatsevo” necropolis. The distinct binary stratigraphic structure– comprising a permeable upper horizon of aeolian sands (0.5–2.0 m) overlying an impervious substrate of loams and clays– creates a specific hydrogeological trap. While the sandy layer facilitates rapid vertical infiltration of Pb and Cd, the underlying clay strata act as an aquitard, redirecting the vertical flux into lateral migration toward the river floodplain.

Furthermore, the extensive network of 140 km of asphalt roads serves as a vector for accelerated pollutant transport. The increased surface runoff from these impervious surfaces, combined with the mechanical soil disturbance in shell craters, significantly enhances the mobilization of heavy metals from ritual artifacts and munitions. Consequently, the recorded concentrations of mobile Pb and Cd in the topsoil (0–20 cm) should be viewed as a primary source for the long-term contamination of the Desna River’s GI nodes.

3.5. Flora composition and invasive dynamics

According to our findings, the vascular flora of the “Yatsevo” necropolis is characterized by high levels of anthropogenic transformation and heterogeneity. The total flora includes 412 species, dominated by the adventive fraction (244 species, or 59.2%), while the native flora is represented by only 168 species. A significant portion of the adventive element consists of acclimatized ornamental introduced plants (87 species), which is a specific feature of memorial landscapes. Over 70% of the adventive flora is composed of weed species from arid regions, such as *Anisantha tectorum* (L.) Nevski, *Camelina microcarpa* Andrz., *Anchusa officinalis* L., and *Echinochloa crusgalli* (L.) P. Beauv., indicating the xerophytization of cemetery ecotopes.

The expansion of *Solidago canadensis* L. poses a particular threat to the biodiversity of the area, with its communities spread throughout the entire territory. Analysis of 17 geobotanical relevés (Table 3) demonstrates the dominant role of this species in shaping the herb cover.

The projective cover of *S. canadensis* ranges from 20% to an extreme 95–98% (relevés 15, 16), forming nearly monodominant stands that displace native vegetation. In areas with lower goldenrod density, codominants include *Elytrigia repens* (up to 75%, relevé 11) and *Calamagrostis epigejos* (up to 50%, relevé 5), indicating intensified ruderalization.

A clear spatial correlation was observed between *S. canadensis* expansion and soil disturbance. Specifically, in shell craters where the soil cover was severely disrupted, a dominance of 1–2-year-old individuals was recorded in 2025 (25–40% cover). Furthermore, in areas corresponding to the highest Pb and Cd concentrations (e.g., Point 18, Table 1), *S. canadensis* outcompetes native grasses and shows high tolerance to chemical stress. This suggests that the combination of physical soil disturbance from shelling and chemical pollution acts as a catalyst for invasion, while the species may facilitate the phytostabilization of heavy metals in the upper soil horizon.

Compared to the regional ruderal and psammophytic communities described by Danko et al. (2021), the “Yatsevo” necropolis exhibits a much higher concentration of ornamental species (87 species). While *S. canadensis* is a common invader in Chernihiv Polesie, its dominance at the necropolis is more extreme. In contrast to typical regional successions where goldenrod coexists with a broader range of native meadow species (Danko et al., 2021), the necropolis environment favors a rapid transition to monodominant stands, likely accelerated by the specific micro-ecological conditions and war-induced soil disturbances.

Beyond the widespread invasion of Canadian goldenrod, localized clusters of other dangerous invasive species, such as *Asclepias syriaca* L., *Ambrosia artemisiifolia* L., and *Reynoutria japonica*, were recorded. Specifically, *Ambrosia artemisiifolia* shows activity in areas with disturbed soil cover, reaching 5% cover (relevés 7, 8). Among ornamental species showing a tendency toward naturalization, *Lupinus polyphyllus* Lindl. and *Rudbeckia hirta* L. were noted.

Table 3. Results of geobotanical relevés (100 m²) showcasing the dominance of *Solidago canadensis* L.

Relevé number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Herb cover [%]	90	50	100	85	90	90	90	100	100	100	100	60	100	65	95	95	95
Solidago canadensis L.	40	20	40	25	45	60	45	35	30	45	40	25	35	60	95	98	40
Acer negundo L.	.	.	.	.	+	.	.	.	.	+	.	.	2	.	.	.	.
Ambrosia artemisiifolia L.	+	.	+	.	.	.	5	5	.	.	.	.	+	.	.	.	+
Anthemis ruthenica M.Bieb.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Artemisia absinthium L.	.	1	.	+	+	+	+	1	+		.	.	.	.	.	.	5
Artemisia scoparia L.	+	.	.	2	20	+	10	.	.	+	+	+	35	.	.	.	.
Balota nigra L.	.	.	+	1	.	.	.	.	.	.	+	.	.	.	.	+	.
Berteroa incana L.	.	.	.	4	+	.	.	5	.	.	.	.	+	.	.	.	+
Bromopsis inermis (Leyss.) Holub	.	.	.	.	.	.	.	.	5	3	+	.	.	.	.	.	.
Calamagrostis epigejos (L.) Roth	15	+	50	.	50	.	40	.	.	.	.	.	10	+	.	.	.
Centaurea diffusa Lam.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.	.	.
Cerastium arvense L.	.	.	.	+	.	.	.	.	.	.	+	+	.	.	.	.	.
Chenopodium album L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cichorium intybus L.	+	.	1	.	.	+		1			.	.	.	.	.	.	.
Convolvulus arvensis L.	10	.	.	55	.	.	.	30	5	3	+	.	+	+	.	.	55
Echium vulgare L.	+	.	.	.	+		+						10	.	.	.	.
Elytrigia repens (L.) Nevski	+	+	+	.	.	+	+	30	65	50	75	35	10	+	+	+	+
Erigeron annuus (L.) Pers.	+	+	3	.	+	+	.	+	+	+	+	.	+	25	.	+	+
Erigeron canadensis L.	.	25	3	.	.	.	.	.	.	.	+	+	.	.	.	.	+
Equisetum arvense L.	15	.	5	+	+	30	+	+	10	+	5	.	.	.	.	.	.
Galeopsis tetrahit L.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Lactuca serriola L.	+	+	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.
Lepidium densiflorum L.	.	.	.	.	.		.	1	.	.	.	.	.	.	.	.	.
Lupinus polyphyllus Lindl.	+	+	1	.	.	+	.	+	.	.	.	.	.	.	.	.	.
Oenothera biennis L.	+	+	.	.	+	+	+	+	.	.	.	+	.	.	.	.	2
Rudbeckia hirta L.	+	.	1	.	.	+	.	.	.	.	.	.	.	.	.	.	+
Saponaria officinalis L.	2	.	+	.	.	+	.	3	.	.	.	.	.	.	.	.	.
Tanacetum vulgare L.	+	.	.	.	.	+	.	+	.	+	.	+	.	+	.	.	.
Verbascum lychnitis L.	.	+	+	1	.		+	.	.	.	+		+	+	.	.	.
Vicia sativa L.	.	.	.	2	.	.	.	.	+	.	.	.	.	.	.	.	1

Specific dynamics are observed in the woody layer. Among native species, *Ulmus glabra* Huds. proved to be the most aggressive, with its seedlings actively colonizing burial points. In contrast, *Robinia pseudoacacia* L., which plays a stabilizing role in the surrounding ravine systems to the southeast and west, shows no invasive activity on the open burial areas, unlike *Ulmus glabra*. This suggests selective species expansion depending on the micro-ecological conditions of the necropolis and site management regimes.

3.6. Ornamental plants and GI potential

Since 2000, landscaping regulations have limited new plantings to herbaceous perennials and low-growing shrubs. The GI of the “Yatsevo” necropolis is formed by a combination of systematic alley plantings and localized decorative compositions directly at burial points. The core of the structural landscaping consists of coniferous exotics, dominated by *Thuja occidentalis* L., which is represented both by alley plantings along major sectors and by numerous cultivars ('Smaragd', 'Little Gem', 'Miky', 'Globosa', 'Woodwardii') within individual plots. Additionally, solitary plantings of *Rhus typhina* L. are occasionally found on graves, adding a specific coloristic accent to the landscape. Smaragd

A significant feature of the cemetery’s cultivated flora is the use of a wide range of highly ornamental plants that, according to our observations, do not exhibit invasive activity or disturb the integrity of natural phytocoenoses. The shrub fraction is primarily represented by evergreen species, providing year-round aesthetic appeal. Key roles are played by *Buxus sempervirens* L. and various forms of the *Juniperus* L. genus (notably *J. sabina* L., *J. chinensis* L. 'Kuriwao Gold', 'Stricta'; *J. horizontalis* Moench 'Prince of Wales', 'Blue Chip'; *Juniperus* × *pfitzeriana* (Späth) P.A.Schmidt 'Old Gold', 'Mint Julep'). In recent years, the popularity of the *Hydrangea* Gronov. ex L. genus and representatives of *Cotoneaster* L. (*C. dammeri* C.K.Schneid., *C. horizontalis* Decne., *C. acutifolius* Turcz., *C.* × *suecicus* G.Klotz 'Coral Beauty') has increased, often serving as groundcover elements.

The herbaceous component of the GI is marked by significant cultivar diversity. Among perennials, culturally stable Lavandula angustifolia Mill. dominates, alongside species of the genera *Hemerocallis* L., *Primula* L., and *Dianthus* L. A special place is occupied by the genus *Chrysanthemum* L., represented by *C.* × *morifolium* (Ramat.) Hemsl. and *C. indicum* L., which are traditional for the memorial culture of the region. Seasonal aesthetics are complemented by biennials of the genus *Viola* L. and popular annual crops such as *Petunia atkinsiana* (Sweet) D.Don ex W.H.Baxter and *Tagetes patula* L.

Analysis of the ornamental flora fraction indicates a substantial potential for the necropolis’s GI. The use of non-invasive introduced plants and stable cultivars allows for the creation of an aesthetically pleasing landscape that simultaneously performs sanitary and hygienic functions and contributes to the local preservation of phytodiversity without the risk of alien species expansion into surrounding ecosystems.

4. Discussion

4.1. Hydrogeological vulnerability and heavy metal accumulation pathways

The findings at the “Yatsevo” necropolis underscore a significant ecological risk that is globally characteristic of large-city cemeteries. The accumulation of heavy metals and polymer waste is not a localized anomaly but a systemic byproduct of high-density urban burial sites. Whether in Eastern Europe, North America, or Asia, the environmental footprint of memorial landscapes represents a global sustainability challenge, which at “Yatsevo” has been acutely compounded by the additional geochemical burden of military operations.

The contrast between peacetime and wartime ecological risks at “Yatsevo” is defined by the transition from chronic to acute (shock) contamination. In peacetime, Pb and Cd input is a slow process of UV-degradation of ritual plastics. However, wartime impacts introduced a “shock” factor: the detonation of munitions directly into burial sectors caused the simultaneous destruction of thousands of monuments and ritual artifacts (Svoboda.fm, 2022). The resulting craters (up to 5.6 m in diameter) became localized “geochemical reactors” where high temperatures and explosive energy mobilized metals from both ammunition fragments and pulverized plastic stabilizers, creating contamination levels 1.7–3 times higher than those observed in undisturbed areas.

The extreme Pb and Cd concentrations at the “Yatsevo” cemetery are fundamentally governed by the site’s specific lithology. The binary stratigraphic structure– comprising permeable sandy upper layers over semi-impervious clays– acts as a selective filter. While high hydraulic conductivity in the sand facilitates the vertical migration of metal ions from degrading polymers and munitions, the underlying clay strata function as an aquitard. This configuration promotes the formation of a perched water table, redirecting vertical infiltration into lateral transport toward the Desna River floodplain. Such hydrogeological risks are consistent with findings by Spongberg & Becks (2000), who noted that sandy substrates lack the cation exchange capacity necessary to effectively sequester heavy metals.

The significant increase in plastic waste per grave (from 0.7 kg to 5.7 kg) directly correlates with the observed Pb and Cd hotspots. These metals, utilized as thermal stabilizers (Pb) and brilliant pigments (Cd) in PVC and polyester products, are released into the soil through UV-induced degradation and acid rain leaching. A notable distinction exists between contamination sources: while shell craters exhibit a “shock” character of immediate pollution, areas near waste accumulation points suffer from long-term, chronic leaching.

The anomalous Pb content at Point 18 (28.117 ± 4.762 mg/kg), exceeding the MPC by 4.7 times, is particularly critical. This accumulation stems from the degradation of lead-based stabilizers in PVC, which, as noted by Turner & Filella (2021), are not chemically bonded to the polymer and thus easily transition into soil solution upon mechanical or atmospheric exposure. Similarly, high Cd levels (up to 2.054 mg/kg) are linked to the use of cadmium sulfide pigments. As ritual decorations transform into heavy-metal-saturated microplastics, the cemetery becomes a persistent source of inorganic contamination, potentially exacerbated by organic decomposition products which, according to Żychowski (2012), can form mobile complexes that further accelerate metal migration.

The established binary stratigraphic structure of the lithological profile renders these waste accumulation zones permanent sources of contamination. Due to the high permeability of aeolian sands, metals leached from artificial flowers can rapidly reach the groundwater table. As cautioned by Kowarik et al. (2016), unregulated ritual waste transforms cemetery green zones into ecological risks for adjacent aquatic systems, such as the Desna River floodplain.

In shell craters, the elevated mobile Pb and Cd levels directly correlate with ammunition composition: lead from primers and detonators, and cadmium from corrosion-resistant coatings. While Certini et al. (2013) identify lead as a relatively inert military contaminant, our results demonstrate its high mobility in light-textured soils. This creates a serious long-term risk. Since the necropolis soils possess low sorption capacity, the metals accumulated in craters are not permanently deposited but rather gradually infiltrate toward the groundwater table. As established by Tariku et al. (2010), shelling significantly increases the concentration of heavy metals, especially in areas with intense combat history. Furthermore, Meerschman et al. (2011) demonstrated through geostatistical assessment that World War I shelling created persistent spatial anomalies of soil heavy metals that remain detectable even a century later. As noted by Heiderscheidt (2018), the long-term impact of warfare on soil environments leads to lasting chemical alterations that disrupt natural ecosystem functions.

The environmental vulnerability of the “Yatsevo” necropolis is further underscored by its soil texture. Unlike the clay-rich barriers (78% clay) described by Skittberg and Borba (2024) in Brazil, which limit contaminant percolation, the permeable sands at our study site offer no such protection. Interestingly, both studies identify Cd as a primary geochemical threat, but its migration potential is significantly higher under the sandy conditions at “Yatsevo”. Consequently, these contamination hubs serve as continuous sources of pollution, threatening the Desna River ecosystem through lateral migration across the impervious clay substrate.

4.2. Synanthropization of flora and vegetation and the ecological role of *Solidago canadensis*

The transition of the "Yatsevo" cemetery into a strategic node of Chernihiv's GI is complicated by intense phyto-invasion. As noted by Itescu and Jeschke (2024), cemeteries often act as "stepping stones" for neophytes due to regular soil disturbance. The high proportion of adventive species (59%) at "Yatsevo" confirms this intense synanthropization. A noteworthy ecological paradox is the differential behavior of woody species: while *Robinia pseudoacacia* remains stable in adjacent ravines as an erosion-control element (Gorban & Huslystyi, 2018), it does not expand into burial sectors. Conversely, the native *Ulmus glabra* acts as an aggressive colonizer, exploiting mineral-rich, disturbed soils through high anemochory. This systemic xerophytization, driven by the low water-holding capacity of the sandy substrate, further favors the dominance of *Solidago canadensis*.

The invasion of Canadian goldenrod presents an ambivalent ecological trade-off. On one hand, its monodominant stands (up to 98% cover) cause a radical decline in alpha-diversity. In the mosaic landscapes of Chernihiv Polesie, *S. canadensis* easily displaces native psammophytic and meadow components (Danko et al., 2021), creating fire hazards from dry biomass (Gilbert, 1991a) and disrupting higher trophic levels. As demonstrated by Moroń et al. (2009), such homogenization reduces the diversity of wild pollinators by replacing nutrient-rich grasslands with species-poor stands.

On the other hand, *S. canadensis* provides vital ecosystem services in technogenically modified landscapes. It serves as a crucial late-summer honey-bearing resource (Lukash et al., 2021) and its robust biomass acts as a "green filter" for atmospheric dust deposition (Kvesitadze & Potemkin, 2023). Crucially, the genus *Solidago* is capable of intensive toxicant metabolism, functioning as an active component of natural soil remediation against munitions-related heavy metals. Given its capacity for Pb accumulation in the root system (Bielecka & Królak, 2019), these stands may act as a biological buffer, immobilizing contaminants within the soil matrix and hindering their lateral migration toward the Desna River.

Consequently, vegetation management at "Yatsevo" should transition from passive maintenance to a strategy of controlled balance. While *S. canadensis* requires strict limitation in active burial zones, its role as a stabilizing element in peripheral areas must be recognized (Szymura & Szymura, 2016).

Despite these biological threats, "Yatsevo" maintains its function as a vital component of the city's "lungs". Its proximity to the southern semi-natural forest tracts ensures ecological connectivity, allowing the cemetery to serve as a buffer zone between urban density and the riparian ecosystem of the Desna River. Integrating the cemetery into a unified GI network requires a shift from passive maintenance to active ecological management. This includes the strategic replacement of invasive *Solidago* L. with the high-decorativity, low-invasive species, which provide ecosystem services without compromising the integrity of the surrounding natural habitats.

4.3. Post-conflict restoration and resilient management

The transition toward sustainable cemetery management is a growing trend across Europe, aiming to mitigate the ecological footprint of ritual activities. Monitoring studies in the Lublin region (Poland) highlight that even traditional cemeteries serve as potential sources of groundwater contamination, with significant fluctuations in nitrate concentrations (Kowalczyk et al., 2020). This risk is further exacerbated by the massive scale of ritual waste– reaching 27.3 kg per grave in some Polish cities. Traditional graves, where candles, flowers and decorations are often left, generate much more waste than columbaria (UMP, 2024) – triggering a shift toward stricter waste segregation and biodegradable alternatives.

The high density of stone-clad graves at “Yatsevo” aligns with these regional traditions in Eastern Europe, where granite accounts for over 70% of all monuments (Kowalczyk et al., 2020). Such “stone-intensive” practices stand in stark contrast to emerging ecological alternatives in Western Europe. In Germany, for example, “ecological” and “forest cemeteries” (Waldfriedhof) are becoming a mainstream choice, transforming memorial sites into biodiversity-rich woodlands where traditional monuments are replaced by natural vegetation (Interia, 2023). Similarly, the United Kingdom has seen a rise in designated “natural burial sites” that prohibit permanent structures to enhance local natural capital. There are now almost 300 natural burial grounds in the UK and more applications for new sites being lodged regularly. (Natural Memorials, 2026). Integrating these resilient management strategies is essential for the “Yatsevo” necropolis to balance resource-heavy ritual traditions with the urgent need for post-conflict environmental restoration.

For the “Yatsevo” necropolis, integrating these European best practices is essential but must be adapted to the unique challenges of post-conflict restoration. While the water quality in Polish cemeteries often meets basic requirements (Kowalczyk et al., 2020), the synergistic impact of ritual polymers and munitions-related Pb/Cd hotspots at “Yatsevo” necessitates a more resilient management strategy. This should combine the European “zero-plastic” approach with targeted phytoremediation, utilizing existing *S. canadensis* stands as a temporary biological buffer to prevent contaminant leaching into the Desna River ecosystem.

The recent history of the "Yatsevo" cemetery as a "landscape of resilience" is defined by the necessity of restoring memorial infrastructure damaged during the 2022 hostilities. The reconstruction of the Church of St. Lawrence and the ongoing restoration of the ATO memorial chapel are acts of social regeneration that must be integrated with sustainable ecological standards (Rugg, 2013). Transitioning from high-maintenance, invasive-prone landscapes to a resilient GI model requires a strategic selection of plant materials. Our study proposes a critical shift away from the pervasive use of artificial ritual flowers and wreaths–which act as sources of microplastic and heavy metal pollution - toward environmentally safe and aesthetically superior live landscaping (Zhang et al., 2022).

The inventory of the "Yatsevo" necropolis's cultivated flora indicates a significant potential for ecological rehabilitation following wartime destruction. Unlike aggressive invasive species, the identified taxa of the genera *Thuja* L., *Juniperus* L., *Buxus* L., *Lavandula* L., and *Chrysanthemum* L. demonstrate high adaptability to sandy soils and anthropogenic pressure. As noted by Gilbert (1991a), urban cemeteries serve as specific refugia where a properly selected assortment of introduced species can maintain landscape structural integrity over long periods even with minimal maintenance. This provides a foundation for transforming the memorial space into a resilient element of Chernihiv's GI.

A promising direction for post-conflict restoration is the expanded use of acclimatized shrubs that have proven effective in the urban environment. Implementing hardy forms of *Spiraea japonica* L.f., *Physocarpus opulifolius* (L.) Maxim., *Berberis thunbergii* DC., and *Ligustrum vulgare* L. will facilitate multi-layered planting structures. The high efficiency of such species as "sand stabilizers" is supported by research from Ren et al. (2024), which emphasizes the ability of such shrub systems to mechanically fix the substrate and improve its physicochemical properties. These biogroups will act as living barriers against dust and wind erosion, which is critical for the open areas of the necropolis.

The core of the ecological strategy must be the complete replacement of short-term polymer attributes (artificial flowers) with long-term phytodesign. As demonstrated previously, plastic degradation is a primary source of soil contamination with Cd and Pb. A biologically active alternative to synthetic products is the use of xerophilous low-growing perennials such as *Sedum acre* L., *Thymus serpyllum* L., and *Sempervivum tectorum* L. According to Gorban & Huslystyi (2018), introducing drought-resistant groundcover plants in challenging edaphic conditions not only stabilizes the soil temperature regime but also fosters the formation of stable vegetation cover that requires minimal resources to maintain. Creating "living carpets" directly on burial sites will transform the necropolis into a node of urban climatic stability.

5. Conclusions

The lithological profile of the “Yatsevo” necropolis (permeable sands over clay) creates a high risk of vertical contaminant infiltration and subsequent lateral migration of necrofiltrate toward the Desna River floodplain.

Military operations in 2022 caused significant geochemical degradation, forming persistent “contamination hubs” in shell craters where mobile Pb levels exceed the MPC by 1.7–3 times across all samples.

Ritual waste (artificial flowers) serves as a chronic source of heavy metals, with anomalous concentrations of mobile Pb (up to 28.1 mg/kg) and Cd exceeding MPC standards by 3–5 times.

The flora is highly synanthropized (59% adventive species), with *Solidago canadensis* (up to 98% cover) acting as an ambivalent factor: it displaces native biodiversity but serves as a temporary phytoremediator of heavy metals in disturbed soils.

Post-conflict restoration requires a resilient management strategy, replacing polymer attributes with low-growing xerophilous perennials (*Sedum* L., *Thymus* L.) and ornamental shrubs (*Spiraea* L., *Berberis* L.) to stabilize the geochemical state and ensure the ecological safety of the urban GI.

References

Andersson, E., Barthel, S., & Ahrné, K., 2007, Measuring social-ecological dynamics behind the generation of ecosystem services. Ecological Applications: a Publication of the Ecological Society of America 17(5): 1267-1278. https://doi.org/10.1890/06-1116.1

Bielecka, A., & Królak, E., 2019, *Solidago canadensis* as a bioaccumulator and phytoremediator of Pb and Zn. Environmental Science and Pollution Research 26(36): 36942–36951. https://doi.org/10.1007/s11356-019-06690-x

Boukita, H., El Ammari, M., Elwahab, F., El Bahja, F., Oudghiri, M., Brhadda, N., & Ziri, R., 2025, Invasive plants in urban settings: a systematic review and bibliometric analysis of trends, gaps, and future implications. Trees, Forests and People 22: 101051. https://doi.org/10.1016/j.tfp.2025.101051

Bricka, R. M., Williford, C. W. & Jones, L. W., 1994, Heavy metal soil contamination at U.S. Army installations: proposed research and strategy for technology development, Technical Report IRRP-94-1, Vicksburg: 1-52.

Certini, G., Scalenghe, R. & Woods, W. I., 2013, The impact of warfare on the soil environment. Earth-Science Reviews 127: 1-15. https://doi.org/10.1016/j.earscirev.2013.08.009

Danko, H., Lukash, O., Morozova, I., Boiko, V. & Yakovenko, O., 2021, The meadow, psammophytic and ruderal plant communities with *Solidago canadensis* L. in Chernihiv Polesie (Ukraine). Studia Quaternaria 38(2): 149-158. https://doi.org/10.24425/sq.2021.136832

Derzhspozhyvstandart Ukrainy [State Consumer Standard of Ukraine], 2007a, Iakist hruntu. Vyznachennia vmistu rukhomykh spoluk kadmiiu v hrunti v bufernii amoniino-atsetatnii vytiazhtsi z pH 4,8 metodom atomno-absorbtsiinoi spektrofotometrii [Soil quality. Determination of the content of mobile cadmium compounds in soil in a buffered ammonium acetate extract with pH 4.8 by atomic absorption spectrophotometry] (DSTU 4770.3:2007) [In Ukrainian].

Derzhspozhyvstandart Ukrainy [State Consumer Standard of Ukraine], 2007b, Iakist hruntu. Vyznachennia vmistu rukhomykh spoluk svyntsiu v hrunti v bufernii amoniino-atsetatnii vytiazhtsi z pH 4,8 metodom atomno-absorbtsiinoi spektrofotometrii [Soil quality. Determination of the content of mobile lead compounds in soil in a buffered ammonium acetate extract with pH 4.8 by atomic absorption spectrophotometry] (DSTU 4770.9:2007) [In Ukrainian].

Gilbert, O. L., 1991a, Cemeteries, [in:] The Ecology of Urban Habitats, Springer, Dordrecht: 218–238. https://doi.org/10.1007/978-94-009-0821-5_13

Gilbert, O. L., 1991b, Vegetation dynamics, [in:] The Ecology of Urban Habitats, Springer, Dordrecht: 55–67. https://doi.org/10.1007/978-94-011-3068-4_5

Gorban, V. A., & Huslystyi, A., 2018, Deiaki osoblyvosti vplyvu nasadzhen *Robinia pseudoacacia* L. na grunty v posushlyvykh umovakh [Some features of the influence of *Robinia pseudoacacia* L. on soils in arid conditions]. Ecology and Noospherology 29(1): 47-51. https://doi.org/10.15421/031808 [In Ukrainian].

Heiderscheidt, D., 2018, The impact of World War One on the forests and soils of Europe, Ursidae. The Undergraduate Research Journal at the University of Northern Colorado 7(3): Article 3.

Interia, 2023, Ekologiczny cmentarz w Niemczech. Miejsce pamięci tętni życiem. Zielona Interia. Available at: https://zielona.interia.pl/wiadomosci/swiat/news-ekologiczny-cmentarz-w-niemczech-miejsce-pamieci-tetni-zycie,nId,7121083 (Accessed: 01 April 2026).

Itescu, Y., & Jeschke, J. M., 2024, Assessing the conservation value of cemeteries to urban biota around the world. Conservation Biology 38: e14322. https://doi.org/10.1111/cobi.14322

Kabinet Ministriv Ukrainy [Cabinet of Ministers of Ukraine], (2021, December 15). Postanova №. 1325 “Pro zatverdzhennia normatyviv hranychno dopustymykh kontsentratsii nebezpechnykh rechovyn u hruntakh” [Decree No. 1325 “On approval of standards for maximum permissible concentrations of hazardous substances in soils”]. https://zakon.rada.gov.ua/laws/show/1325-2021-%D0%BF#Text [In Ukrainian].

Kapanadze, K., Magalashvili, A., & Imnadze, P., 2019, Distribution of natural radionuclides in the soils and assessment of radiation hazards in the Khrami Late Variscan crystal massif (Georgia). Heliyon 5(3): e01377. https://doi.org/10.1016/j.heliyon.2019.e01377

Kowalczyk, J., Wlazło, Ł., Tymczyna, L., Ossowski, M. & Nowakowicz-Dębek, B., 2020, Chemical pollution of well water from the Lublin region cemeteries (Zanieczyszczenia chemiczne wód studziennych z lubelskich cmentarzy). Przemysł Chemiczny 99(12): 1740-1742. https://doi.org/10.15199/62.2020.12.9

Kowarik, I., Buchholz, S., Lippe, M. von der, & Seitz, B., 2016, Biodiversity functions of urban cemeteries: evidence from one of the largest Jewish cemeteries in Europe. Urban Forestry & Urban Greening 19: 68-78. https://doi.org/10.1016/j.ufug.2016.06.023

Kvesitadze, G., & Potemkin, A., 2023, Plants detoxifying toxic compounds, [in:] Homo sapiens and the Technogenic Environment, T. Sadunishvili (ed), UNI Madrid, Madrid: 142–158.

Lima, B. B. M. e R., Marini, A. F., Manhães, A. J. P., Sales, D. da S., Guimarães, H. A., Sales, C. M. R., & Correia, V. G., 2025, Cemeteries and environmental contamination: strategies for control, monitoring and remediation. Revista De Gestão Social E Ambiental - RGSA 19(10): e013549. https://doi.org/10.24857/rgsa.v19n10-018

Lukash, O., Strilets, S., Yakovenko, O., Miroshnyk, I., Dayneko, N., Sliuta, A., Kupchyk, O., Morozova, I. & Sazonova, O., 2021, Prediction (on the content of radionuclides and heavy metals) of the *Solidago canadensis* L. use as a honey resource in Polesie. Ecological Questions 32(4): 35-47. https://doi.org/10.12775/EQ.2021.032

Meerschman, E., Cockx, L., Islam, M. M., Meeuws, F., & Van Meirvenne, M., 2011, Geostatistical assessment of the impact of World War I on the spatial occurrence of soil heavy metals. Ambio 40(4): 417-424. https://doi.org/10.1007/s13280-010-0104-6

Moroń, D., Lenda, M., Skórka, P., Szentgyorgyi, H., Settele, J., & Woyciechowski, M., 2009, Wild pollinator communities are negatively affected by invasion of alien goldenrods in grassland landscapes. Biological Conservation 142(6): 1322–1332

Natural Memorials, 2026, Natural burials and eco funerals in the UK are more popular than ever. Directory of Natural Burial Sites. Available at: https://www.naturalmemorials.co.uk/pages/directory-of-natural-burial-sites (Accessed: 02 April 2026).

Pyrikov, O. V., Lunova O. V., Yermakov, V. M., Petry, R., & Lubenska, N. O., 2022, Impact of the long-time armed conflicts on the ecological safety of industrial objects. Journal of Geology, Geography and Geoecology 31(2): 380-389. https://doi.org/10.15421/112235

Pauleit, S., Hansen, R., Rall, E. L., & Rolf, W., 2020, Urban green infrastructure: Strategic planning of urban green and blue for multiple benefits, [in:] The Routledge Handbook of Urban Ecology, I. Douglas, P. M. L. Anderson, D. Goode, M. C Houck, D. Maddox, H. Nagendra, T. P. Yok (eds), Routledge, Abingdon: 931-942.

Quinton, J. M., Duinker, P. N., Gallant, K. A., Steenberg, J. W. N., & Charles, J. D., 2019, To tree or not to tree: user and management perspectives of cemetery trees. Urban Forestry & Urban Greening 43: 126385. https://doi.org/10.1016/j.ufug.2019.126385

Ren, T., Gao, Y., Yuan, L., & Zhao, C., 2024, *Robinia pseudoacacia* sand stabilizer: its sand fixation effects and mechanical properties. Frontiers in Environmental Science 12: 1304830. https://doi.org/10.3389/fenvs.2024.1304830

Rugg, J., 2013, Choice and constraint in the burial landscape: re-evaluating twentieth-century commemoration in the English churchyard. Mortality 18(3): 259-275 https://doi.org/10.1080/13576275.2013.819322

Sallay, Á., Tar, I. G., Mikházi, Z., Takács, K., Furlan, C., & Krippner, U., 2023, The role of urban cemeteries in ecosystem services and habitat protection. Plants 12(6): 1269. https://doi.org/10.3390/plants12061269

Skittberg, B. T., Borba, W. F., 2024, Características físicas e químicas do solo no cemitério municipal de Braga – RS [Physical and chemical characteristics of the soil in the municipal cemetery of Braga – RS]. Disciplinarum Scientia, Série: Naturais e Tecnológicas 25(1), Santa Maria: 1-15. https://agris.fao.org/search/en/providers/125314/records/674843f47625988a3719ab69

Spongberg, A. L., & Becks, P. M., 2000, Inorganic soil contamination from cemetery leachate. Water, Air, and Soil Pollution 117(1): 313-327. https://doi.org/10.1023/A:1005186919370

Straka, T. M., Mischo, M., Petrick, K. J. S., & Kowarik, I., 2022, Urban cemeteries as shared habitats for people and nature: reasons for visit, comforting experiences of nature, and preferences for cultural and natural features. Land 11(8): 1237. https://doi.org/10.3390/land11081237

Svoboda.fm, 2022, Obsiahy velychezni: u Chernihovi pirotekhniky rozminovuiut kladovyshche "Yatsevo" [Volumes are huge: in Chernihiv, pyrotechnicians are demining the "Yatsevo" cemetery]. Available at: https://svoboda.fm/crime/events/286055.html (Accessed: 02 April 2026).

Szymura, M., & Szymura, T. H., 2016, Interactions between alien goldenrods (*Solidago* and *Euthamia* species) and comparison with native species in Central Europe. Flora 218: 51-61. https://doi.org/10.1016/j.flora.2015.11.009

Tariku, M., Van Meirvenne, M. & Tack F., 2010, Shelling in the First World War Increased the Soil Heavy Metal Concentration, [in:] geoENV VII – Geostatistics for Environmental Applications, P. Atkinson & C. Lloyd (eds), Springer, Dordrecht: 247-256. https://doi.org/10.1007/978-90-481-2322-3_22

Turner, A., & Filella, M., 2021, Hazardous metal additives in plastics and their environmental impacts. Environment International 156: 106622. https://doi.org/10.1016/j.envint.2021.106622

UMP, 2024, Ile śmieci produkują cmentarze? Raport Unii Metropolii Polskich. Centrum Analiz i Badań UMP. Available at: prawo.pl (Accessed: 01 April 2026).

United Nations, n. d., Goals 11: Make cities and human settlements inclusive, safe, resilient and sustainable. Department of Economic and Social Affairs, Sustainable Development. https://sdgs.un.org/goals/goal11

Woodthorpe, K., 2011, Sustaining the contemporary cemetery: Implementing policy alongside conflicting perspectives and purpose. Mortality 16(3): 259-276. http://dx.doi.org/10.1080/13576275.2011.586125

Yakubenko, B. Ye., Popovych, S. Yu., Ustymenko, P. M., Dubyna, D. V., & Churilov, A. M., 2018, Geobotanika: metodychni aspekty doslidzhen [Geobotanics: methodical aspects of research], Lira-K, Kyiv: 128-162. [In Ukrainian].

Yurieva, A., & Udovychenko, V., 2024, Challenges of post-war terrestrial ecosystem restoration in the context of sustainable development implementation (a case study of Kyiv region). Constructive Geography and Rational Use of Natural Resources 5(1): 31-42. https://doi.org/10.17721/2786-4561.2024.5.1.-4/12

Zhang, Z., Cui, Q., Chen, L., Zhu, X., Zhao, S., Duan, C., Zhang, X., Song, D., & Fang, L., 2022, A critical review of microplastics in the soil-plant system: Distribution, uptake, phytotoxicity and prevention. Journal of hazardous materials 424(Pt D): 127750. https://doi.org/10.1016/j.jhazmat.2021.127750

Żychowski, J., 2012, Impact of cemeteries on groundwater chemistry: A review. Catena 93: 29-37. https://doi.org/10.1016/J.CATENA.2012.01.009