INSTYTUT PODSTAW INŻYNIERII ŚRODOWISKA
POLSKIEJ AKADEMII NAUK

Anna Starzewska-Sikorska
Editor

Integrated environmental management of land and soil in European urban areas

Zabrze 2021

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INSTITUTE OF ENVIRONMENTAL ENGINEERING
OF THE POLISH ACADEMY OF SCIENCES

WORKS & STUDIES
PRACE I STUDIA

No. 93

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Redakcja i korekta: Jerzy Szdzuj

Fotografia na okładce: IETU

PL ISSN 0202-4112

ISBN 978-83-60877-19-7

Dofinansowano ze środków Wojewódzkiego Funduszu
Ochrony Środowiska i Gospodarki Wodnej w Katowicach

Treści zawarte w publikacji nie stanowią oficjalnego stanowiska organów
Wojewódzkiego Funduszu Ochrony Środowiska i Gospodarki Wodnej w Katowicach.

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Chapter 1

Introduction

During the last 10 years the urban land and soil management issues have been the subject of various research and application projects in the Institute for Ecology of Industrial Areas, presenting both the diagnoses and solutions aiming at improving the situation in this respect. The projects dealt with issues in European countries in general, but especially in Central European countries, facing problems related to the still existing heritage of the last decades, to which common European problems in this field should be added.

The chapters below show the results of the projects which have been implemented during the last 10 years in IETU. Various aspects of sustainable land management are presented in the projects financed by the INTERREG Programme for Central Europe which include solutions in methodology, tools and instruments supporting land management in urban areas.

Results of other projects on the analysis and assessment of negative effects of unsustainable land management in urban areas consisting in using forest and agricultural land for other purposes are also presented.

Degraded post-industrial sites are an important part of urban areas in many European cities. The methods and tools for managing these sites are presented, including remediation methods and health risk assessment methods which support decision making in management and use of these types of sites. Some aspects of waste management and air quality in urban areas have also been presented as an important element of urban space quality and the life comfort of the inhabitants.

It should be stressed that in all cases land and soil are perceived as a resource which needs protection and reasonable use like other environmental resources. Therefore, in all of these projects, the tools and methods of environmental management have been applied to the field of land use planning and management. This alliance of environmental resources management with land use planning and management is the key idea promising the future improvement in making urban areas better for living.

Chapter 2

The idea of circular land use management

Summary
Circular land use management is an approach following the idea of life cycle analysis applied in relation to land. The CIRCUSE project has presented several examples of how to introduce this idea into the land use planning and management in the scale of a municipality. 6 cases have been shown from 6 countries of Central Europe including one investment in Poland consisting in re-shaping of a post-industrial area into a rest and recreation park.

Keywords: land use management, circular economy, life cycle analysis

2.1. Introduction

Nowadays in European cities land for development is at a premium, particularly in urban & peri-urban areas. To secure land for development, protect non-urbanized land and encourage more sustainable land use, regions and cities face common problems, which manifest themselves in sprawl, greenfield depletion, increasing sealing and extensive brownfield areas. Massive urban sprawl, the current economic crisis and the effects of the demographic change could lead to land use patterns, which are neither competitive (e.g. in attracting viable economies, efficiently providing infrastructures), nor sustainable. Dispersed land use patterns with their high demands of land and energy also accelerate the process of climate change. Furthermore, cities are facing social (e.g. segregation and social tension), economic (e.g. unemployment) and environmental problems (e.g. pollution, noise, traffic congestion) related to urban development. Therefore, they need suitable urban planning policies and implementation tools to cope with them. Many of these issues are transnational, where corporate developers and investors seek opportunities to acquire sites.

Very often they enter areas which offer the least resistance to sustainable development principles. Those developers who would wish to champion sustainable development merits then miss standard process to benchmark, evaluate & reward sites across the EU.

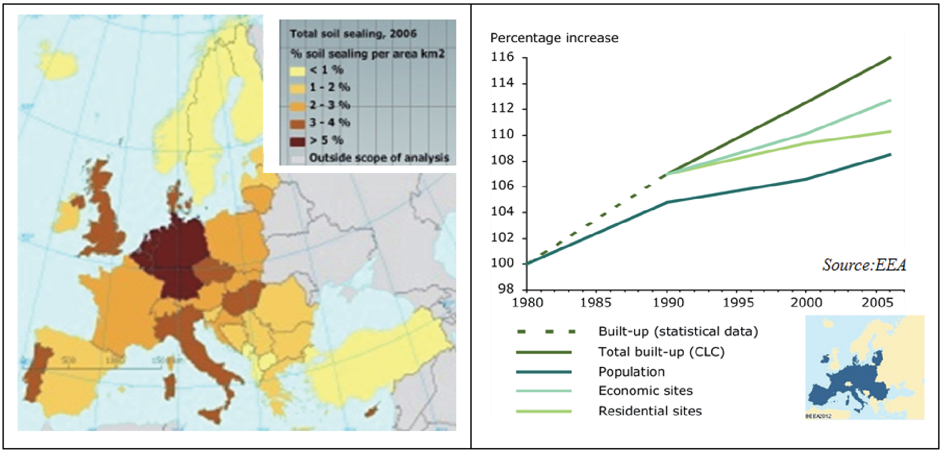

Fig. 2.1. Level of land sealing and level of built up areas in selected EU countries (http://ec.europa.eu/environment/soil/pdf/soil_sealing_guidelines_en.pdf)

Many Central European cities have been developed (or are fast going to be developed) into regional agglomerations. But the available planning methods, institutional structures and the associated management tools have not progressed fast enough to cope with the increasing scale, interconnectivity and complexity, which this growth has generated. The "traditional" planning vision is still applied, despite that it can no longer deliver integrated planning for modern cities, which are facing the demographic changes and challenges presented by the need to react to climate change.

The integrated approach for land use management including public and private stakeholders in Central European Regions is still missing. The existing local, regional, national and European instruments did not succeed in solving this process in the past period. They even had adverse impacts on the former accession states, by distributing grants (ERDF) mainly to greenfield sites. The problem is of specific relevance for regional and local authorities dealing with land management, allocations of land relevant for European and regional funding and investments.

The main objective of the presented idea of circular land use management was to create an approach which would support land use planning and management in a way enabling reduction of excessive use of green areas for urban development.

2.2. The principle of reuse and phases of land use

The idea of "circular land use management" is similar to the well-known recycling and the life cycle analysis in relation to waste and water management. It has been developed by the research team in the German Institute of Urban Affairs in Berlin (Federal Office, 2006). This idea should become the basis for an established policy in sustainable land use. The life cycles of materials serve as a model for circular land use management: the constructed city is understood as a system with a structural makeup which is subject to various usage phases and where, in certain instances, entire districts and industrial areas are dismantled and made suitable for subsequent use, whereby the total area of land used should remain unchanged. Structures no longer fit for reuse are demolished or re-naturalised; infill measures are implemented in areas with high settlement pressure. The idea of a "circular" use thus seizes upon the notion of a use cycle of the allocation of building land, development, use, abandonment and reuse (Fig. 2.2).

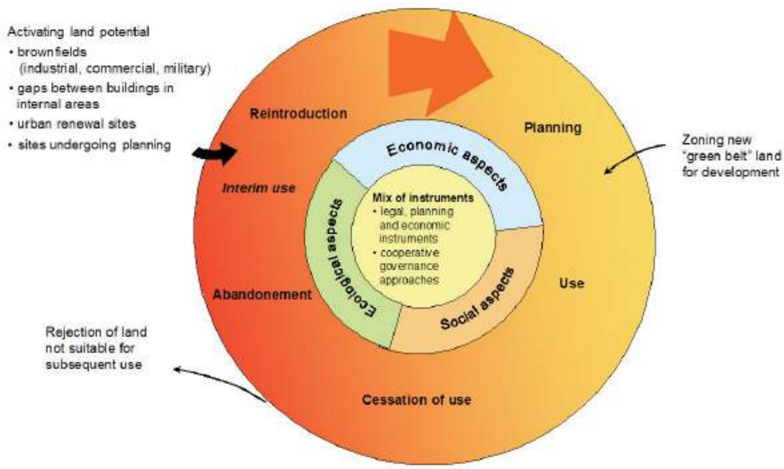

Fig. 2.2. Phases and opportunities of circular land use management (Federal Office, 2006)

2.3. Potential of circular land use management

The approach consisting in circular land use management supports a strategy which primarily and systematically seeks to exploit the potential to develop existing building sites and reuse derelict land. It focuses and strengthens an internal development (recycling abandoned sites, higher density development, infill development, multiple use, etc.). The entire use cycle, from planning, use, disuse, dereliction, building to land recovery forms the core of the strategy. The ultimate aim is dynamic site preservation. In an ideal scenario of this vision, only land which is currently in use would be used for new settlement initiatives.

However, zoning small areas of new land for development is not categorically ruled out, assuming that as mitigatory measures abandoned sites in other areas are being reused. **Therefore, circular land use management, aims to minimize zoning of "greenfield" land (for development) and promotes activation of existing building land, including derelict land, gaps between buildings and also exploiting possibilities for infill development** (cf. Table 1).

Table 2.1. Opportunities for expansion and internal development of land (https://www.refina-info.de/en/akteure/index.html)

Expansion opportunities (outlying land which has yet to be developed)	Theoretical development reserves with no (specific) planning status Regional planning reserves (anticipated building land) Preparatory land use plan reserves (building land awaiting development) Legally binding land use plan reserves which are fundamentally reclaimable (raw building land)
Internal development opportunities	Gaps between buildings (land prepared for building/building land) within the ambit of settlement-epanding legally binding land use plans Gaps between buildings within the ambit of legally binding land use plans using pre-existing developments and unplanned interior areas. Scarcely developed lots/opportunities for infill Brownfields Vacant buidilngs Land which will be abandoned in the foreseeable future

2.4. CIRCUSE project

Circular land management has become a leading theme of the CIRCUSE project, in which 12 partners from 6 countries have developed practical cases of using this idea. The project was implemented between 2010–2013, financed by INTERREG for Central Europe Programme. Projects from the Central Europe Programme are known for implementing pragmatic approaches for various development issues. There are a number of projects addressing the issue of brownfields (COBRAMAN, RESOURCE, URBSPACE, TIMBRE, HOMBRE) or soil (SMS), green urban areas (REURIS) or rural land (RUBIRES), but so far there have not been many projects which directly address the land use management.

Project CIRCUSE (https://ec.europa.eu/regional_policy/pl/projects/europe/circuse) was initiated by the German partners and presented a transnationally valid strategy of land use management based on the circular flow land use management methodology (see Figure 1). It concerned the shape and form of urban living, economy, climate and environment. In particular it concentrated on problems related to urban sprawl and land use economy, with a special focus on compact and polycentric urban development. This is increasingly seen as an important component of sustainable and competitive development of cities and regions. Significant impacts are evident in the economic and social transformation of Central European cities and regions. This is often due to the loss of a number of historical industries, military conversion and collapse of various other social uses, which manifested in a vast amount of brownfields. The social changes, such as inner-urban segregation, migration and demographic changes also had a spatial impact. Concentrated urban development and urban regeneration can help to address some of these changes. But concepts of revitalising urban areas and brownfields will fail if they are not part of an integrated land management system, covering many aspects also including the greenfield developments. Recently the rapid suburbanisation processes were halted by the effects of a financial crisis, which had increased the reluctance of new investors to take on long term urban regeneration projects and related development risks. An outcome of which, would likely be investors´ increased interest in simpler greenfield developments, causing further poorly integrated and unsystematic land use. Additionally, there are inefficient development policies, which continue to exacerbate the land–related conflicts in densely urbanised regions. The aim of the CIRCUSE project was to improve this and also to modernise the historical typologies of land use in Central Europe, strongly "imprinted" on the one hand in the mixed-use structures of the 19th century, and on the other hand in the modern visions of distinct functions, favoured in the post-war period.

The majority of the CIRCUSE project outputs were aimed at the local/regional and also at a transnational level. For example, the CIRCUSE Strategy illustrated that common problems and diversity of national and regional frameworks could be addressed through a common strategy of circular flow land use management. This strategy recommended that setting up of quantified and qualified land use targets is a necessary requirement for successful implementation of a management strategy according to circular flow land use management – on national, regional and local bases. The CIRCUSE Strategy also identified that a development and application of information instruments and data management tools for registration and monitoring of space-oriented potential, is one of the key activities towards the circular flow land use management. Further analyses of the planning and land management practices in the 6 partner countries revealed that it was mainly at the local community level that the qualitative data on urbanised land use were missing. This was mainly due to the fact, that planning did address the actual economic efficiency of the land use (vacant buildings, brownfields, gaps etc.).

To help with this, the project firstly unified the urban land use typologies and then developed a pragmatic inventory tool, focused on the local/regional land use management. This tool can help local communities to become aware of the size of their development potential within their urbanised area. By continuing to work with such data, it is possible to analyse the actual accessibility of this urban development potential, and above all, to propose measures to improve the inner urban development potential accessibility. Data gathering can usually help to size up an issue and monitor the situation. However, a more efficient land use solution can only be achieved through coordinated action, aimed at delivering the good intentions identified in various policies. As a tool which could achieve this, the Action Plan chosen by the CIRCUSE project focused on improving land use efficiency. Six action plans based on a common template were developed, one per each project partner country. The scale of these action plans varied, from site--specific plans (Piekary) city plans (Asti, Freiberg), peripheral regions (Trnava, Voitsberg) to plans based on NUTS 3 (Ústí Region). In the last three plans the multilevel governance approaches and the stakeholders´ participation were tested.

Apart from action plans also pilot actions have been developed in the CIRCUSE project. Pilot actions demonstrated various innovative and efficient practical solutions in selected areas. All the pilot projects support each other's activities, which complement sustainable development of the concerned territories by reducing disparities and promoting competitiveness through the application of innovative solutions. Pilot projects offer possibilities of implementing new land use and land management concepts, which could be applied in other areas and urban spaces once the results of the pilot projects have been validated. CIRCUSE strategies and tools would therefore contribute to increasing the competitiveness and capability of the pilot regions and help them build up regional visions on competitive/climate friendly land use jointly developed by key stakeholders. Also the pilot projects constitute cases referring directly to the idea of "circular economy" in relation to land use.

These pilots would also coordinate planned public interventions and funding, help implement new solutions and promote better access to knowledge and information. They create concepts for intensifying land use changes, reducing land consumption, increasing private investment in urban locations and help upskill public authorities. 6 Central European municipalities or regions would produce integrated Action Plans on sustainable land management and realise pilot projects demonstrating practical solutions by local and regional stakeholders. In five cases the pilots were developed in the form of documents, while the pilot in Poland was a real investment implemented in the framework of the CIRCUSE project.

PILOT 1 – Austria/The region Voitsberg, Steiermark. The Austrian Pilot region is an alliance of five communities (Gemeindeverbund Voitsberg) and represents a shrinking region; i.e. decreasing number of inhabitants, break-down of former coal mining industry but continuous increase of land consumption at the same time. The implementation of the CIRCUSE method shall reduce land consumption and soil sealing and provide the region with a long-term concept for land management. The pilot in Voitsberg is to address the future use of large derelict mining areas (development of bio fuel combustion technologies). In this context the potential to establish pilot biomass plantations at former derelict mining areas shall be explored and tested.

PILOT 2 – The Czech Republic/Usti Region, Ústí nad Labem: For the last 8 years the city has benefited from some growth and urbanised land expansion where the population trends were differentiated into expanding and contracting locations. The present economic climate has made the whole land use and development situation in the city a reality. Investors, owners, politicians and administrators are becoming more receptive to consider new approaches. Recent legal changes and programme tools are forcing the regions and communities to collect land use related data. The pilot in Ústí nad Labem is a Development Action Plan aimed at one of three large brownfield areas in the city.

PILOT 3 – Germany/The region of Saxony: Saxony is confronted with the ongoing economic and demographic change. Despite the shrinking population, land consumption is increasing and historic centres and locations are losing their functions and population. An important consequence is the 7.000 ha of brownfield sites in Saxony, the high costs of maintaining underused infrastructure and high costs of urban interventions. The pilot in the Region of Saxony will initiate a coherent approach to land consumption and urban renewal.

PILOT 4 – Italy/Piedmont, Asti city: Asti is a medium sized city, seat of the Provincial government of Asti, in an area where agriculture is still of great importance, as wine production has become a leading economic asset sector. Located in the city centre, there is an important degraded area, now abandoned. The pilot in Asti is analysis of the city needs and the dynamics of development is needed in order to identify the best suitable new function for the area. The aim of this pilot is to apply the Circular Land Use Management approach, taking into account all the inputs coming both from the local context and from the expectations of stakeholders and future users, in order to set up the re-use and new functions for the area.

PILOT 5 – Slovakia/Trnava: The Trnava sub region is confronted by the intensive sub-urbanisation caused by fast economic growth and ensuing rapid spatial transformation. Trnava is a city of regional significance, which has undergone a very dynamic development in a short period of time. The number of citizens has doubled in the last forty years. In the last decade the city development has been closely connected with the automotive industry (Peugot, Citroen). There is a growing demand especially for housing development in the surrounding suburban settlements. The pilot consists of establishing a consortium by the city of Trnava and the surrounding communes based on the concept of cooperation. This cooperation will be oriented towards effective spatial use of the given region potential and implementation of the CIRCUSE strategic approach.

PILOT 6 – The district of Brzeziny in the City of Piekary Śląskie constitutes a pilot area in the CIRCUSE project. The area is analysed from the view-point of circular land use management. The district is covered to a large extent with post--industrial sites after deep mining exploitation, non-ferrous metallurgical plants and solid wastes dumping heaps. There are also old buildings with substandard housing, which constitute an important category of sites presenting problems of physical and social degradation. There are also sites of previous agricultural activity which are now abandoned areas with a category of “unused land” in the local land use plan of the city. According to the methodology of circular land use management, an integrated action plan is one of the project outputs as a model approach to an area of such conglomerate of problems. It results from the analysis of brownfields issue in Europe that this model will be useful for a number of cases in various countries.

In the framework of the project there is one pilot site, where an investment is planned. The pilot investment is focussing on a highly visible and exponated brownfield site in the Brzeziny district of the city of Piekary. This post-industrial area is a part of a newly established Industrial Park. Areas for the planned investment are either the property of the Piekary Śląskie municipality or the State Treasure (Fig. 2.3, Fig. 2.4).

The final territorial range of the pilot area is 16,5 ha.

The investment foresees systematic “regreening” of the post-industrial site and upgrading of the overall image of the local landscape.

The investment’s objective includes the transformation of the degraded terrains and developing them partly into a city park fulfilling the following functions:

- the function of vegetative buffer separating the areas intended for industrial use and warehousing operations from the residential areas of Brzeziny district,
- the ordered vegetation function – park and recreational landscape for public use, complementing and extending the existing city park in the close vicinity, in particular with the bike trails, Nordic walking tracks, rollerblades and skateboard tracks, that are attractive for the city dwellers and guests arriving from outside, along with the structural landscaping and designed greenery.

Fig. 2.3. Location of Piekary Śląskie in Poland   Location of Brzeziny Śląskie in Piekary Śląskie

Fig. 2.4. Location of the Pilot Investment Site Degraded landscape of Brzeziny Śląskie in the Pilot Area

2.5. Conclusion

The approach to choosing the area for "regreening" and the innovative way of sustainable financial support for its future maintenance can be transferred to other regions in other countries. The strategy of land management within which the investment will be implemented demonstrates innovative long-term thinking about circular land use, which is the idea behind CIRCUSE. This innovative strategic approach has a transnational character and is transferable as an innovation in thinking about future land management in other regions of Europe.

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https://ec.europa.eu/regional_policy/pl/projects/europe/circuse

Chapter 3

Integration of land use management with sustainable environmental management in relation to land as a resource

Summary
Sustainable land use planning and management is an important element for implementation of an idea of sustainable development in general. If we look at the land as a resource we can use methods and tools which concern environmental management of resources. The LUMAT project shows how to integrate environmental management tools and methods used in relation to land as a resource into land use planning processes in functional urban areas.

Keywords: sustainable environmental management, land management

3.1. Introduction

The main problems and challenges concerning nowadays land use management in European urban areas include:

- growing land use pressure leading to user conflicts, landscape fragmentation, biodiversity loss and soil sealing
- increasing unbalanced urban developments and declining urban areas with vacant and brownfield land
- jurisdiction of the respective municipalities management ends at its borders which results in an ineffective management related to the fuzzy character of its borders and the fuzzy interrelation of governance systems.

In the regions, poorly integrated and unsystematic environmental and spatial policies increase land–related conflicts and undermine social cohesion and competitiveness in the urban context and new concepts of ecosystem services are not sufficiently applied. One of the most challenging topics of environmental management of land resources is the disparity present in the territorial governance.

There is a need to find ideas for interregional cooperation, tools and instruments to resolve the conundrum while respecting territorial sovereignty and reflecting the problem of fuzziness of the territorial units. An integrated approach is needed, where multiple actors can participate and cooperate in territorial and environmental management to develop the regions.

The innovative transnational solutions of the LUMAT project have provided an integrated territorial and environmental approach by including new concepts of ecosystem service management (https://www.interreg-central.eu/Content.Node/LUMAT.html).

The project's main objective was strengthening integrated environmental management in functional urban areas (FUA) with sustainable land use and ecosystem services development. The idea of LUMAT is based on the key role of land use and management in achieving the goals of sustainable environmental development. Environmental considerations are present in documents and decision-making procedures concerning land use. Land-use planning integrates environmental, social and economic objectives. However, depending on a firm base of institutional power to foster multilateral cooperation, it often causes territorial conflicts and the need for further extension of urbanised areas into agricultural or semi natural areas. Therefore, environmental management should better enhance the tools available for land use planning to prevent undesired spatial patterns of urban sprawl and land degradation. Also, an ecosystem services-oriented approach offers a promising way to align conservation and production, in developing a market-based mechanism for ecosystem services by ascribing them economic and social values, thus improving human welfare by incorporating economic valuation into environmental management decisions.

The objective and framework of the project supported the CE Programme challenges as well as the European strategic documents concerning reduction of land use – "zero land take by 2050". The project aimed at developing methods and tools which would improve urban land management and allow to reduce urban sprawl as well as other threats such as soil sealing or brownfields. They would also contribute to making urban areas more resistant to the effects of climate change. As part of the project, seven functional urban areas in seven countries have developed action plans and committed to further support integrated environmental management. But apart from that, the project has resulted in closer cooperation of cities and suburban areas in resolving land use conflicts and reducing environmental threats. The training materials developed by the project partners also increased the knowledge of professionals in the field of environmental management and land-use planning, showing a wider perspective of Central European countries in this matter.

3.2. Action plans

The action plan documents for integrated environmental land use management in functional urban areas of seven different regions in Central Europe present an overall common approach while taking into account local specific conditions and needs, which are expressed in strategic documents and presented by societies during public consultations.

The project provided AP documents in 7 FUAs – Polish FUA, Trnava FUA (ZOMOT Association), FUA of Leipzig, FUA of Lipizzanerheimat in Austria, FUA of Moravian-Silesian Region, FUA of Kranj and FUA of Torino – which have significantly improved sustainable environmental management (Table 3.1). Public involvement tools (InViTO, LUMATO and Brownfieldy) were also used in developing the action plans. The project developed interactive tools to engage citizens. The tools offered a platform, where citizens can comment on brownfields management activities. There is also space for making brownfields more visible to citizens (interactive map of brownfields). The tools are described on the project website and they can be transferred and used by other cities and FUAs.

Table 3.1. Characteristics of the LUMAT Action Plans for integrated land use management in 7 functional urban areas

FUA	Vision/mission	Actions	Implementation
FUA Voitsberg (AT)	Creation of jobs by activating under-used areas in the form of business locations focusing on the thematic field “garden” (flowers, vegetables, glasshouses, etc.)	Recognition of the opportunities present in each village of the FUA region and how these could best improve their existing character and present eco-system services. Involvement of the mining company in the region to determine sustainable use of the post-mining land.	Implementation of projects answering to the needs of each village, e.g.: flower gardens for wedding sites, eco-garden concepts using geo-thermal energy, establishing a bike path connection between the communities, and other possible projects.
FUA Ostrava (CZ)	To advance brownfields solution in the Moravian-Silesian Region (FUA Ostrava is part of it) and to help set up the implementation structure in order to ensure a stable approach to the issues of current and future brownfields	Regeneration of brownfield sites for improved air purification through eco-system services (agricultural soil protection) as well as improving land recycling processes in the FUA by targeting active management responsibilities and support for new legislation and education.	Implementation will include for example the creation of a position for “brownfield manager”, creation of an interactive database with information on brownfield potential and re-use solutions as well as carrying out public awareness activities. The Regional Council is responsible for its implementation, with the preparation of a “Working group”.

FUA Green Ring of Leipzig (DE)	Strengthening sustainable soil and land management in the Green Ring of Leipzig (GRL) through the planned LUMAT activities and land resource management for a more balanced settlement structure and supporting the goals of the Regional Action Concept (RHK) to develop an attractive “Green Ring” of Leipzig.	Analysis of multi-sectoral threats to eco-system services present in the FUA and evaluating this information in a specially developed tool with stakeholder involvement. The content also includes an assessment of the potential offered by brownfield sites for the protection of soil resources and the minimisation of threats.	An initial evaluation and prioritisation of the brownfield reuse activities will be performed based on the identification of threats to the land and soil resources present in the FUA in order to take action on these sites.
Chierese--Carmagnolese (IT)	To make the Città Metropolitana di Torino (CMTo) (and the HZs) a quality place where people want to live and work. To improve the attractiveness of the entire territory, enhancing the existing landscape and environmental elements without abandoning the productive vocation, both manufacturing and agricultural.	Transformation and re-naturalisation of brownfield sites for improving the green infrastructure in the FUA. Also, green spaces are to be protected in the area through sustainable planning designations / land management and stakeholder management.	Use of existing structures is envisaged for implementation of responsibilities (staff and offices) for integrated environmental management and the protection of eco-system services. Creation of an Integrated Territorial Program of Environmental Action (ITPEA). Applying an interactive tool (InViTo) to gather stakeholder feedback in-situ for the improvement of living conditions.
FUA Chorzów, Ruda Śląska and Świętochłowice (PL)	Enhancement of green and blue infrastructure system in the FUA of Chorzów, Ruda Śląska and Świętochłowice	Use of the post-industrial sites potential for the creation of blue and green infrastructure, for example through the use of brownfield sites for the creation of bicycle network systems. Also, investment in the implementation of a brownfield revitalisation in a residential area which includes the stabilisation and upgrading of an abandoned heap site for future recreational use.	Site specific actions with interest management in various municipalities of the FUA will be undertaken to improve blue and green infrastructure, with an emphasis on cultural and supporting eco-system services.

FUA Kranj (SI)	FUA Kranj, a generator of circular economy in Gorenjska region.	Sustainable development of the FUA through the application of the circular economy concept, that encourages effective land management of underused and unused sites and contributes towards a zero net land take objective.	Supporting the current development of the Regional Development Programme and the Regional Spatial Development Strategy in the Kranj FUA for the long-term impact of the LUMAT project in the area. Management of business zones, with the use of financial, spatial and legal instruments.
FUA Trnava (SK)	Coordination of sectoral planning and management of activities in the field of land use and the use of its resources. The landscape and its resources are used for various purposes that influence each other and compete between themselves. Therefore, the whole land use process should be planned and managed in an integrated way.	Analysis of threats present in the region to soil and land resources and their mapping for the region and the integrated evaluation of these threats with the FUA stakeholders. An investment in the revitalisation of a contaminated site into a new recreational opportunity for the residents in the FUA is also planned.	Implementation of the Action Plan includes a set of measures in key fields such as: coordination of the usage of brownfields and greenfields, climate change adaptation measures, flood protection measures, water and sewage management, development of web GIS map application for integrated environmental management on the municipal level, development of a plan for sustainable regional mobility by 2025, etc. These measures will be implemented incrementally, depending on the availability of municipal financial sources and external co-financing, mainly from the EU funds.

3.3. Pilot actions

The implementation of the action plans is to be preceded by pilot actions which constitute a part of the plans and show practical steps towards implementation of the planned activities. In each case the pilots looked different depending on the possibilities for undertaking immediate actions.

In **Italian** case the action plan was implemented by creation of a pilot project "Fontaneto" in the Municipality of Chieri. The aim of the project is to experiment with an innovative methodological path to evaluate the effectiveness of the payment procedure of Ecosystem Services as a tool to be adopted in planning tools and in territorial management procedures. The activity is conceived with the aim to formalise a replicable methodology in the territory of the functional urban area of Torino.

The project area of about 80 hectares is located south of the town of Chieri, between two leases of industrial land developed since the '90s that extend up to the ring road of the town. The area was mainly designated for sports facilities and amenities (golf) as well as manufacturing and agricultural services. Currently, the area is used for agricultural purposes, with the exception of the small band along the banks of the "Gioncheto" and "del Vallo" rivers where some arboreal and shrubby specimens are arranged in rows.

The most interesting part of the pilot was the economic evaluation of 4 scenarios in the aspect of ecosystem services improvement. The Ecosystem Services evaluated were: habitats quality, carbon sequestration and storage, pollination, agricultural production, timber production, mitigation of soil erosion by water, water purification. The scenarios were created according to possible alternatives regarding the landscape and functional aspects (for example, crop systems, minor ecological network, fund management techniques, etc.), identifying the optimal solution in terms of ecosystem balance (Table 3.2).

Table 3.2. Comparative economic evaluation of scenarios (Mortari et al, 2019)

Ecosystem services	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Baseline**
	€/year	€/year	€/year	€/year
Crop production	95.105,18	96.586,88	99.620,18	101.724,37
Timber production	139,24	119,41	87,02	87.96
Ground water	45,81	47,22	46,81	45,55
Other production	880,00	0,00	0,00	0,00
Natural risk protection	18.866,34	17,630,23	17.630,23	17.325,31
Habitat quality	6.109,17	6.092,92	5.839,81	5.810,30
Water quality	24.282,36	24.246,16	24.028,07	9.297,66
Climate regulation	89.008,39	90.412,60	89.642,13	60.698,30
Fruition/use	50.585,83	37.846,65	25.969,91	19.273,92
Landscape	47.886,39	27.841,64	5.283,75	1.869,97

The **Austrian** pilot project presents the first sustainable "Lipizzanerheimat" cross-community garden "show" as a recreation and production space for the peri-urban metropolitan area of Graz (Schabl et al, 2019).

It is planned that the five Lipizzanerheimat communities should contribute to one „lighthouse project" on the broad topic of gardening. The following activities will be undertaken in the individual communities:

- Rosental: vegetable cultivation in a pilot glasshouse using mine water for heating

- Voitsberg: Development of a community garden, connection to existing parks (for example energy park) and gardens (Naschgarten/ Obervoitsberg)
- Maria Lankowitz: new garden design at the manor house (wedding garden theme)
- Bärnbach: Energy optimisation of an office property with 1600 m^2 usable area with special greening (potential analysis)
- Lipizzanerheimat „garden route“: creation of a connection of all garden and park elements in a network of bicycle paths.

Since the projects were originally created from public participation processes (Agenda 21), the awareness of the existing potential of the areas has already been awakened and sharpened. The participants can value the stock and develop common ideas for urban development. This „we-feeling" is translated into real space by the project and thus creates additional opportunities for personal identification in public space, which is available to the citizens anyway.

The pilot action in the **Czech** case aimed at creating a priority map of sites potentially suspected to be contaminated due to their previous way of usage (Voivodikova et al, 2019). The map was to be included in the national System of Contaminated Sites Record. The selected sites were initially examined on the basis of their previous use – industrial, agricultural – and also field research was carried out and information forms were processed. Then the data was handed over to a professional company for further evaluation. The final assessment of the findings concerned 52 sites. Furthermore, all these sites were inserted into the ArcMap program as polygons and dots layers, for subsequent data presentation. The data was further evaluated according to selected parameters.

The sites were assessed according to the following criteria:

– location of sites,
– size of the locality,
– former use of localities,
– current use of localities,
– possible migration of contaminants,
– number of potentially endangered people.

All the information from this assessment will be the basis for further decisions regarding the development and planning strategy of the Moravian--Silesian Region.

The **German** case was focused on brownfield regeneration to increase the ecosystem services provided by soil and land (Siemer et al, 2019). To this end, pilot sites were selected within the Green Ring of Leipzig area. The pilot examples show the type of experiences and common problems concerning brownfield areas today.

The question of achieving integrated land management on risk sites was the main goal. To demonstrate how brownfield sites could be better managed for integrated environmental management, the concept of Start-Up Plans was applied to pilot sites in the Green Ring of Leipzig. Also, stakeholder management was the key activity for the pilot actions. With start-up plans, integrated environmental land management decisions are easier to accept by stakeholders because relevant information about the sites is gathered in a central, easy to read plan. The benefits of these actions can then be effectively compared to one another.

Various forms of brownfield re-use have been proposed, taking into account needs and possibilities on the one hand and the objectives on the other, including de-sealing, compensation and enrichment of green areas around Leipzig (Table 3.3).

Table 3.3. Characteristics of the LUMAT pilot actions in sites within the Green Ring of Leipzig area

No. Name of the site	**Present state**	**Pilot action activities**
1 Großsteinberg	Former pigsty, it is currently an abandoned brownfield. About one fifth of the 48.000 m² area is occupied by buildings and open spaces. The remaining four fifths (about 37.000 m²) are farmland. All buildings are in a ruinous condition	The agricultural part will remain. The available open space can be used both as an ecological compensation area which is connected with de-sealing and alternatively through a solar energy system.
2 Fuchshain	Part of the site was used as a storage site for street building materials. The site is raised on average about 2 meters above the surrounding land due to the previous storage of gravel and soil materials on the site. The site is partially covered in vegetation and the soil is not of a natural quality.	The site should be used as a compensation site. This can enrich the surrounding agricultural landscape and strengthen the ecological function of the surrounding green axes of the Threne.
3 Althen	The site is located on the eastern border of the Leipzig city district along the Parthe River. In the southern and western parts of the site the existing green network system of the Parthe starts. The use of this green network however is compromised by the existence of a sewer canal and an electricity line.	The site is to be used as an environmental compensation site and the biodiversity on site is to be strengthened. The site is to be refrained from when considering ecological aspects as well as the importance of flood protection and the regulation of the city climate in the area.
4 Böhlen	Abandoned building structure	The building will be adapted to the previous use as a training centre. On the ground floor of the building, office spaces will be rented out. The northern wing and the laboratory of the building can be deconstructed for a new use of the inner courtyard area.

5 Markranstädt	Soil contamination on the site is an issue that needs to be further detailed when revitalising the site. It is to be investigated whether the site is to remain sealed for the protection of the groundwater resources.	Potential site for commercial and industrial activity. This would minimise the construction of such new uses on greenfields in the peri-urban locations of Leipzig and would reactive the brownfield site, and thus successfully recycle land.
6 Taucha	Part of the Taucha brownfield was previously used as clay pit and later as a dumping site, mostly for dug up materials, ashes as well as a small amount of household wastes. Since the mid-1980s the site has been abandoned in its current form.	The aim for the revitalisation of the site is the integration of the site into the green space development of the city of Leipzig, as well as the neighbouring landscape protection zone. The use of a part of the site for agriculture production can be continueed. The neighbouring commercial use should be secured with the option of using part of the brownfield site as an expansion site.
7 Leipzig - Göbelschelwitz	The site is a built-up area, formerly used for agriculture, which still houses some animal barns. Most of the adjacent barn plots are sealed with concrete slabs.	The plan is to create a new ecologically improved site, and the surrounding community is to be considered to help determine the best use for the common good. The existing buildings and the sealed soil on the site are all to be deconstructed. Then the greening of the site as an environmental compensation measure is to be prepared.

The **Slovenian** case of pilot action is connected with the application of the idea of industrial symbiosis (http://www.symbiosis.dk/en/). Industrial symbiosis is defined as the integration of traditionally separate industries into a common approach involving the physical exchange of materials, energy, water, and/or by-products to achieve a competitive advantage. The paradigmatic example of IS is the link between companies that have spontaneously begun to develop in Kalundborg, Denmark since 1961.

The pilot action located in the Municipality of Kranj in Slovenia explores the non-systematic management of degraded urban areas (DUOs) and business zones in the city and adds to the strengthening of integrated land management in functional urban areas (FUO) with special emphasis on sustainable land use and the development of ecosystem services (Momirski et al, 2019). The latter can be achieved by directing development within already urbanized areas, limiting interventions in greenfield areas, and finding spatial solutions outside the administrative borders of municipalities and regions, all due to the goal of implementing sustainable land use. The objective of the pilot project is to stimulate industrial symbiosis (IS) based on management of industrial sites. At the same time, the pilot project implements the Action Plan of the Functional Urban Region of the Municipality of Kranj.

In order to apply the industrial symbiosis approach as an activity supporting sustainable land use, possible IS scenarios will be presented between selected companies in the Municipality of Kranj, depending on the location of the companies and DUO sites. The purpose of this part of the pilot action is to check the location interaction of DUO and possible IS cases, assuming that the key to a successful IS is the collaboration and synergies offered by geographic proximity.

Two pilot actions in the form of full investments have been implemented in LUMAT. They were located in **Ruda Śląska** and **Trnava** (Slovakia). Both investments consisted in the regeneration of brownfield sites. In Polish case it was the regeneration of a post-industrial wastes dumping site in the very middle of the city of Ruda Śląska. The investment included rehabilitation of a large post--industrial wastes dumping site including application of the phytostabilization technology (Pogrzeba, Krzyżak, 2017). The idea was to reduce bioavailability of heavy metals in the soil instead of removing them. This practical solution, applied on a large scale, has already attracted the attention of other cities and regions with similar cases of sites located in the middle of urban areas. It also became a starting point for further actions on other sites and for building bicycle routes linking these sites into one system (Roztańslki, 2021).

The investment in Trnava to restore a neglected nature park for a sports and recreation zone in Štrky was intended to ensure an overall rehabilitation of a previously abandoned and contaminated area of Štrky, for which it could have been considered a "green brownfield" (Guniš et al, 2019). From the environmental point of view, this pilot investment contributed to the restoration and the enhancement of the original natural value and ecological stability of this biocentre of local importance. Moreover, overall rehabilitation enabled opening up this area to the general public of Trnava City and Trnava functional urban area, offering opportunities for sports, leisure and relaxation activities in the natural environment.

After the implementation, the area became an attractive half-wild park with a pond, additional vegetation and greenery, a network of unpaved footpaths, small architecture and mobiliary, as well as public lighting and low-voltage electricity distribution network.

3.4. The project effects

The implementation of the project, which concerned the strengthening of land use management with methods and tools of the integrated environmental management in relation to land, understood as a valuable and non-renewable resource, certainly required extensive promotion of the new approach among professionals. A very important group of stakeholders were also authorities of cities constituting functional urban areas, as they were to be convinced of the necessity of closer cooperation in the area of sustainable land management. The agreements reached in the seven FUAs of the pilot project, certified by letters of commitment, have become a visible result which is currently of interest to the regional authorities in the Silesian region as a good example of joint activities in a specific area.

Also in the Czech Republic the success of the project is evidenced by the fact that, thanks to a two-year discussion, when the project's research team and an expert company evaluated and described a total of 52 sites, the Ministry of the Environment was convinced to make a decision to register previously unregistered potentially contaminated sites in the Czech Republic and to include them in the Contaminated Sites Database System registration (in the Czech Republic it is expected to be 20,000 sites).

LUMAT has aroused interest in other projects such as Urban Links 2 Landscape (UL2L financed by INTERREG EUROPE) or INSPIRATION (Horizon 2020). LUMAT results were presented at UL2L workshops as a good example of development of urban land as an important part of the landscape. In INSPIRATION the LUMAT results were a basis for proposing research subjects for Strategic Research Agenda for the future European scientific programmes in the field of urban land and soil management.

The visible results of the LUMAT project in the form of two investments show successful examples of degraded areas restoration. In particular in Ruda Śląska, the restoration of such a large area located in the middle of the city of Ruda Śląska has become an important place for the inhabitants. Many people visit the place taking advantage of various forms of recreation. They also appreciate the aesthetic values resulting from the changed landscape in this area.

Within the project seven management structures were established for implementation of action plans (APs) for strengthening integrated environmental management of land resources in functional urban areas (FUAs). These structures have been created and the letters of commitment have been signed by the authorities of the municipalities constituting the FUAs. It was important since the FUAs are not defined administrative units and the letters of commitment confirm the will for cooperation and joint actions in applying for funds for implementation of the APs.

The LUMAT action plans for the development of green and blue infrastructure significantly support activities aimed at climate change adaptation. Therefore, they establish synergies with all projects at all levels related to this priority. Some specific projects in Horizon 2020 (LUMAT supports the defined scientific agenda INSPIRATION) or in INTERREG EUROPE (LUMAT exchanges information with UL2L) and other CE Programme projects, are also closely related to urban land and soil management.

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Chapter 4

Remediation technologies for environmental management to improve the safety and comfort of living in urban areas – an example of application in Ruda Śląska

Summary
This study is part of the LUMAT project, aimed at the reclamation of the brownfield in Ruda Śląska. The chapter presents the results of aided phytostabilisation with the use of *Lolium perenne* cv. STADION. The study was conducted on a laboratory scale. A mixture of two soil amendments was used – 5% of lignite with lime in two doses of 0.25 and 0.5%. The treatments lowered the bioavailable Pb, Cd, and Zn concentration in the soil and *Lolium perenne* tissues. Based on the results, full scale application of the aided phytostabilisation was successfully implemented on the brownfield site, which was recommissioned to the local community.

Keywords: aided phytostabilisation, *Lolium perenne*, heavy metals

4.1. Introduction

Since the 1800s in the Upper Silesia region (southern Poland) the industrial development was intensive, based mainly on hard coal mining and smelting (Pasieczna et al. 2020). The rich industrial and mining history had a significant impact on the economy and population density, and because of the high employment opportunities, it increased the attractiveness of the Upper Silesia region (Machowski et al. 2008). This region also has the potential for urban development in the context of landscapes. On the other hand, poor control of heavy metals emissions affected the quality of the environment and was visible primarily in the soil contamination. Although the amount of Cd in the soil has also decreased during the last 30 years in this area, in many others regions the amount of heavy metals in the soil still exceed permissible levels (Dziubanek et al. 2017, Rusinowski et al. 2019).

Currently, the mining and metallurgical activities in this region are dying out, but waste is left over. Part of the generated waste is reused in construction or technological processes, but most of it is deposited.

Industrial brownfields are an inherent element of the Upper Silesia landscape, some of which are over 100 years old. This situation also applies to Ruda Śląska, where spatial development and landscaping were dictated by mining and metallurgical activities (Machowski et al. 2008). The landscape of Ruda Śląska is created by *i.e.* preserved industrial brownfields. Brownfields in Ruda Śląska cover 3.5 km^2 (approx. 5% of the city area) (https://www.interregeurope.eu), which are being reclaimed or used in the production of aggregates. Among them, there are four post-metallurgic brownfields created from the zinc ore mining leftovers (Jonczy and Gawor 2017). The soil of industrial brownfields is often poor in organic material and nutrients, and it is also a source of toxic elements such as heavy metals, creating difficult conditions for plant growth (Skubała 2017). Reclamation and revitalisation activities change the way the land is used and give it new functions. However, the performed treatments do not always lead to the reduction of contamination level. Due to the significant fragmentation and volatility of grains, as well as often poor plant cover, brownfields may be subject to wind erosion (Duarte Zaragoza et al. 2015). As a result, the contaminated dust may be transfered into the air and expose the population to secondary dusting, which may pose an important health risk (Rusin et al. 2018). Some of the industrial brownfields are located in the city centre; therefore, it is worth considering the risk for the people posed by the vivinity of industrial brownfields and answering the question: Is this a problem of the past or current danger? Due to the rapid development of cities, creating safe living conditions for residents and taking actions related to the remediation of contaminated sites is extremely important. This study aims to present the remediation concept for a brownfield in Ruda Śląska which was implemented in the LUMAT project.

4.2. Site description

The site description was prepared based on the available historical data. Industrial brownfields are a result of industrial activity and intensive coal mining that has been carried out for the last hundred years. The examined brownfield was initially owned by the Liebe-Hoffnung company and served as a waste landfill for the zinc smelter in Ruda Śląska, the operation of which was completed before World War II, in 1925. Figure 4.1 shows the historical area of the landfill. After the end of World War II, the area became the property of the State Treasury, thus the responsibility for the functioning of this industrial brownfield fell on the municipal authorities (www.dzieje.pl/dziedzictwo-kulturowe/ruda-slaska-pocynkowa-halda-w-centrum-miasta-ma-stac-sie-miejscem-wypoczynku).

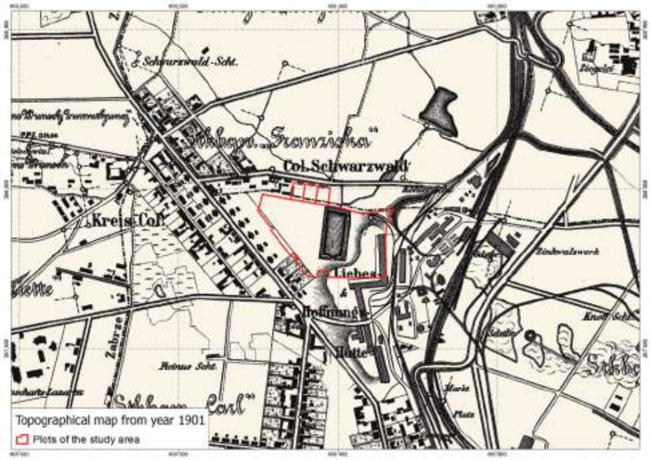

Fig. 4.1. Topographical map of the site from the year 1901. Source: State Archives, ORSIP

The brownfield is located in one of the districts of Ruda Śląska – Wirek and covers an area of 6.5 ha with a maximum height of 293 m above sea level. The brownfield deposit, located on Quaternary subsoil, formed from zinc processing waste, forms a heap with a thickness of approx. 20 m. The location of the brownfield is of key importance, as it is basically in the city centre, close to housing infrastructure, schools, workshops, and garages. From the east, the brownfield is adjacent to the "Pokój" coal mine (Fig. 4.2), and its slope in this part is flattened along the mine's technical road. The southern and central parts of the brownfield were reclaimed in the 1970s by covering them with a 1m thick layer of soil. The southern and western parts are slightly sloping, while the northern slope is steep and the top of the spoil heap is flat.

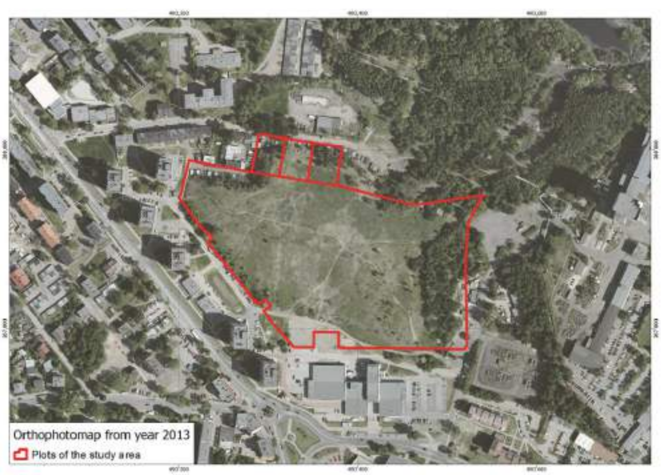

Fig. 4.2. Ortophotomap of the site from the year 2013. Source: State Archives, ORSIP

Waste from metallurgical and mining processes, such as slag, shale and silt, was deposited in the brownfield. Most of it is non-cohesive, brown-red in color, with fractions ranging from sand to gravel. The surface of the brownfield is covered with grassy vegetation; trees are present in the north-western part. The material was classified under the code 10 05 01 – slags from primary and secondary production (except 10 05 80) in accordance with the Regulation of the Minister of Climate on the catalogue of wastes (Official Journal of Laws of the Republic of Poland of 2020 item 10) and the genesis of the wastes. Due to the use of slag production technologies other than those currently used, the exact classification of waste was difficult. Historical data showed that the permissible values specified for industrial areas were exceeded, *i.e*. zinc 270-fold, while lead 100-fold above the mentioned standards.

4.2.1. Physico-chemical characteristics of top layer of the brownfield

The pH of the soil was acidic to slightly alkaline, north to south of the brownfield. The electrical conductivity (EC) of the soil surface layer varied across the brownfield, from 116 to over 2000 μS cm^{-1}. The highest values of EC were found at the bottom of the brownfield, which could be explained by the run-off of the mineral salts and organic matter, especially form places with less dense plant cover.

Research has shown that soil and ground contamination with heavy metals, especially lead, cadmium, and zinc, is a serious problem related to the existence of a post-industrial brownfield. Total metal concentrations were assessed based on the results of soil sampling at the depth 0–20 cm and the limit values of heavy metals content in the ground and soil, according to the Regulation of the Minister of Environment (Official Journal of Laws of the Republic of Poland of 2016 item 1395).

The concentration of lead exceeded the permitted value for industrial areas by 2 to 38-times, except for a small area located in the eastern part of the brownfield. The highest content was recorded in the north-western part. 70% of the area exceeded the limit value for cadmium by 1.5 to 11-times, while the highest content of this metal was found in the north-eastern and also in the north--western part. The zinc content exceeded the limit value for industrial areas by 1 to 40-times, whereas the highest content of this metal was recorded in the north-western part of the brownfield. Similar to lead, the lowest concentration of zinc was found in the eastern part.

Contrary to the total content of heavy metals, no applicable regulations have been established in Polish law regarding the bioavailable metal fraction in soil. Therefore, only the raw data will be discussed. Bioavailable lead concentration (mg kg^{-1} dw) represented 0.01–0.3% of its total content in the soil. The highest lead bioavailability was observed in a similar area as its highest total concentration. The bioavailable content of cadmium was high and was estimated at 0.14 to 14% of its total content. The range of area where the highest values of bioavailable fraction were noted, coincided with the area with the highest values of the total content of this element. In case of bioavailable fraction of zinc, the concentration ranged from 0.01 to 3% of its total concentration. As with the previous metals, the area with highest bioavailability fraction of zinc was covered with the highest total concentration.

According to the above results, the objectives of remediation of the brownfield site should be directed primarily at reducing the mobility of lead, cadmium, and zinc, based on the stabilisation processes and limiting the bioavailability of these elements, which are particularly dangerous in the context of human health. Based on the models of contaminant distribution within the brownfield, it was found that remediation activities should be concentrated in the north-western and western parts of the area.

4.2.2. Plant cover of the brownfield

Inventory of the vegetation on the surface of the brownfield showed that it was covered mainly with grass and trees in the north-western part, represented by species such as *Betula pendula* and *Pinus sylvestris*. During the research, based on surveys in the vicinity of the sampling points, the dominant species in the vegetation covering the brownfield were also determined. In the central and southern parts of the brownfield, the species of the *Asteraceae – Soildago canadensis* and a representative of the *Calamaceae – Calamagrostis epigeios* were recorded. Moreover, two species of metallophytes, *Silene vulgaris* and *Cardaminopsis arenosa,* characterised by tolerance to high levels of heavy metal contamination in the substrate, were observed.

4.3. Aided phytostablisation

To restore plant cover and reduce the risk associated with the release of heavy metals into the environment from post-industrial areas, phytoremediation processes are used. Among phytoremediation techniques, the aided phytostabilisation is a promising method for restoring the function of brownfields. This technique is based on the use of biological and chemical processes in the plant root zone to convert the bioavailable forms of heavy metals into their less available forms. Heavy metals accumulate in the roots, are adsorbed on their surface or are transformed into less soluble compounds (Barbosa and Fernando 2018). Phytostabilisation can be supported by organic and inorganic additives to improve heavy metals stabilisation or immobilisation, and support plant growth (Norinia et al. 2019). The plants create a dense plant cover on the soil surface. The roots stabilise the soil and prevent leaching of the contaminants to deeper layers of soil and groundwater. They also deter erosion and recontamination (Shackira and Puthur 2019). A schematic diagram of the aided phytostabilisation process is presented in Figure 4.3.

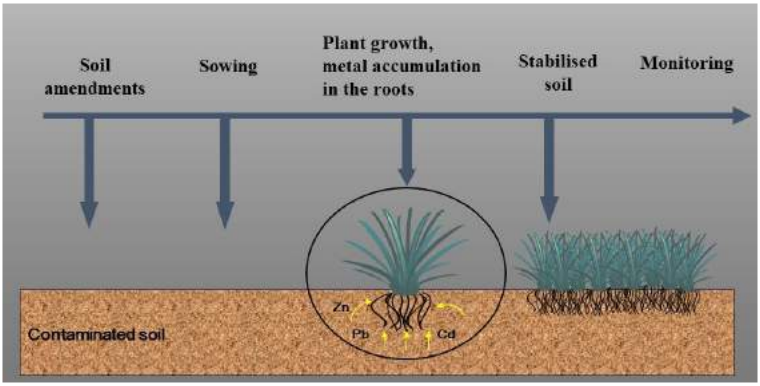

Fig. 4.3. Aided phytostabilisation process (own source)

4.4. Soil amendments for diminishing metals bioavailability

The most common practice used to improve phytostabilisation is the use of soil additives such as: organic matter, lime, fertilisers, chalcedony, limestone, activated carbon, *etc.*, the key role of which is to reduce the mobility or bioavailability of heavy metals in the soil (Barbosa and Fernando 2018).

Iron oxides amendments diminish the mobility and bioavailability of trace metals such as Cd and Cu, and combined with $CaCO_3$ are also able to reduce metal{loid} concentrations in the plant tissues (Li et al. 2019). Moreover, Fe oxides might act as an important agent for stabilising soil (Šimanský and Jonczak 2020). **Zeolites** are natural hydrated aluminosilicate minerals of the alkaline earth elements, and they can be successfully used to improve fertility and physio-chemical properties of soil. For example, they are highly efficient in reducing the bioavailability of heavy metals in the soil (Jakkula and Wani 2018) and in increasing nutrient and water use efficiency (Nakhli et al. 2017).

Fly ash is an amorphous, ferro-aluminosilicate material, which is able to stabilise heavy metals in contaminated soils, can be used as a fertiliser to improve soil properties such as increasing soil pH and as a nutrient reservoir (Bidar et al. 2016).

Phosphorus compounds are used for immobilisation of metals such as Cd, Cu, Pb, and Zn in contaminated soil by reducing their mobility or solubility, through direct adsorption by P compounds, P anion-induced metal adsorption, and precipitation as metal(loid) phosphates (Huang et al. 2016). Most phosphate compounds are used for effective immobilisation of lead, to form stable, insoluble phosphate minerals (Su et al. 2015).

The addition of **organic matter** to soil contaminated with heavy metals reduces their solubility and bioavailability, so it can be successfully used for remediation of contaminated areas (Kwiatkowska-Malina 2018). In particular, organic matter in the form of **lignite** or **biochar** is used to improve the physicochemical and biological properties of the soil or to immobilise heavy metals, such as Pb, Zn, and especially Cd (Ahmad et al. 2017). Also, additions of **calcium compounds** have been used to immobilise heavy metals in soils (Yang et al. 2018).

The summary of soil amendments used in diminishing of metals bioavailability is presented in Table 4.1.

Table 4.1. Soil amendments and their influence on heavy metals mobility (Kumpiene 2010, modified)

Amendment	Influence on metal mobility			Comments
	Positive	Varied	Negative	
Iron oxides	As	Cd, Cu, Ni, Pb, Zn		Immobilisation depends on soil pH, too high manganese concentration is toxic to plants
Manganese and aluminum oxides	As, Zn, Cd, Ni, Cu, Pb		Cr	
Loam	Pb, Cd, Cu, Zn	As		Low efficiency for heavily contaminated soils, might be leached under acidic conditions
Zeolites		Cu, Zn, Mn, As		
Fly ashes	Pb, Cd, Cu, Zn	As		
Phosphorus compounds	Pb, Cu, Zn, Cd		As	
Lignite	Cu, Pb, Zn, Cd			Wide range of applications
Peat	Cu, Pb, Zn, Cd			Low physico-chemical stability
Biodegradable wastes		Cu, Pb, Zn, Ni, Cd, As		Possibility of additional soil contamination from the amendments
Calcium compounds	Cu, Zn, Cd, Pb	As, Cr		Soil pH control is needed

4.5. Plant species used for aided phytostabilisation of soil contaminated with heavy metals

The selection of plant species is crucial for the success of the phytostabilisation process. The species used should be selected in terms of their ability to grow on soils contaminated with heavy metals, high resistance to environmental stress factors, such as high temperature or nutrient deficiency. Moreover, the species selected for phytostabilisation should be characterised by a well--developed root system and the ability to uptake or adsorb pollutants mainly into or onto the roots with limited translocation to aboveground parts of the plant (Fernando et al. 2018). Additionally, plant characteristics such as high dry matter production and rapid growth are desirable in the phytostabilisation process (Chen et al. 2012). Among the plants that can be successfully used in the phytostabilisation processes, there are mainly grass species such as:

Lolium perenne (Radziemska et al. 2018), *Deschampsia cespitosa* (Kucharski et al. 2005), *Miscanthus × giganteus*, *Spartina pectinata* (Korzeniowska and Stanislawska-Glubiak 2015, Pogrzeba et al. 2017, Pogrzeba et al. 2018), and *Dactylis glomerata* (Visconti et al. 2020).

4.6. Experiment design

The experimental soil comes from a brownfield in Ruda Śląska (Upper Silesia, Poland), an area heavily contaminated with Pb, Cd, and Zn. The soil was collected from a depth of 0–20 cm, from the place where, based on previous physicochemical analysis, the highest content of the bioavailable fraction of heavy metals was indicated. The soil was pre-dried and sieved through a <4 mm sieve to remove large particles. The experiment assumed the following experimental variants, each in 5 replications:

– C – no amendments,
– I – soil amended with 5% of lignite and 0.5% of lime,
– II – soil amended with 5% of lignite and 0.25% of lime.

Soil samples for analysis to determine the stabilisation progress were collected at the beginning of the experiment and after 6 weeks. After 2 weeks, *Lolium perenne* cv. STADIUM was sown and grown under controlled conditions: temperature 24°C, 300 µmol (photons) m^{-2} s^{-1} and humidity 50%. After the end of the experiment, the aboveground parts of plants and roots were collected for analysis.

The soil samples were dried and sieved through a <2 mm sieve to determine the pH and EC, and also through <0.25 mm sieve to determine the content of the pseudo-total and bioavailable fraction of heavy metals (0.01 M $CaCl_2$ extractable fraction) according to Pogrzeba et al. (2017).

The aboveground parts of plants and roots were cleaned of surface contamination, dried for 3 days at 70°C and ground to a homogeneous form to determine the Pb, Cd, and Zn concentration in the plants' extract by flame atomic absorption spectrometry (iCE 3500 FAAS, Thermo Scientific) after hot plate digestion in concentrated HNO_3 and $HClO_4$ (4:1 v/v) (ETHOS 1, Milestone, Italy). Based on the obtained results, the dose of amendments for field application will be selected.

4.7. Results

4.7.1. Initial soil characteristics

Initial soil was slightly acidic and electrical conductivity (EC) was low – 176 µS cm^{-1}. Pseudo-total Pb, Cd, and Zn concentrations were 100 mg kg^{-1}, 22 693 mg kg^{-1}, and 41 461 mg kg^{-1}, respectively. The bioavailable fraction values were 0.007%, 5.4%, and 0.29% of the total concentration these metals, respectively (Tab. 4.2).

Table 4.2. Physico-chemical soil parameters

Parameters	**C**
pH (H_2O)	6.56
pH (KCl)	6.02
EC (µS cm^{-1})	176
Pb_{total} (mg kg^{-1})	22 693
Cd_{total} (mg kg^{-1})	100
Zn_{total} (mg kg^{-1})	41 461
$Pb_{bioavailable}$ (mg kg^{-1})	1.70
$Cd_{bioavailable}$ (mg kg^{-1})	5.40
$Zn_{bioavailable}$ (mg kg^{-1})	122

Values are mean, n = 5. C – control soil sample,
EC – electrical conductivity.

4.7.2. Changes in physico-chemical parameters

Amendments, irrespective of the dose, increased the soil pH by 10% to neutral (Fig. 4.4). Variant with 5% lignite and 0.5% lime increased EC by 22% (Fig. 4.5).

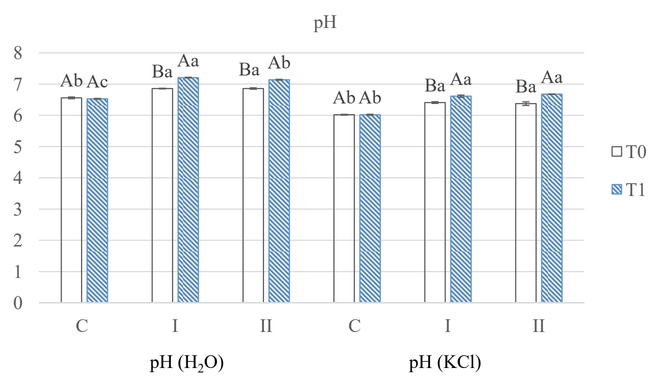

Fig. 4.4. Soil pH.

Values are mean, ±SE, n=5. Upper case letters (A, B, C) denote significant differences between parameters while considering the time of collection within one variant, and lower case letters (a, b, c) denote significant differences between different variants separately for the time of collection, according to Fisher LSD test ($P \leq 0.05$). T0 – initial soil sampling, T1 – 2nd soil sampling (six weeks after amendment application). C – control soil sample, I – 5% lignite and 0.5% lime, II – 5% lignite and 0.25% lime.

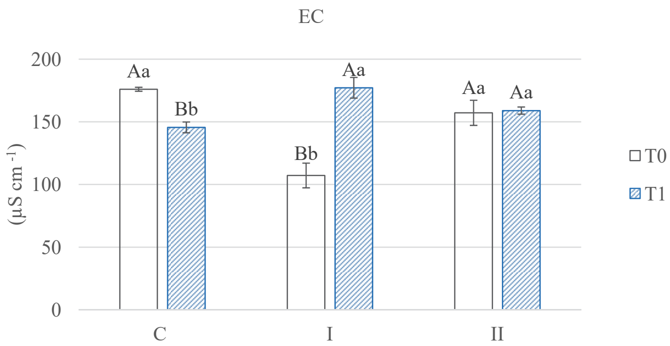

Fig. 4.5. Electrical conductivity.

Values are mean, ±SE, n=5. Upper case letters (A, B, C) denote significant differences between parameters while considering the time of collection within one variant, and lower case letters (a, b, c) denote significant differences between different variants separately for the time of collection, according to Fisher LSD test ($P \leq 0.05$). T0 – initial soil sampling, T1 – 2nd soil sampling (six weeks after amendment application). C – control soil sample, I – 5% lignite and 0.5% lime, II – 5% lignite and 0.25% lime.

Soil amendments lowered the concentration of bioavailable fraction of heavy metals in the tested soil (Tab. 4.6–4.8). Immediately after the application of soil amendments, the bioavailable Pb fraction decreased by approximately 75% and 84% in the case of 5% of lignite and 0.5% of lime, and 5% of lignite and 0.25% of lime, respectively. After six weeks, lower concentration of the bioavailable fraction of Pb was observed in both treated variants by approximately 78% (Fig. 4.6).

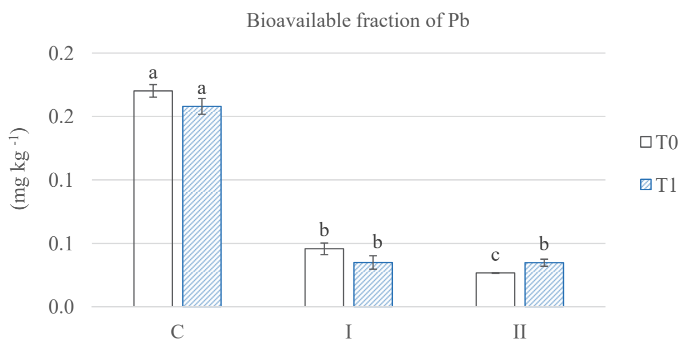

Fig. 4.6. Bioavailable fraction of Pb.

Values are mean, ±SE, n = 5. Lower case letters (a, b, c) denote significant differences between different variants separately for the time of collection, according to Fisher LSD test ($P \leq 0.05$). T0 – initial soil sampling, T1 – 2nd soil sampling (six weeks after amendment application). C – control soil sample, I – 5% lignite and 0.5% lime, II – 5% lignite and 0.25% lime.

Immediately after the application, the amendments lowered the concentration of Cd-bioavailable fraction in the tested soils by 84% and 89%, respectively. Six weeks after applying the dose of 5% lignite and 0.5% lime, the concentration of bioavailable Cd decreased by 89% compared to the control soil sample. In the case of the application of 5% of lignite and 0.25% of lime, a decrease in the bioavailable Cd fraction by 84% was observed (Fig. 4.7).

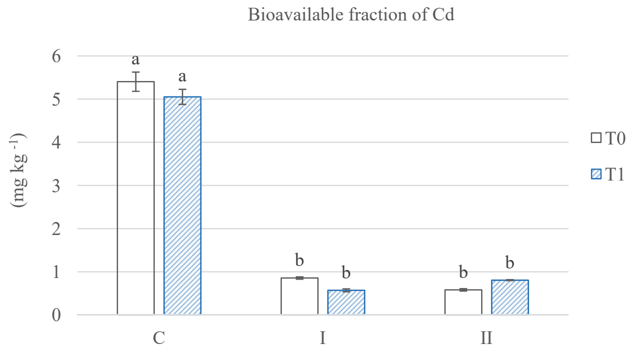

Fig. 4.7. Bioavailable fraction of Cd.

Values are mean, ±SE, n = 5. Lower case letters (a, b, c) denote significant differences between different variants separately for the time of collection, according to Fisher LSD test ($P \leq 0.05$). T0 – initial soil sampling, T1 – 2nd soil sampling (six weeks after amendment application), C – control soil sample, I – 5% lignite and 0.5% lime, II – 5% lignite and 0.25% lime.

The highest decrease in the bioavailable fraction was observed for Zn. Both of the used combinations of amendments decreased the bioavailable Zn fraction by 90–96% (Fig. 4.8).

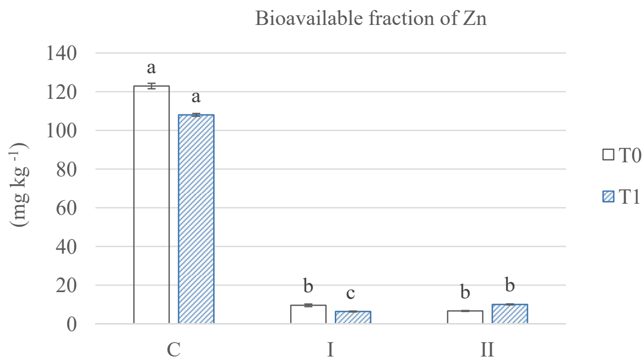

Fig. 4.8. Bioavailable fraction of Zn.

Values are mean, ±SE, n = 5. Lower case letters (a, b, c) denote significant differences between different variants separately for the time of collection, according to Fisher LSD test ($P \leq 0.05$). T0 – initial soil sampling, T1 – 2nd soil sampling (six weeks after amendment application), C – control soil sample, I – 5% lignite and 0.5% lime, II – 5% lignite and 0.25% lime.

4.7.3. Concentration of heavy metals in plant tissues

Pb concentration in the aboveground part of *Lolium perenne* was lower in treated variants by 7% and 3% compared to the control samples, but no statistically significant differences were observed (Fig. 4.9). Whereas, the value of this element in the roots cultivated in treated variants decreased in comparison to control samples by 39% and 28%, respectively (Fig. 4.10).

Reduction of Cd concentration in the aboveground parts of plants compared to control samples by 31% and 37% (Fig. 4.9) was also observed. There were no statistically significant differences in the concentration of Cd in the roots between the plants grown in the control soil and in the treated soil (Fig. 4.10).

Uptake of Zn to aboveground parts of plants from the treated variants was lower compared to the control samples by 25% and 12%, respectively (Fig. 4.9). The addition of 5% of lignite and 0.5% of lime reduced the Zn concentration in the roots compared to the control samples by 17%, while the lower dose of lime (0.25%) resulted in a decrease by 45% (Fig. 4.10).

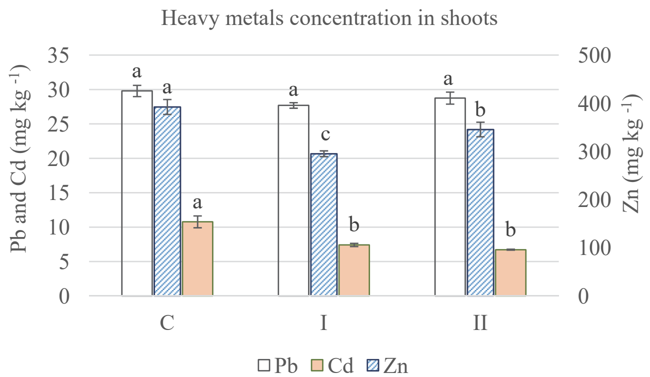

Fig. 4.9. Concentration of heavy metals in the aboveground part of *Lolium perenne*.

Values are mean, ±SE, n = 10. Lower case letters (a, b, c) denote significant differences between different variants, separately for the parameters, according to the Fisher LSD test (P ≤ 0.05). C – control sample, I – 5% lignite and 0.5% lime, II – 5% lignite and 0.25% lime.

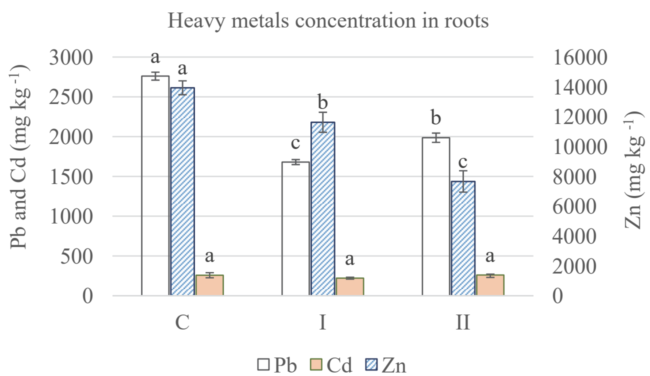

Fig. 4.10. Concentration of heavy metals in roots of *Lolium perenne*.

Values are mean, ±SE, n = 5. Lower case letters (a, b, c) denote significant differences between different variants, separately for the parameters, according to the Fisher LSD test (P ≤ 0.05). C – control sample, I – 5% lignite and 0.5% lime, II – 5% lignite and 0.25% lime.

4.8. Discussion

Soil contamination in Ruda Śląska is attributed to industrial activities carried out in this area, mainly brownfields (Pasieczna 2018). The content of pseudo--total heavy metal was as follows Cd < Pb < Zn. The pseudo-total Pb, Cd, and Zn concentration in the soil exceeded the limit values for industrial areas (Official Journal of Laws of the Republic of Poland of 2016 item 1395) by 38 times, 7 times, and 41 times respectively. Some of the metals are essential for plants growth, but their high concentration in the soil might cause a toxic effect. The concentration of available fraction of heavy metals is especially important for plants. However, in Polish law there are no regulations on the limits of bioavailable fractions of heavy metals in soil.

The application of lime and lignite mixture to the soil increased the EC and pH of the soil regardless of the dose. Li et al. (2021) observed an increase in soil pH and EC after the application of lignite. Whereas, Lee et al. (2004) reported that after the application of lime, the soil pH increased to 7.5. It is assumed that increase in soil pH due to the use of lime is related to the formation of metal hydroxide or carbonate mineral precipitate (Xiao et al. 2017).

Together with changes in soil pH, the concentration of bioavailable fraction of heavy metals decreased significantly, irrespective of the dose. As studies presented, the increase of soil pH above 7 caused by the use of lime reduces the bioavailability of metals, except Mo and As (Lwin et al. 2018, Hartley et al. 2004). In our study, the application of a mixture of lime and lignite resulted in a decrease in the bioavailability fraction of Pb, Cd, and Zn in the experimental soil. The largest decrease in bioavailable fraction was observed for Zn. Also Khan and Jones (2008) observed a decrease in the extractable form of Cu, Fe, and Zn after the application of lime, however soil samples were extracted with DTPA. Also, Sanderson et al. (2015) showed reduction of Pb water-extractable fraction in soil by 90%. In contrast to this research, Briceño et al. (2018) showed that lignite lowered pH while increasing the availability of metals such as Fe, Ni, and Zn proportionally with the dose.

Reducing the heavy metal content of the soil can also reduce the uptake of heavy metals by plants (Xiao et al. 2017). The combination of lime and lignite reduced the uptake of Cd and Zn into the aboveground parts and also Pb and Zn into the roots of *Lolium perenne*. Lower uptake of metals was associated with the reduction in the available content of the given elements in the soil. Similar results were shown by Simmler et al. (2013), where lignite application reduced the bioavailable fraction of Cd in soil by binding Cd to organic sulphur. As a result, Cd uptake by *Lolium perenne* was reduced. The studies showed that addition of lime to Cd-contaminated soil caused immobilisation of Cd and reduced the uptake of this element by food-crops (lettuce, Chinese cabbage, Chinese broccoli, white amaranth, and purslane) by 40% to even 70% (Tan et al. 2011, Al Mamun et al. 2016). Also other authors reported that lime-enriched soil reduced Cd concentration in mustard (Bolan et al. 2003) and white lupin (Castaldi et al. 2005). Immobilising of Cd in soil and limited accumulation by plants after liming was reported by Zhu et al. (2016) and Hong et al. (2007). According to Yang et al. (2018) the content of Zn and Cd in rice increases at low lime concentrations and decrease at high lime concentrations.

Higher concentrations of heavy metals in the roots of *Lolium perenne* compared to the shoots showed that *Lolium perenne* can be effectively used for phytostabilisation of Pb, Cd, and Zn. Also, Radziemska et al. (2017) and Gołda and Korzeniowska (2016) demonstrated the potential of using of *Lolium perenne* for the revegetation and phytostabilisation of contaminated soils.

4.9. Conclusions

Based on the pot experiment results, the method was implemented on a field scale at the top of the heap, in an area of approximately 1.2 ha. To protect people from heavy metals present in metallophyte plants grown in this area, the existing vegetation on the spoil heap top was removed and replaced with grass species, accumulating heavy metals in the root zone with limited transfer to the aboveground biomass. The contaminated topsoil was mixed to the depth of 0–20 cm with the selected dose of lignite and lime, based on the preliminary experimental data. After the stabilisation of heavy metals, *Lolium perenne* cv. Stadion was sown on the surface. During the growing season plants created a dense cover, which allows to decrease wind erosion, while plant root system stabilises the soil and helps reduce water erosion. Currently the phytostabilised area has been recommissioned to the citizens.

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Chapter 5

Application of robust estimators of dispersion and local indicators of spatial associations in assessment of soil contamination

Summary
In the paper four different robust estimators of dispersion (scale) were used to check their usability in general assessment of soil contamination under small sample conditions (up to 20 observations). Besides the two already used in the assessment of soil contamination, i.e. the interquartile range (*IQR*) and the median absolute deviation about the median *MAD*, the estimators of scale elaborated by Croux and Rousseeuw S_n and Q_n were analysed. It was demonstrated that the first two estimators performed better when the number of observations was 3 or 8, while the last two estimators performed better when the number of observations was 13 or 17. All of them proved their usability in skewed distributions. The paper also presents successful application of local indicators of spatial association (LISA) specifically Local Moran I in clustering of observations into pools containing normally distributed data (concept of the so-called normalisation through regionalisation). In the paper data from EC FP7 TIMBRE and Interreg GreenerSites projects were used.

Keywords: soil contamination assessment, LISA, robust estimators of scale, S_n, C_n, median confidence limits

5.1. Introduction

In assessment of data on soil contamination, generally three cases may be distinguished. In the first case one deals with normally distributed data, which may be an example of a site with entirely contaminated soils or a site with natural level of elements or substances. In the second case one deals with more or less skewed, lognormally distributed data, which may be an example of soil that is a mixture of at least two kinds of soils in terms of contaminant contents, each with normally distributed data. In the third case one has data without defined statistical distribution, which may be an example of soil that is a mixture of many kinds of soils of normal distribution, including soils with a concentration of a given element or substance below the detection limit. Evaluating the soils of a given site, one uses appropriate estimators of location and dispersion according to the character of data statistical distribution. When one deals with not normally distributed data one uses robust statistics including median as an estimator of location and an interquartile range (*IQR*) and median absolute deviation about median (MAD) as estimators of dispersion (estimators of scale). Except *IQR* and *MAD*, in this paper two other robust estimators of dispersion S_n and Q_n were used in assessment of soil contamination (Croux and Rousseeuw 1992). Not normal distribution of data constitutes a limitation in use of statistical and geostatistical tools where the requirement of normality of data exists. In the paper a proposal to overcome this problem is presented. It can be called normalisation by regionalisation which, in a nutshell, is the spatial arrangement of data into spatially autocorrelated groups so that each group contains normally distributed data. In spatial rearrangement of the observation values, the local index of spatial association (LISA) was used (Anselin 1995). The goal of the paper was to demonstrate the usability of four robust estimators of dispersion (*IQR*, *MAD*, S_n and Q_n) in assessment of soil contamination under the conditions of a small sample (up to 20 observations) as well as usability of LISA in regionalisation of soil due to its contamination.

5.2. Method

5.2.1. Classical approach

Just as a reminder, in classical approach when the observations match the normal distribution, the arithmetic mean, standard deviation and eventually lower and upper confidence limits of the mean are calculated. Arithmetic mean is calculated according to the following formula:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad 1$$

where n – number of observations and x_i represents single observations $x_i \ldots x_n$.

Sample standard deviation is expressed by the following formula:

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad 2$$

Both estimators have a breakdown point equal to 0, which means that one contaminated (erroneous) observation value is enough to distort the results obtained by these estimators. For normally distributed data the lower or upper confidence limits of mean are calculated according to the formula:

$$CL_{mean} = \bar{x} \pm \frac{t_{\alpha,n-1}S}{\sqrt{n}} \qquad 3$$

where $t_{\alpha,n-1}$ is cumulative distribution of the t-student function for $1-\alpha$ and $n-1$ degrees of freedom and S is sample standard deviation.

5.2.2. Robust estimator of location

The most widely known and applied robust estimator of location is a median. If we have an ordered set of observations $\{x_i, ..., x_n\}$, the median $med_i\,(x_i)$ represents the middle of the set. It is $(n + 1)/2$ order statistics when n is odd and average of the order statistics with ranks (n/2) and (n/2)+1 when n is even. The median has the breakdown point of 50% which means that even if we have 50% of contaminated measurements, it does not influence the value of the estimator. In terms of soil contamination assessment this estimator of location was used among others in Atlas of Urban Soils Contamination in Poland as an estimator of locations of general soil contamination of Polish towns and cities (Pasieczna 2003).

5.2.3. Robust estimators of dispersion

Robust estimators of dispersion constitute an alternative to standard deviation. Interquartile range is the most popular estimator of dispersion incorporated in statistical packages. It is expressed by the formula:

$$IQR = X_{3n/4} - X_{n/4} \qquad 4$$

where $X_{3n/4}$ represents the third quantile, $X_{n/4}$ represents the first quantile of the observations. The *IQR* has a breakdown point of 25% (Altenburg 1994) and has 37% efficiency for normally distributed data (Lanzante 1996). It is resistant to outliers of both the highest and lowest extremes, due to its focus on the central part of the distribution (Redfern 2010). Interquartile range was used in Atlas of Urban Soils Contamination in Poland as an estimator of dispersion in the characteristics of variability of contaminant contents in soils of geochemical background, surface urban soils (0,0–0,2m) and subsurface urban soils (0,4–0,6m).

Except interquartile range, the median absolute deviation (about the median) is the most popular among robust estimators of dispersion also available in statistical tools intended for soil assessment. It is expressed by the formula:

$$MAD_n = b\, med_i \left| x_i - med_j x_j \right| \qquad 5$$

where:
b equals 1,4826 is a factor for consistency for normally distributed data and MAD_n is the median of differences between observations and their median (Rousseeuw and Croux 1993).
MAD_n depends on the location estimate (namely median), it has a breakdown point equal to 50%, and it has 37% efficiency for normally distributed data (Ripley 2004).

Because of its implicit assumption of symmetry (first, one calculates the median) it has limited use in very skewed data (Rousseeuw and Croux 1993). The estimator MAD_n and median med_i may be used in screening for outliers by use of the following formula:

$$\frac{\left| x_i - med_j x_j \right|}{MAD_n} \qquad 6$$

If for a given x_i this statistic exceeds a certain level, let's say 2,5 or 3,0, we may label it as outlier (Rousseeuw and Croux 1993). The MAD estimator was incorporated in the US EPA ProUCL software developed for facilitating sound decision in management of polluted sites (Singh Anita and Singh Ashok 2015).

As alternatives to the interquartile range and MAD_n Rousseeuw and Croux proposed two estimators of dispersion – S_n and Q_n. Both estimators calculate absolute pairwise difference statistics. The first of the two is the so-called recursive median S_n (Hedges 2008). It is expressed by the following formula:

$$S_n = c_{Sn} c\, med_i \left\{ med_j \left| x_i - x_j \right| \right\} \qquad 7$$

where:
c is a consistency factor for normally distributed data and equals 1,1926,
c_{Sn} is the bias correction factor based on the sample size equal to n/(n-0,9) if n is odd, or to 1 if n is even (Croux and Rousseeuw 1992).

The internal median (med_j) is the high median while the external median (med_i) is the low median (Altenburg 1994). Similarly to MAD, S_n estimator is a combination of absolute differences but it does not depend on the location estimate. Instead of looking at distances between observations and their central estimator, it focuses on the typical difference between observations. It has a breakdown point of 50% and 58,23% efficiency for normally distributed data.

Another robust estimator of dispersion is Q_n. It represents k^{th} ordered statistics of differences between pairs of observations. It is expressed by the following formula:

$$Q_n = c_{Qn} d \left\{ \left| x_i - x_j \right| ; i < j \right\}_{(k)} \quad 8$$

where:
d equals 2.2191, calculated as $1/\left(\sqrt{2} \cdot \Phi^{-1}(5/8)\right)$ and is a consistency factor for normally distributed data (Rousseeuw and Croux 1993).
The symbol Φ^{-1} stands for the inverse standard normal distribution (Altenburg 1994).
The c_{Qn} is the bias correction factor based on the number of observations n. If the sample size is greater than 12, c_{Qn} equals: 1 / (((1,60188 + ((- 2,1284 – (5,172 / n)) /n)) / n) + 1) if n is odd, and 1 / (((3,67561 + ((1,9654 + ((6,987 – (77 / n)) / n)) / n)) / n) + 1) if n is even. If sample size is not greater than 12, the c_{Qn} has the following values between n = 2 and n = 12: 0,399356; 0,99365; 0,51321; 0,84401; 0,61220; 0,85877; 0,66993; 0,87344; 0,72014; 0,88906; 0,75743 (Maechler et al. 2010). In formula $(k) = f(f-1)/2$ and $f = [n/2]+1$, square brackets indicate the largest integer not greater than n/2 and k indices represent the k^{th} smallest value (Hedges 2008).
The Q_n estimator does not depend on the location estimate. Q_n, has the breakdown point equal to 50% and about 82% efficiency for normally distributed data. However, Q_n loses some of its efficiency at small sample sizes[1] (Rousseeuw and Croux 1993, Shawiesh et al. 2011). The calculated robust estimators of scale (dispersion) were validated on the basis of results obtained using R software and specifically using the Basic Robust Statistics “robustbase” package, version 0,93–8 (Maechler et al. 2010).

5.2.4. Confidence intervals of estimators of location

When the condition of normality is not met, instead of using confidence limits of mean, confidence limits of median are used, which are expressed as k^{th} ordered statistics of the formula:

[1] Small sample contains less than 30 observations (O’Sullivan David, Unwin David J. 2003)

$$CL_{med} = nq \pm \Phi^{-1}(\alpha/2) \cdot \sqrt{nq(1-q)} \quad 9$$

where:
n is the number of observations,
q equals 0.5 for median and $\Phi^{-1}(\alpha/2)$ is the inverse standard normal distribution with probability $\alpha/2$ (Bland 2000, Wilson 2010).
The calculated median confidence limits as well as confidence intervals cover were validated on the basis of test data and results obtained using JMP programme (Burke 2016).

Calculations of the robust estimators of location and dispersion of soil contamination constitute the first step of generic soil assessment of the site, be it singular allotment, city district or entire town, etc. In this work all calculations of estimators of location and dispersion were conducted using spreadsheets software (LibreOffice Calc and MS EXCEL).

5.2.5. Normalisation through regionalisation

In dealing with data which are not normally distributed, normalisation can be obtained by removal of outliers or by, for instance, logarithmic transformation of the original data. An alternative solution is a decomposition of the entire set of observations into spatially autocorrelated clusters so that all contain normally distributed data, or at least the most numerous cluster. The division of the sample may be realised, among others, on the basis of lithological characteristics of soil samples, their relation to the technological installations of a factory (history of land use), or the division may be conducted on the basis of results of autocorrelation analysis. If observations are grouped on the basis of their values and spatial location with the aim to obtain clusters with normally distributed data, one can call it data normalisation by regionalisation. In that case spatial autocorrelation measures including local indicators of spatial associations (LISA) may by applied. The process of grouping starts with calculation of one of the most well-known parameters of global autocorrelation, which is Global Moran's I (Moran 1950, O'Sullivan and Unwin 2003). It is given by the formula:

$$I = \frac{\sum_i \sum_j w_{ij}\, z_i \cdot z_j / S_0}{\sum_i z_i^2 / n} \quad 10$$

where:
$z_i = x_i - \bar{x}$, are deviations from the mean, x_i is the observation value in i location and $\bar{x}$ – is the mean, $z_j = x_j - \bar{x}$ – is the observation value in j neighbouring locations, $S_0 = \Sigma_i \Sigma_j w_{ij}$ – the sum of all the weights, w_{ij} is the weight matrix and n is the number of observations.

Weights may be expressed as a function of distance:

$$w_{ij} = \left(\frac{1}{d_{ij}}\right)^k \quad 11$$

where:
d_{ij} is the distance between observation points or zones and k is the power.

Global Moran's I is similar to the correlation coefficient, its values range from -1 to +1. Value zero indicates no spatial correlation. If the autocorrelation is high, the Moran's I assumes values close to +1 or –1. Positive or negative values of the Moran's I indicate positive or negative spatial autocorrelation. Global Moran's I gives general measure of spatial autocorrelation and expresses in what extent the observations which are close together have on average similar values. In case when the cluster of observations with similar values is to be detected, local indicators of spatial association (the so-called LISA) are used. One of them is the local version of global Moran's I, the so-called local Moran's I.

According to Luc Anselin (1995) the LISA for each observation gives an indication of the extent of significant spatial clustering of similar values around that observation. Besides, the sum of LISAs for all observations is proportional to a global indicator of spatial association. Global Moran's I decomposes into its local form and may be defined as Local Moran (Anselin et al. 2006):

$$I_i = z_i \sum_j w_{ij} z_j \quad 12$$

where:
z_i, z_j are deviations from the mean, and summation over j is such that only neighboring values $j \in J_i$ are included (Anselin et al. 2006).

It was observed that the spatially lagged variable (the spatial lag) – $\sum_j w_{ij} z_j$ (the average of the deviations from the mean observed at the neighbouring locations J_i) is sensitive to the presence of outliers (Anselin et al. 2006). As a solution to this problem the median of the neighbours is used in the place of the average as a median spatial lag (Anselin et al. 2006). It is the so-called Median Local Moran which is expressed by the following formula:

$$I_i^M = z_i \cdot med(z_j, j \in J_i) \quad 13$$

where:
J_i is the neighbour set of location I, i.e. those locations for which $w_{ij} \neq 0$ (Anselin et al. 2006).

Local Moran and Median Local Moran estimators are a measure of similarity of an observation or zone to its neighbours. When both the observation (zone) and its neighbourhood have either high or low values, the Local Moran will have positive values. When both the observation and its neighbourhood have contrasting values, the Local Moran will have negative values. In the first case when we have at least two observations with positive Local Moran, we have a cluster of high values or a cluster of low values. In the second case, when an observation is surrounded by other observations with contrasting values, we have either the so-called hot spot or cold spot. In the second case, the contrasting observations may be considered as outliers. The latest version (1.18) of GeoDa software was used (Anselin et al. 2006) to calculate the Global Moran I, Local Moran I and Median Local Moran. The map composition was prepared with ESRI ArcMap.

5.3. The workout case studies

To achieve the goal of the paper, assessment of soil contamination of two sites using robust estimators of scale were conducted. The first site is a former military airbase and the second one is a residential area of Łęgnowo-Wieś settlement, city district of Bydgoszcz. The assessment of the soils of the second site was extended to include local indicators of spatial relationship.

5.3.1. Site No. 1 – Former military airbase in Szprotawa

The first case study used data from the TIMBRE project (Tailored Improvement of Brownfield Regeneration in Europe) funded by the European Commission under FP7. The Polish case study in that project was represented by an area of a former military airbase in Szprotawa located in western Poland. The main problem hindering the reuse of the site is soil contamination with jet fuel (TIMBRE 2014). The soil characterisation of the site was based on a series of composite soil samples in which benzine content was analysed. Simultaneously, on the basis of two series of individual soil samples constituting composite sample, the variability of benzine contents in composite soil samples was determined. The maximum allowable benzine content for sandy subsurface soils in Poland is 50 mg/kg.

The first composite soil sample (N1) consisted of 9 individual samples. The content of benzine in the composite sample was 28,75 mg/kg of dry weight. The individual results are as follows:

115,0; 27,78; 16,39; 16,25; 11,54; 6,66; 6,51; 3,14; 0,25

The second composite soil sample (S36) consisted of 13 individual samples and contained 0.11 mg/kg of benzine. The individual results are as follows:

16,92; 14,54; 13,03; 9,11; 6,51; 6,40 5,97; 3,83; 3,68; 2,51; 2,34; 1,33; 1,12

These results were presented in an ordered form to facilitate the calculation of robust estimators of location and dispersion. To illustrate the sensitivity of statistical estimators (of location and dispersion), new series of data were added. And so, from the first series the maximum value was removed (series N1a) and in the second series, the maximum value was multiplied by 10, simulating a typo done by moving the decimal point one digit to the right (series S36b). The results of the calculation of estimators of location and dispersion are presented in the table below and expressed in mg/kg of dry weight (Table 5.1).

Table 5.1. Statistical estimators of location and dispersion for Szprotawa site

Estimator	**Series N1**	**Series N1a**	**Ratio N1a/N1**	**Series S36**	**Series S36b**	**Ratio S36b/S36b**
n	9	8		13	13	1,00
minimum	0,25	0,25		1,12	1,12	
maximum	115,00	27,28		16,92	169,20	
$\bar{x}$	22,61	11,07	0,49	6,71	18,43	2,74
S	35,63	8,90	0,25	5,21	45,50	8,72
med_i	11,54	9,10	0,79	5,97	5,97	1,00
IQR	9,88	10,62	1,07	6,60	6,60	1,00
MAD_n	7,46	9,72	1,30	5,13	5,13	1,00
S_n	13,14	10,07	0,77	5,13	5,13	1,00
Q_n	12,13	9,31	0,77	5,13	5,15	1,00
LCL_{mean}	-4,78	3,62	–	3,56	-9,06	–
UCL_{mean}	50,00	18,51	0,37	9,87	45,92	4,65
CI_{mean}	54,78	14,89	0,27	6,30	54,99	8,72
LCL_{med}	3,14	3,14	1,00	2,34	2,34	1,00
UCL_{med}	27,78	16,39	0,59	13,03	13,03	1,00
CL_{med}	24,64	13,25	0,54	10,69	10,69	1,00
CI_{med} cover	96,09%	92,97%	0,97	97,75%	97,75%	1,00
Normality	No	Yes	–	Yes	No	–

Source: Calculations based on data of soil contamination conducted within framework of TIMBER project

The first scenario (series N1/N1a).
It was observed that the benzine content in the composite sample is 1,27 times greater than the arithmetic mean calculated on the basis of the benzine content in single samples. It may be the result of poor homogenisation of the samples prior to chemical analyses. It was also observed that the observation of 115 value is an outlier in the first series. It distorts the data distribution from normal into lognormal. As a result, the arithmetic mean is about 2,0 times higher than

the median. The standard deviation is about 3,3 times higher than the average of all four calculated other estimators of dispersion. Removal of the outlier almost completely eliminated the differences between the arithmetic mean and the median as well as differences between standard deviation and other estimators of dispersion. The above-mentioned ratios are now 1,24 and 0,84. In the above-mentioned examples, the results of robust estimators are observed to be more stable compared to parametric statistics (arithmetic mean, sample standard deviation, and confidence limits of the mean). In this very case of the composite soil sample the exceeded value of benzine is undetected. As a result of data normalisation by removal of the outlier, confidence intervals of the mean decreased by 73% while confidence intervals of the median decreased by 46%.

The second scenario (series 36/36b).
The second series consists of normally distributed data. In it, distortion was introduced by multiplying the maximum value by 10, thus the series lost its normality. There are no changes in the median because the number of soil samples is constant (13). At the same time the arithmetic mean increased 2,74 times. While robust estimators of dispersion stay at the same level, standard deviation increased 8,72 times due to the input error and squaring the differences in its calculations. The increase of the confidence intervals of the mean and the stability of the median confidence intervals is observed.

5.3.2. Site No. 2 – Łęgnowo-Wieś settlement, city district of Bydgoszcz

In the second case study, data from the GreenerSites Environmental Rehabilitation of Brownfield Sites in Central Europe CE394 Interreg project were used. Within the framework of the project, Health Risk Analysis (HRA) was developed for residents of Łęgnowo-Wieś settlement, city district of Bydgoszcz (Wcisło et al. 2019). The HRA was based on the soil test results for contaminants in 20 composite (mixed) samples. Each composite sample represented individual soil samples taken from one assessment sector. The assessment sector consisted of several neighbouring land parcels, which were sometimes adjacent to one another and sometimes not (Fig. 5.1).

It was shown that the decisive factor in determining soil degradation was its contamination with polycyclic aromatic hydrocarbons (PAHs). Among them, the most frequent and the highest exceedances of soil quality standards concern the content of three PAHs: benzo(α)anthracene, benzo(α)pyrene and benzo(β) fluoranthene. The data on PAH content in soils of the assessment sectors are presented in Table 5.2.

Estimators of location and dispersion are expressed in mg/kg of dry weight. The maximum permissible level of the analysed PAHs in soils of residential areas for all three PAHs is 0,1 mg/kg of dry weight. Using Shapiro-Wilk normality test,

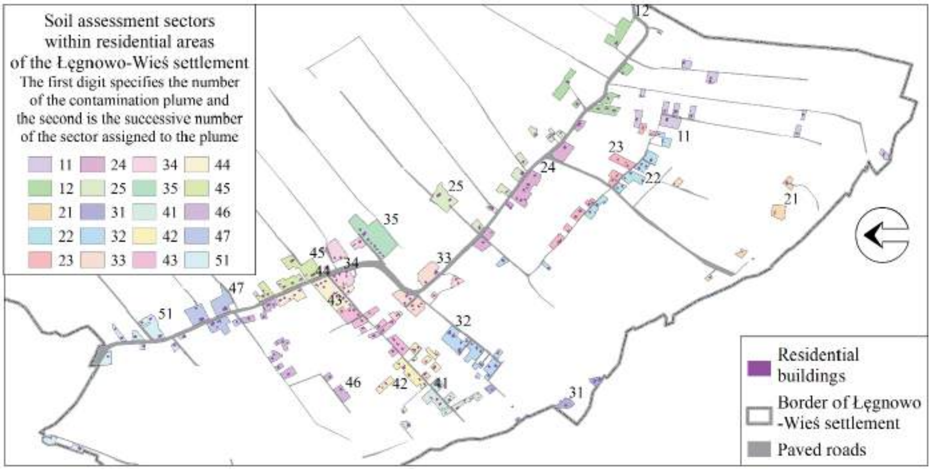

Fig. 5.1. Spatial distribution of soil assessment sectors of the Łęgnowo-Wieś settlement

Table 5.2. Concentrations of selected PAHs in soils of assessment sectors in mg/kg of dry weight

Sector	B(α)A	B(α)P	B(β)F	Sector	B(α)A	B(α)P	B(β)F
11	0,245	0,245	0,340	34	1,320	2,320	3,370
12	0,505	0,538	0,729	35	4,250	3,120	3,840
21	0,174	0,264	0,389	41	<0,025	<0,025	<0,025
22	0,239	0,233	0,325	42	<0,025	<0,025	<0,025
23	0,209	0,213	0,286	43	0,073	0,065	0,082
24	0,476	0,544	0,759	44	0,489	0,575	0,815
25	0,524	0,608	0,836	45	0,280	0,316	0,446
31	0,329	0,472	0,636	46	0,209	0,208	0,293
32	6,380	5,098	7,510	47	0,563	0,639	0,946
33	0,717	0,632	1,130	51	0,332	0,347	0,508

Source: GreenerSites Project

it was shown that all three series do not fit the normal distribution (with α=0,05). The coefficient of variation is in all cases above 1,5 while the arithmetic mean is at least twice the median. It may be observed that the standard deviation is 3,55 to 5,29 times higher than the mean of all four robust estimators of dispersion for the three PAHs (Table 5.3).

A high level of consistency in the results of all 4 calculated estimators of dispersion is observed. Taking into consideration the results presented in the table above, one may conclude that the geochemical characteristics of the tested soils are distorted by outliers, and thus the median and robust estimators of dispersion describe the true characteristics of the soils. In this case study, the challenge was to divide the observation values in such a way that they resulted

Table 5.3. Statistical estimators of location and dispersion for Łęgnowo-Wieś site

Estimator	B(α)A	B(α)P	B(b)F
n	20	20	20
minimum	<0,025[2]	<0,025	<0,025
maximum	6,380	5,098	7,510
$\bar{x}$	0,867	0,823	1,163
S	1,587	1,264	1,799
coefficient of variation	1,830	1,536	1,547
med_i	0,331	0,410	0,572
IQR	0,325	0,386	0,547
MAD_n	0,247	0,293	0,403
S_n	0,298	0,357	0,500
Q_n	0,328	0,368	0,552
LCI_{mean}	0,124	0,231	0,321
UCI_{mean}	1,610	1,415	2,005
CI_{mean}	1,485	1,183	1,684
LCI_{med}	0,209	0,233	0,325
UCI_{med}	0,524	0,608	0,836
CI_{med}	0,315	0,375	0,511
CI_{med}cover	95,86%	95,86%	95,86%
Normality[3]	No	No	No

Source: Calculations based on data from GreenerSites project

in new groups with data that fit the normal distribution. In this step, spatial analyses were conducted. The spatial distribution of the three analysed PAHs is presented in the box maps below (Fig. 5.2, Fig. 5.3, Fig. 5.4). It is observed that assessment sectors number 32, 34 and 35, located in the central part of a residential area, are characterised by higher content of the analysed PAHs than the other sectors.

Using equation No. 6 and the results of Dixon's Outlier tests, it was shown that the observed PAH values in these sectors are outliers, what was corroborated by the box maps where these observations are classified as upper outliers or the so-called far out values. In the next step of the data analysis, the general spatial autocorrelation of PAH content in soil was calculated. The results of Moran I calculation are presented in the table below (Table 5.4)

It may be seen that the calculated Moran I indices for all PAHs are negative. The same is true for the z-value statistics. Additionally, having a high p-value,

[2] The value <0,025 constitutes content below limit of detection (LOD). In calculation ½ LOD was used

[3] Shapiro-Wilk normality test was applied

it can be concluded that the spatial distribution of the three analysed PAHs does not differ from random distribution.

As stated earlier, the Global Moran I decomposes into the Local Moran. To find existing clusters or outliers, Local Moran maps of the three analysed PAHs were generated. When calculating the weights in the Weights Matrix, all interpoint connections were used (the neighbourhood encompassed the whole site). Because of the presence of outliers, in the analysis of local spatial autocorrelation, the Local Moran Median was used. As a result of the application of the Local Moran Median, statistically significant outcomes with a significance level below 0,001 were obtained. Thus, the assessment sectors were divided into two groups.

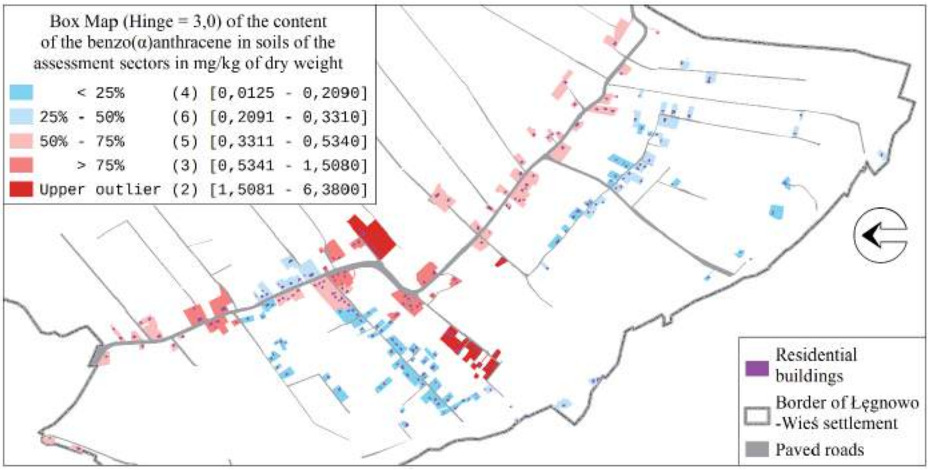

Fig. 5.2. Box map of the content of benzo(α)anthracene in soils of Łęgnowo-Wieś settlement

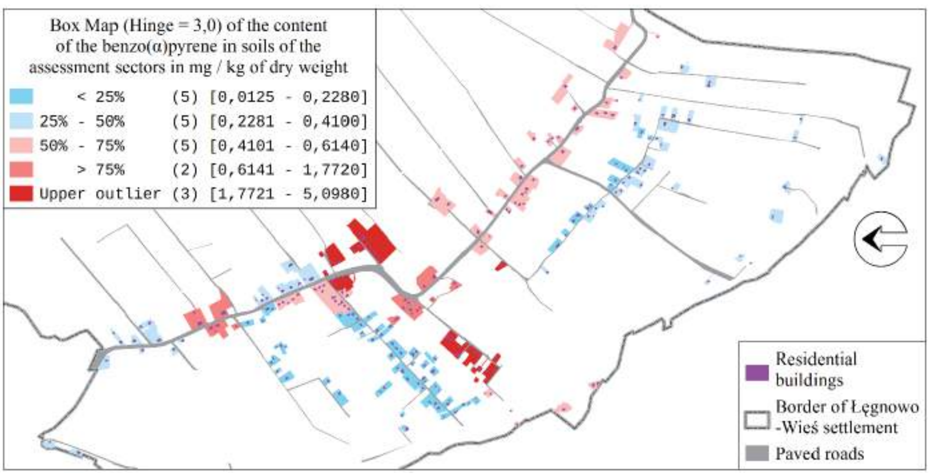

Fig. 5.3. Box map of the content of benzo(α)pyrene in soils of Łęgnowo-Wieś settlement

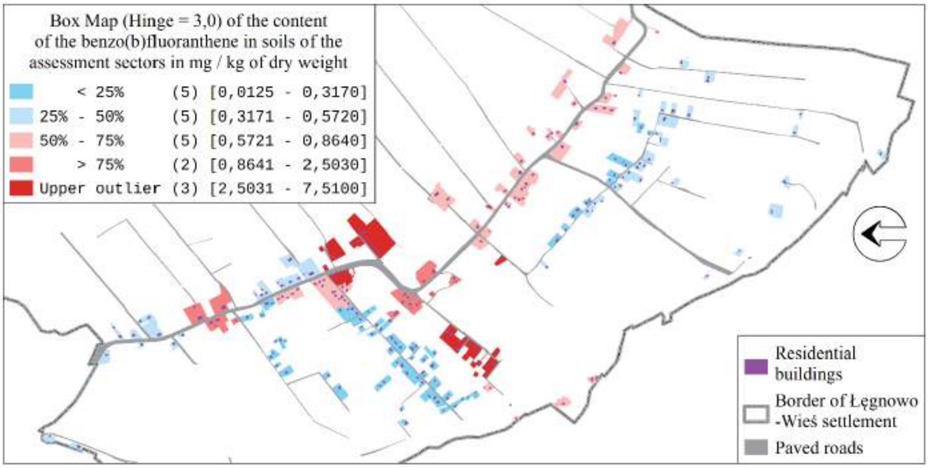

Fig. 5.4. Box map of the content of benzo(b)fluoranthene in soils of Łęgnowo-Wieś settlement

Table 5.4. Values of the Moran I index, z statistics and p-value for the PAH content in soils

PAH	Moran I	z-value	p-value	spatial distribution
B(α)A	-0,1125	-0,5155	0,3219	random
B(α)P	-0,1050	-0,4223	0,3948	random
(B(b)F	-0,1042	-0,4383	0,38175	random

Source: Calculations based on data from GreenerSites project

Sectors representing Low-Low cluster constitute the first group, while sectors with numbers 32, 34 and 35, representing High-Low outliers, constitute the second group (Fig 5.5). The results of Local Moran Median analyses corroborate the results of statistical analyses of the data.

The two groups of sectors now contain observations that fit the normal distribution, which was the aim of this spatial analysis. The calculated estimators of location and dispersion are presented in two consecutive tables (Table 5.5, Table 5.6).

In regard to the first group, it is observed that only one estimator of dispersion Q_n performs well under normal conditions due to its high efficiency for data with normal distribution. The values of that estimate are in the range of standard deviation values (Table 5.5). The opposite is true for IQR and MAD_n and to some extent for S_n, they are higher than the sample standard deviation by about 1,39, which may be due to the lower efficiency for normally distributed data. The IQR and MAD_n are sometimes higher than or equal to the median, which is not the case for S_n and Q_n. It is also observed, that both the lower confidence limit of the mean and the lower confidence limit of the median exceed the maximum permissible level of PAHs content in soils – 0,1 mg/kg of dry weight (Table 5.5).

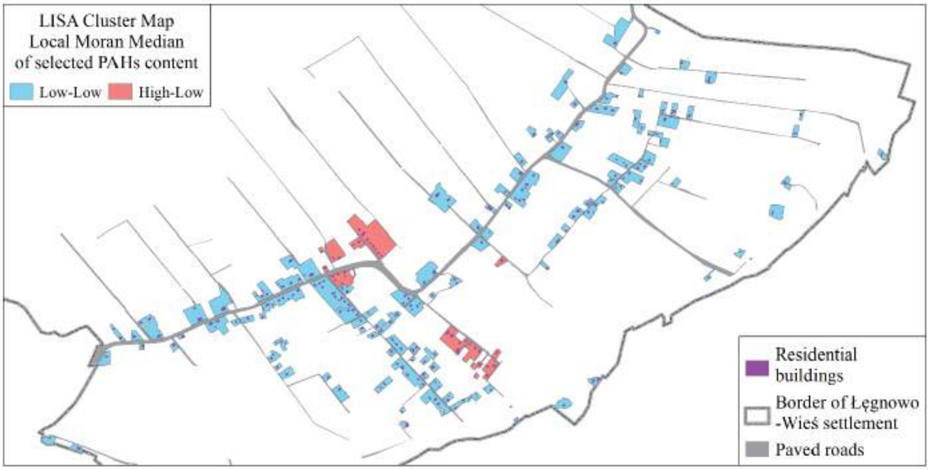

Fig. 5.5. Results of LISA analyses for PAHs content in soils of Łęgnowo-Wieś settlement

Table 5.5. Statistical estimators of location and dispersion
for the Łęgnowo-Wieś site – 17 selected sectors

Estimator	**B(α)A**	**B(α)P**	**B(b)F**
n	17	17	17
minimum	<0,025	<0,025	<0,025
maximum	0,717	0,639	1,130
$\bar{x}$	0,317	0,348	0,503
S	0,202	0,216	0,331
coefficient of variation	0,638	0,621	0,659
med_i	0,280	0,316	0,446
IQR	0,280	0,331	0,466
MAD_n	0,291	0,329	0,420
S_n	0,261	0,286	0,428
Q_n	0,217	0,208	0,382
LCL_{mean}	0,213	0,237	0,332
UCL_{mean}	0,421	0,460	0,673
CI_{mean}	0,208	0,223	0,341
LCL_{med}	0,209	0,213	0,293
UCL_{med}	0,489	0,544	0,759
CI_{med}	0,280	0,331	0,466
CI_{med}cover	95,10%	95,10%	95,10%
Normality	Yes	Yes	Yes

Source: Calculations based on results from GreenerSites project

In regard to the second group with three observations, the interquartile range of B(α)A, B(α)P and B(b)F content performs well in terms of its consistency with the standard deviation (Table 5.6).

The table below sums up the differences between the standard deviation and the four robust estimators of scale when the series of observational data fit the normal distribution (Table 5.7).

Table 5.6. Statistical estimators of location and dispersion for Łęgnowo-Wieś site – 3 selected sectors

Estimator	**B(α)A**	**B(α)P**	**B(b)F**
n	3	3	3
minimum	1,320	2,320	3,370
maximum	6,380	5,098	7,510
$\bar{x}$	3,983	3,513	4,907
S	2,541	1,430	2,267
coefficient of variation	0,638	0,407	0,462
med_i	4,250	3,120	3,840
IQR	2,530	1,389	2,070
MAD_n	3,158	1,186	0,697
S_n	4,702	1,766	1,038
Q_n	4,697	1,764	1,036
Normality	Yes	Yes	Yes

Source: Calculations based on data from GreenerSites project

Table 5.7. Differences between robust estimators of scale and standard deviation

Series	**N**	***IQR***	$\boldsymbol{MAD_n}$	$\boldsymbol{S_n}$	$\boldsymbol{Q_n}$
B(α)A	3	0,011	0,617	2,161	2,156
B(α)P	3	0,041	0,244	0,336	0,334
B(b)F	3	0,197	1,570	1,229	1,230
Benzine N1a	8	1,715	0,816	1,165	0,089
Mean of above 4		0,492	0,813	0,930	1,741
Benzine S36	13	1,385	0,085	0,090	0,089
B(α)A	17	0,078	0,088	0,058	0,014
B(α)P	17	0,115	0,113	0,069	0,008
B(b)F	17	0,135	0,088	0,097	0,051
Mean of above 4		0,430	0,093	0,077	0,037

Source: Calculations based on data from TIMBRE and GreenerSites projects contained in tables nr 5.1, 5.3, 5.5 and 5.6

In the paper 4 series with normal distribution were analysed. It may be concluded that the series with a lower number of observation points, on average, are characterised by higher differences of robust estimators of dispersion in relation to the standard deviation (in our case, the ratio of differences between these two groups is 6,26 to 1). When we deal with an extremely small sample, let's say 3 observations, which is the minimum number of observations (composite soil samples) required to assess soil contamination according to Polish regulations (Official Journal of Laws of the Republic of Poland of 2016, item 1395), it is difficult to reject the hypothesis of normality of distribution. Under such conditions, the interquartile range can be used as a robust estimator of dispersion. When the number of observations exceeds 10 (in our case at least 13), one may observe that the estimators of dispersion calculated as absolute pairwise differences statistics (S_n, Q_n) perform well and much better then *IQR* and *MAD*. It is also observed that the median absolute deviation (MAD), on average, has the smallest differences in relation to standard deviation, especially when the number of observations is at least 8. When the number of observations nears 20 (in our case it is 17) Q_n is the best estimator of scale among the analysed in terms of the difference from standard deviation under normality conditions.

5.4. Conclusions

It can be restated (especially when the variability of the contaminant content in a composite soil sample is known) that conclusions drawn from soil assessment based on composite sampling should be approached with extreme caution. In the case of the Szprotawa site (composite sample N1), the dilution of the contaminant in the composite sample is observed. On the other hand, for the same soil, the arithmetic mean overestimates the benzine content in the soil. To avoid such situation, an insightful analysis of archival data should be done prior to soil assessment to precisely define the boundaries of the subareas from which soil samples are taken.

By analysing the two case study sites, it has been proved that robust estimators of location and dispersion are usable in assessing soil contamination, especially in the first step of the assessment when general characteristics of the site are the main focus of the study. All the robust estimators of dispersion used in the paper constitute good alternatives to standard deviation. It was observed that when dealing with small samples (less than 30 observations) robust estimators of dispersion calculated as absolute pairwise difference statistics (Q_n and S_n) perform (in terms of their consistency with standard deviation) surprisingly well in comparison to *IQR* and *MAD*. Only when the sample consists of less than 10 observations (3 or 8) poorer performance of Q_n and S_n is observed.

Soil assessment in case study No. 2 showed the occurrence of elevated PAH content in 3 soil assessment sectors. It seems that these three observation values constituting High-Low outliers come from a different process than the other observations. The cause of the elevated PAH concentrations in the soils of sector No. 32 was revealed at a meeting with the residents of the site. Information was obtained that the soil contamination could have been caused by the use of ash and slag from the power plant during the construction works (Wcisło et al. 2019).

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Chapter 6

Urban environmental acupuncture for improving access to green spaces in cities – example from an urban region in Central Europe

Summary
Green spaces make our urban environment more sustainable and livable and provide ecosystem services such as biodiversity and climate regulation. This paper aims to present the possible results of the implementation of Action Plan for urban environmental acupuncture (UEA). The Action Plan for UEA is a strategy to support integrated environmental management, increasing green areas in Functional Urban Areas (FUAs). The strategy is a part of the SALUTE4CE project funded by the Interreg CENTRAL EUROPE Programme. The UEA might be a tool for increasing access to green spaces, which has been shown on the example of Chorzów city.

Keywords: Community, ecosystem, urban green spaces, urban environmental acupuncture, SALUTE4CE

6.1. Introduction

Half of the world's population lives in cities today, 5 billion people are projected to live in cities by 2030. Moreover, 70% of the world population is predicted to live in urban settlements by 2050 (The Sustainable Development Goals.., 2015). This phenomenon causes the progressive development of cities. Large-scale disappearance of green spaces in the cities results from the urban development process (Odindi, Mhangara, 2012). Urban green areas play a significant role in citizens' lives, increasing the quality of life in an aesthetic context and reducing the negative impact of the climate change process (Harasimowicz, 2018).

Moreover, they are an essential component of any community's development. The observed growth of cities demands a significant increase in the ecosystem services provided by urban green spaces (Chang et al. 2017). Enhancement of green infrastructure will provide environmental, economic and social benefits such as fresh air, drinking water, flood regulation, surface run-off attenuation, thermal regulation, noise attenuation and recreational areas. According to the EEA, "Green infrastructure is crucial for strengthening the resilience of ecosystems and for sustaining the key ecosystem services that help in adapting to climate change" (Urban sustainability issues..., 2015).

To address this issue, the SALUTE4CE project proposes an urban environmental acupuncture (UEA) approach, which will help city authorities increase greenery. The method is based on urban acupuncture, which is nothing more than a well-planed, target-oriented green intervention to address urban fabric issues. The concept of urban acupuncture is a well-known topic in the literature, thanks to Jaime Lerner, the author of the "Urban Acupuncture" book (Lerner, 2014). This concept has become the core of the SALUTE4CE project. In the project, the consortium is developing Action Plans, which are strategies for implementing the UEA concept in 4 cities/FUAs in 4 counties.

The article aims to demonstrate an example of Chorzów city's predicted results in improving access to green spaces in Polish FUA by implementing the Action Plan developed under the Interreg Central Europe project.

6.2. Action Plan for FUA

Action plans play an essential role in the SALUTE4CE project, representing, beyond investments, a tangible achievement of the urban environmental acupuncture concept. The Action Plan supports the creation of a system of UEA green spots in the city/FUA and increasing their availability for citizens. Through the SALUTE4CE project, project partners have proposed an implementation path to make cities greener and more livable. For this purpose, the transnational Action Plan concept has been developed by the Leibniz Institute of Ecological Urban and Regional Development. The transnational concept is based on the Methodology of selecting spots for urban environmental acupuncture (UEA) developed by the Silesian Botanical Garden in work package T1. These two documents are the backbone of the project and help pilot sites preparing consistent structural documents.

The Action Plan structure includes common issues such as objectives, vision and aim of the City/FUA challenges, and characteristics of the present situation. The whole document contains an implementation plan with indicator measures, management and maintenance planning including financial instruments.

The second part, the design phase, includes an inventory and selection of sites implementing the UEA. The UEA concept proposed an approach to the urban fabric where large open spaces for greenery are not available, but its structure includes many small areas (spots), often without current use. For that purpose, green spots/sites of 0.2 hectares or less are suggested areas in the SALUTE4CE. The green spots might create a dense system connecting large and small sites that complement one another (D.T2.2.1 The transnational concept..., 2020). This provides an opportunity for interventions to improve and increase access to green spaces. The added value of the project is based on Nature-based solutions (NBS) using native and climate-resistant plants (D.T1.2.1 Report on principles for selection..., 2020).

Strategy development consists of another issue responsible for the success of the Action Plans – the involvement of stakeholders and citizens. Stakeholders should be involved throughout the planning, building, maintaining and monitoring of UEA sites. These actions are significant for raising awareness and holding citizens responsible and accountable for these places. Only these types of activities are very positively received by the people and aimed at those very goals.

Finally, the entire activities accompanying the Action Plan reinforce the establishment of a management structure, responsible for organising the work on the Action Plan implementation, monitoring and disseminating the results. This will enhance natural capital by improving local climate and strengthening FUAs resistant to climate change and social capital by involving local communities.

Functional Urban Area (FUA) in Poland represents three cities: Chorzów, Ruda Śląska and Świętochłowice located within the Metropolitan Association of Upper Silesia and Dąbrowa Basin, usually referred to in Poland as the Silesian Metropolis or Metropolis GZM. The Silesian Metropolis consists of 41 municipalities in the Silesian Voivodeship in Poland. The City of Chorzów is one of the SALUTE4CE project partners responsible for developing the Action Plan. The FUA covers an area of 124.19 km^2 with over 250 000 inhabitants (BDL 2019) and is located in the centre of Metropolis GZM, which is very important for the development of the area. The peculiar structure of land use is mainly due to the many years of operation off the industry within its borders. The industrial landscape was characterised by the industrial and post-industrial objects and areas located in the neighbourhood of the city centres as well as spoil heaps and dumping sites. The proportion of anthropogenic areas reaches over 55% of the whole FUA surface, implying a high level of its transformation. The post-industrial areas are treated as an opportunity due to their characteristic environmental properties – valuable due to vegetation succession (D.T2.2.1 Action plan for integrated..., 2018).

6.3. GIS analysis

The GIS analysis was prepared using Landsat 8 hyperspectral images obtained from the official U.S. Geological Survey platform. The Landsat images are used to analyse thermal and vegetation conditions and cover the period since February 2013. The years 2016–2020 were selected as the reference period for the presented case, with 23 images acquired during a warm period (between April and October). After verifying the cloud cover, which was below 20%, only 14 images from the warm period were included in the analyses.

For the purposes of the analyses, the Land Surface Temperature (LST) for each image was calculated, using sensors NIR (Near Infra-Red), SWIR (Shortwave Infra-Red) and TIRS (Thermal Infrared Sensor) – Equation 1. The data were converted from spectral radiance to brightness temperature, which is the effective temperature viewed by the satellite assuming the emissivity of unity (Landsat 8 (L8) data users handbook..., 2019; Ogunode, Akombelwa, 2017).

$$LST\ [°C] = \frac{T}{1 + \left(\lambda * \frac{T}{\rho}\right) * \ln \varepsilon} - 273.15 \qquad (1)$$

where:
T – brightness temperature
λ – the average wavelength of band 10
ε – the emissivity
ρ – is equal to 1.438 × 10–2 mK calculated from: σ – the Boltzmann constant (1.38 × 10–23 J/K), h – Plank's constant (6.626 × 10–34) and c – the velocity of light (3 × 108 m/s)

For each image, the arithmetic mean of LST was calculated. Then, the LST distribution in Chorzów, Świętochłowice and Ruda Śląska for the warm period 2016–2020 was calculated, which is illustrated in Figure 6.1. After collecting and compiling the statistical data (Table 6.1), it can be seen that the highest maximum temperatures, over 39°C, were recorded in Chorzów City, which is characterized by a dense urban fabric. The analysis of Table 6.1 shows that Świętochłowice City is characterized by the highest average temperature (over 27°C), which is caused by the smallest area of the city and the smallest surface of green areas (including forests). Due to the lack of green spaces and forests, Świetochłowice has the highest minimum surface temperature above 22°C among the analysed cities. Ruda Śląska city, characterised by separate districts and a polycentric structure, recorded the lowest minimum temperature of 21.11°C, and the lowest mean temperature of 26.07°C. In the entire analysed area, over 60% of the surface is characterized by a temperature of 25–30°C. 22% of the area of Świętochłowice and 26% of the area of Chorzów has an average temperature below 25°C, 10% of the area of Chorzów and Świętochłowice has a temperature of 30–35°C. The highest percentage of the city area with a temperature above 35°C is observed in Chorzów (1%), and about 0,5% of the area of Świętochłowice and Ruda Śląska.

Table 6.1. LST FUA statistic (2016–2020) [Landsat 8]

FUA/city	Temperature < 25°C [ha]	Temperature 25 –30°C [ha]	Temperature 30–35°C [ha]	>35°C [ha]	Temperature maximum [°C]	Temperature minimum [°C]	Temperature mean [°C]
Chorzów	26%	62%	10%	1%	39.25	21.35	26.73
Świętochłowice	22%	68%	10%	0.05%	35.19	22.16	27.07
Ruda Śląska	35%	60%	4%	0.04%	36.22	21.11	26.07

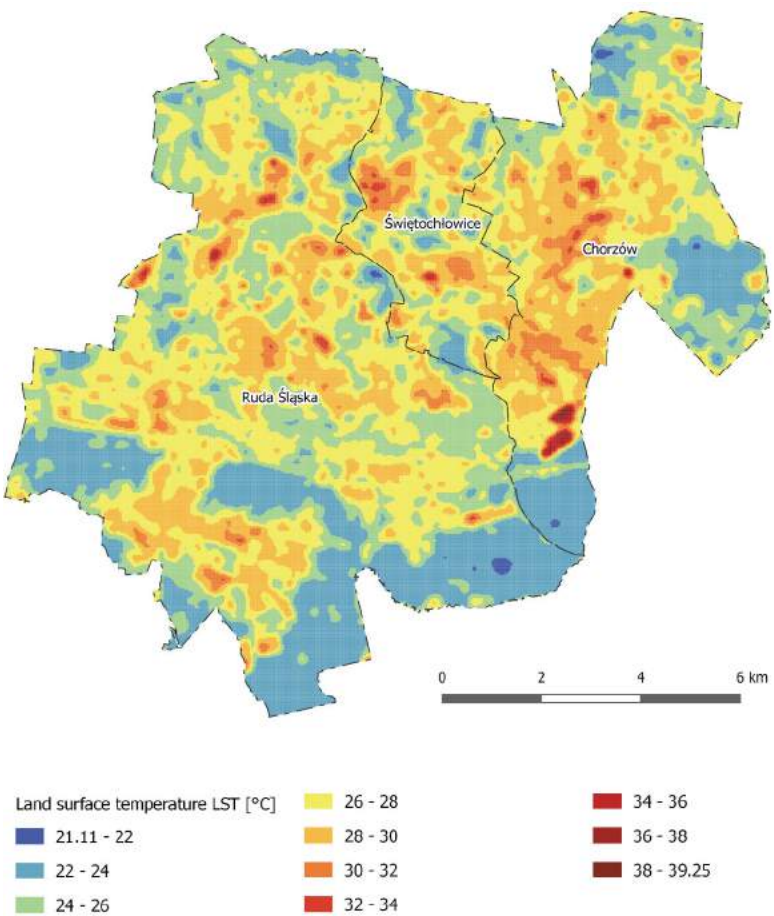


Fig. 6.1. LST distribution in FUA Chorzów, Świętochłowice, Ruda Śląska (2016–2020) [Landsat 8]

The next step included an analysis of thermal aspects related to land use. The land use analysis was based on the Urban Atlas 2018, which shows functional zones of urban areas. The database aggregates Land Cover/Land Use data compiled for the most populous European cities (most cities with over 50 000 inhabitants). The Urban Atlas classifies areas with a minimum size of 0.25 ha for urban classes and 1 ha for other classes. The classification distinguishes 17 urban classes (including five building classes with different densities) and ten other classes related to other land cover forms (UA code). The structure of the FUAs' land use is demonstrated in Figure 6.2.

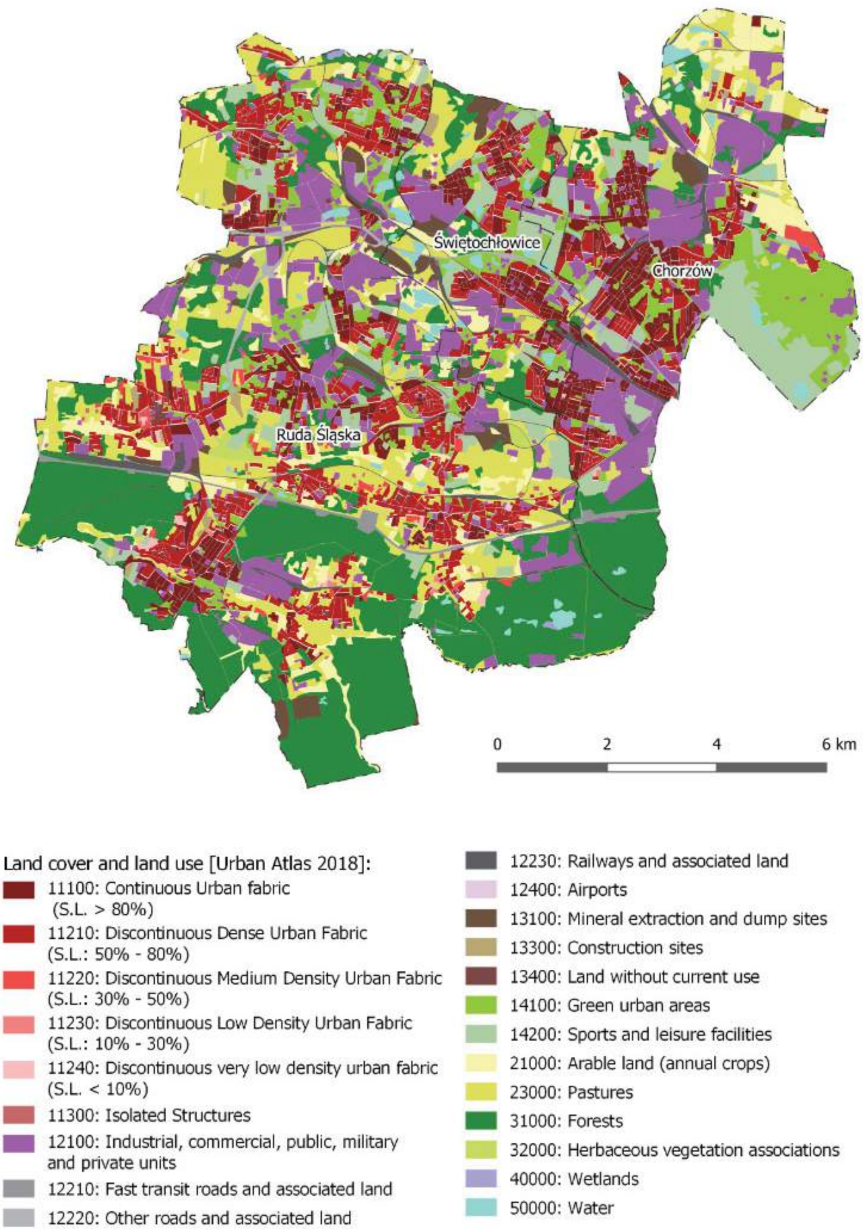


Fig. 6.2. FUA's land use structure by Urban Atlas 2018 [UA2018][Landsat 8]

The analyses carried out for the three cities show that the highest maximum temperatures are observed in the 12100: Industrial, commercial, public, military and private units (39.25°C). They are characterised by at least 30% of the ground covered with artificial surfaces. More than 50% of these artificial surfaces are occupied by buildings and/or artificial structures with non-residential use, i.e. industrial, commercial, or transportation-related uses are dominant.

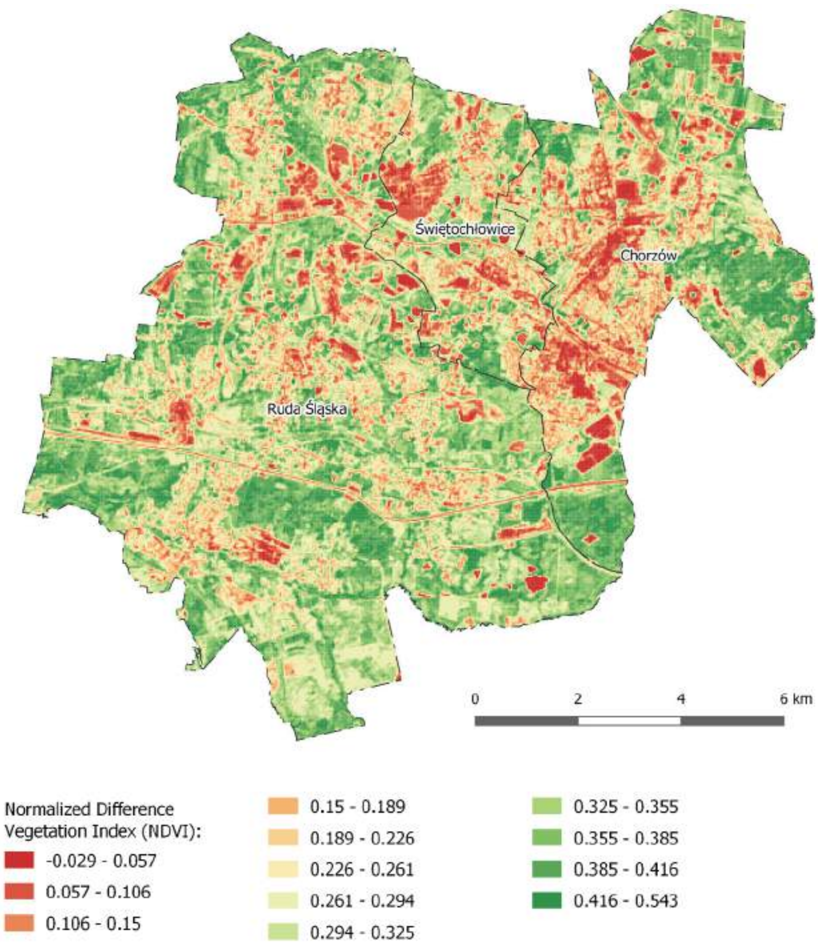
The highest minimum temperatures are observed in the area with UA code 11100 – Continuous Urban fabric (sealing degree > 80%) – Table. 6.2. The lowest temperature is observed at the green urban areas (14100), forests (31000), agriculture (21000) areas – minimum temperature of around 21°C.

Table 6.2. LST by the land use in FUA (2016–2020) [Landsat 8]

Kod UA 2018	Min. Temperature	Max. Temperature	Range	Artmetic Mean	Std. Dev	Mean
11100	24.471132	33.02165985	8.5505276	28.604247	1.1074908	28.573017
11210	23.3055	33.36845016	10.06295	27.426067	1.07279	27.485031
11220	23.515245	29.47149849	5.9562531	26.260962	1.0201026	26.296124
11230	24.255241	29.34422684	5.0889855	27.266898	1.0076731	27.388651
11240	24.373499	28.82884407	4.4553452	27.053313	0.832085	27.160016
11300	22.607016	28.44157219	5.8345566	25.733806	1.1575322	25.739988
12100	22.909185	39.25037766	16.341192	28.317509	1.9894638	28.237248
12220	23.771278	29.07626534	5.304987	26.442193	1.0586747	26.398034
12230	21.968958	33.25868225	11.289724	27.131591	1.9060205	27.123066
13100	23.167078	33.25868225	10.091604	27.95553	1.7098995	27.97319
13400	24.117294	36.22075653	12.103462	27.55574	1.6774643	27.428833
14100	21.763224	30.86105919	9.0978355	25.995928	1.897061	26.18338
14200	22.917402	31.13026237	4.7469788	26.383284	1.2672515	26.339905
21000	21.108709	31.30618095	10.197472	26.039003	1.5274355	26.021817
23000	22.524248	31.31013107	8.785883	26.044805	1.2493829	25.952908
31000	21.378296	33.25868225	11.880386	24.145963	1.4182302	23.742262
40000	23.060928	27.24059868	4.1796703	24.147674	1.1268653	23.690378
50000	21.108709	28.80640984	7.6977005	23.927808	1.515827	23.721395

The Normalised Difference Vegetation Index – NDVI – is one of the most popular indices for characterising vegetation first used by J.W. Rouse in 1973 (Vermote et al., 2016). The index allows the condition of vegetation and its degree of development to be determined, based on the contrast between the reflection in the Near Infra-Red (NIR) channel and the absorption in the red (RED) channel (Borsa et al., 2017).

Figure 6.3 illustrates the FUAs' NDVI condition of vegetation. The index takes a value of -1 to 1. The higher the index value, the better and lusher the vegetation. Negative values are found in areas without vegetation – built-up areas covered with concrete, surface water areas or exposed soils. NDVI informs us about the intensity of photosynthesis. It is also used to forecast yields or tell us about the amount of biomass produced by the ecosystem. It is also a component in determining the kinetic temperature (LST), which is needed to determine the surface urban heat island (SUHI). The analyses carried out for the three cities show that the NDVI for the build-up area ranges from -0.029 to 0.217, the green area represents values above 0.296, with a maximum of 0.543.



Fig, 6.3. FUA's NDVI condition of vegetation [Landasat 8]

6.4. Chorzów Case Study

For the purpose of this article, as part of the Action Plan for urban environmental acupuncture (UEA) for Polish FUA, the case study of Chorzów has been described as a result of GIS analyses which showed the highest maximum temperatures in the city and the highest percentage of areas with the temperature above 30°C.

Chorzów City contains extensive resources of green infrastructures on its territory, but it is distributed very unevenly. We define green infrastructure (GI), in line with the EC position as "a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. The GI, being a spatial structure providing benefits from nature to people, aims to enhance nature's ability to deliver multiple valuable ecosystem goods and services, such as clean air or water." (Building a Green Infrastructure..., 2013). These GIs have been analysed in the context of accessibility. Many views on what defines 'accessibility to Public Green Spaces' in the literature are well described by de Sousa Silva and others (de Sousa Silva et al., 2018). Generally, it is characterised by time interval (5, 10 or 15 minutes), distance (300, 400, 500 meters) or green surface per capita. For the purposes of this article, in accordance with WHO recommendations, 300 m was assumed, i.e. a linear distance (about 5 minutes on foot) from citizens' homes.

Furthermore, this distance has been shortened to 100 m due to the SALUTE4CE philosophy of 'putting the green space close to the people'. In the case of Chorzów, which is a relatively small city with an area of 33.2 km^2 (3 320 ha), but high a population density (3 243 people/km^2), and a population of 107 807 (BDL 2019), green areas are mainly represented in the southern part of the city (forest complex) and the eastern part of the Silesian Park. The model of population distribution has been prepared to show the spread of citizens among the city districts – Figure 6.4.

It is statistically described as 552.72 ha of parks, 235.11 ha of forests and 141.22 ha of other green areas (2019 BDL). Taking into account the city surface and the spatial and functional structure of Chorzów City, 93% of citizens have access to the green areas within a radius of 300 m and almost 30% within a radius of 100 m. Following the SALUTE4CE concept, the UEA interventions significantly modify the quantity, quality, and accessibility of urban green spaces. This can be achieved by establishing new UEAs' green spots or by changing the functions of the existing ones. Using small areas (less than 0.2 ha) allows for the creation of a dense network of green spots by providing a wide range of interventions using Nature-Based Solutions (NBS). 36 sites have been assessed in the Action Plan. Out of 36 sites, 9 have been described in detail using 24 types of green spots (D.T1.3.2 Training materials..., 2020; D.T2.2.1 Action plan..., 2021). These include, among others, street trees, park trees, green pergolas/ green arbours, linear wetlands for stormwater filtration, green facades with vines, or urban meadows. The examples of NBS were proposed through the detailed analysis of over 50 preliminaries selected sites in Chorzów city, 4 of them, as the pilot investments have been already implemented in 2021.

Moreover, it is strongly recommended to implement native species, better suited to adapt to local climate change due to their genetic structure (Opinia

Europejskiego Komitetu..., 2009). All these SALUTE4CE interventions might increase the surface of green areas and biodiversity in Chorzów. GIS spatial analysis showed that the Action Plan for Chorzów City might increase GIs accessibility for citizens living within a 100 m radius by 19%, and for those living within a 300 m radius by 4%. Figure 6.5 shows the map of accessibility to green spaces using the walkability method.

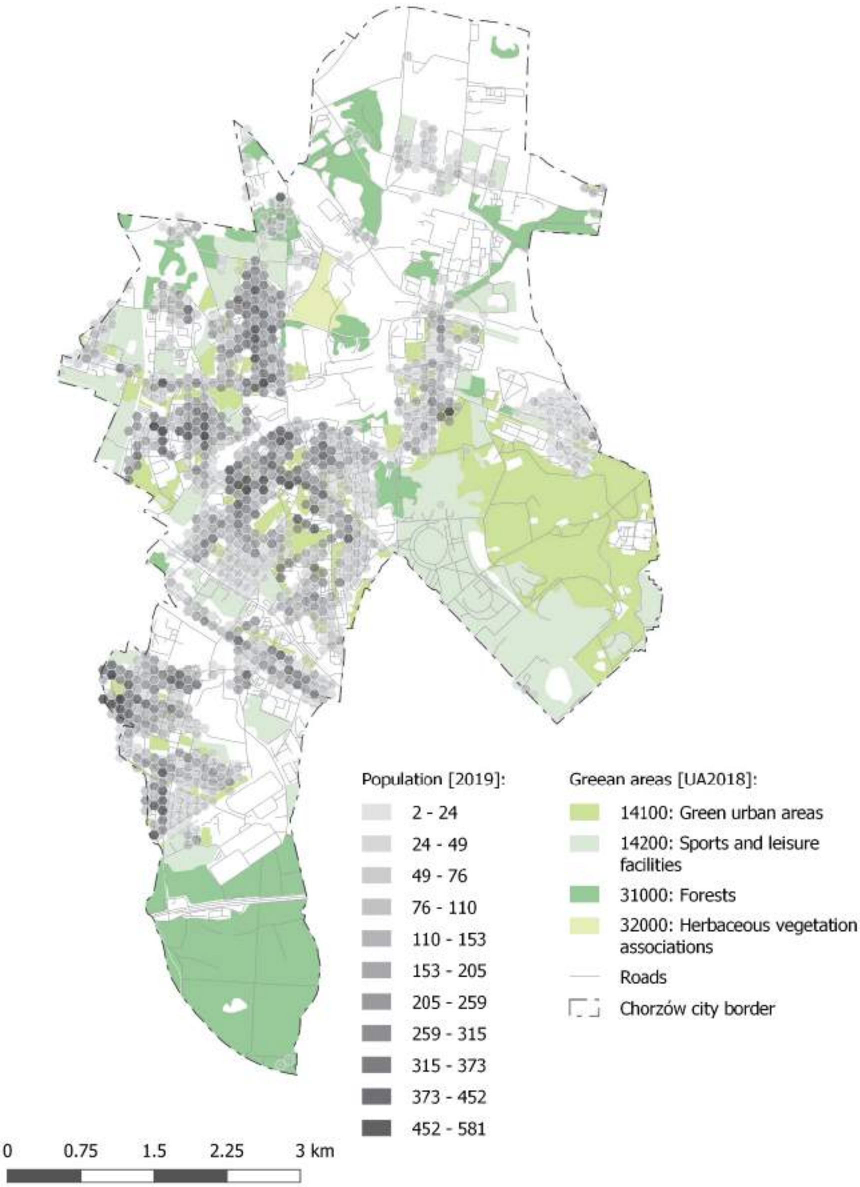


Fig. 6.4. Distribution of the population and green areas in the Chorzów city [UA2018, BDL 2019, BDOT10k]

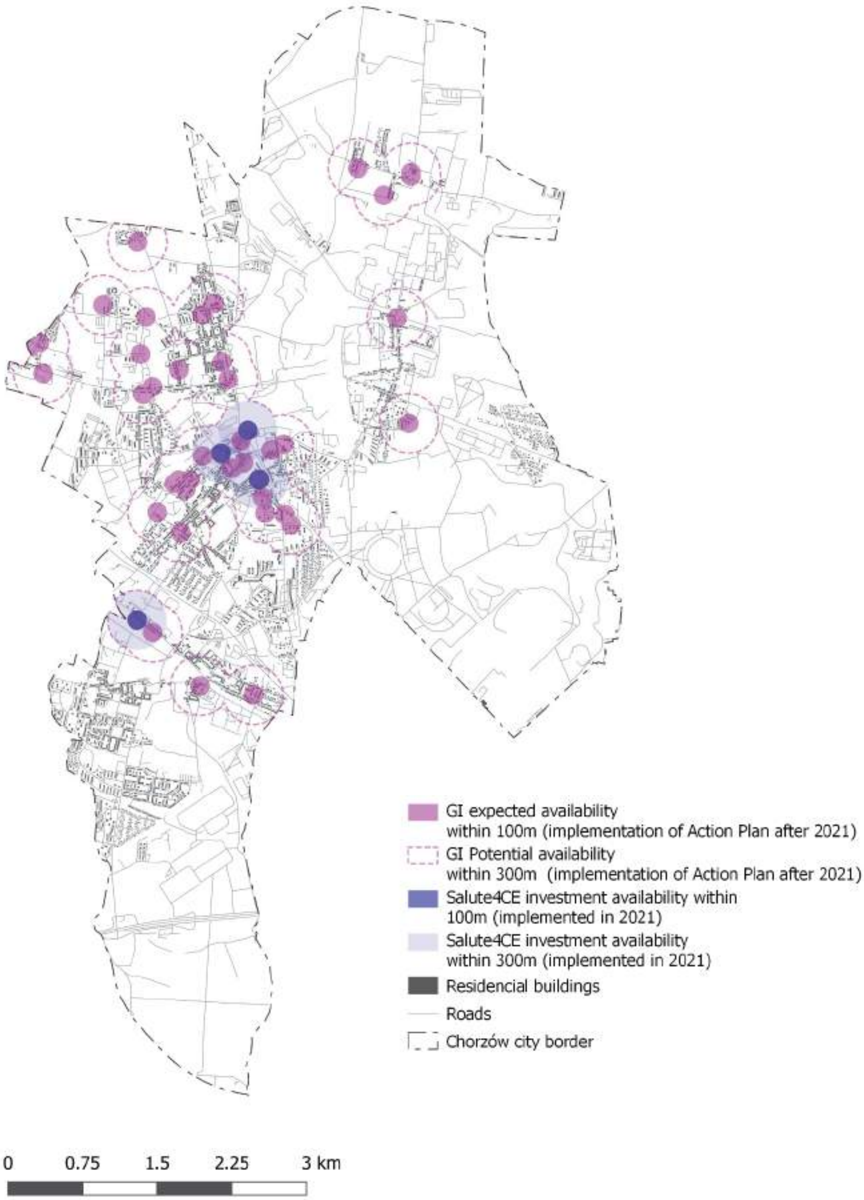


Fig. 6.5. Expected increase the accessibility of GIs within a radius of 100 m and 300 m using the UEA approach in the Chorzów city [UA2018, BDOT10k, SALUTE4CE]

6.5. Conclusions

Green infrastructure is crucial to improve the population's wellbeing. However, in many cities, green areas decrease significantly, or their distribution around the city is unequal. These pose a challenge to local authorities and urban planners, who must preserve green spaces to guarantee ecosystem services and quality-of-life benefits. To address these challenges, the SALUTE4CE project proposes the urban environmental acupuncture approach, which is a tool to bring green space closer to people. The Action Plans developed in the project provide an opportunity to plan a variety of green areas, responding to different requirements, with simple design features – using nature-based solutions. Nature-based solutions are relatively low-cost interventions for cities, while the implementation of urban green acupuncture in the form of a dense network of green spots contributes to climate change mitigation and adaptation efforts. The Chorzów case study is a good example of the possibility of improving access to green spaces in cities. In Chorzów city it is expected to increase by 19% in case of citizens living in the nearest vicinity of 100 m, and by 4% in case of citizens living within a radius of 300 m. Especially since low accessibility to green infrastructure in some areas of the city, or for some demographic groups, is an environmental justice issue. Public initiatives and actions supported by local authorities aimed at inhabitants regarding urban green spaces, parks and gardens in public areas should demonstrate their commitment to sustainable development and the environment.

Furthermore, the Task Group established under the project for the co-operation of cities towards strengthening green infrastructure will ensure the sustainability of implementation by implementing the Urban Environmental Acupuncture as part of the integrated environmental management in FUAs in response to providing services to meet the needs of users.

This work is published within the international project co-financed by the Minister of Science and Higher Education entitled "PMW" in the years 2019–2022; contract No. 5062/INTERREG CE/19/2020/2

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Chapter 7

Reduction of forest and agriculture land on urban areas basing on the analysis of statistical and spatial data

Summary
The paper shows the scale and rate of disappearance of green areas. The preliminary study covered agricultural and forest land in 19 cities of the Upper Silesian Conurbation. On the basis of available statistical data and planning documents, three cities with the largest loss of agricultural and forest land were selected. Further GIS analyses covering all land categories were derived from the Urban Atlas (UA). The analyses were complemented by calculating the average NDVI index for each area from the Urban Atlas.

Keywords: Upper Silesia Conurbation, green areas, statistical analyzes, GIS

7.1. Introduction

In the cities of the Silesian Voivodeship, especially those belonging to the Upper Silesian Conurbation, the problem is the disappearance of green areas in favour of built-up areas. This is especially true in suburban areas where agricultural land or other green areas are replaced by detached houses or/and multi-family housing areas. Moreover, shopping centres are often located in suburban areas. These green areas are fragmented and subsequently reduced and/or they disappear. In turn, in the areas which are already developed, gradual soil sealing is observed. These processes lead to the decrease in biodiversity and the productivity of these areas. In addition, in the areas where the land surface is successively developed and the urban fabric is densified (the intensity of development increases), the risk of flooding and water shortages grows. Moreover, numerous studies have shown that the disappearance of green areas and the increase in buildings/soil sealing contribute to an increase in the ambient temperature (Urban adaptation to climate change in Europe 2012, Gertland 2012, Geneletti and Zardo 2016, Gorgoń et al. 2014a, Graves et al. 2001, McPherson 1994). This phenomenon is exacerbated by global climate change.

The aim of this paper is to determine the scale and rate of the disappearance of green areas, especially agricultural areas in selected cities of the Upper Silesian Conurbation. Statistical methods such as average, variable normalisation and geostatistical methods, i.e. average values for a given area and the sum of the area were used in this study.

The analysis was carried out on the basis of open access data. Planning documents of municipalities, such as the local spatial development plan and the study of conditions and directions of spatial development were also used. GIS tool was used in the study.

7.2. The role of green spaces in the city in adapting to climate change

The European Union policy indicates the need to implement adaptation measures to mitigate climate change at the urban level (An EU Strategy on adaptation to climate change 2013, Ministerstwo Środowiska 2015). Urban adaptation plans (UAP) assess the sensitivity and vulnerability of the city to climate change. The experience of IETU, which participated in the 44 MPA project, shows that numerous problems, including those related to climate change, occur in sealed areas with significant development density (i.e. built-up areas, occupied by infrastructure and roads). In this type of areas (i.e. heavily urbanised areas where deforestation, surface sealing, reduction of wetlands and river regulation have taken place), there are changes in water conditions, precipitation, and humidity has decreased (Field et al. 2012). In addition, water from precipitation has a limited possibility of entering the soil. Flooding occurs as a result of sudden and intense rainfall (Gorgoń et al. 2014a, Gorgoń et al. 2014b, Gorgoń 2019).

Slightly different problems occur in areas of former natural river floodplains, which are now, due to progressive expansion of cities, used for development. During extreme weather events, these areas reveal their original character, causing catastrophic consequences and significant material damage.

Another problem that appears in the areas with intensive development and a high degree of soil sealing is elevated temperature in relation to the surrounding/suburbs. This phenomenon, called the Urban Heat Island (UHI), can reach an intensity of up to 6–10°C in extreme cases (Shaw et al. 2007, Gartland 2012, Sadowski 2013). On average, this is usually 0.5–0.8°C, and in winter it is 1.1–1.6°C (Urban adaptation to climate change in Europe 2012). UHI is typically associated with urban areas, where there is a significant accumulation of artificial surfaces, a small share of greenery and poor ventilation (Miejska wyspa ciepła

2020). The latter phenomenon is closely related to the urban layout of the city, where high-rise buildings and the road network create ventilation corridors (Wong et al. 2010). Their improper arrangement may affect the air quality.

From the point of view of the quality of life in the city and protection against dangerous phenomena (among others related to climate change), the depletion and fragmentation of green areas is a serious problem. The functions of green areas related to the urban fabric and its surroundings, called ecosystem services, are extremely important (Usługi ekosystemów 2021). Green spaces are a source of nature's natural processes and resources such as usable water and food. They play a very important regulatory role, e.g. in climate regulation or weather mitigation. In addition, these areas perform cultural functions such as recreation and tourism

7.3. Introduction and scope of work

The Upper Silesian conurbation area was selected for the study in its former division (based on the Statistics Poland from 2006 (Konurbacja górnośląska według GUS 2006, Konurbacja Górnośląska 2021)), i.e. covering 19 cities: Gliwice, Zabrze, Katowice, Bytom, Świętochłowice, Siemianowice Śląskie, Sosnowiec, Dąbrowa Górnicza, Jaworzno, Czeladź, Mysłowice, Będzin, Tychy, Ruda Śląska, Piekary Śląskie, Chorzów, Mikołów, Tarnowskie Góry oraz Knurów.

The study analysed strongly biologically active open green areas. After preliminary analyses of Statistics Poland (SP) data and a review of planning and strategic documents of the selected cities (the study of conditions and directions of spatial development and the local spatial development plan available on the websites of the Public Information Bulletin of the cities, city geoportals or voivodship geoportal, e.g. Dokumenty obowiązujące | BIP Miasta Jaworzno, Geoportal Gliwice, Geoportal Województwa Śląskiego ORSIP), it was noticed that the biggest changes in the so-called open areas can be observed among the agricultural and the forest lands.

Therefore, further analyses focused on two categories of green areas, i.e. agricultural and forest land. Detailed statistical analyses were carried out at the Local Data Bank (LDB) on the Statistics Poland portal (BDL 2021a). Figures 7.1 and 7.2 show the location of data sets selected for analysis in the LDB hierarchy.

During the data collection, it turned out that the agricultural land areas, depending on the date of collection, were in two data groups, i.e. agriculture, forestry and hunting (archival data) and the territorial division/geodetic area (Head Office of Geodesy and Cartography data). In the first group, the data were from 1995 to 2005[4]. In the second group, data were from 2012 to 2014. Forest

[4] In the period from 2006 to 2011, the SP tables contain information about the lack of data

area data, however, were from 2000 to 2018 (Table 7.1). As shown in Table 7.1, further comparative analyses were possible in two time periods, i.e. 2000–2005 and 2012–2014. In the analyses of data obtained from the SP portal, the year 2000 was used as the base year and was compared with the years 2001–2005 and 2012–2014. However, the most interesting from a statistical point of view were the extreme dates, i.e. the years 2000 and 2014. The analysed time period in this case was 15 years. The analysis of changes in the area of forests and agricultural

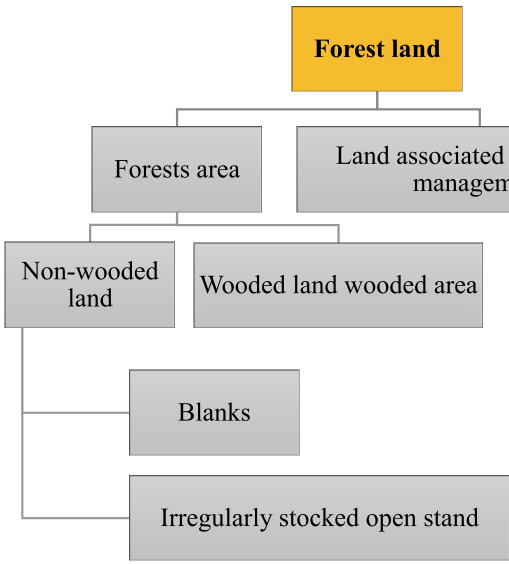

Fig. 7.1. Hierarchy of data statistics in the SP on the category: forest land

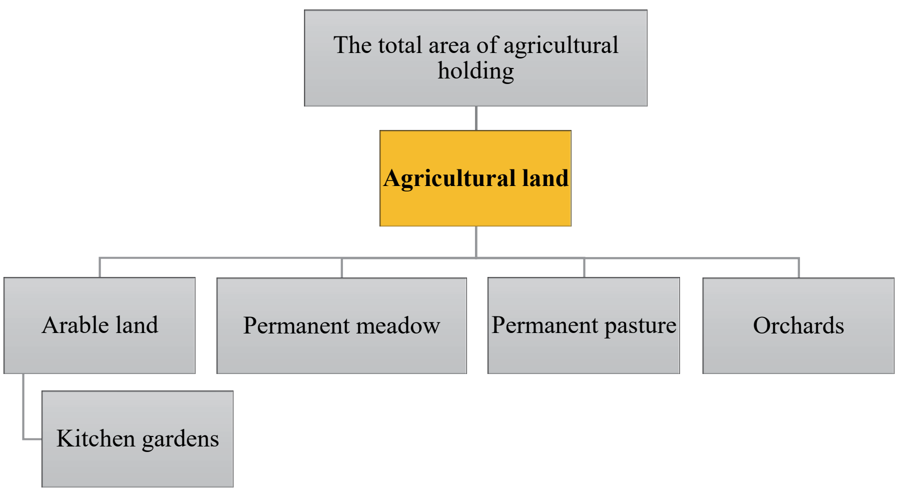

Fig. 7.2. Hierarchy of data statistics in the SP on the category: the total area of agricultural holding

Table 7.1. Summary of data availability in the LDB for the dimensions: agricultural land and forest land

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LDB groups for agricultural land	**AGRICULTURE, FORESTRY AND HUNTING/ARCHIVAL DATA/Utilised agricultural land - area of agricultural land (Dimensions: Types of agricultural land; Forms of ownership)/agricultural lands area / total**																	**TERRITORIAL DIVISION/GEODETIC AREA (DATA OF THE HEAD OFFICE OF GEODESY AND CARTOGRAPHY)/ Geodetic area of the country according to the directions of use (Dimensions: Directions of land use)/agricultural land total**						
Data availability	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	no	no	no	no	no	yes	yes	yes	no	no	no	no
LDB group for forest land	**AGRICULTURE, FORESTRY AND HUNTING/ FORESTRY OF ALL FORMS OF OWNERSHIP/Forest land (Dimensions: Forest land)/total**																							
Data availability	no	no	no	no	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

land was used to distinguish 3 cities in the Silesian conurbation with the greatest decline. Subsequently, in selected cities, an analysis of changes over time in other categories of area was carried out. GIS data from the two available Urban Atlas 2006 and 2012 were used for the analysis. The time period that can be analysed was 7 years. To complete the analyses, the NDVI index was calculated, which was used to analyse the condition of vegetation in a given area. For this purpose, the average NDVI index was calculated for each area of the Urban Atlas category. The results of the study are presented in the following chapters.

7.4. The results of the analyzes

7.4.1. Statistical analyzes of SP data

Analysis of the change in the area of agricultural and forest land in 19 cities of the Upper Silesian Conurbation in the years 2000–2014

After the collection and compilation of the statistical data of the 19 cities in the Upper Silesian Conurbation for the two categories mentioned above, preliminary analyses were performed. As a result, it was concluded that forest and agricultural land areas should be added together to minimise the distortions that may occur when these categories are counted separately. This was due to the fact that a lot of arable land (constituting a subcategory of agricultural land) was afforested in particular years, mainly 2003–2017. Such activities have been legally regulated and specified in the rules of granting financial aid for afforestation of agricultural land (ARiMR 2006, ARiMR 2015). Therefore, the agricultural land and the forest land cannot be analysed separately, because often the loss in the first category means an increase in the second (cf. Fig. 7.3–7.4). Both of these categories were summed up for further analysis. A decline in these two categories means that the city is getting rid of the green areas in favour of other areas, e.g. single-family housing. Categories other than forests and agricultural land, such as urban greenery or parks, were not analysed at this stage. Their changes over time are not large and do not have a significant impact on the selection of cities with the largest decrease in area.

In the next step, three cities with the greatest decrease in forest and agricultural area were selected. GIS analyses were then performed for the selected cities.

7.4.2. Selection of three cities with the greatest decline in agricultural and forest area

The change in agricultural and forest area was calculated using an indicator, which is the ratio of the difference in the area from a given year to the base year. The

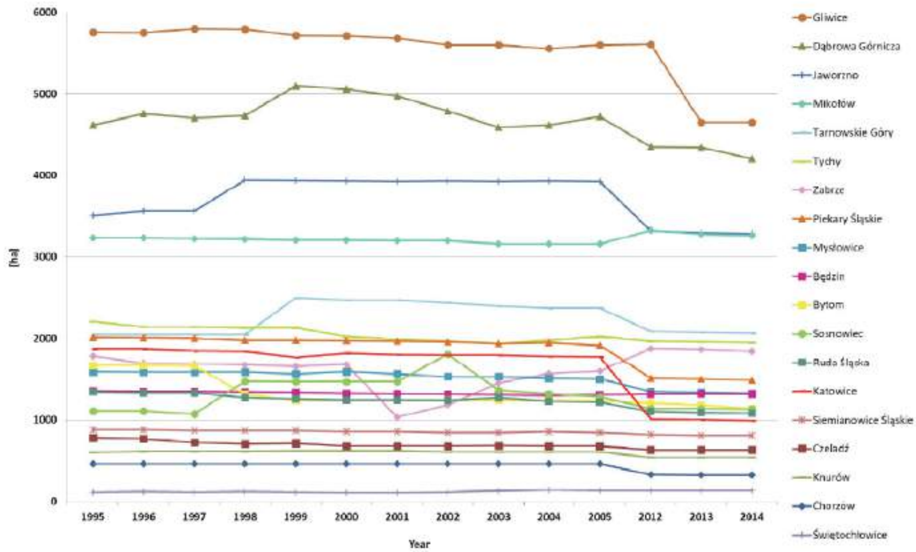

Fig. 7.3. Agricultural land area [ha] in particular years for 19 cities of the Upper Silesian Conurbation

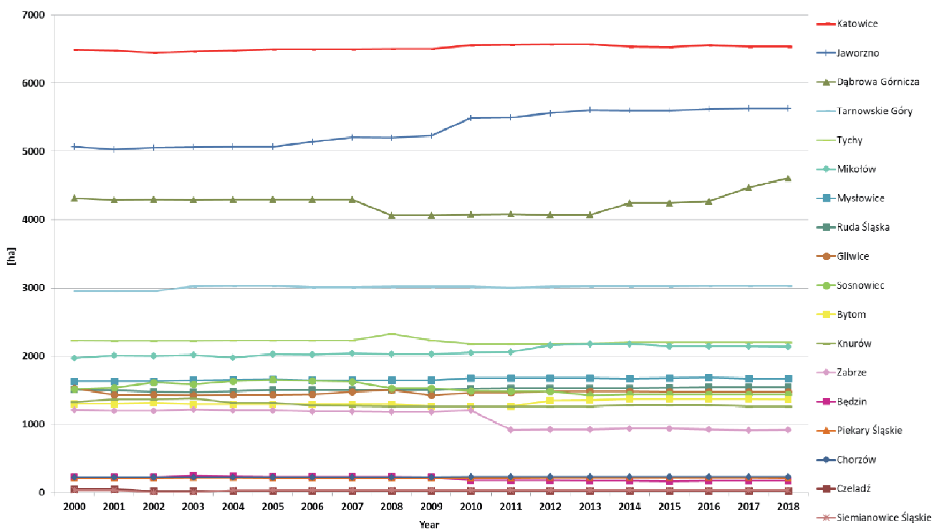

Fig. 7.4. Forest land area [ha] in particular years for 19 cities of the Upper Silesian Conurbation

indicator was calculated according to the formula given by Kowalik (2017) with minor modifications. This formula takes into account the change in the area of territorial units that occurred in 2006 as a result of the new calculation method. It was introduced by the Head Office of Geodesy and Cartography, based on the computer data of the State boundaries and territorial divisions register (BDL 2021b).

$$W_{GL} = \left(\frac{PGL_{2000+n}}{P_{2000+n}} - \frac{PGL_{2000}}{P_{2000}}\right) \times 100\% \qquad (1)$$

where:
W_{GL} – indicator of change in the area of agricultural and forest land (from 2000 to 2014)
PGL_{2000} – total area of agricultural and forest land in the base year 2000
PGL_{2000+n} – total area of agricultural and forest land in the following year
P_{2000} – total area of the commune in the base year 2000
P_{2000+n} – total area of the commune in the following year

The percentage values of the indicator are summarised in Table 7.2.

Table 7.2. Value of indicator of change in the area of agricultural and forest land in [%] in each year compared to the base year 2000, calculated according to formula (1) for the cities of Upper Silesian Conurbation

City/Year	**2001 & 2000**	**2002 & 2000**	**2003 & 2000**	**2004 & 2000**	**2005 & 2000**	**2012 & 2000**	**2013 & 2000**	**2014 & 2000**
Będzin	-0.05	-0.22	0.33	-0.03	-0.07	-2.51	-2.56	-2.81
Bytom	0.01	0.07	-0.50	-0.78	-0.83	0.17	-0.15	-0.81
Chorzów	-0.06	0.00	0.00	-0.03	-0.02	-4.05	-4.35	-4.45
Czeladź	0.66	-0.91	-0.36	-0.54	-0.48	-2.53	-2.47	-2.47
Dąbrowa Górnicza	-0.62	-1.74	-2.19	-2.43	-2.34	-5.65	-5.71	-5.52
Gliwice	-0.56	-1.19	-1.24	-1.69	-1.19	0.45	-9.51	-9.50
Jaworzno	-0.33	-0.20	-0.19	-0.10	-0.17	3.14	2.96	2.73
Katowice	-0.19	-0.43	-0.36	-0.38	0.21	-3.47	-3.62	-3.90
Knurów	1.12	0.89	1.29	-0.62	-0.88	-3.33	-3.44	-2.95
Mikołów	0.44	0.35	-0.78	-1.30	-0.35	3.26	2.70	2.49
Mysłowice	-0.24	-1.29	-1.00	-1.30	-1.33	-3.32	-3.82	-4.15
Piekary Śląskie	-0.18	-0.33	-0.54	-0.39	-0.97	9.04	8.60	7.92
Ruda Śląska	-0.22	-0.57	-0.20	-0.67	-0.09	-1.17	-1.43	-1.60
Siemianowice Śląskie	-0.08	-2.11	-2.15	-0.07	-0.64	-2.00	-2.27	-2.31
Sosnowiec	0.22	5.72	-0.68	-1.73	-2.26	-5.96	-6.68	-6.67
Świętochło-wice	-0.15	0.00	0.91	1.51	1.21	1.06	1.13	1.21
Tarnowskie Góry	-0.21	-0.43	0.05	-0.02	-0.10	-3.73	-3.97	-4.08
Tychy	-0.57	-1.43	-1.90	-3.05	-3.01	-3.39	-3.55	-3.88
Zabrze	-9.75	-8.13	-3.64	-2.25	-1.97	0.14	0.24	0.07

Subsequently, the percentage value of the change indicator for agricultural and forest land in 2014 only in relation to the base year 2000 was calculated according to the following formula:

$$\boldsymbol{W_{GL}} = \left(\frac{\boldsymbol{PGL_{2014}} - \boldsymbol{PGL_{2000}}}{\boldsymbol{P_{2000}}}\right) \times \mathbf{100\%} \tag{2}$$

where:
W_{GL} – indicator of change in the area of agricultural and forest land (from 2000 to 2014)
$PGL_{2000,\,2014}$ – total area of agricultural and forest land in the year 2000 and 2014
P_{2000} – total area of the commune in the base year 2000.

This is the second method of calculating the indicator of change in the area of agricultural and forest land, but it does not take into account minor modifications of the area of territorial units in 2006. In this case, it was assumed that the area of the commune from 2000 to 2014 was the same.

The indicator values calculated by the two methods given above, i.e. according to formula (1) and (2), were normalised so that they could be compared with each other, and a final selection of the 3 cities with the greatest decrease in the analysed areas could be made. The calculations were made according to the formula:

$$\boldsymbol{WN_{ij}} = \frac{\boldsymbol{WGL_{ij}} - \boldsymbol{min_i}\left(\boldsymbol{WGL_{ij}}\right)}{\boldsymbol{max_i}\left(\boldsymbol{WGL_{ij}}\right) - \boldsymbol{min_i}\left(\boldsymbol{WGL_{ij}}\right)} \tag{3}$$

where:
WN_{ij} – indicator after normalisation of the variable
WGL_{ij} – indicator of change in the area of agricultural and forest land in a commune
$min_i(WGL_{ij})$ – the lowest value of the indicator of change in the area of agricultural and forest land among 19 cities of the Upper Silesian conurbation
$max_i(WGL_{ij})$ – the highest value of the indicator of change in the area of agricultural and forest land among 19 cities of the Upper Silesian conurbation.

As a result of applying the above normalisation formula, we obtain variables "scaled" to values belonging to the range [0; 1]. The results are summarised as the arithmetic sum of two normalised variables (Table 7.3).

The table above shows that the largest percentage decrease in the area of agricultural and forest land according to formula (1) in 2014 compared to 2000 was recorded in Gliwice and it amounts to almost 10%. The largest increase in surface area for the longest period 15 years can be observed in Piekary Śląskie, almost 8%. Taking into account formula (2), the largest decrease in surface area was observed in Chorzów, i.e. about 21%, while an increase of 19% can be observed in Piekary Śląskie.

Table 7.3. Value of indicator of change in the area of agricultural and forest land in [%] in 2014 compared to the base year 2000, calculated according to formula (1) and (2), and the normalisation of variables and the arithmetic sum of two normalised variables for the cities of the Upper Silesian Conurbation.

City	Change in relation to the base year according to formula (1) [%]	Change in relation to the base year according to formula (2) [%]	Normalisation of a variable calculated from formula (1)	Normalisation of a variable calculated from formula (2)	Arithmetic sum of two normalised variables
Będzin	-2.81%	-4.55%	0.38	0.41	0.793
Bytom	-0.81%	-1.72%	0.50	0.48	0.980
Chorzów	-4.45%	-20.54%	0.29	0.00	0.290
Czeladź	-2.47%	-6.59%	0.40	0.36	0.760
Dąbrowa Górnicza	-5.52%	-8.07%	0.23	0.32	0.548
Gliwice	-9.50%	-15.17%	0.00	0.14	0.137
Jaworzno	2.73%	4.12%	0.70	0.63	1.333
Katowice	-3.90%	-6.97%	0.32	0.35	0.668
Knurów	-2.95%	-5.53%	0.38	0.38	0.760
Mikołów	2.49%	3.49%	0.69	0.61	1.303
Mysłowice	-4.15%	-7.35%	0.31	0.34	0.645
Piekary Śląskie	7.92%	18.57%	1.00	1.00	2.000
Ruda Śląska	-1.60%	-3.44%	0.45	0.44	0.891
Siemianowice Śląskie	-2.31%	-4.84%	0.41	0.40	0.814
Sosnowiec	-6.67%	-15.71%	0.16	0.12	0.286
Świętochłowice	1.21%	12.50%	0.61	0.84	1.460
Tarnowskie Góry	-4.08%	-5.24%	0.31	0.39	0.702
Tychy	-3.88%	-5.61%	0.32	0.38	0.704
Zabrze	0.07%	0.09%	0.55	0.53	1.077

To facilitate an overview of the cities with the greatest decrease in surface area, the arithmetic sum is compiled again in Table 4 below, according to normalised variables, and arranged from lowest to highest values. The three cities with the lowest value of this parameter were selected for further analysis.

The table above shows that the three cities with the greatest decline in green areas (understood in this case as agricultural and forest land together) were **Gliwice, Sosnowiec and Chorzów**. These cities were selected for further analysis. The values of the arithmetic sum of two normalised variables were

Table 7.4. The arithmetic sum of normalised variables from lowest to highest values in 2014 compared to the base year 2000

City	Arithmetic sum of two normalised variables
Gliwice	0.137
Sosnowiec	0.286
Chorzów	0.290
Dąbrowa Górnicza	0.548
Mysłowice	0.645
Katowice	0.668
Tarnowskie Góry	0.702
Tychy	0.704
Knurów	0.760
Czeladź	0.760
Będzin	0.793
Siemianowice Śląskie	0.814
Ruda Śląska	0.891
Bytom	0.980
Zabrze	1.077
Mikołów	1.303
Jaworzno	1.333
Świętochłowice	1.460
Piekary Śląskie	2.000

the lowest in them, which means, a significant decrease in the analysed areas. It should be emphasised that not all 19 cities of the Upper Silesian Conurbation experienced a decrease in the analysed area. In comparison, in Piekary Śląskie, an increase is visible over the course of 15 years, and the sum of the two normalised variables has the highest value, i.e. equal to 2. Other cities where the increase is visible are: Świętochłowice[5], Jaworzno, Mikołów and Zabrze.

7.4.3. GIS analysis

7.4.3.1. Calculation of land cover change according to Urban Atlas 2006 and 2012 (7-year time period)

After the selection of the three cities, GIS analyses were started, which were to show which area categories, according to available sources, recorded the largest

[5] however, the city does not have many green areas

decreases, and which increases. The resource of thematic maps available on the website https://land.copernicus.eu/ was used (Urban Atlas – Copernicus Land Monitoring Service). Urban Atlas maps were selected for the analysis. The areas of two Urban Atlases (UA) from the years 2006 and 2012 for the Katowice region were analysed. Then the changes of these areas over 7 years were calculated (Tables 7.5–7.8). It should be emphasised that the 2012 Urban Atlas has slightly more divisions than the 2006 UA. The additional divisions are: arable land (annual crops), herbaceous vegetation associations (natural grassland, moors), pastures and discontinuous very low-density urban fabric (S.L.: < 10%). For the purposes of the analyses, it was decided that all these areas (except for the area known as 'discontinuous very low-density urban fabric') would be summed and compared to the agricultural, semi-natural areas, wetlands, as was done in the 2006 Urban Atlas. The category 'discontinuous very low-density urban fabric' was created as a new division, where the former areas, most often green ones, were built up, so it was left as it was in the 2012 Urban Atlas.

The analysis of Tables 7.5–7.8 confirms the decrease in the area of agricultural and forest land in all three cities selected for further analysis. In Gliwice (Table 7.5), this decrease is particularly visible. In total, about 200 ha of land changed its form of use. In Sosnowiec, there are much smaller decreases, exceeding 70 hectares. Against this background (i.e. compared to the first two cities), agricultural and forest area in Chorzów decreased only by 15 ha during the 7 years. Over 280 ha of the above-mentioned areas disappeared in all three cities in total.

In all three cities, there was a significant increase in the area occupied by industrial, commercial, public, military and private facilities. In Gliwice it was an increase of 96 ha, in Sosnowiec – 24 ha, and in Chorzów – 30 ha, 150 ha in total. These areas were established, in many cases, on farmland and also in forest areas. In Gliwice, this tendency was clearly visible, because new areas occupied by the above-mentioned facilities appear along the main communication routes (see Fig. 7.5–7.6).

New areas called 'discontinuous very low density urban fabric' (S.L.: < 10%) also emerged in all three cities: Gliwice, Sosnowiec and Chorzów, covering approximately 32 ha, 14 ha and 2 ha, respectively, which is approximately 47 ha in total. Thus, it can be seen that there was a certain correlation between the decline of forest and agricultural areas in favor of mainly industrial and commercial areas. Moreover, the areas formerly used for agriculture are occupied by new housing developments, although these were much smaller than commercial areas. In addition, the A1 motorway was built in Gliwice in the analysed period, which resulted in an increase in the area of fast transit roads and associated land – 124 ha. In 2006, this area was classified mainly as construction land. In two cities, new communication routes were built, classified as 'other roads and associated land'. In Gliwice, these areas increased by 26 ha, and in Sosnowiec by 3 ha.

Table 7.5. Surface change – urban atlas 2012 and 2006 comparison – Gliwice

Types of surfaces according to Urban Atlas 2012	**Area according to Urban Atlas 2012 [ha]**	**Types of surfaces according to Urban Atlas 2006**	**Area according to Urban Atlas 2006 [ha]**	**Surface difference according to UA 2012–2006 [ha]**
Arable land (annual crops), herbaceous vegetation associations (natural grassland, moors) and pastures	5418.28	Agricultural, semi-natural areas, wetlands	5584.50	-166.22
Construction sites	1.49	Construction sites	119.28	-117.79
Continuous urban fabric (S.L.: > 80%)	530.92	Continuous urban fabric (S.L.: > 80%)	518.03	12.89
Discontinuous dense urban fabric (S.L.: 50% – 80%)	1420.11	Discontinuous dense urban fabric (S.L.: 50% – 80%)	1409.31	10.80
Discontinuous low density urban fabric (S.L.: 10% – 30%)	8.45	Discontinuous low density urban fabric (S.L.: 10% – 30%)	0.25	8.20
Discontinuous medium density urban fabric (S.L.: 30% – 50%)	89.30	Discontinuous medium density urban fabric (S.L.: 30% – 50%)	84.00	5.30
Discontinuous very low density urban fabric (S.L.: < 10%)	31.95	–	–	31.95
Fast transit roads and associated land	194.90	Fast transit roads and associated land	70.83	124.07
Forests	1735.15	Forests	1768.84	-33.70
Green urban areas	617.50	Green urban areas	616.60	0.90
Industrial, commercial, public, military and private units	1719.93	Industrial, commercial, public, military and private units	1623.74	96.20

Isolated structures	12.04	Isolated structures	9.28	2.76
Land without current use	41.52	Land without current use	37.27	4.25
Mineral extraction and dump sites	149.36	Mineral extraction and dump sites	161.05	-11.70
Other roads and associated land	425.05	Other roads and associated land	398.98	26.07
Port areas	23.55	Port areas	23.55	0.00
Railways and associated land	183.06	Railways and associated land	184.58	-1.53
Sports and leisure facilities	661.39	Sports and leisure facilities	654.68	6.71
Water	105.32	Water	104.48	0.84

Table 7.6. Surface change – urban atlas 2012 and 2006 comparison – Sosnowiec

Types of surfaces according to Urban Atlas 2012	**Area according to Urban Atlas 2012 [ha]**	**Types of surfaces according to Urban Atlas 2006**	**Area according to Urban Atlas 2006 [ha]**	**Surface difference according to UA 2012–2006 [ha]**
Arable land (annual crops), herbaceous vegetation associations (natural grassland, moors) and pastures	1841.08	Agricultural, semi–natural areas, wetlands	1902.57	-61.49
Construction sites	0.44	Construction sites	36.22	-35.78
Continuous urban fabric (S.L.: > 80%)	420.16	Continuous urban fabric (S.L.: > 80%)	419.72	0.44
Discontinuous dense urban fabric (S.L.: 50% – 80%)	1447.29	Discontinuous dense urban fabric (S.L.: 50% – 80%)	1441.69	5.60

Discontinuous low density urban fabric (S.L.: 10% – 30%)	5.16	Discontinuous low density urban fabric (S.L.: 10% – 30%)	0.00	5.16
Discontinuous medium density urban fabric (S.L.: 30% – 50%)	61.28	Discontinuous medium density urban fabric (S.L.: 30% – 50%)	56.16	5.12
Discontinuous very low density urban fabric (S.L.: < 10%)	13.86	–		13.86
Fast transit roads and associated land	0.00	Fast transit roads and associated land	0.00	0.00
Forests	1900.56	Forests	1908.38	-7.82
Green urban areas	546.80	Green urban areas	545.10	1.69
Industrial, commercial, public, military and private units	1080.13	Industrial, commercial, public, military and private units	1055.76	24.36
Isolated structures	13.00	Isolated structures	13.53	-0.53
Land without current use	48.35	Land without current use	21.93	26.42
Mineral extraction and dump sites	632.31	Mineral extraction and dump sites	612.83	19.48
Other roads and associated land	413.51	Other roads and associated land	410.04	3.47
Port areas	0.00	Port areas	0.00	0.00
Railways and associated land	153.45	Railways and associated land	153.45	0.00
Sports and leisure facilities	456.16	Sports and leisure facilities	456.16	0.00
Water	70.97	Water	70.97	0.00

Table 7.7. Surface change – urban atlas 2012 and 2006 comparison – Chorzów

Types of surfaces according to Urban Atlas 2012	**Area according to Urban Atlas 2012 [ha]**	**Types of surfaces according to Urban Atlas 2006**	**Area according to Urban Atlas 2006 [ha]**	**Surface difference according to UA 2012–2006 [ha]**
Arable land (annual crops), herbaceous vegetation associations (natural grassland, moors) and pastures	463.99	Agricultural, semi-natural areas, wetlands	473.00	-9.01
Construction sites	1.24	Construction sites	28.18	-26.94
Continuous urban fabric (S.L.: > 80%)	376.68	Continuous urban fabric (S.L.: > 80%)	375.22	1.46
Discontinuous dense urban fabric (S.L.: 50% – 80%)	252.24	Discontinuous dense urban fabric (S.L.: 50% – 80%)	254.45	-2.21
Discontinuous low density urban fabric (S.L.: 10% – 30%)	2.10	Discontinuous low density urban fabric (S.L.: 10% – 30%)	0.00	2.10
Discontinuous medium density urban fabric (S.L.: 30% – 50%)	4.74	Discontinuous medium density urban fabric (S.L.: 30% – 50%)	0.42	4.32
Discontinuous very low density urban fabric (S.L.: < 10%)	1.68	–		1.68
Fast transit roads and associated land	14.80	Fast transit roads and associated land	14.80	0.00
Forests	417.48	Forests	423.75	-6.27
Green urban areas	410.45	Green urban areas	406.41	4.04
Industrial, commercial. public, military and private units	593.28	Industrial, commercial, public, military and private units	563.56	29.72

Isolated structures	0.73	Isolated structures	0.73	0.00
Land without current use	6.96	Land without current use	7.55	-0.59
Mineral extraction and dump sites	60.04	Mineral extraction and dump sites	60.21	-0.17
Other roads and associated land	127.65	Other roads and associated land	127.65	0.00
Port areas	0.00	Port areas	0.00	0.00
Railways and associated land	89.38	Railways and associated land	89.38	0.00
Sports and leisure facilities	449.20	Sports and leisure facilities	447.34	1.87
Water	54.40	Water	54.40	0.00

Table 7.8. Surface change – urban 2012 and 2006 comparison – the sum of the 3 cities of Gliwice, Sosnowiec, Chorzow

Types of surfaces according to Urban Atlas 2012	**Area according to Urban Atlas 2012 [ha]**	**Types of surfaces according to Urban Atlas 2006**	**Area according to Urban Atlas 2006 [ha]**	**Surface difference according to UA 2012–2006 [ha]**
Arable land (annual crops), herbaceous vegetation associations (natural grassland, moors) and pastures	7723.34	Agricultural, semi-natural areas, wetlands	7960.06	-236.73
Construction sites	3.17	Construction sites	183.68	-180.51
Continuous urban fabric (S.L.: > 80%)	1327.77	Continuous urban fabric (S.L.: > 80%)	1312.98	14.79
Discontinuous dense urban fabric (S.L.: 50% – 80%)	3119.64	Discontinuous dense urban fabric (S.L.: 50% – 80%)	3105.45	14.19

Discontinuous low density urban fabric (S.L.: 10% – 30%)	15.72	Discontinuous low density urban fabric (S.L.: 10% – 30%)	0.25	15.47
Discontinuous medium density urban fabric (S.L.: 30% – 50%)	155.33	Discontinuous medium density urban fabric (S.L.: 30% – 50%)	140.59	14.74
Discontinuous very low density urban fabric (S.L.: < 10%)	47.48	–	–	47.48
Fast transit roads and associated land	209.70	Fast transit roads and associated land	85.63	124.07
Forests	4053.19	Forests	4100.97	-47.79
Green urban areas	1574.75	Green urban areas	1568.11	6.64
Industrial, commercial, public, military and private units	3393.34	Industrial, commercial, public, military and private units	3243.06	150.28
Isolated structures	25.78	Isolated structures	23.54	2.23
Land without current use	96.84	Land without current use	66.75	30.09
Mineral extraction and dump sites	841.71	Mineral extraction and dump sites	834.09	7.61
Other roads and associated land	966.22	Other roads and associated land	936.68	29.54
Port areas	23.55	Port areas	23.55	0.00
Railways and associated land	425.89	Railways and associated land	427.41	-1.53
Sports and leisure facilities	1566.75	Sports and leisure facilities	1558.17	8.57
Water	230.68	Water	229.84	0.84

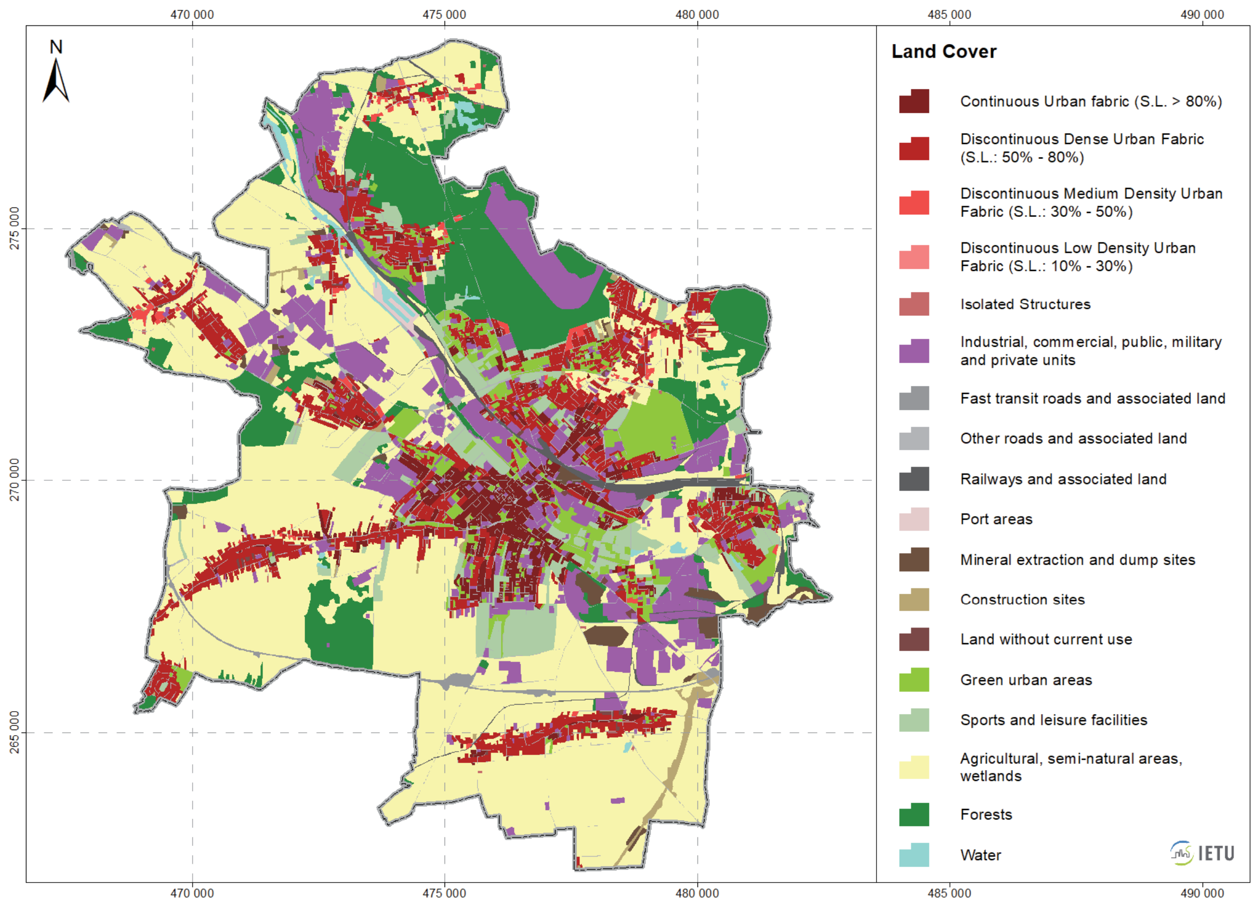

Fig. 7.5. Land cover on the example of the city of Gliwice according to Urban Atlas 2006

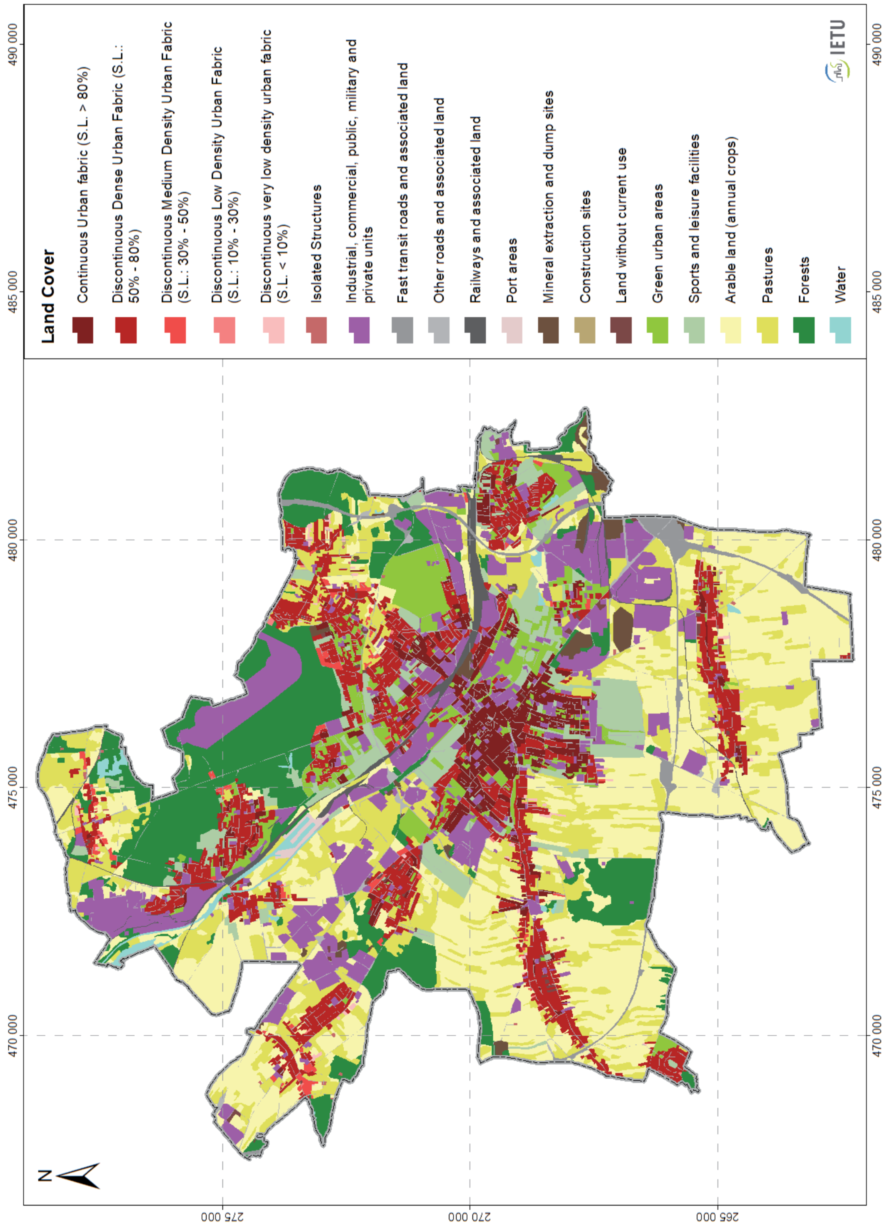

Fig. 7.6. Land cover on the example of the city of Gliwice according to Urban Atlas 2012

Analysis of urban tissue with different levels of sealing/intensity shows that its surface area in the three cities increased over the past 15 years. This was most noticeable in Gliwice, where the continuous urban fabric (with the sealing level > 80%) increased by about 12.89 ha, and the discontinuous dense urban fabric (S.L. 50–80%) increased by about 10.8 ha. In Sosnowiec it was 0.44 ha and 5.6 ha, respectively. In Chorzów, continuous urban fabric increased by 1.46 ha, while discontinuous dense urban fabric decreased by 2.21 ha. Unfortunately, in the remaining categories of urban fabric area (i.e. S. L. 30–50% and 10–30%) there was also an increase of several ha in all three cities. Therefore, in these categories there has been an increase in the intensity of development in the urban area.

The analyses carried out for the three cities show that there was some increase in green urban areas which was a very interesting and positive trend. In Gliwice it was about 1 ha, in Sosnowiec – almost 1.7 ha, and in Chorzów – over 4 ha. In total, in all three cities, this area gained about 6.6 ha.

7.4.3.2. Calculation of the NDVI index (Normalized Difference Vegetation Index)

To complement the above analyses, additional data were collected from available satellite imagery so that the Normalized Difference Vegetation Index (NDVI) could be calculated. This indicator allows for precise measurement of plant health condition using the red band and the near infrared (NIR) band (NASA 2021a). It is calculated from the formula:

$$NDVI = (NIR - Red) / (NIR + Red) \quad \text{(Prasomsup et al. 2020)} \qquad (4)$$

where:
Red – Red,
NIR – near-infrared.

The indicator takes average values from -1 to 1. It is used, for example, in agriculture because, as already mentioned, it indicates the condition of plants. The higher the infrared reflection and the lower the red band, the greener the plants are and the higher the NDVI value (Wang et al. 2004, Jarocińska and Zagajewski 2008).

Research indicates that the average values for vegetation in good condition, in the full growing season, where moisture and nutrients are correct, range from 0.4 to 0.85. In agriculture, when the value of this index is below 0.15, it means a fragment of the plot with plowed land and no vegetation (AgTechStudio 2020). An index value from 0.15 to 0.2 may indicate plants before the growing season, and from 0.2 to 0.3 indicates enrty into the vegetative phase.

In urban areas, this indicator looks slightly different, i.e. if the shares of built-up area and greenery are the same (50% each), then the resulting NDVI for the entire area is 0.35 (Będkowski and Bielecki A. 2018). Everything depends on the season in which the image was taken. Values below 0 indicate no vegetation, including artificial areas and water reservoirs (values close to 0).

The following satellites can be sources of satellite imagery useful for NDVI indicator analysis: Aster, Landsat 7 and Landsat 8 (GloVis n.a.).

After preliminary analysis, satellite images of Aster were excluded as they did not cover the entire area of the three cities. Landsat 7 images have been available since 1999, however in 2003 the SLC (Scan Line Corrector) failed and there are data gaps in the images after that time (NASA 2021b). These errors can be removed by applying an appropriate mask to the raster, but they are of little use for statistical analyses. Nevertheless, for the year 2000, taken as the base year in the paper, the satellite images are of full value. The new Landsat 8 satellite has been in operation since 2013, from which images from 2014 were used. Images with a cloudiness of no more than 30% were used for the analysis so as not to cover the studied area. Another important assumption was that both Landsat 7 images from 2000 and Landsat 8 images from 2014 should be from the same month, from March to September (growing season), which is important for calculating the NDVI index. The images obtained under the above assumptions are summarised in Table 7.9. Landsat 7 images from May 14, 2000 and Landsat 8 images from May 6, 2014 were selected for further analysis of the NDVI index.

The average NDVI index values for 2000 were calculated on the basis of UA 2006, while the average index values for 2014 were based on UA 2012. Figures 7.7 and 7.8 show the average values of the NDVI index for individual UA areas, based on the example of the city of Gliwice, where the declines in this area were the largest. It should be noted that the only images acquired for the two periods, i.e. 2000 and 2014, showing changes over the 15-year time interval, are from mid-May. Plants at that time were not in the full growing season, as can be seen from the vegetation index. This is especially evident in Figure 7.7, where the agricultural areas have an average NDVI index of 0.21–0.25. Therefore, it

Table 7.9. List of Landsat 7 and 8 satellite images

Month	Landasat 7 (L7)	Landsat 8 (L8)	Notes
March	02.03.2014	-	Images of the L7 after the crash
April	03.04.2014	-	Images of the L7 after the crash
	28.04.2000	-	-
May	14.05.2000	06.05.2014	Images selected for NDVI analyses
		22.05.2014	-
August	02.08.2000	-	-
	06.08.2013	-	-
	02.08.2014	-	-

is not possible to compare the NDVI of the two periods. However, there are clearly visible built-up areas with continuous urban tissue (> 80%), industrial and commercial areas or water reservoirs, largely devoid of vegetation or with vegetation in poor condition.

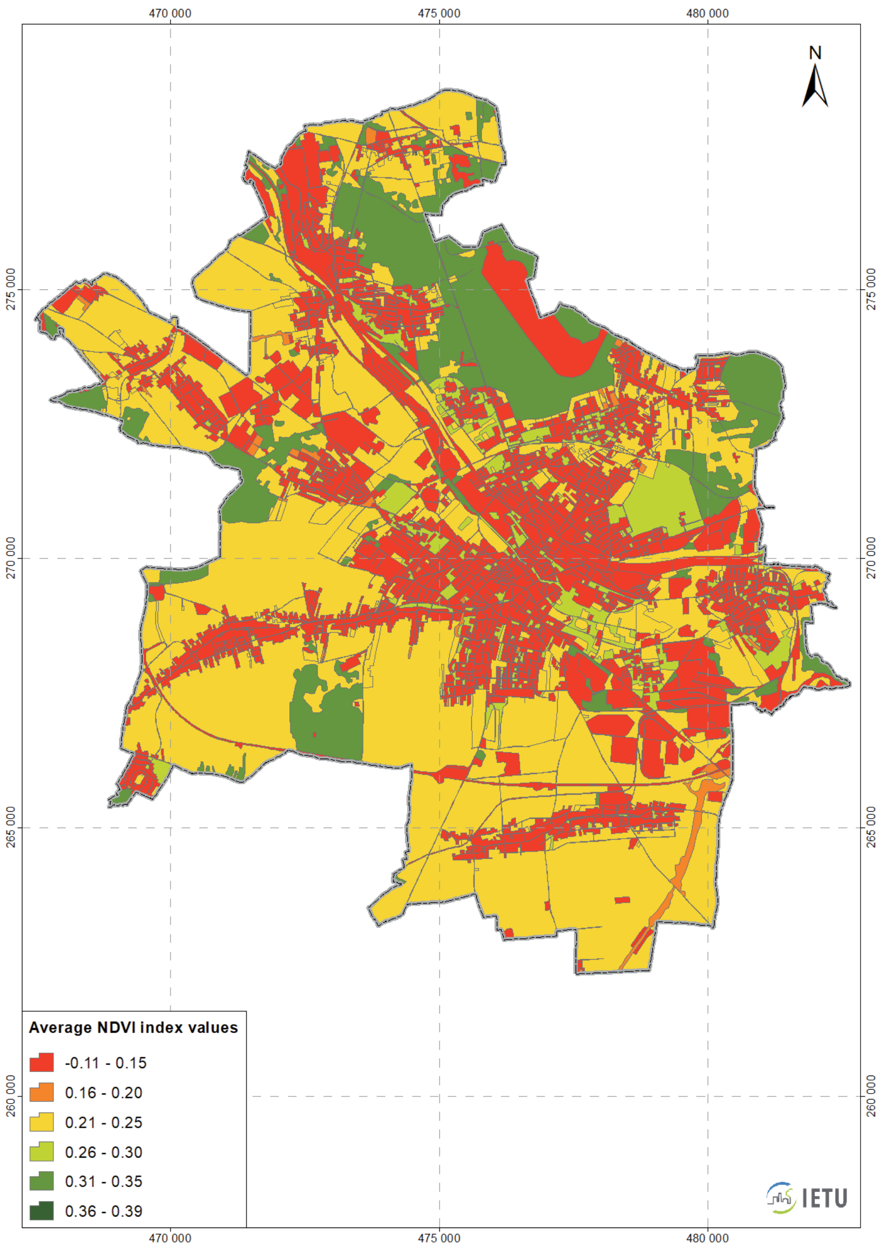

Fig. 7.7. Average values of the NDVI index on the example of the city of Gliwice according to the Urban Atlas 2006

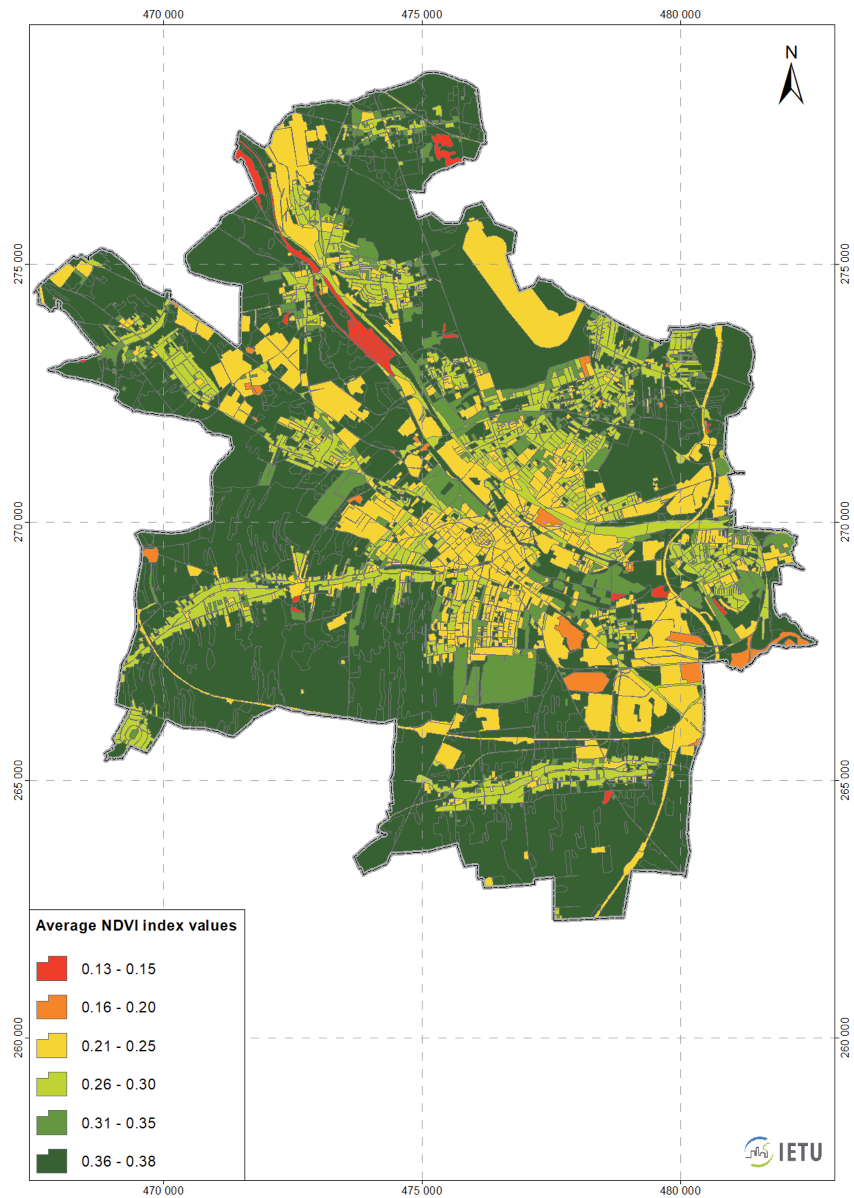

Fig. 7.8. Average values of the NDVI index on the example of the city of Gliwice according to the Urban Atlas 2012

7.4.4. Identification of data gaps

Data gaps emerged during their collection. They were related to data quality, completeness and variability over time. The first problems related to data incompleteness and their variability over time are described in Chapter 7.3 and presented in Table 7.1 in the context of the analyses presented on the basis of SP – LDB.

Another problem was the variability of the divisions of the respective surfaces in relation to the Urban Atlas 2006 and 2012, described in subsection 7.4.2. However, after the analyses it turned out that most of the new surface classes in UA 2012 are irrelevant because they were created as additional areas from former agricultural land, semi-natural areas and wetlands of UA 2006.

In the analysis of the satellite imagery, the selection of images from 2000 and 2014, so that the two time periods could be compared, proved to be problematic. Details of raster quality and availability are described in Chapter 7.4.2.

7.5. Conclusions

The disappearance of green spaces in urban areas of selected cities in the Upper Silesian Conurbation is presented on the basis of the collected data. The most important green areas are classified in two categories, i.e. agricultural and forest land. This is because these two categories are most often transformed, degraded and in many cases built-up.

From the area of the Conurbation comprising of 19 cities: Gliwice, Zabrze, Katowice, Bytom, Świętochłowice, Siemianowice Śląskie, Sosnowiec, Dąbrowa Górnicza, Jaworzno, Czeladź, Mysłowice, Będzin, Tychy, Ruda Śląska, Piekary Śląskie, Chorzów, Mikołów, Tarnowskie Góry and Knurów, the largest decrease in green areas was observed in Gliwice, followed by Sosnowiec and Chorzów. In Gliwice, this decrease reached a value close to 10% of the city's area over the analysed 15 years.

After the selection of three cities, further GIS analyses were started, covering all categories of areas. The available data from the Urban Atlas (UA) 2006 and 2012 were used for this purpose. These data cover a much shorter period of 7 years. They confirm the previous analyses that the largest declines in surface area are in the categories of arable land, grassland, pastures and forests. In total, it is a 280 ha decline in all 3 cities. These losses correlate with a significant increase in another category of space allocated in the UA, namely industrial and commercial areas. This represents an increase of 150 ha. This was confirmed by the comparison of maps, which showed that these areas were most often occupied an agricultural land (located e.g. along main roads) and, in a single case, a forest area.

In addition, a slight increase in the continuous and discontinuous dense urban fabric, i.e. the area of which the sealing level is > 80% and 50–80%, can be observed, and thus also an increase in the intensity of development. In total, it is almost 30 ha.

The average NDVI index for individual categories of areas was also calculated. This study presents only maps from the city of Gliwice, due to the fact that the losses in green areas were the largest there. However, it was difficult to clearly indicate on the basis of the analysis, whether the reason for the relatively low values of the average NDVI index in agricultural areas was the selected season, i.e. May. This is the period at the beginning of plant vegetation. Unfortunately, it was not possible to obtain images from the summer period, due to the strong cloud cover during the operation of the satellites in the study area in 2000 and 2014. However, there was a clear tendency that in areas where the intensity of development increased, the average values of the NDVI indicator decreased. This was evident in both 2000 and 2014.

Vegetation plays a very important role in the city, such as regulating the climate and providing recreational functions. It reduces air temperature and increases humidity, which has a positive effect on mitigating the effects of heat. In addition, it has an impact on air quality in the city, performing a purifying function. Unsealed surfaces allow water to freely soak into the ground, which in turn prevents local flooding. Getting rid of this type of surface, its fragmentation, depletion or destruction significantly affects the quality of life of inhabitants and increases financial losses during violent weather phenomena.

The conducted research, due to the complexity of the problem of estimating changes in the share of green areas, has not been performed so far for the areas of the above-mentioned Conurbation, which translates into its utilitarian nature. However, the topic has not been exhausted due to the huge potential and data availability in terms of GIS tools.

Acknowledgements

The statutory work was financed by a subsidy from the Minister of Science and Higher Education. It was conducted at the Institute of Ecology of Industrial Areas in the area of Transformation of the urbanised environment entitled “Correlation analysis between soil sealing and increasing development intensity and the decline of open green areas”.

Many thanks to Dr. Joachim Bronder for his help in developing statistics and geostatistics.

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Chapter 8

Health risk assessment in contaminated site management

Summary
Pursuant to the Polish Environmental Protection Law, assessment of significant risk is required in remediation plans and remediation project plans for contaminated soil but no reference methods for its assessment have been set down. To fill this legislative gap, the human health risk-based approach to contaminated sites was proposed. The approach is a modification of the risk assessment procedure proposed to be applied in Poland in 2009. It is a two-tier process, including: Tier 1 – screening human health risk assessment and Tier 2 – site-specific human health risk assessment. The risk-based assessment of the contaminated sites can effectively support the decision-making process connected with soil remediation in Poland.

Keywords: health risk assessment, contaminated site management

8.1. Introduction

The problem of industrially contaminated soil remains widespread although it differs territorially with regard to the type, level and extent of contamination. According to the European Commission Joint Research Centre (JRC) report (from 2014), estimates for the extent of local soil contamination in Europe are an average of about 4.2 for potentially contaminated sites per 1 000 inhabitants and about 5.7 for contaminated sites per 10 000 inhabitants. Mineral oils and heavy metals are the main soil contaminant categories contributing to about 60% of soil contamination in Europe (Van Liedekerke et al. 2014). A new JRC report (from 2018) indicates that polluting activities potentially took place in 2.8 million sites in the European Union (EU) and since 2011 over 5 000 new sites have been subject to remediation or risk-reduction measures. The report also shows that there are more than 650 000 officially registered contaminated sites across Europe. More than 170 000 sites are still to be investigated, 68 000 are currently under investigation and more than 125 000 sites need or might need remediation, while 65 500 sites have already been remediated, or are under aftercare measures (Payá Pérez and Rodríguez Eugenio 2018).

In 2006, taking into account the serious problem of soil degradation in Europe, the European Commission published the Thematic Strategy for Soil Protection (COM(2006) 231) and the accompanying proposal for Soil Framework Directive (COM(2006) 232). The overall objective of the Strategy was protection and sustainable use of soil through a) preventing further soil degradation and preserving its functions, and b) restoring degraded soils to a level of functionality consistent at least with current and intended use. In the Strategy 'soil contamination' was recognised as one of the eight soil threats. The proposal for Soil Framework Directive recommended using a risk-based approach for contaminated site assessment and remediation. However, in 2014 the proposal for Soil Framework Directive was withdrawn by the European Commission due to the lack of qualified majority of countries in the Council in favour (EU 2014).

At the EU level, there is no binding overarching framework or strategy that defines policy priorities or parameters for soil protection. Soil protection issues are addressed in other laws which define the environmental objectives that are not explicitly soil focused, as for example reducing contamination (EC 2021a). Currently, the European Commission is working on the new EU Soil Strategy. The aim of the new EU Soil Strategy will be to address soil- and land-related issues in a comprehensive way and to help achieve land degradation neutrality by 2030 (EC 2021b).

EU Member State approaches to contaminated sites are different. In some Member States comprehensive policies cover identification, risk assessment and remediation of contaminated sites, including setting thresholds for contaminants, in others – the policies cover these aspects only partially (Frelih-Larsen et al. 2017, Payá Pérez and Peláez Sánchez 2017).

In order to determine whether the contaminated soil is safe for humans or requires remediation, human health risk assessment (HRA) is applied throughout and outside Europe, particularly intensively in the United States (Rodrigues et al. 2009). The human health risk assessment methods are applied through the entire remediation process. Their main uses are: development of risk-based remedial levels depending on current and anticipated land use patterns, evaluation of short- and long-term risks associated with potential remedial technologies and evaluation of residual risks remaining at the site after remediation (USEPA 1991a,c, Phillips 2001).

Two kinds of risk assessment for contaminated sites are used in practice: 1) based on soil quality standards (generic risk assessment or screening risk assessment), 2) based on site-specific conditions (site-specific risk assessment). The generic risk assessment is mainly used as the first tier in the risk assessment approach, when results may indicate that risk at the site could be unacceptable. Then detailed site-specific risk assessment, which requires site-specific data, is implemented (Swartjes 2011). Risk assessment focuses primarily on human health but ecological receptors are also taken into account in many cases (Carlon and Swartjes 2007, Swartjes 2011). Soil contamination may adversely affect human health through direct exposure to soil contaminants, such as incidental soil ingestion, dermal contact and inhalation of soil particles, or indirect exposure via, for example, inhalation of volatiles, consumption of crops or vegetables cultivated in the contaminated area (Payá Pérez and Rodríguez Eugenio 2018, Swartjes and Cornelis 2011).

8.2. Polish perspective

8.2.1. Legal background

In Poland there is no 'programme' dedicated specifically to contaminated sites. Land-surface (soil and ground) protection from contamination and its remediation is regulated by three legal acts:

- Act of 27 April 2001 on Environmental Protection Law (Journal of Laws 2017, item 519 as amended), hereinafter referred to as EPL,
- Act of 13 April 2007 on environmental damage prevention and remediation, hereinafter referred to as EDA (Journal of Laws 2007, No 75, item 493),
- Regulation of the Minister of the Environment on the method of conducting the assessment of land surface contamination (Journal of Laws 2016, item 1395), hereinafter referred to as RME.

Under EPL the land surface contamination that occurred before 30 April 2007 or was caused by activity that was completed before that date is referred to as 'historic land surface contamination'. It also includes environmental damage of land surface (land or soil) in the meaning of EDA, caused by emission or an event, from which more than 30 years have elapsed. Liability for historic soil surface contamination lies with the holder of the property. Under EDA the land surface contamination caused on or after 30 April 2007 is referred to as 'environmental damage' and is subject to a 'polluter pays' principle. This means that the liability for remediation is at the side of the entity which uses the environment and causes the environmental damage.

RME specifies the methods of the land surface contamination assessment, including harmful substances particularly important for land surface protection and their permissible levels in soil. The permissible levels are determined separately for different types of land use and soil properties. Pursuant to EPL land is considered to be contaminated when the permissible levels are exceeded.

The permissible level means the level below which none of the functions of land surface is significantly harmed, considering the influence of this substance on human health and the environment. Soil is considered as uncontaminated if the content of substances is of a natural origin. RME also specifies general requirements regarding the derivation of the permissible levels in soil of the substances not listed in RME. The permissible levels of such substances should be derived based on the analysis of the impact on human health and the environment, including human health risk characterisation. However, RME does not set down any reference methodologies or specific guidance for characterising this type of risk.

Persuant to the EPL provisions there is a necessity to remediate the historic land surface contamination. The remediation consists in the removal of contamination at least to the permissible levels of harmful substances in soil. However, also other measures aimed at the removal of significant risk to human health or the environment are allowed, taking into account the current and planned land use patterns. They include: diminishing the volume of contamination and reducing the possibility of contaminant spread, soil contamination monitoring, natural attenuation or enhanced natural attenuation of the land surface, restricting the access of people to the contaminated site or changing the land use pattern.

There is also a possibility to waive the remediation obligation or limit its scope if the analysis of risk shows that contamination does not pose any *significant risk to human health or the environment.* Therefore, the assessment of risk to human health or the environment is a crucial factor deciding whether the remediation is necessary or the exemption from it may be allowed.

8.2.2. The proposed risk-based approach to contaminated sites

In Poland HRA method was introduced in the 90's and applied later to support the contaminated site remediation process under international projects (Kuperberg et al 1996, Wcisło et al. 2002, 2005, 2012, 2016). The method was the adaptation of the USEPA site-specific HRA methodology (USEPA 1989, 1991a,b, 1996a,b, 2001, 2002, 2004). Based on this experience the risk-based approach was proposed in Poland for the process of contaminated land remediation in 2009 (Wcisło, 2009). However, the procedure has not been incorporated into the policy and legislation but has been applied in practice in Poland and Spain (Adamiec 2017, Kubicz 2014, Pawełczyk et al. 2018, Wcisło et al. 2016, Wcisło et al. 2019). Since then some updates have been introduced to the USEPA HRA methodology that were mainly associated with inhalation exposure assessment and bioavailability assessment (USEPA 2009, 2021). The last one was related to the progress in bioavailability research (Bradham et al. 2014, Kuppusamy et al. 2017, Li et al. 2019, Petruzzelli et al. 2020, USEPA 2021). Taking it into consideration the relevant updates have been introduced to the procedure proposed in 2009 to be applied in Poland. Since the procedure is human health risk-based, it can be applied for assessing the significant risk as required under EPL.

The proposed risk-based procedure is human health focused, two-tiered soil risk assessment (Figure 8.1):

Tier 1 – screening human health risk assessment,

Tier 2 – site-specific human health risk assessment.

Tier 1 follows a preliminary soil investigation (characterisation of site, identification of current and future land uses, collection and evaluation of geochemical data – total contaminant content). In this tier, simple conservative assumptions are applied in the initial assessment to identify contaminants which pose the greatest risk to human health and identify contaminated sub-areas, which require additional investigation. This allows carrying out more detailed investigation and site-specific risk assessment with particular focus on aspects that require the greatest concern. The screening risk assessment consists in the comparison of the total contaminant content detected in soil at a site against risk--based soil screening levels (RBSSLs) relevant to the considered land use pattern. If the contaminant concentrations are below RBSSLs, no further action or investigation will be required and the assessment will be regarded as completed.

Since the scientific basis and procedure employed for establishing the permissible levels of substances used in soil contamination assessment in Poland (RME 2016) are unknown, there is the necessity of developing the relevant RBSSLs. They should be developed on the basis of the human health safety criterion, using default parameter values for environmental and exposure conditions as it was proposed in the previous study by Wcisło (2012). The RBSSLs can be considered as general or conservative levels (see Figure 8.1). For assessment consistency the same methodology should be used for the RBSSL derivation and site-specific HRA.

Tier 2 – site-specific human health risk assessment – is required if the content of one or more contaminants exceeds RBSSLs. The site-specific HRA follows the more detailed site investigations. If contaminant content, which exceeds RBSSLs, is below natural levels (if relevant data are available, e.g. for metals), the site may not be considered to be contaminated despite the fact that RBSSLs are exceeded.

8.2.2.1. Site-specific human health risk assessment

A modified site-specific HRA methodology that could be used in the assessment of contaminated sites in Poland (Wcisło 2009) is presented in Figure 8.1.

The site-specific HRA process consists of two main phases: (1) baseline human health risk assessment (BHRA) and (2) development of site-specific risk--based remedial levels (RBRLs). BHRA consists of exposure assessment and toxicity assessment which applied together allow risk characterisation. BHRA

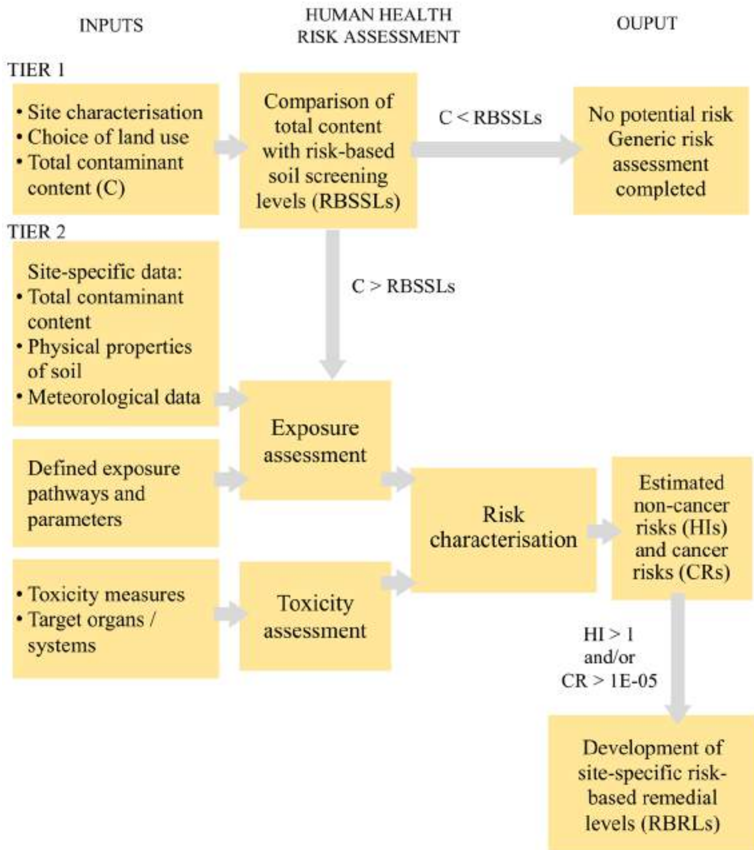

Fig. 8.1. The proposed risk-based approach to contaminated sites in Poland

is based on more detailed site investigation data including geochemical data, site-specific environmental conditions (soil properties, meteorological data) and site-specific exposure parameter values.

Exposure assessment

During the exposure assessment, site-specific exposure scenarios are developed which are subsequent to identification of current and/or intended future land use patterns for a given site and related human receptors. The proposed site-specific risk assessment methodology considers three land use patterns which may be most often applicable at contaminated sites, i.e. industrial, residential and recreational. Under each exposure scenario the relevant receptors are identified, i.e., adult workers under the industrial land use pattern, and children and adults under residential and recreational land uses. The considered soil exposure pathways include:

- incidental soil and dust ingestion,
- dermal contact,

- inhalation of fugitive soil particles, and
- outdoor inhalation of volatiles.

The soil exposure pathways considered in the exposure scenarios are the most typical for the majority of contaminated sites. For some sites, additional (different) exposure scenarios (e.g., agricultural), and different exposure pathways (e.g., ingestion of contaminated crops or indoor inhalation of volatiles) may be appropriate.

Results of the exposure assessment are pathway-specific contaminant intakes, under the developed exposure scenarios.

The exposure equations employed for the exposure pathways are presented in Table 8.1 – Equations (8.1) to (8.4). These equations were generally adapted from USEPA documents (USEPA 2001, 2002, 2004, 2021).

Table 8.2 presents exposure parameters to be used as defaults under the considered scenarios when the site-specific data are unavailable or incomplete.

Table 8.1. Exposure pathway-specific equations.
Adapted from USEPA (1996a, 2001, 2002, 2004, 2021; Wcisło 2009).

Exposure pathway	Exposure equation
Ingestion exposure	$CI = \frac{CS \times EF \times ED \times IR_O \times CF_1 \times RBA}{BW \times AT}$ (8.1)
Dermal exposure	$AD = \frac{CS \times EF \times ED \times SA \times AF \times ABS_d \times CF_1}{BW \times AT}$ (8.2)
Inhalation exposure (fugitive soil particles)	$PE_P = \frac{CS \times EF \times ED \times ET \times \frac{1}{PEF}}{AT}$ (8.3)
Inhalation exposure (volatiles)	$PE_V = \frac{CS \times EF \times ED \times ET \times \frac{1}{VF}}{AT}$ (8.4)

CI – contaminant ingestion intake (mg/kg/day)
CS – concentration in soil (mg/kg)
EF – exposure frequency (days/year)
ED – exposure duration (years)
IR_o – ingestion rate for soil (mg/day)
CF_1 – conversion factor (10^{-6} kg/mg)
BW – body weight (kg)
AT – averaging time (days)
RBA – relative bioavailability factor (unitless), (see subsection: Bioavailability assessment)
AD – absorbed dose (mg/kg/day)
SA – skin surface area – soil contact (cm^2)
AF – soil-to-skin adherence factor ($mg/cm^2/day$)
ABS_d – chemical-specific dermal absorption fraction (unitless)
PE_P – pulmonary exposure (fugitive soil particles), (mg/m^3)
PEF – particulate emission factor (m^3/kg)
PE_V – pulmonary exposure (volatiles), (mg/m^3)
VF – volatilisation factor (m^3/kg)
ET – exposure time (h/h)

According to USEPA recommendations, in the case of carcinogens with mutagenic mode of action, to calculate residential and recreational cancer risks special corrected exposure indices should be applied for early lifetime for all exposure routes (USEPA 2005, 2021). They refer to four human life periods (child 0–2 years, child 2–6 years, adult 6–16 years, adult 16–30 years).

Toxicity assessment

Toxicity assessment is based on the available scientific data on potential adverse health effects of contaminants in humans, which should be usually compiled in the form of a toxicological profile for each contaminant. This step also includes identification of important measures of toxicity and collection of the following chemical-specific toxicological data: oral reference doses (RfDs), inhalation reference concentrations (RfCs), oral cancer slope factors (CSFs), inhalation unit risks (IURs), gastrointestinal absorption factors (ABS_{GI}) and primary target organs or critical effects for non-carcinogens for oral/dermal and inhalation exposures.

Table 8.2. Exposure parameters to be used as defaults under the residential, industrial and recreational exposure scenarios.
Adapted from USEPA (1991a, 2002, 2004, 2021) and Wcisło (2009).

Exposure parameter	Residential scenario		Industrial scenario	Recreational scenario	
	Child	Adult	Adult	Child	Adult
EF – exposure frequency (days/year)	350	350	240[a]	60[c]	60[c]
ED – exposure duration (years)	6	24	40[b]	6	24
BW – body weight (kg)	15	70	70	15	70
IR_o – ingestion rate for soil (mg/day)	200	100	100	200	100
SA – skin surface area – soil contact (cm^2)	2 800	5 700	3 300	2 800	5 700
AF – soil-to-skin adherence factor ($mg/cm^2/day$)	0.2	0.07	0.2	0.2	0.07
ET – exposure time (h/h)	1[d]	1[d]	0.33[e]	0.083[f]	0.083[f]
AT – averaging time (non-carcinogens) (days); AT = ED × 365 days	2 190	8 760	14 600	2 190	8 760
AT – averaging time (carcinogens) (days); AT = 70 years × 365 days	25 550	25 550	25 550	25 550	25 550

[a] 240 working days per year (average number of working days per year in Poland taking into consideration 14-days' holidays) are assumed
[b] 40 years' work period (upper-bound value) is assumed as a professional judgment
[c] 3 days per week for 20 weeks per year are assumed as a professional judgment
[d] The whole day, i.e., 24 h/24 h
[e] The work day, i.e., 8 h/24 h
[f] 2 hours per day, i.e., 2 h/24 h

The USEPA recommends to acquire toxicity measures from the following sources of toxicological information and lists them according to the hierarchy of their importance:

- Integrated Risk Information System (IRIS),
- USEPA's Provisional Peer Reviewed Toxicity Values (PPRTVs),
- USEPA's Office of Pesticide Programmes (OPP) Human Health Benchmarks for Pesticides (HHBPs),
- Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk levels (MRLs),
- California Environmental Protection Agency Office of Environmental Health Hazard Assessment (OEHHA),
- Screening toxicity values in an appendix to certain PPRTV assessments,
- EPA Superfund Programme's Health Effects Assessment Summary Tables (HEAST).

Following the USEPA approach to the toxicity sources importance, the same approach is recommended for toxicity assessment in the proposed site-specific risk assessment procedure.

Risk characterisation

Risk is characterised separately for carcinogenic and non-carcinogenic effects. Chemicals which produce both non-carcinogenic and carcinogenic effects are evaluated with regard to both types of effects.

Non-cancer risks are expressed by the hazard quotients (HQs). To calculate this type of risk, the equations depending on the exposure pathway are applied, as it is shown in Table 8.3 – Equations (8.5) to (8.8).

The HQs calculated for each exposure pathway are summed up (assuming additivity of effects), and expressed as the hazard index (HI) for individual substances (USEPA 1989). To assess the overall non-cancer risk posed by multiple chemicals, the single HIs are summed and expressed as the total HI. The total HI higher than 1 indicates that there might be a potential for adverse health effects (USEPA 1989). Then the HQs for the chemicals which affect the same primary target organ or system are summed for each receptor and expressed as the target organ/system-specific HIs (USEPA 1989). Because of the potential for different toxic effects through oral/dermal and inhalation exposures, these exposures are evaluated separately (USEPA 2002). When the HIs for the given target organ/system exceed the value of 1, some toxic effects may be expected on this target organ/system. The approach for non-cancer risk assessment is presented in Figure 8.2.

Cancer risks (CRs) are estimated as the incremental probability of an individual to develop cancer over a lifetime as a result of exposure to the potential carcinogen (USEPA 1989). To calculate this type of risk, the equations

Table 8.3. Non-cancer risks (hazard quotients – HQs) equations for different exposure pathways. Adapted from USEPA (2001, 2002, 2004, 2021).

Exposure pathway	Exposure equation
Ingestion exposure	$HQ_O = \frac{CI}{RfD_o}$ (8.5)
Dermal exposure	$HQ_d = \frac{AD}{RfD_d}$ (8.6) *were* $RfD_d = RfD_o \times ABS_{GI}$ (8.6a)
Inhalation exposure (fugitive soil particles)	$HQ_{inh\_P} = \frac{PE_P}{RfC}$ (8.7)
Inhalation exposure (volatiles)	$HQ_{inh\_V} = \frac{PE_V}{RfC}$ (8.8)

HQ_o – oral hazard quotient (unitless)
CI – contaminant ingestion intake (mg/kg/day)
RfD_o – oral reference dose (mg/kg/day)
HQ_d – dermal hazard quotient (unitless)
AD – absorbed dose (mg/kg/day)
RfD_d – dermally adjusted reference dose (mg/kg/day)
ABS_{GI} – chemical-specific gastrointestinal absorption factor (unitless), (USEPA 2004)
HQ_{inh_P} – inhalation hazard quotient (fugitive soil particles), (unitless)
PE_P – pulmonary exposure (fugitive soil particles), (mg/m^3)
HQ_{inh_V} – inhalation hazard quotient (volatiles), (unitless)
PE_V – pulmonary exposure (volatiles), (mg/m^3)
RfC – inhalation reference concentration (mg/m^3)

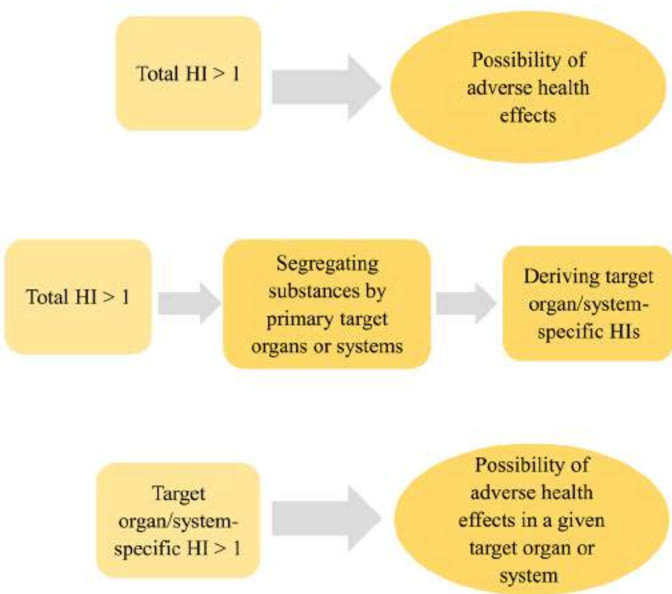

FIg. 8.2. The approach for non-cancer risk assessment

depending on the exposure pathway are applied, as it is shown in Table 8.4 – Equations (8.9) to (8.12).

The oral, dermal and inhalation CRs are summed to get the value of the cancer risk for each carcinogen. When a receptor is exposed to multiple carcinogens the total cancer risks are estimated by summing the single CRs.

Under the scenarios referring to both receptors – a child and an adult (i.e., residential and recreational), cancer risks are calculated for the aggregate resident/recreational user, that is, an individual exposed in his/her childhood (6 years) and adult life (24 years), (PEA 2015, USEPA 1996a, 2002, 2021).

The CRs are compared with the acceptable cancer risk values. The value of 1E-05 (one – in hundred thousand) is proposed to be considered as *the acceptable cancer risk for the individual carcinogen*, as it is required in RME (2016). In contrast, the value of 1E-04 is proposed to be established *as the maximum acceptable total cancer risk*, which is accepted also by USEPA at the site (USEPA 1991a,b).

In order to communicate properly the final risk estimates to decision-makers, it is important to address all uncertainties associated with each step of risk assessment. It is a critical issue because the uncertainties may lead to either overestimation or underestimation of the final risk outputs. The information on the uncertainties may help make more informed decisions about contaminated sites and risk management actions (USEPA 1989, 2000, 2001).

Table 8.4. Cancer risk equations for different exposure pathways.
Adapted from USEPA (2001, 2002, 2004, 2021).

Exposure pathway	Exposure equation
Ingestion exposure	$CR_O = CI \times CSF_O$ (8.9)
Dermal exposure	$CR_d = AD \times CSF_d$ (8.10) where $CSF_d = \frac{CSF_o}{ABS_{GI}}$ (8.10a)
Inhalation exposure (fugitive soil particles)	$CR_{inh\_P} = PE_P \times IUR$ (8.11)
Inhalation exposure (volatiles)	$CR_{inh\_V} = PE_V \times IUR$ (8.12)

CR_o – oral cancer risk (unitless)
CI – contaminant ingestion intake (mg/kg/day)
CSF_o – oral cancer slope factor $(mg/kg/day)^{-1}$
CR_d – dermal cancer risk (unitless)
AD – absorbed dose (mg/kg/day)
CSF_d – dermally adjusted carcinogenic slope factor $(mg/kg/day)^{-1}$
ABS_{GI} – chemical-specific gastrointestinal absorption factor (unitless)
CR_{inh_P} – inhalation cancer risk (fugitive soil particles), (unitless)
PE_P – pulmonary exposure (fugitive soil particles), (mg/m^3)
CR_{inh_V} – inhalation cancer risk (volatiles), (unitless)
PE_V – pulmonary exposure (volatiles), (mg/m^3)
IUR – inhalation unit risk $(mg/m^3)^{-1}$.

Bioavailability assessment

When the human health risk from soil contaminated with metal and metalloids is assessed, bioavailability consideration should be taken into account. It may be relevant especially for arsenic and when the main exposure pathway is ingestion of soils by humans (ITRC 2017, Ng et al. 2010, USEPA 2007). USEPA has developed specific guidance on using relative bioavailability data in the risk assessment of contaminated sites. The guidance advises when a bioavailability assessment may be appropriate in the risk-based assessment process. It is recommended to use first the default values for bioavailability (USEPA 2007). In calculating the arsenic ingestion intakes the default relative bioavailability factor (RBA) of 0.6 is recommended by USEPA (2021). The decision whether to conduct the site-specific bioavailability assessment is usually taken based on a cost-benefit analysis. Following the USEPA findings, it is recommended to employ the bioavailability assessment approach to risk assessment process in Poland, when justified.

8.2.2.2. Development of RBRLs and RBSSLs

The proposed human health risk assessment procedure for Poland assumes the necessity of developing RBSSLs on the basis of the human health safety criterion to be used as preliminary soil assessment values (Wcisło 2009, 2012). RBSSLs should provide a general and conservative level of protection to humans under the defined exposure scenarios. Therefore, they should not be used as remedial levels. The remedial levels are established based on site-specific conditions using human health risk assessment methods, i.e., site-specific risk-based remedial levels (RBRLs).

There are two methods for deriving RBRLs:

Method 1 – using risk estimates obtained in the site-specific HRA (USEPA 2021),

Method 2 – employing the equations which are used to derive RBSSLs (USEPA 2021).

Method 1

Using this method the RBRLs are calculated for the individual contaminants separately for non-cancer and cancer effects, oral/dermal and inhalation exposures under all considered exposure scenarios, using Equation (8.13), (USEPA 2021):

$$RBRL = C \times \frac{TR}{Calculated\ Risk} \tag{8.13}$$

C – chemical content in soil (mg/kg)

RBRL – risk-based remedial level (oral/dermal or inhalation)

TR – target risk (non-cancer target risk – NTR – HQ/HI or cancer target risk – CTR).

The RBRLs correspond to the NTR (HQ) of 1 for non-carcinogens and to the CTR of 1E-05 for carcinogens. If more than one considered non-carcinogen affects the same primary target organ or system, additive effects could be taken into account in the RBRL development by applying relevant apportionment. The adjustment could be made, for example, by dividing the RBRL calculated for the individual non-carcinogen by the number of chemicals with the same target organs/effects (CEHT 2005, USEPA 2002).

If a given non-carcinogen adversely affects the same target organ or system via both oral/dermal and inhalation pathways, the total risk-based remedial level ($RBRL_N$) is derived by the mathematical combination of the equations used to calculate oral/dermal and inhalation RBRLs ($RBRL_{N\text{-}o/d}$, $RBRL_{N\text{-}inh}$) for a given exposure scenario, receptor and health endpoint, on the assumption that HI for the non-carcinogen is lower than the value of 1. The total $RBRL_N$ equation is a reciprocal of the sum of the reciprocals of pathway-specific RBRLs (Equation 8.14), (USEPA 2021).

$$RBRL_N = \frac{1}{\frac{1}{RBRL_{N-o/d}} + \frac{1}{RBRL_{N-inh}}} \tag{8.14}$$

The total risk-based remedial level for a given carcinogen ($RBRL_C$) is calculated similarly, on the assumption that CR for this carcinogen is lower than the value of 1E-05. The total $RBRL_C$ equation is the reciprocal of the sum of the reciprocals of pathway-specific RBRLs ($RBRL_{C\text{-}o/d}$, $RBRL_{C\text{-}inh}$), (Equation 8.15), (USEPA 2021).

$$RBRL_C \frac{1}{\frac{1}{RBRL_{C-o/d}} + \frac{1}{RBRL_{C-inh}}} \tag{8.15}$$

Afterwards, all types of RBRLs are compared, and the lowest of them is pointed out as the appropriate RBRL for a given contaminant. It is related to the given exposure scenario and receptor.

Method 2

Using this method the RBRLs are derived from standardised sets of equations and site-specific exposure and environmental data. This method is totally consistent with the principles of site-specific human health risk assessment, presented above (USEPA 2001, 2002, 2004, 2021). When the default values of chemical--specific toxicity and exposure parameters are used, the same set of equations could be applied to derive the generic RBSSLs in Poland (see 8.2.2 section, Tier 1 description).

The RBSSLs are estimated for the most sensitive human receptors under the defined land use scenario. Adult outdoor workers are considered as such receptors under the industrial scenario. Under the residential and recreational scenarios, the choice of sensitive receptors depends on the type of contaminants – carcinogenic or non-carcinogenic. For non-carcinogenic effects, RBSSLs are derived only from the "childhood exposure". This is a conservative approach and might be appropriate for screening analysis. For carcinogenic effects, aggregate residents and recreational users are considered as sensitive receptors, respectively. The RBSSLs correspond to the NTR of 1 or CTR of 1E-05.

In the development of RBSSLs the following exposure pathways are considered: incidental soil and dust ingestion, dermal contact with soil, inhalation of fugitive soil particles and inhalation of volatiles. The exposure pathway-specific RBRLs are calculated separately for oral/dermal exposure and inhalation exposure, and separately for carcinogenic and non-carcinogenic effects. The total non-cancer RBSSLs and the total cancer RBSSLs are derived in a similar way as it is in the case of method 1. For the contaminants that produce both non-carcinogenic and carcinogenic effects the total non-cancer and cancer RBRLs are compared and the lower of them is selected as the appropriate RBSSL under a given land use scenario. They are used in Tier 1 (screening human health risk assessment) of the risk-based procedure (see Figure 8.1).

8.2.3. Significant health risk assessment

Pursuant to EPL, assessment of significant risk is required in remediation plans and remediation project plans. If site contamination does not pose any significant risk to human health or the environment, the remediation obligation might be waived. However, the term 'significant risk' is not defined in the relevant legislation and no reference methods for its assessment have been recommended. Before the relevant legislation is implemented, the site-specific human health risk assessment method might be proposed to be applied in Polish conditions for this purpose. *The total HI higher than the value of 1 may be considered as the significant non-cancer risk and the cancer risk value of 1E-04 – as the maximum acceptable total cancer risk to make remediation decision at the contaminated site.*

To perform screening assessment of the human health risk from multiple contaminants at the site the USEPA methodology called the '*sum of the ratios*' approach may be applied (USEPA 2021). For non-cancer risk estimates, the site-specific non-carcinogen content (C) (maximum or 95th percent of the upper confidence limit on the mean (UCL)) is divided by the relevant non-cancer RBSSL. All ratios are added and the sum is multiplied by NTR (HI) equal to 1 to estimate the total non-cancer risk (total HI), (Equation 8.16).

$$Total\ HI = NTR \times \sum_{j=1}^{k} \frac{C_j}{RBSSL_{Nj}} \tag{8.16}$$

The total HI of 1 or lower is generally considered 'safe'. When the total HI is higher than 1, further evaluation is suggested. For cancer risk estimates, the site-specific carcinogen content (C) (maximum or 95th percent of the upper confidence limit on the mean (UCL)) is divided by the relevant cancer RBSSL. All ratios are multiplied by CTR (e.g., 1E-06 or 1E-05) to estimate the total cancer risk (total CR), (Equation 8.17).

$$Total\ CR = CTR \times \sum_{j=1}^{m} \frac{C_j}{RBSSL_{Cj}} \tag{8.17}$$

The total CR higher than 1E-04 suggests further evaluation.

8.3. Conclusions

Contaminated sites are a serious problem and might threaten human health and the environment. The assessment of the possible health impact of contaminated sites is, in many cases, a big challenge, especially where the complex contamination and long-lasting human exposures occur. In this context, a risk assessment is an important tool that may support decision-making process associated with soil remediation.

Though risk assessments are widely applied around the world, in Poland no guidance has been issued in this field. On the other hand, according to RME (2016), the permissible levels of the substances which are not listed in this regulation should be derived based on the analysis of the impact on human health and the environment, including human health risk characterisation. Moreover, pursuant to EPL there is an obligation to incorporate significant health risk assessment to remediation plans but no reference method has been set down. The proposed human health risk-based approach can fill a gap in this legislation. The method is a modification of the risk assessment procedure proposed to be applied in Poland in 2009 (Wcisło 2009). The procedure is a two-tiered process, including: Tier 1 – screening human health risk assessment and Tier 2 – site-specific human health risk assessment.

The screening risk assessment is based on the comparison of total contaminant content detected in soil at a site against risk-based soil screening levels (RBSSLs) relevant to the considered land use pattern. The site-specific human health risk assessment is based on estimating the level of risk that occurs in a given site or may occur there in the future.

The proposed human health risk-based approach may be applied within the entire remediation process. It can assist in the identification and preliminary selection of remedial options and a detailed selection of the appropriate remediation type or land use option. The risk-based assessment of the contaminated site can effectively support the decision-making process associated with soil remediation, as required under EPL.

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Chapter 9

Application of air pollutant emission and air quality forecasts for better air quality management and improvement of living conditions of the inhabitants at a local level

Summary
This chapter presents the possibility of using the already launched system of air quality and health risk forecasts for the Silesian Voivodship to manage air quality at the local level. By combining the model of meteorological forecasts with the pollutant emission forecasting model, and then with the pollutant concentration forecasting model, spatial distributions of projected meteorological parameters, pollutant emission forecasts and forecasts of pollutant concentrations are created for each of the 6700 2 km × 2 km squares covering the area of the Silesian Voivodship. The diversified values of the forecast emission parameters and pollutant concentrations enable the identification of the areas in the commune where the largest emission sources are located, as well as the areas with the worst air quality. This knowledge can be used by local authorities to prioritise short- and long-term activities aimed at the improvement of air quality and quality of life of the inhabitants.

Keywords: air pollution emission, air quality management

9.1. Introduction

Air quality improvement has been a priority in national, regional and local programmes for over thirty years. Actions taken at the national level to reduce emissions from industrial sources in accordance with the commitments of the UN Convention on Long-Range Air Pollution (CLRAP) and EU directives and their implementation into the national law resulted in a significant reduction of emissions from industrial sources, and thus a significant reduction in the share of industrial emissions in determining pollutant concentrations at a national and regional level. As a result of the reduction of industrial emissions in the years 1990–2000, the air quality in Poland improved significantly, but there are still areas where air quality standards are exceeded due to the emissions from municipal and linear sources (transport).

In the subsequent air quality assessments made by the European Environment Agency (EEA, 2020), in 50 cities with the most polluted air, there are as many as 35 cities from Poland, in that 15 from the Silesian Voivodship. In this situation the authorities of the Silesian Voivodship decided to launch their own project together with partners from the voivodship, under which an IT system for air quality forecasting for a period of 48 hours would be developed together with a related health risk forecasting system for residents of the Silesian Voivodship.

The aim of the system is to alert the inhabitants of the Silesian Voivodship to the occurrence of smog in the next 48 hours and indicate the level of health risk for an individual inhabitant with specific medical disorders.

The system was launched on the internet platform: www.slaskiesmogstop.pl and as a mobile application in the Google AppStore and iOS store in January 2021. The system is dedicated primarily to inhabitants of the Silesian Voivodship, so that they can plan their outdoor activities depending on the air quality, taking into account their health problems.

The system is also designed to support local authorities in informing about the areas of increased emissions in the commune in the period of 48 hours and areas of above-standard concentrations, which would allow for undertaking short-term actions, referred to in the Air Protection Action Plan (POP, 2020), in a given area.

The analysis of the annual results of the forecast emissions and pollutant concentrations in the commune will allow designation of priority areas for investment in activities aimed at reducing local emissions, and thus improving air quality at the local level and the quality of life of the inhabitants in a several-years' perspective, which covers the period of financing / co-financing activities for communes from various sources.

9.2. Air quality forecasting system

Air quality forecasting system is part of the InfoSMOG-MED system and provides forecast numerical values of the hourly concentrations of PM10, PM2.5, SO_2, NO_2, CO, and the air quality index. A diagram of generating air quality forecast is shown in Fig. 9.1.

The system consists of the following elements:

- Meteorological forecast model WRF,
- Emission model,

- Calpuff pollutant dispersion model,
- Air pollutant concentration forecasting model.

The system also includes:
- emission database containing:
  - characteristics of point emission sources (physico-chemical parameters of the emitters),
  - characteristics of municipal sources/buildings (surface of flats heated individually, thermal modernisation degree, type of the applied heating source, type of fuel used for heat production, coefficients of daily emission variability),
  - characteristics of linear sources (road classification, traffic intensity, vehicle structure, coefficients of daily, weekly, seasonal and annual variability of traffic intensity and vehicle structure),
- database of meteorological parameters from the airport meteorological stations METAR,
- database of air quality measurements from the State Air Monitoring Stations of the Chief Inspectorate of Environmental Protection (GIOŚ).

The air quality forecasting system is based on its own meteorological forecast carried out using the WRF model in a 2 km grid. Meteorological forecast is

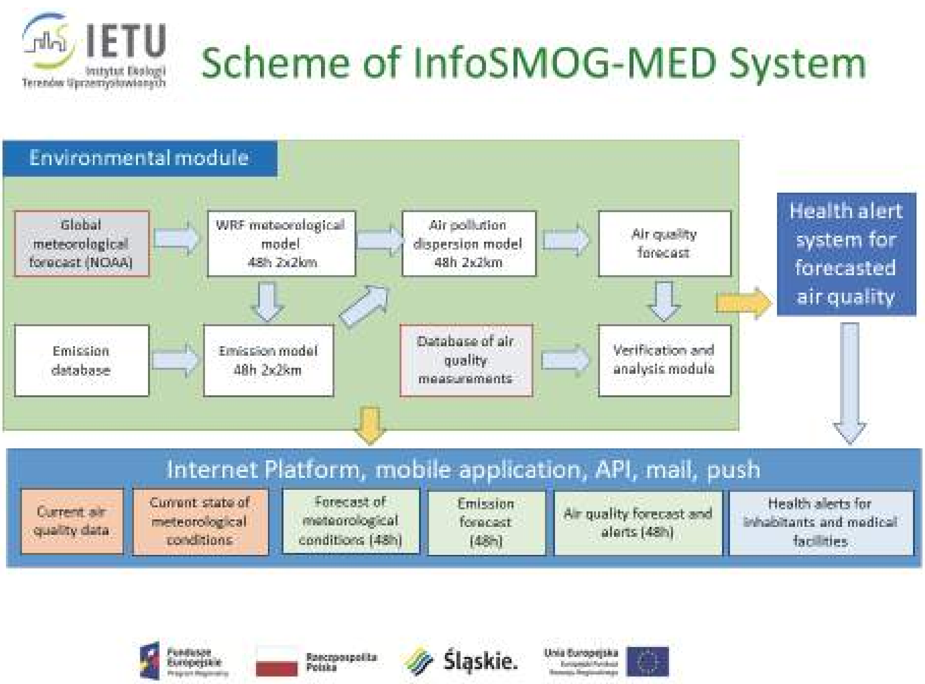


Fig. 9.1. Diagram of air quality forecasting under the InfoSMOG-MED System

based on Global NOAA forecast and is specified in the subsequent domains: domestic and Silesian Voivodship.

Forecasts in the WRF model are corrected depending on the messages obtained from METAR, coming from airports located in Poland and the neighbouring countries. The forecasts of temperature, pressure, wind direction and velocity are generated twice a day at 6 a.m. and 6 p.m. for the next 48 hours. Forecast values of these meteorological parameters are presented on the map of the Silesian Voivodship in a 2 km × 2 km grid and pointwise for the indicated location in the form of a graph and table. Fig. 9.2 shows the range of the domains for which the calculation of meteorological parameters is performed and the location of the METAR stations. Domain 2 was reduced to the borderlines of the Silesian Voivodship.

The emission model takes into account air pollutants from point sources, municipal sources and road transport. Point emission includes emission from high industrial emitters. The emission data comes from the database of the National Centre for Emissions Management (KOBIZE) from 2018. The emission forecast for pollutants from municipal sources is determined in the model based on the projected air temperatures and technical data of buildings concerning thermal

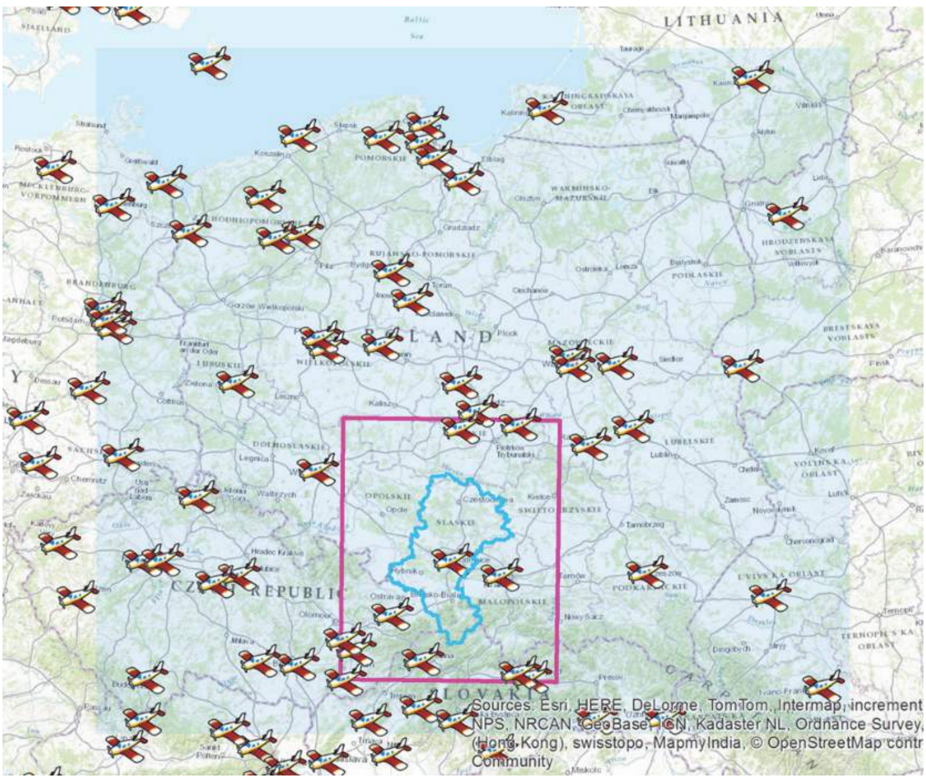


Fig. 9.2. WRF model domains and METAR stations

insulation, structure of heat sources used to heat demands in residential buildings and structure of fuels used for heat production.

The emission volume is determined for each hour and the calculated emission of pollutants is averaged for the area of residential buildings in a given square of the calculation grid.

In the power supply system of the emission model, the linear emission from road transport is based on the General Road Traffic Measurement of 2015 (GDDKiA, 2015). The traffic intensity on road sections not covered by this measurement (poviat and municipal roads as well as voivodship and national roads in urban poviats) was adopted according to the data obtained from communes and poviats of the Silesian Voivodship. The emission model takes into account the periodic variability of the traffic intensity and vehicle structure (daily, weekly and seasonal variability).

The air quality forecasting system re-analyses the following forecast values:

- meteorological parameters and values measured at METAR stations in order to correct the forecast against the actual data,
- air quality parameters and values measured at the State Air Quality Monitoring Stations at the Chief Inspectorate of Environmental Protection (GIOŚ) in order to assess the accuracy of the generated forecasts and their possible correction. Air quality forecasts in the InfoSMOG-MED system are the basis for generating health alerts for the inhabitants of the Silesian Voivodship.

Air pollutant concentration forecasts for PM10, PM2.5, SO_2, NOx and the air pollution index are presented on the internet platform www.slaskiesmogstop on a map in a 2 km × 2 km grid and pointwise for a selected location in the form of a graph or table. These data are updated twice a day at 6.00 a.m. and 6.00 p.m. for the next 48 hours. The system which is available on the internet platform and in applications for Android and iOS allows the user to log in and select the type and form of receiving messages on the expected exceedances of air pollutant concentrations as well as generate alerts on health hazards.

The innovation of this system is the generation of personalised health messages for users registered with a specific profile of pulmonary, diabetic, cardiovascular and paediatric diseases, separate for women and men in a specific age range. The user who is logged in can receive individual messages for his location in the form of “push” or e-mail.

Air quality forecast combined with the information on the level of health risk for inhabitants of the Silesian Voivodship was the main goal of creating the InfoSMOG-MED system initiated by the Marshal’s Office of the Silesian Voivodship, but the launch of this system also gives the possibility of using the information available in this system by local governments of the Silesian Voivodship to manage air quality at the local level and to improve the quality of life of the inhabitants in the communes.

9.3. The use of emission forecasts and air quality forecasts for air quality management

The IETU air quality forecasting system is innovative compared to the fuzzy forecast of the meteorological situation and exploratory data analysis on pollutant concentrations used so far, because it is a system for forecasting emissions from low level emission sources in real conditions. The innovation consists mainly in the use of an emission model for low level emission sources (buildings) in the system, which predicts the emission of pollutants for a given hour in relation to the outside air temperature, taking into account the heat demand related to this temperature in the building, its thermal insulation, type and consumption of fuel for heat production as well as the type and efficiency of the combustion source, which was not ensured by the previously applied air quality forecasting system of the Institute of Meteorology and Water Management presented by the Voivodship Inspectorate of Environmental Protection in Katowice until 2018, and now by the Chief Inspectorate of Environmental Protection (GIOŚ) and AIRLY.

The forecast of the emission volume calculated in the model is related to a specific area of housing development, and not, as in other forecast systems, to the average emission per square kilometre of the city/commune area, which means that emissions from municipal sources also occur in areas covered by residential buildings based on a heat supply network. The use of the IETU air quality forecasting system in the InfoSMOG-MED project ensures greater precision in spatial identification of areas with increased accumulation of low level emission, directly affecting the areas where it occurred, and thus greater precision in predicting pollutant concentrations and assessing the exposure of the population to their negative effects, in particular in the context of the planned health modelling.

The forecast of pollutant emissions from sources available in the InfoSMOG – MED system allows local authorities to take preventive measures in the areas which generate pollutant emissions in the commune, and in the longer perspective to prioritise actions in the commune, in which high emissions from low level emission sources are most often generated and air quality standards are exceeded.

The following examples show emission forecasts and air quality forecasts in two communes with poviat rights, where an attempt was made to indicate how local authorities, by using information from the InfoSMOG-MED system, can make ad hoc decisions to reduce local emissions and smog situations in their area. For this purpose, Chorzów – the commune with the poviat rights located in the central part of the Metropolis GZM which remains under the influence of the pollutant emissions from the surrounding cities on the level of air pollutant concentrations in the commune was selected together with the commune of Rybnik, where in the city centre one of the highest air pollutant concentration levels in Poland are recorded, and which is under the impact of the concentration level determined by the emissions generated in the neighbouring areas.

Fig. 9.3 shows the projected PM10 emissions in the Chorzów commune during the period of high concentrations of air pollutants, i.e. in January 2021 – today, tomorrow and the day after tomorrow as well as in the areas of neighbouring communes, while Fig. 9.4 shows the forecast for PM10 concentrations for the next 48 hours.

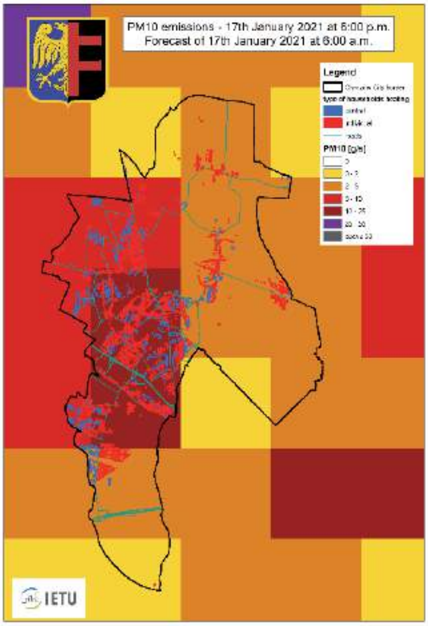
The analysis of these two sets of information shows that high emissions of PM10 in the Chorzów commune in the central part of the city and at its western neighbours significantly exceed the normative concentrations of PM10 pollution throughout the city, which should result in warning the inhabitants by municipal services on the potential health hazard, as well as in an appeal to the inhabitants of the districts with the highest emission to comply with the anti-smog resolution of the Silesian Assembly. In particular, municipal services should intervene in the Centre district, where the projected PM10 emission on the following day will remain high, exceeding the normative level.

These actions are necessary due to the predicted increase in PM10 emissions on the next day (the day after tomorrow) in a larger area of the city (Chorzów II and Chorzów Batory districts) in the morning.

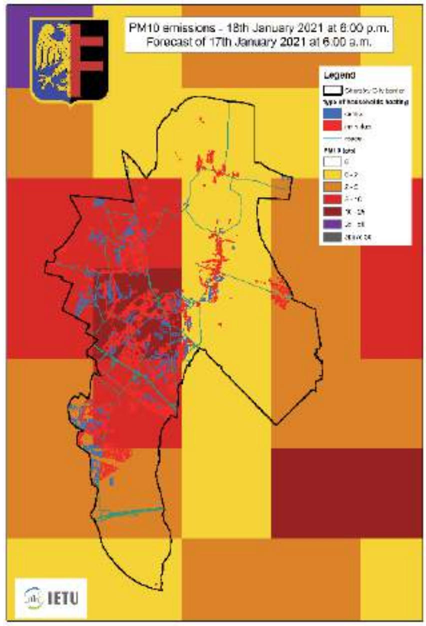
The change of meteorological conditions will probably cause a decrease in PM10 concentrations in the city in the afternoon and the day after tomorrow to a level defined as moderate in districts Centre and Chorzów II, remaining acceptable in other parts of the city.

The second example mentioned above is the commune of Rybnik, for which a set of forecast data for PM10 emissions and the resulting concentrations of this pollutant for the next two days, i.e. today, tomorrow and the day after tomorrow in January 2021, was prepared in a similar way as for Chorzów. Distributions of the projected PM10 emissions and expected concentrations of this pollutant are presented in Figs. 9.5 and 9.6, respectively.

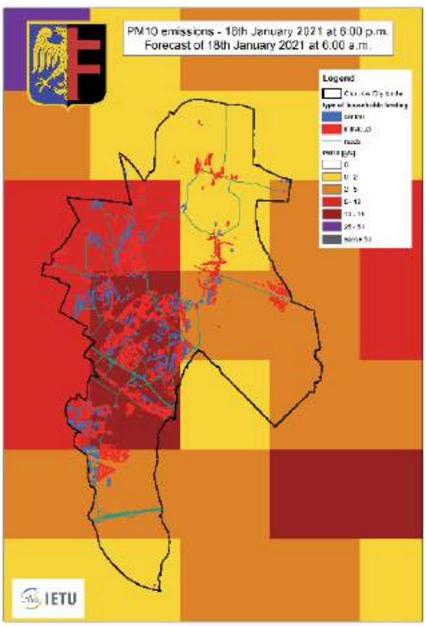
The analysis of the projected emissions and concentrations of PM10 presented in Figs. 9.5 and 9.6 shows that today, despite high emissions in the centre of Rybnik, PM10 concentrations remain at a moderate level, which suggests the presence of favourable conditions for airing the area, while the next day, despite the forecast of lower emission of this pollutant in the centre of Rybnik, an increase in the level of PM10 concentrations similar to the level which requires informing the public about threats posed by the air quality is expected, therefore, already today local authorities should take appropriate actions to prevent the occurrence of smog, including warning the inhabitants against the possibility of a smog situation, launching services responsible for controlling emissions from municipal sources and implementing other short-term measures referred to in the current Air Quality Action Plan, regardless of the fact that the next day (the day after tomorrow), despite the increase



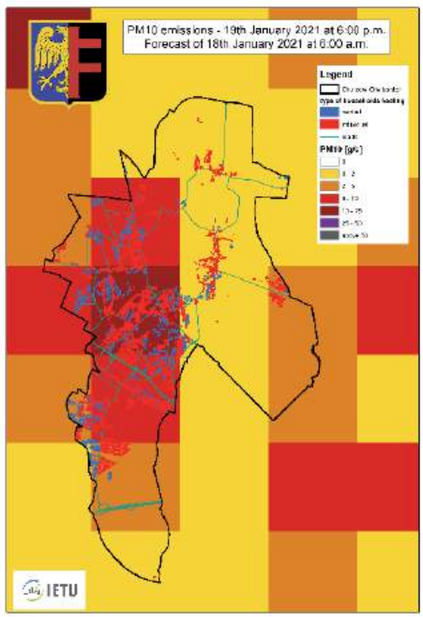
Today



Tomorrow I

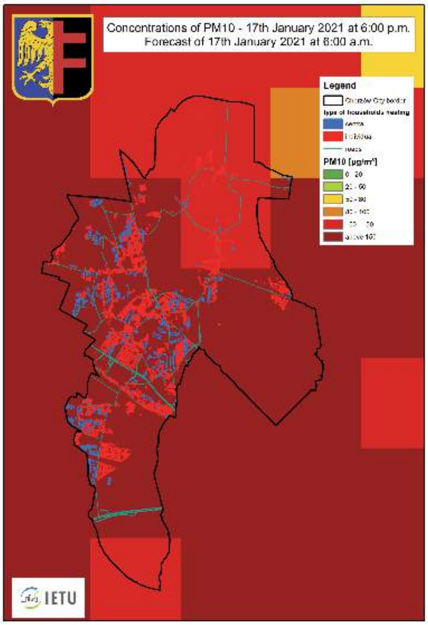


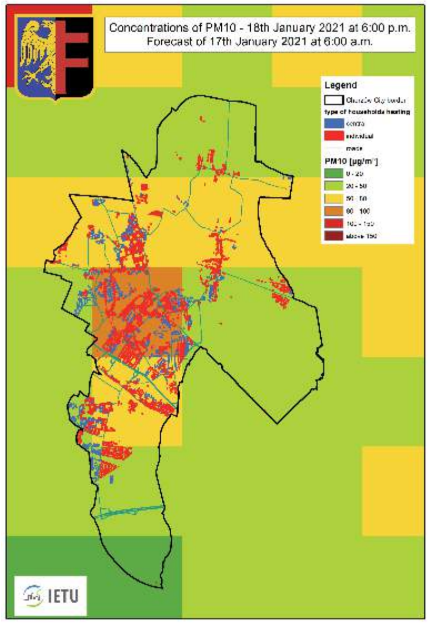
Tomorrow II



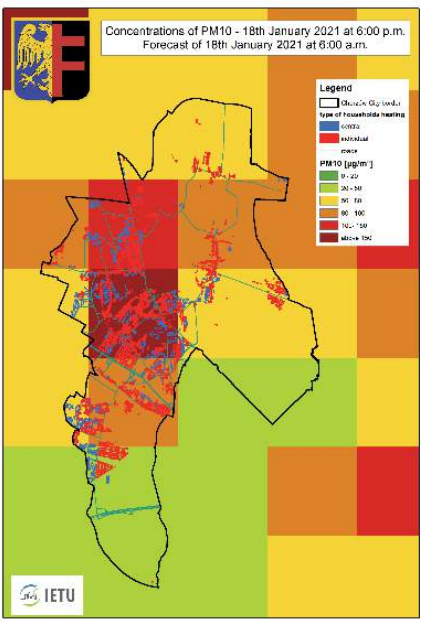
Day after tomorrow

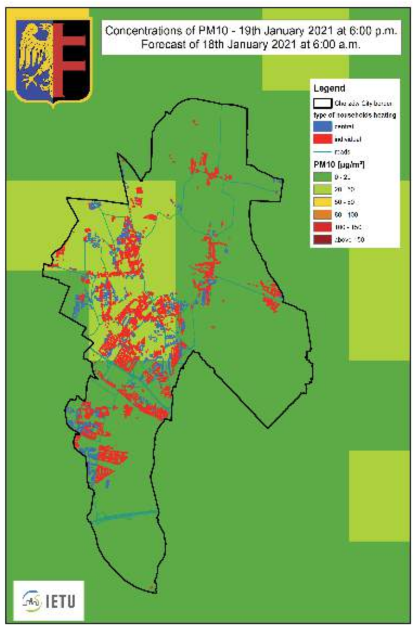
Fig. 9.3. PM10 emission forecast for the area of Chorzów in the period of the next 48 hours





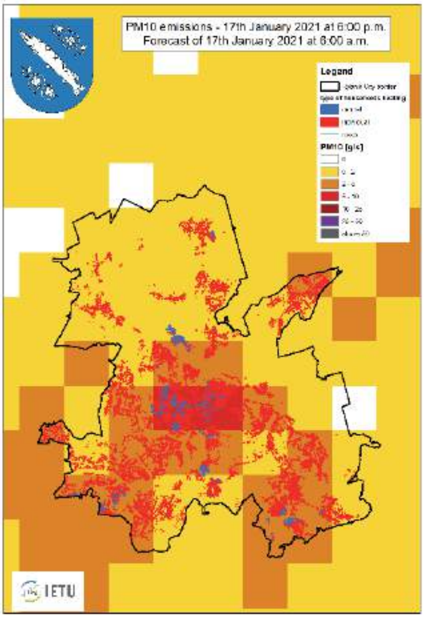
Today	Tomorrow I



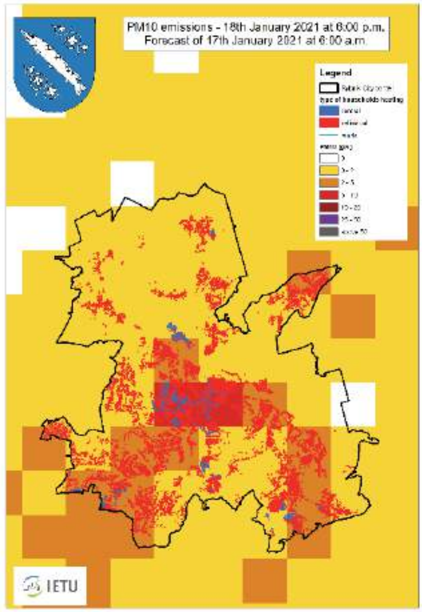


Tomorrow II	Day after tomorrow

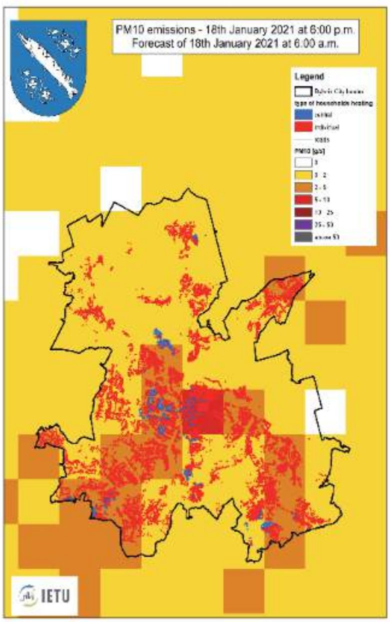
Fig. 9.4. PM10 concentration forecast for the area of Chorzów in the period of the next 48 hours



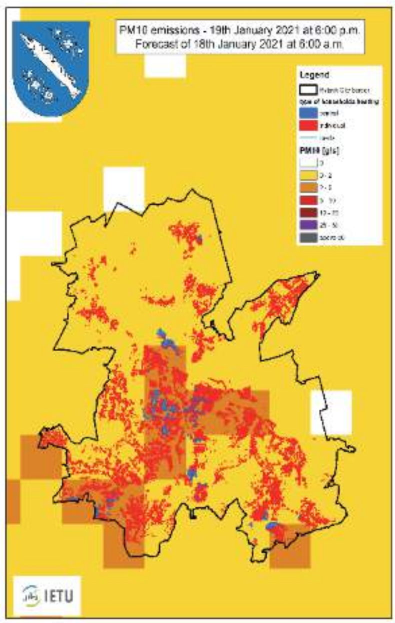
Today



Tomorrow I



Tomorrow II



Day after tomorrow

Fig. 9.5. PM10 emission forecast for the area of Rybnik in the period of the next 48 hours

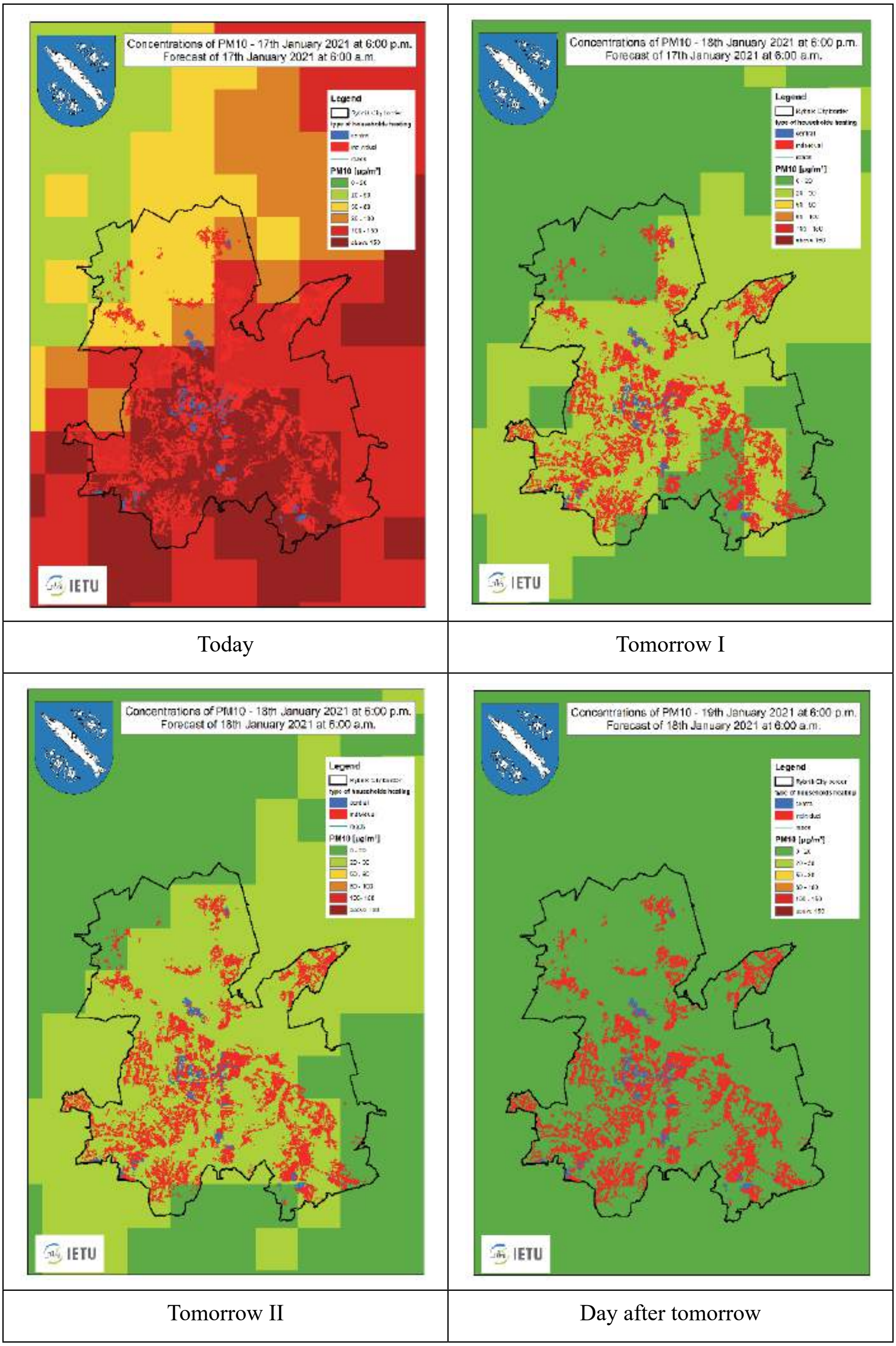


Fig. 9.6. PM10 concentrations for the area of Rybnik in the period of the next 48 hours

of emissions in the city centre and the expected decrease of PM10 concentrations to the level of moderate air quality in the morning and low level of concentrations in the evening.

This is how the air quality management at the local level can look like with the use of information from the InfoSMOG-MED system, launched by the Marshal's Office of the Silesian Voivodship. However, it is up to local governments to decide whether they find it useful or not.

After one-year operation of the system, it is possible to generate data from the system on the average annual emission distributions in the communes of the Silesian Voivodship and distributions of average annual pollutant concentrations in the communes. It is well known that not all communes have authorised air quality measurement stations, and the modelling of spatial distributions of pollutant concentrations is permitted by Polish legislation.

The information obtained from the InfoSMOG-MED system will allow the identification of areas where the highest emissions are generated in the commune and identification of areas where the highest concentrations of air pollutants occur. This will allow local authorities to target long-term activities planned under local strategic programmes (Air Protection Action Plan – POP, Low Carbon Economy Plan – PGN, Low Emission Reduction Programme – PONE, Urban Plans to Adapt to Climate Changes – MPA) to appropriate districts, which should result in greater efficiency in improving the air quality at the local and regional level in comparison to the incoherent measures previously implemented in the communes.

9.4. Conclusions

The air quality and health risk forecasting system developed as part of the InfoSMOG-MED project is dedicated primarily to the inhabitants of the Silesian Voivodship, who have access to the air quality forecast for the next 48 hours at their location and to information on health risks resulting from the current and projected air pollution, taking into account their personalised disease profile, gender and age.

The developed air quality forecasting system, taking into account the emission model which provides the forecast of the pollutant emission from municipal sources based on the projected air temperature and the related heat demand in flats, taking into consideration the technical condition of buildings, the quality and quantity of fuels used as well as the type and efficiency of combustion sources, allows to forecast the emission of pollutants from these sources only to housing areas without heat supply system, and thus to estimate emissions in the areas of real actual emission.

The emission model enables to determine the spatial distribution of the highest emissions in the commune, while the concentration forecast model allows to determine the areas where the highest concentrations of pollutants occur within the commune.

This information can be the basis for local authorities to make decisions on short- and long-term measures which should be taken to improve air quality, reduce health risks and improve the quality of life of the inhabitants.

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Chapter 10

Spatial aspects of waste management in inhabited areas of Poland

Summary
The aim of this study is to examine the spatial needs related to the collection of household waste. The study analysed the factors influencing the use of space for household waste collection sites and estimated its size on a national scale, including the costs of its preparation. Solutions to reduce the built-up area used for such purposes were also recommended.

Keywords: waste management, waste collection, selective collection, waste containers, underground containers

10.1. Introduction

The guidelines for development of built-up areas resulting from planning policies and documents, such as studies of conditions and directions of spatial development and local spatial development plans, take into account a number of parameters resulting from natural conditions of the area and social needs of its development. In the case of functional allotment of surfaces, there are also those, related to waste management. However, this most often applies to the location of large waste treatment installations such as incineration plants, sorting plants, transfer stations or landfills.

There is also a very large group of facilities related to the management of waste generated in built-up areas with residential and service functions, which are not allotted in planning documents due to their connection with the basic function of the area and relatively small unit area.

However, there are so many of them that an attempt should be made to estimate their share in the total space for development, including factors which contribute to it.

10.2. Legal conditions for collecting solid waste in inhabited areas

The Act on maintaining cleanliness and order in municipalities (Journal of Laws 2021.888) defines tasks of a municipality and the obligations of property owners regarding maintenance of cleanliness and order as well as the conditions for carrying out activities in the field of collecting municipal waste from property owners and managing this waste.

Municipal councils adopt regulations for maintaining cleanliness and order in municipalities, which are in the form of an act of the local law. In the field of waste management these regulations take into account both the provisions of the Act on maintaining cleanliness and order in municipalities as well as the Act on waste and a number of executive provisions. The regulation of the Minister of Climate and Environment on the method of selective collection of selected waste fractions (Journal of Laws 2021.906) has a significant impact on the way waste is managed by residents. It specifies methods of selective collection of paper, glass, metals, plastics, multi-material packaging waste and bio-waste in containers marked with appropriate colour and label. Therefore, the municipal regulations impose on each owner of a property, in which municipal waste is generated, an obligation to have four containers for separately collected waste (plastics, metals and multi-material packaging can be collected in one container), in addition to a mixed waste container.

Detailed conditions of the waste collection facility are specified in the building regulations, mainly the regulation on technical conditions for buildings and their location (Journal of Laws 2019.1065).

Pursuant to provisions of this regulation, on each real property a space for containers for temporary collection of solid waste should be prepared, taking into account the possibility of their segregation. These places may be:

– a roofed covers or rooms with solid or openwork walls;
– separate rooms in the building, with the floor above the surface of the driveway for transport vehicles collecting the waste, but not higher than 15 cm, including the lower chute chambers with direct exit to the outside; equipped with a canopy with a projection of at least 1 m and extended sideways by at least 0.8/1.0 m; with washable walls and floors, water inlet point, drain grate, ventilation and artificial lighting;
– hardened areas for placing containers with closed filling openings;
– a paved square with above-ground chutes and underground or partially underground containers.

There should be a hardened access between the entrances to the rooms or squares and the place where garbage trucks pick up loads of waste, enabling the containers to be moved on their own wheels or on carts. Places for the collection of solid waste at multi-family buildings should be accessible to disabled people.

Solid waste containers should have impermeable walls and bottom, tight cover with a lockable filling opening and a lockable opening for waste disposal. A hardened access route should be provided to these containers.

The site for collecting solid waste must be located at least 10 m from the windows and doors of the buildings with rooms intended for people and 3 m from the border with the neighbouring plot, but it cannot be more than 80 m away from the farthest entrance to a multi-family residential building, collective residence or public utility facilities.

10.3. Implementation of the obligation to collect waste by property owners

In the case of individual owners, it is necessary to locate at least 5 containers on the property (according to some municipal regulations homes with gardens are allowed to compost bio-waste, therefore the container for organic waste is not required) with a capacity that ensures that the generated waste in the period between its collections is kept by the designated entity collecting waste (usually it is one week in multi-family housing and up to two weeks in single-family housing). In the case of multi-family housing, waste collection sites are arranged by property managers representing residents, most often for each building, and the capacity or number of containers is selected on a similar principle.

The method of arranging the site for placing the containers is, therefore, influenced by the legal considerations discussed above, as well as order, practical and aesthetic aspects and the obligation to keep the collected waste in a non-deteriorated condition.

To ensure order in the vicinity of the containers, they are most often secured against access by third parties who could move them to another place, put their own waste in them contrary to the purpose of the containers or spread waste around them. In some locations, containers may also move or even overturn due to vibration, wind or animals, children playing around, or as a result of hooliganism.

The obligation to harden the ground and driveway to the site where the containers are placed and the lack of architectural barriers at the driveway are purely practical – they allow full containers to be moved to place of collection (recipients usually want them to be put outside the plot or in front of the room where they are stored) and help maintain order there. To ensure the appropriate aesthetics and protect the place of waste collection, architectural covers in form of lockers, gazebos or sheds are used, the size of which depends on the type and number of containers used. The area of such a separated space must allow easy manoeuvring of individual containers inside and towards the exit, and it should be assumed that it is at least twice as large as the vertical projection of the standing containers on the ground.

For example, a set of five 120-liter containers (cost from 700 to 800 PLN – all prices quoted here are from market offers from mid-2021) in a low cover made of powder-coated light sheets, enabling independent moving of each of them (cost about PLN 2000) covers an area of 3.5 m^2, excluding the driveway, which at the location on the plot border at the collection point will occupy at least the same area. The cost of laying paving stones from the cheapest materials is about PLN 100 per square meter, excluding ground preparation. Thus, the lowest estimated cost of a small secured and aesthetic waste collection facility which covers 8 m^2 plot area is approximately PLN 4000.

In the case of multi-family housing, costs are of course much higher. Securing five 1100 l containers (one cost from 650 to 950 PLN) requires a shelter with an area of at least 15 m^2 (the cost of a wooden or metal shelter ranges from 8 to 15 thousand PLN depending on the materials used and quality of workmanship). Together with the driveway to this type of waste collection site, it will cover the area of at least 25 m^2. It is difficult to comment on the total costs in this case due to the surcharge of local costs: administrative and management, Byzantine procurement procedures and local costs of adapting the building site, the use of heavy equipment and heavy HDS transport.

Fortunately, construction of a shelter with a building area of up to 35 m^2, in a situation where no more than two shelters are built on each of the 500 m^2 of the plot area, is only subject to notification in accordance with the current construction law (Journal of Laws 2020.1333), and the construction supervision authority may object to starting work only up to 21 days from the date of application.

Summarising, the considerations on the proper waste collection practice in built-up areas and referring to the presented estimated minimum spatial needs (locations on the plot border were adopted there), taking into account the access areas and a distance of 3 or more meters from the plot border, it is accepted for further considerations, without the risk of overestimation that in single-family houses it will require about 12 m^2, and in the case of multi-family buildings – about 30 m^2 of the real estate area.

10.4. Demography and housing statistics

Using data from public statistics, which collects demographic information and information on housing, it is possible to estimate the number of waste collection sites in built–up areas.

The first illustration shows the population density per km^2 in Poland in 2015.

The purpose of this illustration is not to consider the population in particular areas, but to provide a graphical representation of the country's demographics in spatial terms. Light-coloured areas represent densely populated areas, and dark-coloured areas represent sparsely populated or uninhabited areas. The presented picture proves that although the greatest needs in terms of serving the population are concentrated in the area of agglomerations and larger cities, they also apply to most of the country, including non-urbanised areas.

The next illustration shows the share of the developed land in the total area of the country and the number of residential buildings by voivodship. The average share of the developed land in the country's territory is 5.23 percent. However, there is no strong correlation between the share of built-up land and the number of buildings.

Detailed information on the number of buildings and their type in Poland is presented in Table 1.

According to the thematic publication of the Central Statistical Office (CSO, 2011) based on the results of the 2011 National Census of Population and Housing, there were over 6 million buildings in Poland with at least one flat.

Over 5.5 million buildings were inhabited. These were both residential and collective accommodation buildings or non-residential buildings, i.e. buildings more than half of which was occupied for purposes other than residential (school, commercial, office, etc.).

There were 3.4 million inhabited buildings in the countryside and 2.2 million in cities.

Single-family buildings dominated in the residential development in rural areas, they constituted approx. 97% of the inhabited buildings, and in cities

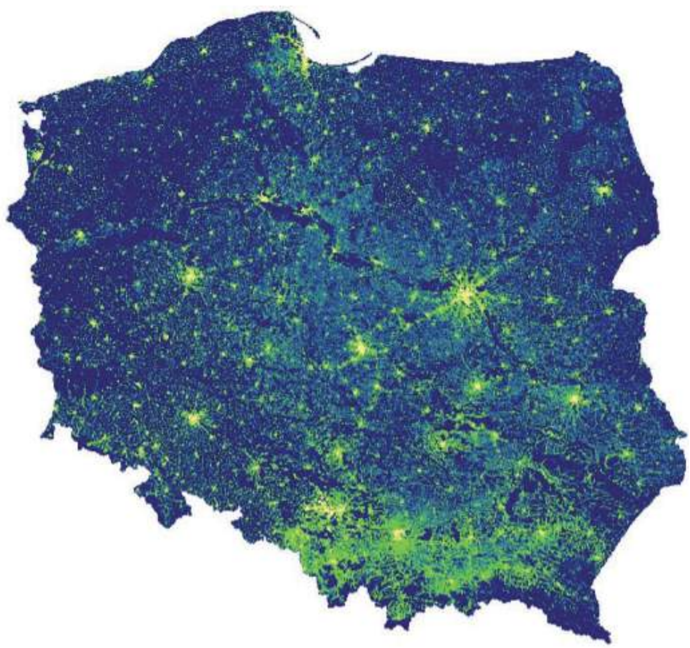

Fig. 10.1. Population density per km² in 2015, according to the Central Statistical Office. (bright areas – high population density, dark areas – sparsely populated or unpopulated) Source: CSO https://geo.stat.gov.pl/imap/

– almost 80%, with the majority of flats, located in multi-apartment buildings. These buildings housed approximately 79% of urban flats and almost 15% of rural flats (CSO, 2011).

Single-family buildings dominated in the residential development. In rural areas, they constituted approx. 97% of the inhabited buildings, and in cities – almost 80%, with the majority of flats, located in multi-apartment buildings. These buildings housed approximately 79% of urban flats and almost 15% of rural flats (CSO, 2011).

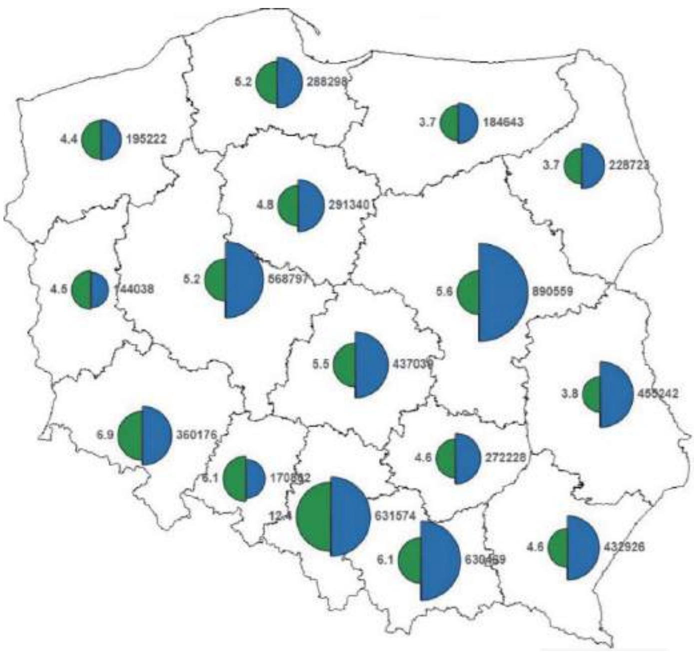

Fig. 10.2. Share of the developed land in the total area of the country (%; green colour) and the number of residential buildings in 2014 (blue colour), according to the Central Statistical Office Source: CSO https://geo.stat.gov.pl/imap/

Table 10.1. Buildings [in thousands] by type in 2011 (CSO, 2011)

Year 2011	Buildings together	Inhabited together	Of which:					Uninhabited
			Residential:			Collective accommodation facilities	Non-residential	
			Residential together	Single-family	Multi- -apartment			
Total	6 047,1	5 567,6	5 542,6	5 007,5	535,1	3,3	21,0	479,5
Cities	2 285,6	2 189,2	2 176,4	1 738,2	438,2	1,8	10,8	96,4
Village	3 761,5	3 378,4	3 366,2	3 269,3	96,9	1,4	10,3	383,1

Based on the data presented in Table 1 it should be assumed that in 2011, 5.5 million residential buildings were used in Poland, of which 5 million were single-family buildings and about half a million – multi-family buildings. There is also an obligation to collect and transfer municipal waste generated in a non-residential buildings, however, due to their differentiation as sources of this type of waste, they do not have to be included in a multi-container collection system in each case and, therefore, were not included in the estimation of the space requirement. Within ten years, the number of buildings increased, but accurate data on this subject will be provided by 2021 National Census of Population and Housing.

10.5. Estimation of the space occupied by waste collection sites in inhabited areas

On the basis of the presented analysis, the following estimation can be made:

- in the case of five million single-family houses with a floor space requirement of 12 m^2 for a waste collection site, this amounts to a total of approximately sixty million m^2;
- in the case of five hundred thousand multi-family buildings with the space requirement for a waste collection site of 30 m^2, this is a total of about fifteen million m^2.

Thus, in a national scale, the space occupied by waste collection sites is around 75 million m^2, or 7500 ha, which is 0.02% of the total area of the country and 2.4% of the inhabited area of around 316000 ha.

The third picture shows the prices of m^2 of building plots in Poland in June 2020.

The average offer price for large cities from the Bankier.pl (http://www.bankier.pl/) portal for May 2021 is approximately PLN 428/m^2. Thus, the expenditure on arranging a waste collection site in a single-family property may additionally include the value of the land at a level comparable to other investment components. In the case of multi-family housing it is similar, and in extreme cases – exceptionally attractive locations, the value of land may be the dominant component.

10.6. Solutions reducing the use of space and expenses

In the case of multi-family housing more and more often a solution based on the replacement of several waste collection sites arranged separately for each building with a common set of semi-underground and less frequently large-size underground waste containers is being introduced. If an agreement can be concluded by several property managers, it is possible to allocate costs favourably, recover part of the property area for other purposes and reduce the costs of waste collection. Thanks to these advantages and scalability of the solution, its popularity should be expected despite significant implementation costs (the container itself, without the underground housing, costs about PLN 30,000, but usually has a 10-year warranty, not only the manufacturer's warranty). A comparison to other waste management methods is shown in Figure 4.

Underground and semi-underground containers are more capacious than municipal waste containers. The containers used so far can contain about 1100 litres of waste, while underground containers – up to 6000 litres of waste. So much greater capacity results in less frequent emptying of the containers by the collector, which lowers the collection costs. The sheer shape and size of the container as well

Fig. 10.3. Prices per m² of building plots in Poland in June 2020 (https://www.bankier.pl/)
Source: https://www.bankier.pl/

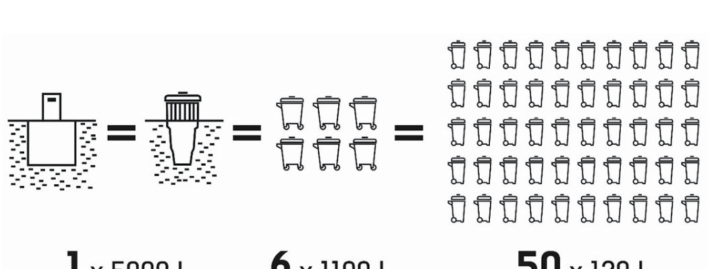

Fig. 10.4. Comparison of municipal waste collection systems – number of containers with a capacity of 120 and 1100 liters replaced by one underground or semi-underground container
Source: http://ppbin.com/pojemniki-polpodziemne/

as dropping them from a height make the waste compress under its own weight which contributes to reducing the free space between the thrown objects.

Overground containers on wheels are often unaesthetic, their surface is sometimes dirty or scratched. In the case of underground and semi-underground containers, the aesthetic impression is much better – the structure of the container hides most of it in the ground. Above the ground, there is an elevated part that allows convenient and safe throwing of waste. It is in the form of a coloured cover with a self-closing tight flap or a small-sized drop-in kiosk with a discharge mechanism. The size of the drop station for underground and semi--underground containers, the method of opening the flap and the height of the inlet opening were specially designed so that each social group could use them. The overground casing can be harmonised with the surroundings by using the following faces made of: wood, coloured aluminium panels or other materials adapted to the environment.

The underground and semi-underground waste collection system protects against leakage of liquid escaping from containers. Another advantage of implementing this solution is reduction of odour, which results from the storage of waste underground, where there is a naturally lower temperature and limited ventilation. Thanks to this, the putrefactive process is slowed down, the smell near the underground waste container is not as unpleasant as in the case of municipal waste containers, and many harmful microorganisms spreading in the surroundings of ordinary containers do not get onto the surface. Besides, tight self-closing flaps reduce the presence of rodents in the vicinity and eliminate potential feeding places for other animals.

Underground waste containers meet the requirements related to the location of waste collection sites and do not require any additional above-ground structures, therefore property owners can easily choose their location, and the space requirement for a set of containers takes also about 30 m^2, but can replace several container shelters.

Unlike traditional containers, pickup does not require direct access to the container. The emptying system is carried out using cars with a HDS double hook lifting system, which pulls the container to the surface and pours the waste into the vehicles, and the entire process takes about 5 minutes. Due to the extent of the lifting device, it is possible to install the containers in tight hard-to-reach places and it can free up other easily accessible space that was occupied by surface containers.

10.7. Conclusions

The approach used in the study allowed for an approximate determination of space used for the location of a large group of five million sites related to the management of domestic waste generated in Polish residential and commercial areas. The obtained results indicate that 2.4% of such areas are used for this purpose.

The value of the space occupied is an important component of the expenses related to the organisation of the waste collection site, especially in cities.

This component can be reduced thanks to joint actions of property managers and the use of new technologies.

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Chapter 11

Comprehensive inventory of the post-industrial area in terms of restoring the site functions and re-use of waste. Case study of industrial heap of unknown origin

Summary
The paper is based on the results of one of the research studies carried out at the Institute for Ecology of Industrial Areas. The study concerned the inventory of the post-industrial heap, potentially considered by the investor as a source of secondary raw minerals for road construction. With regard to the heap, it was assumed that it could be related to the coal mining or iron metallurgy industry, but the origin and age of the object were not fully recognised. As part of the study, a historical analysis of the available archival materials was performed, as well as field research and laboratory analyses of the rock material samples, on the basis of which its genesis was verified. Environmental characteristics of the accumulated mineral material for contaminants was also made. Based on the results of the investigations and LIDAR data from the numerical surface model, volume and weight of the rock that could be obtained as an aggregate were estimated.

Keywords: post-industrial area, heap, dump, historical analysis of brownfields, circular economy, aggregate from waste

11.1. Introduction

The central part of the Silesian Province, referred to as the Upper Silesian Industrial Region, is historically closely connected with mining, processing of coal and metallurgy of ferrous and non-ferrous metals. Currently, the remnants of this more than 100 years' activity are post-industrial areas in the form of degraded and contaminated land, remains of construction infrastructure, as well as dumpsites towering in the landscape of Upper Silesia. The numerous scientific projects and revitalisation investments that have been successfully implemented for the last few decades result in restoration of further areas or changing their land use pattern (e.g. projects CIRCUSE, TIMBRE, and BRIDGE). In the case of industrial waste heaps, there can be different management methods. One of the solutions is revitalisation for recreational purposes or forests. Nevertheless, in the case of heaps containing clean and good quality rock material, the preferred solution is their demolition, waste excavation and classification in order to obtain aggregates and building materials. Ultimately, this results in the recovery of land that can be re-invested.

This study is an example of a comprehensive inventory of the post-industrial heap of unknown origin, potentially regarded as a source of secondary raw material for application in road construction. The study shows step by step how the genesis of the heap was established, the origin of the disposed mineral waste was investigated, and how the environmental characteristics focused on potential impurities was carried out. At the last stage of the work, volume and weight of the rock that can be obtained as an aggregate were estimated, including the assignment of the waste code in accordance with the legal classification. The work complies with the Circular Economy (CE) environmental assumptions by changing its land use pattern and reuse of waste as potential secondary raw material.

11.2. Materials and methods

Mining waste landfills are referred to as heaps or dumps. Both of these names appearing in the study are synonymous. In the study a stepwise approach was applied. In order to determine the likely age of the object and the origin of the stored waste, a historical analysis of the available material (information) and an analyses of historical maps were made as the first step. Then, a site inspection was conducted, and the assessment of the possibility of sampling of the dumped waste was made. Location of further drilling points and surface samples was designated (Figure 11.1). Due to the limited availability of the dump plateau, steep slopes and the occurrence of numerous self-sown trees, drilling works were limited to two holes with a total length of 22 meters (10 and 12 meters; in both cases drillings reached the top surface of the subsoil). Boreholes were made with a rotary mechanical drill bit with a diameter of a 100 mm. From the total of 12, 5 soil samples were collected from the 1-st borehole (OB1) and 7 from the 2-nd borehole (OB2). In the profiles, the deepest samples represented the natural ground (subsoil). Additionally, 5 surface samples from the dump slopes were collected. Samples were taken on the 30th of January

2020 (boreholes OB1, OB2), and on the 31th of January 2020 (samples from the slopes). The weather was cloudy, frosty with light wind. Air temperature was -2°C.

Historical analysis, statistical analysis of results, map figures, model of the heap allowing estimation of its volume and weight and analysis of thermal activity based on Landsat data were performed by the GIS team of the Institute for Ecology of Industrial Areas in Katowice (IETU). Physico-chemical studies and grain size analysis of the samples were made by the Central Laboratory at IETU. Soil samples were taken in accordance with the PN-ISO 10381-5: 2009 standard – Soil quality – Sampling – Part 5: Principles of conduct when examining urban and industrial areas for soil contamination. Losses on ignition (LOI) were determined by the weight method according to PN-EN 15169: 2011 – Characterisation of waste – Determination of loss on ignition of waste, sludge and sediment. The heat of combustion was determined using the calorimetric method according to PN-EN 15400: 2011 – Solid recovered fuels – Determination of the calorific value. The content of carbon and sulphur was determined by the high-temperature combustion method with IR detection. Carbon content in accordance with PN-EN 15407: 2011 – Solid recovered fuels – Methods for the determination of carbon (C), hydrogen, (H) nitrogen (N) and sulphur content in accordance with PN-G-04584: 2001 – Solid fuels – Determination of total sulphur and ash content with automatic analysers.

Laboratory analyses of waste and subsoil samples for heavy metals (metalloids) and PAHs were conducted according to the reference methodologies specified in the Polish guidelines on assessing soil contamination (Journal of Laws 2016.1395). The grain size analysis was performed according to the PN 04032: 1998 standard using the Bouyoucos sieve and aerometric method, modified by Casagrande and Prószyński. The grain curves were drawn based on the results of the grain size analysis using the HydrogeoSieveXL tool (Devlin 2016).

11.3. Site characterisation

The case study area is located in the southern part of Poland, in the Silesian Province, in the commune of Łaziska Górne. The considered heap extends in the axis of the oval basin of SSW-NNE direction, which falls towards NNE. From three sides the trough is surrounded by a 10 m elevated area. The thickness of the stored waste reaches 15.45 m with an average of about 6.93 m. The highest is the southern part of the dump. The body of the analysed object cuts off from the surrounding surface by the slope with a gradient of about 30 degrees. Within the heap two main surfaces can be identified, which are separated by a slope of a similar gradient and height of about 5 m. Mapping of the dump shape and location of sampling points is presented in Figure 11.1

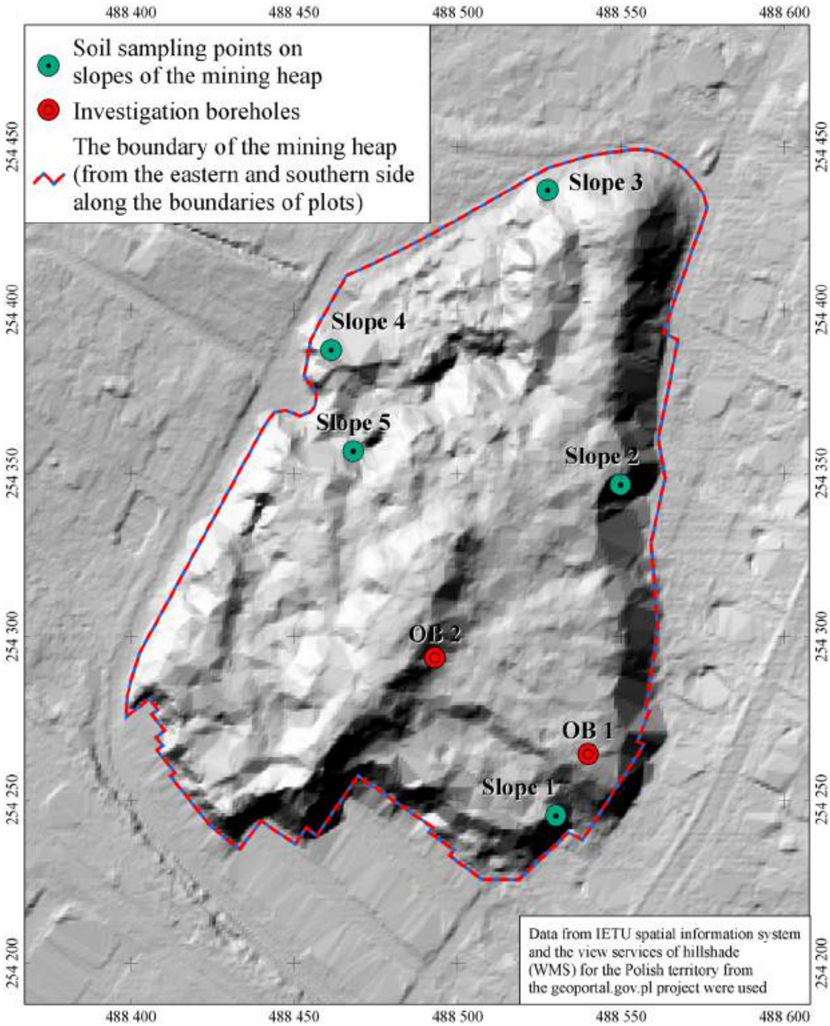


Fig. 11.1. Shape of the analysed heap and location of sampling points

11.4. Historical analysis – Age determination and genesis of the heap

A historical analysis aimed at determining the most probable activities, as a result of which waste was generated and finally dumped on this site, was prepared on the basis of available cartographic materials, information from residents living in the vicinity of the heap, and a publication released online by the commune. Unfortunately, there were no living witnesses who could remember the time and circumstances of the heap formation, however from oral reports it is known that in the 1940s the heap has already existed. Due to the lack of other documentation, changes in the land use were tracked on the basis of 7 topographic maps covering the period of about 114 years – from 1879 to 1993 (Figure 11.2a-g). The archive map browsing service is available through the Polish National Spatial Information Platform „Geoportal” (Geoportal krajowy 2021).

Based on the analyses of the maps it can be concluded that until 1913 the research area was free of waste (Figure 11.2a, b). Essential information for further study can be found on the map from 1933, where a narrow embankment on the considered area is drawn (Figure 11.2c), which, according to the map from

a) 1879–1889 b) 1901–1913 c) 1933

d) 1936–1943 e) 1960–1966 f) 1984–1986

g) 1993 h) photograph (1918)

Fig. 11.2. A historical analysis based on available maps and photograph
Source: Geoportal krajowy 2021 (a–g), Gazeta Łaziska 2019 (h)

1936–1943, a few years later already had a much larger extent (Figure 11.2d). On the map from 1960–1966 (Figure 11.2e), as well as on the maps from the 80's and 90's (Figure 11.2f, g), the shape of the object is similar to that observed nowadays. Mine shafts are visible on all discussed maps. There are mine shafts named Anna, Konrad, Bolko, and Brada. On the basis of the listed facts it can be concluded that the currently existing heap is closely related to the extraction of hard coal. This is confirmed by the fact that no information was found on the historical maps about any other industrial activity that could have influenced the formation of the heap.

Supplementary information and confirmation of the results of the map analyses were obtained from interviews with people living in the vicinity of the heap and an article published in the local newspaper (Gazeta Łaziska 2019), focused on the heap and its surroundings. Although the publication concerns the threats to nearby buildings connected with the expansion of rock material coming from the processes of weathering and leaching through rainwater, it also contains valuable historical information about the genesis of the heap. The newspaper contains information from the inhabitants and reminiscences passed on between generations, which clearly shows that it is a post-mining waste landfill from the Brada coal mine (the name appears on the map between 1936–1943). The article contains a photograph of the object dated 1918 which indicates that at that time, an outline of the heap already existed (Figure 11.2f). Valuable information is the fact that since the 1950s, among the local community, the site has been known colloquially as the "Red Heap", which confirms its origin and supposed age (i.e. that it is an old burnt-out coal dump). The self-initiated process consists in combustion of the carbon remains contained in the structure of the rock material stored on the dump. Due to the limited amount of air, this process is extended over time and can last several dozen years (Parfiniuk 2012, Szopka 2007). The process is broadly discussed in paragraph 11.6.1.

Summarising the historical analysis – already at this stage of study it was found out that the considered dump is an old, burnt-out coal mining landfill. Dumped waste originated from the operation of a hard coal exploitation facility, existing there in the first part of the 20th century. It has not been established when exactly the operation was completed, but it is known that in 1990 the area of the closed heap which belonged to the State Treasury, became the commune property. Nevertheless, according to the original assumption of the presented study, further research was performed which allowed to characterise the dumpsite, waste and their properties.

11.5. Results

The grain size composition of 15 samples of waste was determined, including 10 from boreholes and 5 from the slopes of the heap (Table 11.1).

Table 11.1. Results of the grain size analysis for waste samples – fraction content in [%]

Sample no.	25–10 mm	10.0–6.3 mm	6.3–4.0 mm	4.0–2.0 mm	2.0–1.0 mm	1.0–0.5 mm	0.50–0.25 mm	0.250–0.125 mm	0.125–0.063 mm	<0.063 mm
OB1/ 1.5–3.0	27.2	19.6	9.1	12.2	8.5	6	5.5	4	2.9	5
OB1/ 3.0–4.5	9	14.8	11.2	14.3	13.1	9.6	8.5	6.3	4.6	8.6
OB1/ 4.5–6.0	31.5	6.7	7.7	11.8	9.7	8.2	7.2	5.6	3.9	7.7
OB1/ 6.0–7.5	17.9	12.5	10.9	16.7	11.4	8.3	6.6	4.9	3.4	7.4
OB2/1.5–3.0	16.9	22.5	16.3	17.2	8.7	5.6	4.3	0	7.8	0.7
OB2/3.0–4.5	46.9	11.4	6.8	10.2	7.2	5.5	3.8	1.1	6.8	0.4
OB2/4.5–6.0	27.7	12	15.3	4.6	11.8	10.7	9.2	7.6	0.7	0.4
OB2/6.0–7.5	37.2	6.3	5.4	13.1	9.6	8.4	7.1	3.4	8.9	0.6
OB2/7.5–9.0	37.8	10.5	6.3	10.9	16	0.1	0.1	10	7.2	1.1
OB2/9.0–10.5	34.8	14.5	11.7	10.5	17.3	5	4.1	1.7	0.4	0
Pr1 slope	90.7	0.9	1.6	1.4	1.3	3.7	0.3	0.1	0	0
Pr2 slope	99	0	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0
Pr3 slope	63.7	7.3	5.4	9.9	8.9	0.1	2.9	1.3	0.4	0.1
Pr4 slope	92.3	0	0	4.7	1	0.9	0.8	0.2	0	0.1
Pr5 slope	55.2	6.3	5.1	12.2	14.6	3.8	1.9	0.8	0.1	0.1

Source: IETU's calculations based on its own research results (2020)

Apart from the analysis of the waste from the heap the grain size composition of 2 samples of the subsoil was determined (OB1/ 8.4–9.0 and OB2/11.2–12.0). The average water permeability coefficient for subsoil samples calculated on the basis of the particle size distribution curves is $3.4*10^{-8}$m/s, which indicates a poorly permeable soil. The soil was classified as sandy loam (OB1) and heavy loam (OB2).

Due to the presumption as to the nature of the waste deposited on the heap, basic physico-chemical analyses were performed (in the context of the conducted research) to verify the hypothesis that in the analysed case we are dealing with waste from hard coal mining. The analysis covered such parameters as: LOI, heat of combustion, total carbon, sulphur and iron content (Table 11.2.).

According to the scope of research provided for the areas related to the exploitation of hard coal specified in the legal guidelines on the method of assessing the pollution of the earth's surface (Journal of Laws 2016.1395) 12 metals (and metalloids) and 10 PAHs were determined in 17 collected samples.

The content of metals in the collected and prepared soil samples was determined after prior mineralisation in aqua regia in accordance with

Table 11.2. Basic physico-chemical parameters of the analysed waste

Sample no.	LOI [%]	Heat of combustion MJ/kg	C [%]	S [%]	Fe [mg/kg]
OB1/ 1.5–3.0	3.39	<3	1.33	0.243	48052
OB1/ 3.0–4.5	2.34	<3	<0.1	1.230	35743
OB1/ 4.5–6.0	3.28	<3	<0.1	1.050	29274
OB1/ 6.0–7.5	1.53	<3	<0.1	0.621	25100
OB1/ 8.4–9.0	1.47	<3	0.789	0.045	4540
OB2/1.5–3.0	7.67	<3	4.86	0.119	35321
OB2/3.0–4.5	2.94	<3	1.02	0.326	28659
OB2/4.5–6.0	2.20	<3	0.467	0.315	24457
OB2/6.0–7.5	1.91	<3	0.374	0.340	24127
OB2/7.5–9.0	5.69	<3	2.33	0.220	26560
OB2/9.0–10.5	2.09	<3	0.251	0.030	19612
OB2/11.2–12.0	1.72	<3	<0.1	0.104	17888
Pr1 slope	2.23	<3	<0.1	1.03	14795
Pr2 slope	0.49	<3	<0.1	0.095	10145
Pr3 slope	0.56	<3	<0.1	0.021	10554
Pr4 slope	0.79	<3	0.188	0.301	13598
Pr5 slope	0.96	<3	<0.1	0.348	10425

Source: IETU's calculations based on its own research results (2020)

PN-ISO 11466: 2002 – Soil quality – Extraction of trace elements soluble in aqua regia. The content of barium, chromium, tin, zinc, cadmium, cobalt, copper, molybdenum, nickel, lead and iron (Journal of Laws 2016.1395) was determined by the inductively coupled plasma atomic emission spectrometry (ICP-OES) according to the test procedure PB-08/2, 6th issue of June 28, 2019. The content of arsenic was determined by the hydride generation atomic absorption spectrometry method (HGAAS) according to the test procedure PB-08/4, issue 5 of August 30, 2017. The mercury content was determined by the method of cold vapour atomic absorption spectrometry (CVAAS) according to the test procedure PB-20, issue 2 of August 30, 2017. Polycyclic aromatic hydrocarbons (PAHs) were determined after prior extraction of soil samples with diatomaceous earth with dichloromethane in an automatic ASE extractor and separation of compounds from the PAH group with Florisil. The extract was analysed by the high-performance liquid chromatography method with fluorescence detection (HPLC-FLD) according to the test procedure PB-09, issue 7 of August 30, 2017.

The results are presented in Table 11.3. The content of cadmium, molybdenum and PAHs was lower than the detection range of the applied laboratory methods, thus these results were not included in the further discussion.

Table 11.3. Results of laboratory analyses – heavy metals (and metalloids) [mg/kg]

Sample no.	As	Ba	Cr	Sn	Zn	Co	Cu	Ni	Pb	Hg
OB1/ 1.5–3.0	34.3	414	40.6	24.2	76.1	15.4	57.0	41.9	117	0.31
OB1/ 3.0–4.5	26.3	70.6	26.4	<10	34.0	15.8	38.2	39.1	<20	0.04
OB1/ 4.5–6.0	33.2	282	23.8	<10	33.1	15.4	38.2	37.0	<20	0.04
OB1/ 6.0–7.5	23.4	68.1	18.4	<10	12.8	12.6	35.4	31.3	<20	0.02
OB1/ 8.4–9.0	3.09	50.8	7.87	<10	49.6	<5	5.34	5.71	<20	0.05
OB2/1.5–3.0	19.1	596	38.7	16.3	143	17.2	457	47.8	63.0	0.35
OB2/3.0–4.5	27.3	562	27.9	18.0	79.2	17.0	452	41.6	37.9	0.11
OB2/4.5–6.0	16.9	110	21.4	<10	33.8	11.7	143	29.9	<20	0.04
OB2/6.0–7.5	20.9	137	22.3	12.57	37.0	11.9	178	28.4	29.3	0.06
OB2/7.5–9.0	20.3	122	25.5	13.6	67.4	13.2	151	32.1	56.3	0.12
OB2/9.0–10.5	4.78	91.0	22.6	<10	35.7	7.88	19.1	15.4	<20	0.05
OB2/11.2–12.0	3.76	57.6	21.7	<10	49.3	10.4	13.5	21.4	<20	0.05
Pr1 slope	27.7	476	22.9	<10	61.4	19.9	63.9	42.8	<20	0.02
Pr2 slope	20.8	252	13.3	<10	14.1	15.0	24.0	35.5	<20	0.02
Pr3 slope	19.6	189	9.22	<10	25.9	10.1	35.8	27.9	<20	0.01
Pr4 slope	32.2	186	14.5	<10	28.4	10.6	50.4	24.0	<20	0.03
Pr5 slope	41.6	338	9.81	<10	27.3	13.6	30.7	28.0	<20	0.01

Source: IETU's calculations based on its own research results (2020)

To verify whether the heap still shows thermal activity a map of the land surface temperature was developed for the area of the entire commune. The Land Surface Temperature (LST) was calculated based on the satellite data from LANDSAT8. The analysed 8 scenes represented the "cool" months from November to March. The temperature variation range was 0.594°C with the minimum of -4.023°C and maximum of -3.429°C. Regardless of the analysis of the LST the air temperature was measured in boreholes (OB1. OB2) during field work and sampling. The results were 6.4°C (OB1 at the depth of 0.5 m bgl[6]) and 6.5°C (OB2 at the depth of 1.6 m bgl), respectively. At the sampling time the air temperature at the surface was -2°C.

11.6. Discussion

11.6.1. Physical properties of the waste

The waste stored on the analysed heap should be characterised as burnt coal shale. The examined material is shaped in the form of compact conglomerates

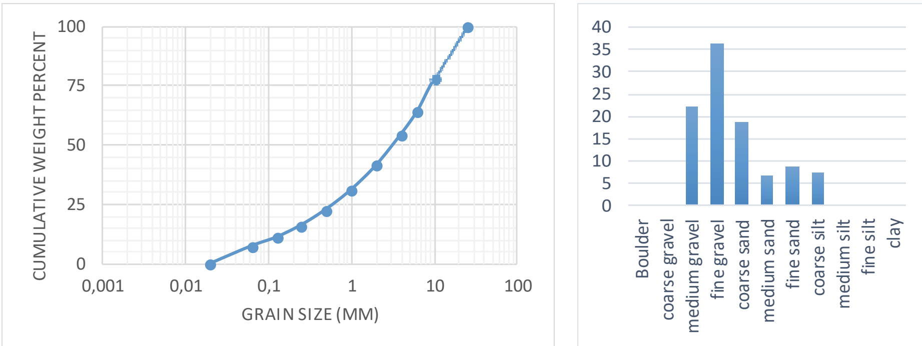
[6] bgl – below ground level

with a structure resembling natural rocks such as puddingstones, breccias or tuffs. Within the sampled matrix grains of rocks shaped in brick-red colour were identified. This colour is the result of the burning-out process of the so-called black coal slate which is sedimentary rock accompanying hard coal beds. These rocks are the main type of waste stored on the coal mine heaps in Poland. At the fracture of larger fragments in their central part irregular black or dark grey discolourations are visible as remnants of the original rock colour. Smaller fragments are completely burnt-out. Some grains can be identified as co-existing coal sandstones. The rock grains of the burnt-out slate have a dense structure resembling building ceramics (bricks or roof tiles). These grains are contained in a compact but loose rock material with a porous structure. It is a brittle matrix, and brick-red colour means that it is also a burnt-out material. Its structure shows that it was originally a fine-grained material and it contained hard coal residues.

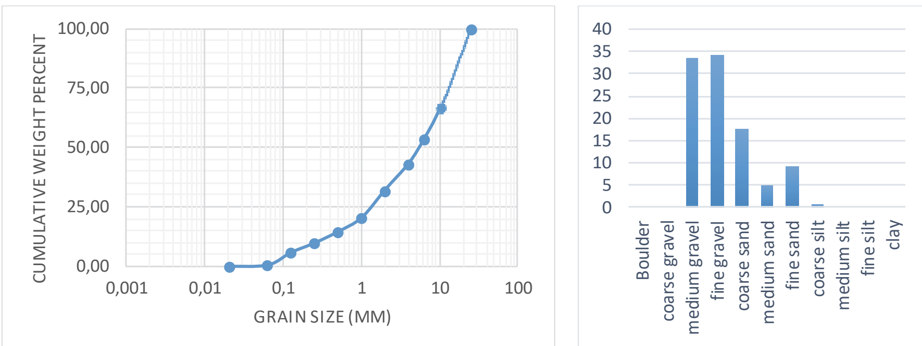
The burning-out process is a typical phenomenon for hard coal mining heaps. The fire hazard is usually caused by a significant amount of residual coal in the deposited waste which may reach 30%, and inappropriate dumping technologies (Buchta and Molenda 2007). The mechanisms of thermal and aerological processes are complex. This phenomenon is widely discussed in literature (Wasilewski and Korski 2010, Wasielewski and Skotniczy 2015, Buchta and Molenda 2007, Parfiniuk 2012, Hanak and Porszke 2006, Nowak 2006, Abramowicz et al 2020, Korski 2010).

The temperatures inside the burning coal mine dump may reach 850–1400°C (Buchta and Molenda 2007). The exothermic process is a source of gaseous pollutants in the atmosphere and a direct fire hazard (Wasielewski and Skotniczy 2015, Nowak 2006), however, as a result of burning-out process the properties of the rock material are significantly improved and new minerals may also be formed (Wasielewski and Skotniczy 2015, Buchta and Molenda 2007). The thermal effect on coal waste is marked by a colour change from black or grey (in various shades) to beige, brick-red, brown and grey-brown, and by the presence of slags resulting from partial or complete remelting of rock material and joining individual fragments with each other (Hanak and Porszke 2006, Nowak 2006). Coal slate as fresh material presents low value due to the fact that it slakes quickly, weathers and decomposes. However, after burning it becomes a valuable building material which currently is widely sought, especially as a substrate for the production of road aggregates.

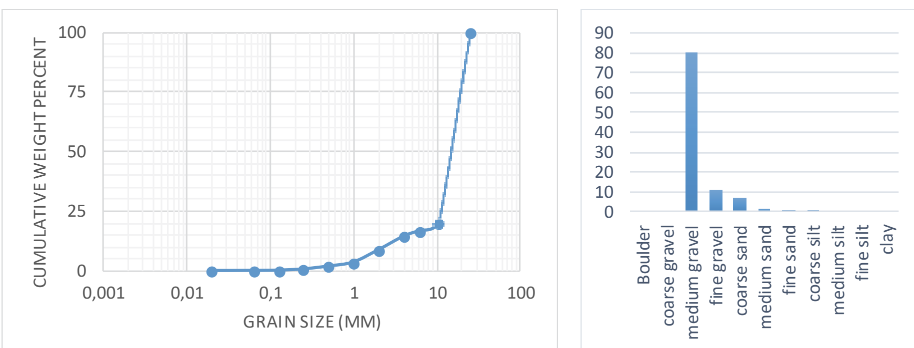
The grain size curves prepared for the averaged results of samples obtained from OB1, OB2 boreholes and the slope material are presented in Figure 11.3. The water permeability coefficient *(k)* calculated on the basis of the graining curves indicates that the stored waste (embankment) is well permeable. The average permeability of the embankment (the geometric mean) was calculated as $4.0 * 10^{-4}$m/s. It can be argued that in in-situ conditions this permeability may be lower because the research concerns samples from boreholes obtained with a mechanical drill, and the natural lithification as an effect of the age and burning-out process of the heap may be higher. The average water permeability coefficient for surface samples (mineral material from slopes) was calculated as $1.4*10^{-1}$ m/s.



a) Borehole OB1. Matrix classification: Poorly sorted sandy gravel low in fines



b) Borehole OB1. Matrix classification: Poorly sorted sandy gravel low in fines



c) Slope embankment. Matrix classification: Poorly sorted gravel low in fines

Fig. 11.3. Grain size curves. Boreholes (a, b) and slope embankment (c)

11.6.2. Basic physico-chemical analyses

The presence of the elements building the pyrite mineral (FeS_2) which commonly co-occurs in hard coal beds indicates the most likely origin of the waste material collected from the analysed dump. The central value (geometric mean) of the sulphur content in the heap soil is 0.22%, while the average iron content is 2.23%. Due to the low levels of LOI, low heat of combustion (below detection level) and low carbon content (the median carbon content is 0.19%) it should be concluded that the heap burnt-out in the past.

11.6.3. Contaminant content assessment and evaluation of geochemical parameters

The geochemical evaluation of the embankment and subsoil was conducted by comparing the content of measured parameters with the permissible content according to legal standards, in this case with standards for land use of group III (forest areas[7]). The permissible contaminant content is determined in relation to the soil permeability coefficient determined by the tests [Table 11.4].

Table 11.4. Permissible content of soil contaminants in group III (forest areas) [mg/ kg]

Parameter	0÷0.25m bgl	Below 0.25m bgl, $k>10^{-7}$ m/s	Below 0.25m bgl, $k<10^{-7}$ m/s
As	50	20	50
Ba	1000	300	600
Ch	500	300	500
Sn	100	30	50
Zn	1000	300	500
Cd	10	3	5
Co	100	30	60
Cu	300	150	300
Mo	100	25	50
Ni	300	100	200
Pb	500	100	300
Hg	10	3	5

[7] Appropriate land use category in accordance with the local spatial development plan

11.6.4. Waste and subsoil contamination assessment in individual samples

The first step in the geochemical assessment was the assessment of individual samples. For the assessment the exceedance index (IP_{MAX}) was used. It is the maximum quotient of the determined content to the permissible content for a given sample calculated according to the formula below:

$$IP_{MAX} = max\{\frac{P_1}{N_1} \cdots \frac{P_n}{N_n}\}$$

where:
$P_1 \ldots P_n$ – determined content of the contaminant in the sample [mg/kg]
$N_1 \ldots N_n$ – permissible content of the contaminant [mg/kg].

Simultaneously the substance (SIP_{MAX}) reaching the maximum exceedance quotient (IP_{MAX}) was indicated. The results of this assessment are presented in Table 11.5.

Table 11.5. Contamination assessment in individual samples

Item	Sample No.	Type of sample	IP_{MAX}	Result of assessment	SIP_{MAX}
1	OB1/ 1.5–3.0	waste	0.690	non-contaminated	Ba
2	OB1/ 3.0–4.5	waste	0.525	non-contaminated	As
3	OB1/ 4.5–6.0	waste	0.663	non-contaminated	As
4	OB1/ 6.0–7.5	waste	0.467	non-contaminated	As
5	OB1/ 8.4–9.0	waste	0.200	non-contaminated	Cd
6	OB2/1.5–3.0	waste	1.523	contaminated	Cu
7	OB2/3.0–4.5	waste	1.505	contaminated	Cu
8	OB2/4.5–6.0	waste	0.475	non-contaminated	Cu
9	OB2/6.0–7.5	waste	0.593	non-contaminated	Cu
10	OB2/7.5–9.0	waste	0.503	non-contaminated	Cu
11	OB2/9.0–10.5	subsoil	0.200	non-contaminated	Cd
12	OB2/11.2–12.0	subsoil	0.200	non-contaminated	Cd
13	Pr1 slope	waste	0.554	non-contaminated	As
14	Pr2 slope	waste	0.417	non-contaminated	As
15	Pr3 slope	waste	0.392	non-contaminated	As
16	Pr4 slope	waste	0.643	non-contaminated	As
17	Pr5 slope	waste	0.832	non-contaminated	As

In assessing the contamination of samples taken from the depth below 0.25 m the average water permeability coefficient calculated for subsoil was assumed ($3.4*10^{-8}$ m/s). The analysis of the results (Table 11.5) shows that in two samples from borehole No. 2 the permissible content of one of the metals (samples taken at the depth of 1.5 to 4.5 m below the surface) is exceeded. It refers to copper, the content of which is exceeded in both samples by about 50%.

11.6.5. Overall assessment of the heap contamination

The overall assessment was performed using statistical position measures (arithmetic mean, geometric mean or median) and dispersion measures (upper confidence intervals) appropriate to the fitted statistical distribution. If the measurement data had a normal (N) distribution, the arithmetic mean was used in the contamination assessment and in the case of a log-normal (LN) distribution – the geometric mean. If the measurement data could not be fitted to any statistical distribution (ND), the median was applied. Statistical analysis was performed using the significance level $\alpha = 0.05$. The results are shown in Table 11.6.

Table 11.6. Results of statistical analysis and parameters for waste contamination assessment

Parameter / Variable	As	Ba	Cr	Sn	Zn	Co	Cu	Ni	Pb	Hg
Statistical parameters										
Number of samples	17	17	17	17	17	17	17	17	17	17
Minimum [mg/kg]	3.09	50.8	7.87	5.00	12.8	2.50	5.34	5.71	10.0	0.01
Maximum [mg/kg]	41.6	596	40.6	24.2	143	19.9	457	47.8	117	0.35
Arithmetic mean [mg/kg]	22.07	235	21.6	8.51	47.6	13	105	31.2	24.9	0.08
Geometric mean [mg/kg]	18.0	174.6	19.6	7.10	39.8	12.0	53.9	28.5	16.4	0.04
Median [mg/kg]	20.9	186	22.3	5.00	35.7	13.2	38.2	31.3	10.0	0.04
Standard deviation [mg/kg]	10.8	181	9.19	6.05	31.5	4.08	141	10.7	29.3	0.10
Standard error of the mean	2.63	43.9	2.23	1.47	7.64	0.99	34.1	2.59	7.10	0.02
Skewness coefficient [mg/kg]	-0.35	0.88	0.49	1.55	1.85	-0.82	2.05	-0.73	2.32	2.21
Kurtosis coefficient	-0.16	-0.48	0.24	1.40	4.44	1.56	3.36	0.68	5.61	4.10
Coefficient of variation	0.49	0.77	0.43	0.71	0.66	0.31	1.33	0.34	1.18	1.29
Assessment parameters										
Statistical distribution	N	N	N	ND	LN	N	ND	N	ND	LN
Central measure [mg/kg]	22.1	235	21.6	5.00	39.8	12.96	38.2	31.2	10.0	0.04
Upper confidence interval (GPU) [mg/kg]	26.7	312	25.5	5.00	49.6	14.7	63.9	35.7	10.0	0.05
Permissible content	50	600	500	50	500	60	300	200	300	5
Assessment according to the central measure	44.1%	39.2%	4.3%	10.0%	8.0%	21.6%	12.7%	15.6%	3.3%	0.9%
Assessment according to GPU	53.3%	52.0%	5.1%	10.0%	9.9%	24.5%	21.3%	17.8%	3.3%	1.0%

Source: IETU's calculations based on its own research results (2020)

The results presented in Table 11.6 indicate that the waste stored on the analysed heap meets the quality demands for the land (soil) of forest areas. The central value (arithmetic mean, geometric mean, median) of the analysed contaminants does not exceed the permissible level. Also the upper confidence interval of the mean or median does not exceed the permissible level. This also applies to the content of copper in soil, the average content of which expressed as a median (due to the lack of adjustment to the normal distribution) amounts to approximately 13% of the permissible level.

11.6.6. Thermal activity assessment

The key parameters presented in Table 11.7 summarise the analysis of the land surface temperature distribution. On the basis of these results it can be concluded that the area of the analysed heap does not show any thermal deviations from the wastelands and forest areas of the commune.

The analysis indicates that in comparison to the considered area higher temperatures of the land surface are observed for residential areas and the highest ones for currently operating industrial areas (local power plant and steelworks). Taking into account the above results it can be concluded that there are no exogenous processes responsible for heat release within the examined heap.

Table 11.7. Results of the statistical analysis of the surface temperature of the analysed heap and the Łaziska Górne commune

Area	Minimum [°C]	Maximum [°C]	Range [°C]	Average [°C]	Standard deviation [°C]
Dumpsite	-4.023	-3.429	0.594	-3.716	0.143
Commune	-5.617	3.527	9.144	-3.645	0.817

Source: IETU's calculations based on LANDSAT 8 satellite data

The direct temperature measurements carried out independently of the analysis of the land surface temperature during the drilling of the boreholes did not show any thermal activity of the considered heap.

11.6.7. Calculations of the volume and weight of the heap

In the calculations of the volume of waste collected in the heap the LIDAR data of the Numerical Terrain Model, the numerical map of the area of the heap and data on the thickness of the waste material obtained during the drilling of boreholes were used. The surface model and then the solids model were developed in several steps (Table 11.8). The obtained model of the thickness of waste stored on the heap is presented in Figure 11.4.

According to the calculated model, the area of the analysed heap is 24.687.50 m^2, and the estimated volume of the collected waste is 171.000 m^3. Assuming the bulk density of the tested material, based on own investigation and literature studies as 1850 kg/m^3 (Szopka et al 2007, Zapał and Ratomski 2007, IBDiM 2004), the amount of waste collected on the dump should be estimated at 317 thousand tons.

11.6.8. Characteristics of the stored mineral waste according to waste classification

According to the European Waste Catalogue (EWC) transposed to Polish law (Journal of Laws 2013.21) waste from mining activities related to the exploitation of hard coal is classified in group 1. Taking into account the results of physico--chemical tests, the analysed mineral waste does not show any characteristics of hazardous waste. The considered dumpsite is likely to contain waste coming directly from the extraction and enrichment of the hard coal output. Thus, the waste code assignment can be as follows (Table 11.9).

Table 11.8. Procedure for preparing a heap thickness model

Step 1	Based on the LIDAR data two terrain surface models were developed. M1 – the model of the currently existing land surface and M2 – the model of the land surface without the heap
Step 2	A 5-meter buffer around the border of the heap (polygon) was created
Step 3	The polygon created with the buffer was converted to a convex polygon
Step 4	The polygon was converted to lines with high vertex density (1 vertex per 1 meter of line) and the line was converted to points. For these points heights were read from the terrain surface model
Step 5	The heights at points were adjusted in such a way that the height course at the points retained the general trend existing in the area of the heap, i.e. the height drop towards NNE (bumps in the height course were removed).
Step 6	On the basis of the data on the height of the terrain at points prepared in this way a triangulation model of height was created which was simultaneously trimmed to the boundaries of the heap
Step 7	The triangulation model was transformed into a raster model with a resolution identical to the previously developed land surface model on the basis of LIDAR data. i.e. 0.5 m
Step 8	The preliminary model of the heap thickness was developed by subtracting from the height of the ground surface (M1 model) the height of the land surface without the heap (M2 model)
Step 9	The obtained volume model was corrected taking into account the actual thickness of the embankment in the drilled test holes and the differences in relation to the values at these points according to the preliminary model (Step 8)

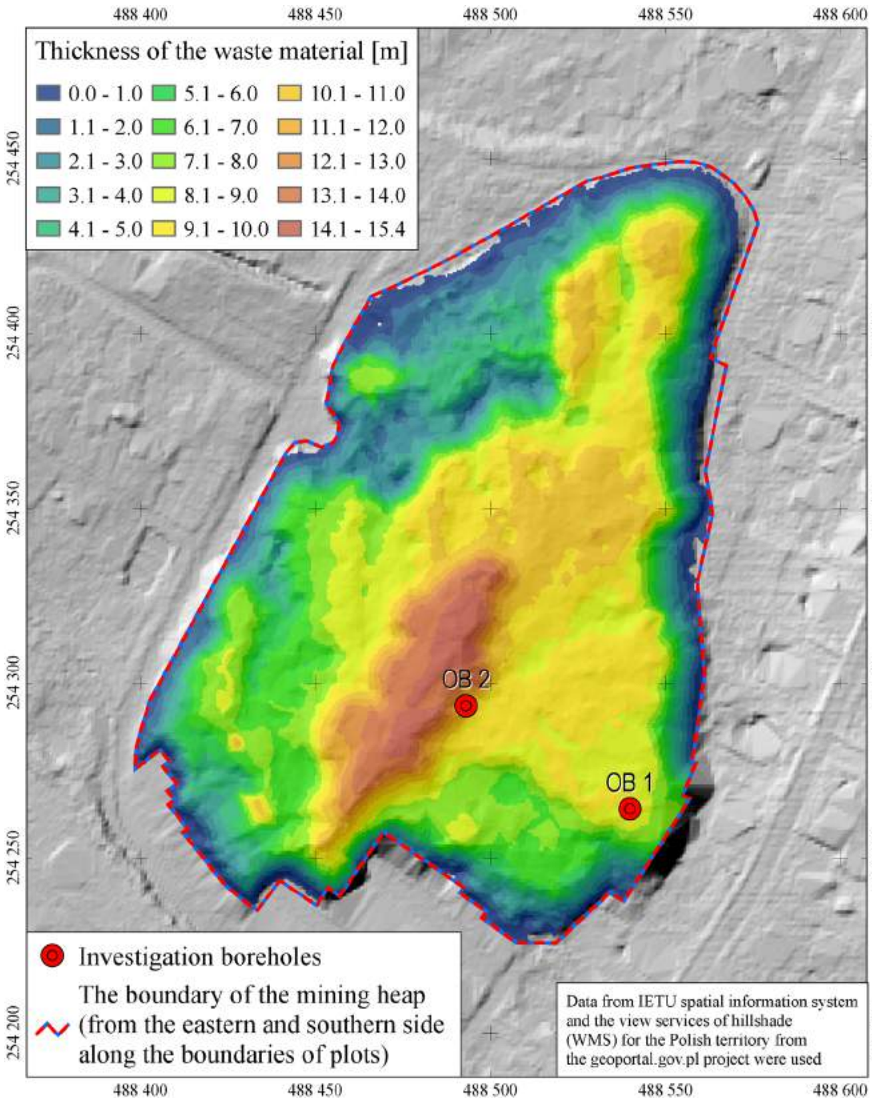


Fig. 11.4. Map of the thickness of the stored waste

Table 11.9. Waste characterisation according to EWC

Group 01	**WASTE RESULTING FROM EXPLORATION, MINING, QUARRYING, AND PHYSICAL AND CHEMICAL TREATMENT OF MINERALS**
Subgroup 01 01	Waste from mineral excavation
Waste code: 01 01 02	*waste from mineral non-metalliferous excavation*
Subgroup 01 04	Waste from physical and chemical processing of non-metalliferous minerals
Waste code: 01 04 08	*waste gravel and crushed rocks other than those mentioned in 01 04 07*

In principle, the collected waste is most likely a mixture of both mining and coal processing waste. Taking into account the fact that the heap was burnt-out in the past and the entire volume of waste was subjected to a secondary high-temperature physico-chemical process from both codes it would be more appropriate to classify the considered waste under the code 01 04 08.

11.7. Conclusions

The results of a comprehensive inventory of the post-industrial heap of unknown origin presented in this paper allowed to summarise the conducted investigations and draw up the following conclusions:

- waste deposition and the heap exploitation began between 1913–1918;
- as was proven by the results of the site inspection, historical analysis, macroscopic examination of the samples and physico-chemical tests – the inventoried waste comes from mining activities related to the exploitation of hard coal;
- simultaneously, due to low concentrations of zinc, cadmium and lead, the general characteristics of the deposited waste and the conclusions of the historical analysis non-ferrous metals metallurgy was excluded as a potential source of waste;
- in terms of geochemistry the analysed material meets the quality requirements for the current land use function, i.e. forest areas. This assessment takes into account the water permeability of the subsoil layer of the heap ($<1\times10^{-7}$ m/s);
- based on the age and the examined structure and colour of the stored waste, (brown-brick in the place of primeval dark grey or black), as well as the results of the performed investigations it can be concluded that in the past the process of burning-out the coal residues (contained in the deposited waste rock) must have taken place in the heap;
- the stored waste contains a negligible amount of carbon (as remains of hard coal). On average this value is 0.19% (median). This is also confirmed by the low level of LOI and heat of combustion;
- currently, the dumpsite should be defined as a burnt-out heap. No thermal activity of the heap was recorded. The area of the analysed dumpsite does not show any thermal deviations from the wastelands and forest areas of the commune;
- the waste stored on the heap can be classified under the waste code 01 04 08 (waste from physical and chemical processing of non-metalliferous minerals – waste gravel and crushed rocks other than those mentioned in 01 04 07);
- the performed calculations allowed to estimate the volume of the collected waste at 171 000 m^3 and its amount at approximately 317 000 tones.

As a result of the burning-out process the waste from the heap has more favourable physical properties than the primarily deposited slate. According to the overall assessment of soil contamination from the heap this material does not exceed the environmental standards. Taking this into account, the analysed material is a valuable raw material for the construction industry as the so-called alternative aggregates. Such aggregates are used, among others, in road construction. According to literature and branch requirements (IBDiM 2004, Machniak and Kozioł 2014), the so-called “red slate” (burnt-out slate) is the most desirable one for this purposes. The most common applications of the red slate are: a substructure, base surface and supporting material for the road construction (including the improved aggregates) and material used in the formation of slopes, embankments and surface levelling (Journal of Laws 2020.10). In the case of dismantling the heap for the obtained material the “end-of-waste” procedure may be carried out, specified in the Waste Act (transposed into Polish law from Directive 2008/98/EC) (Journal of Laws 2013.21). After the recovery process and meeting the formal requirements specified in the Waste Act this material loses the waste status and simultaneously becomes a product. Such an approach complies with the national and EU ecological policy and CE principles where one of the assumptions is avoidance of waste, promoting secondary raw materials and their circular use in the environment. Moreover, in the case of liquidation of post-industrial heaps a measurable effect of the CE is the recovery of usually large areas which may be circularly converted into new land-use functions.

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PL ISSN 0208-4112
ISBN 978-83-60877-19-7