

Article

Towards Sustainable Modes for Remote Monitoring in Waste Management: A Study of Marginalized Urban Areas in Romania

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Abstract: Implementing circular and carbon-neutral waste management practices is essential for promoting environmental sustainability and public health. This is particularly critical in marginalized areas, where effective waste management strategies play a pivotal role in addressing environmental challenges, promoting community well-being, and fostering sustainable development. The article will explore waste management in marginalized urban areas in an integrated manner, exploring key European research domains: waste management, housing in informal settlements, and spatial information. We examined 37 Local Development Strategies (LDSs) for marginalized urban areas (MUAs) in Romania to determine whether they incorporate waste management measures. In addition, we used QGIS along with imagery accessible on the European Space Agency's platform. This supplies Copernicus Sentinel-2 satellite data. We referred to a specific urban area, namely the Municipality of Turda, selected from the endorsed LDS, where the illegal landfills are present. Based on the data presented in the LDS and confirmed with the in situ verification or remotely using street view platforms, we have determined that the identified areas indeed contain illegal waste deposits. To validate these findings, the methodology employed, along with observations and results from the Turda study area, can be extended to other territories and marginalized urban areas.

Keywords: waste management; marginalized urban areas; illegal waste dumps; monitoring



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1. Introduction

The rapid urbanization and unplanned growth of many cities have given rise to infrastructural challenges. These challenges have, in turn, hindered the ability of national and municipal governments to meet the increasing demand for improved household waste management service levels [1–3]. In developing countries, waste management professionals grapple with issues, such as the ongoing expansion of slums [4], insufficient general infrastructure [5], limited budgets [6], corruption, ineffective educational measures [7], and a lack of trust within communities toward government initiatives [8]. As per the findings of [9], who conducted research on municipal solid waste management in Yaoundé, Cameroon, several challenges hinder suitable waste management and long-term sustainability in developing countries, namely the distance to waste disposal facilities, the lack of infrastructure, the absence and non-involvement of stakeholders in the planning and decision-making process, the absence of long-term waste management strategies, unskilled staff, insufficient coordination between authorities and local workers, and a low level of concern about sustainability.

Marginalized urban areas, often referred to as MUAs, are characterized by poor living conditions, underdeveloped technical and infrastructure facilities, a population with low incomes, predominantly young people, and a low level of education. In many cases, the legal status of lands and housing is uncertain, and the level of sanitation is low [10–12]. Residents in MUAs have the lowest level of connection to sanitation services [13,14].

Despite Romania's commitments to improving living conditions in informal and marginalized settlements through European agreements, such as the European Social

Charter and the Vienna Declaration on Informal Settlements in South-Eastern Europe, authorities have neglected these areas. Recent efforts to assess needs in Marginalized Urban Areas (MUAs) have largely overlooked cleanliness and illegal waste dumps, leading to environmental pollution and heightened health risks for residents [15–18]. This sustains the negative perception of disadvantaged residential areas. Inadequate waste management presents multifaceted challenges, including the burning and dumping of waste, often used for heating homes or, in some cases, disposed of through burning [19], which releases toxic gases into the atmosphere, leading to health issues, like skin allergies and cancer. Improper incineration also emits harmful chemicals, worsening air quality and causing respiratory conditions and skin irritations [20]. Additionally, waste dumping in vacant lands contributes to the spread of diseases, such as dengue fever, diarrhea, and malaria, creating breeding grounds for disease vectors, like mosquitoes, and contaminating water sources [21]. Therefore, implementing effective waste management practices is essential to safeguard human health and the environment, minimize disease transmission, and ensure a high quality of life.

Remote sensing (RS) has been employed in solid waste management for various purposes, such as identifying suitable locations for waste disposal landfills, assessing the ecological impact of covered waste, and monitoring waste landfill areas [22,23]. In a study conducted in the urban regions of Suzhou city and Wuxi in China, researchers [24] utilized a Geographic Information System (GIS) database in conjunction with RS techniques to analyze five waste sites. Previous work by [23] involved the use of satellite data and aerial images to identify suitable locations for waste disposal in underground corridors. Subsequently, Zhao et al. [24] utilized data from field sensors and NASA's Aqua and Terra satellites to conduct an ecological study, assessing pollution and the recovery status for the environmental appraisal of waste dumping.

Therefore, to eliminate illegal waste dumps, mapping and monitoring are essential, and the use of spatial information is a feasible option. Geospatial technologies, such as Geographic Information Systems (GISs), were not employed so far to map locations where illegal waste dumps have been established and to monitor their evolution over time in MUAs. This spatial information can provide authorities and organizations with effective tools for making informed decisions in managing and properly disposing of illegal waste dumps. It can also facilitate law enforcement efforts related to waste management regulations, helping to prevent the proliferation of these unwanted deposits and protecting the environment [25–27].

The issue of waste management in marginalized urban areas needs to be approached globally, taking into consideration all stakeholders and seeking integrated solutions that encompass social, economic, and environmental aspects. This approach requires collaboration among local authorities, communities, non-governmental organizations, the private sector, and other stakeholders [28,29].

In response to the needs of marginalized communities, the European Commission has adopted the concept of Community-Led Local Development (CLLD). This strategy gives precedence to a bottom-up approach, encouraging partnerships to foster collaboration among the public sector, private sector, and civil society. The main objective is to create and implement an integrated development strategy. Originating from the LEADER program, which was implemented in rural areas from 2007 to 2013 [30], the CLLD instrument is considered applicable to urban areas with a population of less than 150,000. The available funds, comprising financial support from the European Regional Development Fund (ERDF) and the European Social Fund (ESF), can be combined to bolster the Local Development Strategy (LDS) [31].

Local Action Groups (LAGs), established in specific geographic areas within cross-sectoral, area-based partnerships for CLLD [32], play a pivotal role in this instrument. It serves as an essential component of the local development strategy, which is generated through the identification of target areas and populations, inclusive of a SWOT analysis, and follows for conventional steps of local development strategy formulation [33].

In Romania, the CLLD program allocates funding to two types of Local Action Groups (LAGs): (1) LAGs representing communities in Municipalities with populations exceeding 20,000 (currently, 37 urban LAGs have received funding); (2) LAGs serving rural areas and cities with populations below 20,000, consisting of 239 rural LAGs and 14 Fisheries Local Action Groups (FLAGs). Rural LAGs typically prioritize collaboration across different areas, involving the private sector and non-governmental organizations to address specific challenges in local development. On the other hand, urban CLLDs concentrate predominantly on addressing the needs of marginalized communities, placing a specific focus on mitigating the vulnerability to poverty and social exclusion, particularly within the Roma community.

The limitation of previous research results, which this work addresses, is the lack of a holistic perspective on waste management practices in MUAs. Prior studies may have focused on individual aspects, but the integrated examination of waste management within the broader context of informal settlements and spatial information is relatively scarce. The article seeks to explore waste management in disadvantaged urban residential areas in an integrated manner. This involves exploring three key research areas at the European level: (i) waste management, (ii) housing in informal settlements and marginalized urban areas, and (iii) spatial information.

Examining the gaps and constraints in the literature cited above, we formulate two research questions: (a) is waste management in MUAs a priority for LAGs funded through the CLLD instrument in Romania? (b) Does spatial and remote sensing monitoring serve as an effective approach to monitoring illegal landfills in the MUAs?

To address these questions, two research objectives have been formulated: (1) analyzing waste management in MUAs based on the 37 local development strategies under the CLLD mechanism, addressing research question (a), and (2) assessing the feasibility of using GIS and remote sensing tools as a response to research question (b).

The innovation of this work lies in its integrative approach to waste management in MUAs within the European context. The article combines insights from waste management, informal settlement housing, and spatial information to address environmental challenges. The use of geospatial technology, such as QGIS and Copernicus Sentinel-2 satellite data, adds a novel dimension to the study. Geospatial analysis provides a dynamic and visual means to assess waste management practices, offering insights that traditional methods might overlook, while the integration of spatial information enhances the precision and reliability of the findings. The examination of an LDS for MUAs in Romania allows for a macro-level analysis of urban development plans, providing a strategic lens to assess how waste management is incorporated into broader developmental frameworks. The subsequent validation through on-site verification and remote sensing techniques contribute to a comprehensive understanding of the waste management scenario in these areas. The methodology employed in the Municipality of Turda, Romania, can be extended to other territories and MUAs. This emphasis on scalability and transferability underscores the practical utility of the study's methodology in addressing waste management challenges in diverse geographical and socio-economic contexts.

Our paper is organized as follows: in Section 2, we outline the methods and materials used for analyzing LDSs in marginalized urban areas in Romania and the spatial investigation method. Section 3 presents the research findings, detailing the results of analyzing 37 LDSs concerning waste management in MUAs. This section also discusses potential approaches for the remote monitoring of illegal waste dump deposits with a focus on the Turda area. Section 4 concludes the paper.

2. Materials and Methods

2.1. The First Research Objective

To address the first research objective, the first part of the methodology was to acquire the 37 endorsed Local Development Strategies corresponding to 36 urban areas from the official websites of LAGs. Formulated for execution during the programming period

2014–2020 and applicable until 2023, the majority of these strategies were devised between 2015 and 2016, undergoing minimal subsequent modifications. Leveraging these strategies, LAGs successfully obtained European Union funds to support their respective projects and activities. The selection of these initiatives occurs through local grant competitions, which are supervised by LAG decision councils comprised of representatives from public authorities, entrepreneurs, local non-governmental organizations, and citizens. Figure 1 presents the geographical distribution of the existent LAGs attained in Romania: 37 distinct LAGs in 36 urban areas (because two are situated within the same administrative-boundary).

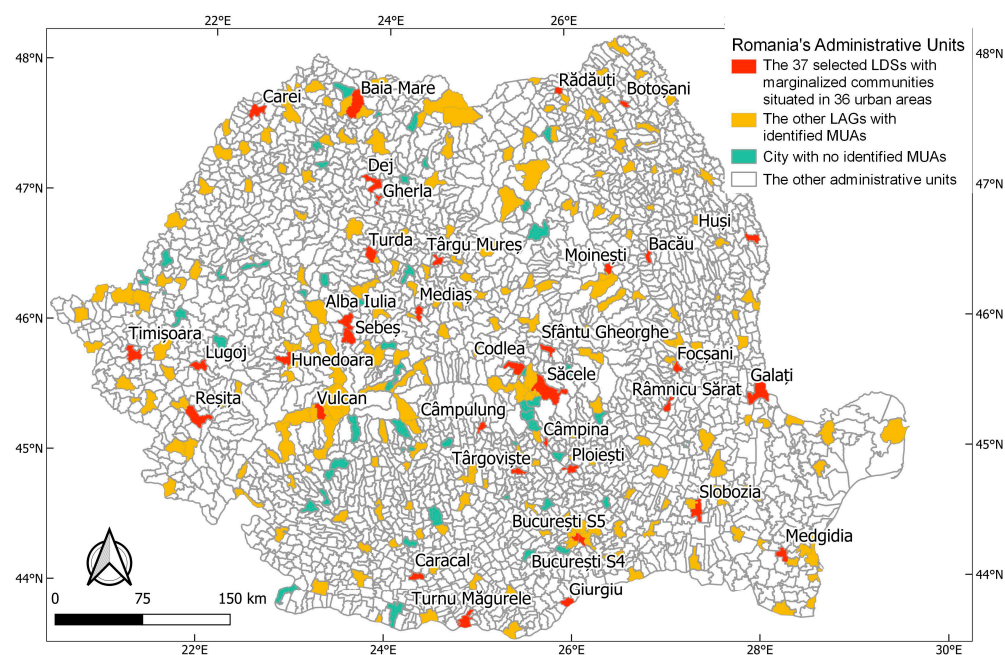


Figure 1. LAGs in Romanian urban areas—with the emphasis on the MUAs present in LAGs with approved LDSs as developed from the Atlas of Urban Marginalized Areas [14,34]. Source: Produced by authors.

The analysis of waste management in the LDSs was conducted considering 3 levels: (a) analysis of needs and problems of the population in the LDS territory and SWOT analysis; (b) the LDS objectives; (c) the LDS action plan.

2.2. The Second Research Objective

The main point of this objective is illegal waste dumpsite sustainable monitoring, the regular confirmation of their presence and location, activity which for an Environmental Department would be very costly [27]. One of the World Bank's policy recommendations in 2021 in the sphere of contending illegal debris include systematically monitoring waste data [35]. There is a possibility of locating and supervising these actually small illegal waste deposits following the classical methods, but in the context in which each country needs to regularly locate, count, and continue to monitor the illegal waste deposits, it may take "several years to scan the satellite map of a single country manually" [27]. Even though an automated method would be superior in performance (time) based on remote sensing techniques applied to illegal waste deposits' detection and monitorization, there are also some drawbacks. Firstly, "the existing literature has not publicly released specific global datasets for classified dumpsites, making it challenging for researchers and institutions wishing to investigate further" [27,36]. Secondly, the limits and the inflexibility of the older or newer algorithms, and lastly the low resolution of openly available satellite images, make the labor qualification and costs rise to very high and non-sustainable. The solution consists of the innovative methodology we propose in this paper, in its integrative approach of waste management in MUAs, proposing not a manual but a sustainable expert-knowledge

approach, based on an assessment through geospatial technology employing GIS analysis, geospatial tools, and geo-algorithms, which combine insights from waste management, informal settlement housing, and GIS. The expert-knowledge model we propose contributes to a comprehensive understanding of the waste management scenario in these areas and provides the possibility of being practical and sustainable.

The methodology we propose in Figure 2 is intended to achieve the second research objective, namely to assess and to derive an optimal and efficient way to monitor the presence of illegal waste disposal sites. The methodology we designed is flexible, integrative, and sustainable as it can be adapted to monitor a variety of MUAs and can incorporate a number of different data types and sources, such as satellite or aerial imagery, and numerous types of thematic information, such as the open vector layers from the spatial data set TopRo50 available under the Open Government License on the Romanian Open Data Geoportal [37] in conjunction with potential imagery classifications and expert knowledge geospatial analysis of the illegal waste deposits.

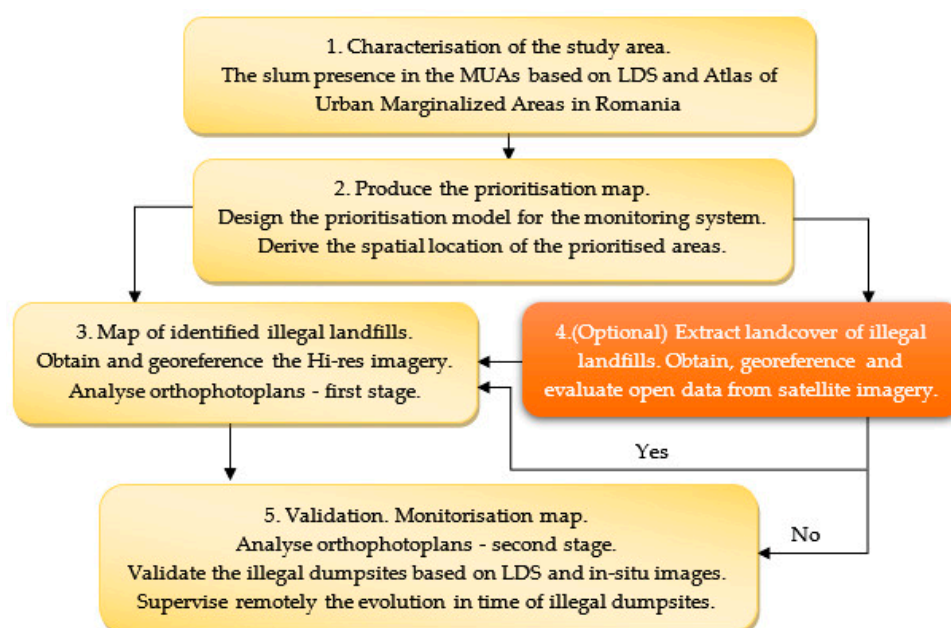


Figure 2. The methodology for remote monitoring of illegal waste deposits.

2.2.1. Characterization of the Study Area

The World Bank's report (Atlas of Urban Marginalized Areas in Romania or Atlas) on the "Elaboration of integration strategies for urban marginalized communities: the atlas of urban marginalized communities in Romania" [14] defines the cities containing marginalized communities identified as MUA. The Atlas specifies five types of urban disadvantaged areas and the urban 'pockets' of urban marginalization, of which we identified only two areas suitable for our study: slum-type areas with houses and slum-type areas with improvised shelters. These two types are of special interest due to such socio-economic parameters that can determine the emergence of illegal waste deposits. Thus, these communities are situated on the outskirts of the cities with extremely poor populations, which may include Roma and non-Roma. In addition to low-quality housing, many additional improvised shelters are often made of plastic, paperboard, wooden frames, etc., and are very small but accommodate large families with many children. These types of areas are usually located next to a river or train tracks. In these slums, the community tends to be spread over a large territory, and there is little or no infrastructure. There is also a problem of a lack of identity papers, property, and land documents, which seems to be common to all slum areas. The LDSs of a city covers an area that consists of its entire territory, and these strategies also identify MUAs that overlap with one or more identified census sectors as

marginalized in the Atlas [14]. The LDSs will be used to adjust the proper identification of the MUAs and as a base for the in situ confirmation of the presence of illegal waste deposits.

2.2.2. Production of the Prioritization Map

There are various factors that can influence the presence of illegal waste disposal areas [26,38], which can be accounted for in the prioritization of monitoring sites. In this paper, we propose the following five categories of factors that can be used to probe the geography of illegal waste deposits, as outlined in Table 1.

Table 1. The five categories of factors proposed to probe the geography of illegal waste deposits.

Categories of Factors	Description
Economic	Income (per capita), employment rate, the affordability of legal waste services: people cannot afford to pay for the services of legally disposing of the waste due to the lack of income plus the level of taxation
Environmental	Availability of waste facilities or services, the presence of industrial areas: people do not have easy or a fast enough access to the disposal site, or the services do not cover certain types of household waste. Moreover, there are many dismantled industrial facilities that serve as both causes and effects of illegal waste disposal
Landscape-based	The presence of water, the presence of forest: the presence of certain landscape elements allows for easier disposal without the risk of being discovered
Social	Demographics (big families), sociocultural acceptability of illegal waste disposal: people with a lack of means and time to legally dispose of certain categories of waste, also people with a sociocultural lack of will to do it
Infrastructure-based	The presence of available communication roads, the presence of railways, remoteness of illegal waste disposal potential locations (city's outskirts): some waste, the larger quantitative one, must be carried to the illegal disposal site with a vehicle, which means that there must be some sort of road that makes this transportation possible, making it also more remote from the city since the complaints and risk of discovery are lesser

These categories will then be spatially identified and mapped using GIS tools. The main tool used for this activity was QGIS 3.28.15-Firenze, a free and open-source Geographic Information System software.

To identify the criticality of the five types of factors described above, factors that can influence the presence of illegal waste disposal areas, we introduced the employment of the DEMATEL (Decision Making Trial and Evaluation) technique for the remote GIS-assisted spatial decision support model for illegal waste deposit monitoring. The DEMATEL analysis referred to the five-point Likert scale [39], from 0 (no influence) to 4 (very high influence). The values of the degree of importance of each factor in the entire system and the values of the net effects of each factor on the system based on our experts' assessments were introduced to develop the influence matrix presented in Table 2. C represents the summed values of a column to quantify the total influence the other factors have on each critical factor. R represents the summed value of each row in the total influence matrix. C+R represents the degree of importance a certain critical factor has in the entire system and R-C represents the effects the respective factor contributes to the system. In our case, environmental and social factors are ranked in the first places in terms of the degree of importance, while the other factors (economic, landscape, and infrastructure) were placed last. Environmental and infrastructure factors have the largest cause, while the landscape, economic, and social factors are regarded as effects. The infrastructure-based factor (the presence of available communication roads, of railways, remoteness of possible

illegal dumpsites at city's outskirts) is the factor less influenced by others according to the experts' assessment, while the economic factor (the affordability of legal waste services, employment rate, income, level of taxation) is the most influenced. Our findings were compared with existing peer studies; thus, according to [40], incentive policies, norms and culture, availability and charge of waste facilities, regulations, and penalties have the lowest importance and correspond to our factors placed in the economic category, which also resulted as being less important in our matrix. Market maturity in the waste cycle and the willingness and attitude of people have the largest importance in [40], which corresponds to the social and environmental categories that we defined, and which also resulted as being less important in our case. The investments of capital and the willingness and attitude of people have the highest sum of cause in the mentioned study, categories which can fit to our environmental and infrastructural factors, again turning out corresponding results of being cause factors.

Table 2. The influence matrix of the critical factors that can influence the presence of illegal waste disposal areas determined with the DEMATEL method.

Factor	C	R	R+C	R-C
Economic	4.226	3.345	7.57	−0.881
Environmental	3.857	4.763	8.62	0.906
Landscape	4.054	3.857	7.911	−0.197
Social	4.305	4.077	8.383	−0.228
Infrastructure	3.422	3.821	7.243	0.399

In order to spatially prioritize certain areas, we proposed a set of buffer zones [41,42], around the spatial factors identified as critical in the geography of illegal waste deposits. The distances suggested in Figure 3 were chosen based on relevant cover areas—larger for landscape and big infrastructure and smaller for the human scale of mobility. Also, the buffer zone ranges necessary to determine the potential area of illegal waste disposal were established based on past studies conducted on solid waste disposal sites and at the same time taking into account the order in the prioritization sequence in Table 2. Thus, we considered the buffer zones to be less than or equal to the site selection distances identified in previous studies, since usually the illegal dumping is more convenient in terms of distances, as, for example, in the case of [43], only 39% of respondents indicated that they would travel further than 1 km to drop off their waste. Thus, extrapolating from different studies for disposal site selection [44,45], we adopted the 1100 m buffer distance for industrial buildings and sport grounds and 1000 m for a railway line [46]. The 1100 m distance is an average parameter between the 1000 m and 700 m distances mentioned in the literature and the 1500 m from the “transport-related walking” in the “walking distance” paradigm [47]. Due to their 2nd place in the prioritization sequence, the buffer distance from the railway was limited down to 800 m [44,48], and likewise, the buffer from the roads, as in their case one study [48], found that a distance of 1 km works best. In the [48] study, it was identified that dumpsites are more likely to appear in proximity to a specific road type, and in the study of Bratislava, 20% of the illegal waste deposits were found within 100 m of the main road or rather next to the main road. However, the 80% of dumpsites are not reported near the side of the roads, but the further away from a road was considered a better predictor of where a dumpsite might occur. Thus, wastes are estimated to be too large to be manually transported, confirming that the largest dumpsites tend to be further away from motorways [48,49]. To account for the 20% of dumpsites near the roadside [48] we selected the 100 m buffer distance for streets, and therefore, to add up to the 100% dumpsites, these buffer zones (for roads and streets), pertaining to the 2nd critical factor—infrastructure—were united into a single buffer. Some studies [43,50] assert that people are willing to walk the usual “walking distance” of 400 m; hence, for the illegal waste travel disposition, the selected buffer distance around the slum area was 400 m. The scenario adopted in our paper has established the buffer zone distance of 700 m for

rivers and forests, which is an average parameter between the 1000 m and 700 m distances mentioned in the literature and the 400 m from the “walking distance” paradigm identified in other studies [47]. From a spatial point of view, the 4th and the last critical factor in Table 2 are the same, so they received the buffer distance according to the lowest priority.

	BufferIndustrySport1100	1100 m for industry and sports ground
	BufferRoads800	1000 m for roads
	BufferStreet100	300 m for streets
	BufferRailway800	800 m for railway
	BufferRiver700	700 m for forest
	BufferForrest700	700 m for river
	BufferMUAs400	400 m for MUAs

Figure 3. The distance for each buffer around the spatial key factors that determine the geography of illegal waste deposits. Source: elaborated by the authors.

2.2.3. Map of Identified Illegal Landfills

For the suitable resolution for this kind of observation of illegal waste disposal sites, based on the fact that the debris is in relatively small quantities and dimensions and has a relatively large distribution in situ, high-resolution images are the first option among remotely sensed imagery [26]. The option in our case is the use of orthophotoplans obtained from the Geoportal operated by the National Agency of Cadastre and Land Registration of Romania—the Address View Application named RENNS [51]. The RENNS web application basemaps’ functionality is accessible from its web interface in the form of a collection of base maps offered as an image service. Available base maps open up with an orthophotoplan-type map and may include satellite images, topographic maps, etc. [51]. The priority areas are identified in the orthophotoplans based on expert-based interpretation in order to establish the areas of potential illegal waste dumps [52]. The presence of illegal waste disposal sites in the images is visually interpreted based on the expert-knowledge analysis of the orthophotoplans in the same way as for the semi-automatic methods of interpretation that employ supervised classification by selecting the regions of interest for training or verification. The visual interpretation results in a GIS layer covering the areas susceptible to illegal waste disposal on an observation basis.

2.2.4. Extract Landcover of Illegal Landfills (Optional)

At this stage, the expert-based analysis examines their suitability in demonstrating the presence of illegal waste deposits. The highest resolution among the open data satellite coverage suitable for the purpose are the images available on the European Space Agency’s platform providing the Copernicus Sentinel-2 satellite data.

2.2.5. Validation. Monitorization Map

The second-stage analysis of the orthophotoplans checks the overlap of the potential illegal waste disposal land cover with the priority areas. The resulting illegal waste disposal sites will be confirmed with the help of the LDSs, which usually present the information related to the illegal waste deposits in the slums or other MUAs’ areas and will be confronted with the in situ inspection.

3. Results and Discussion

3.1. Examination of Waste Management in MUAs

The examination of the LDSs has brought to light several significant issues pertaining to the MUAs. These areas exhibit a range of challenges, including substandard housing conditions, underdeveloped technical and sanitary infrastructure, and a population characterized by low educational attainment. Additionally, many residents in these areas have large families, contributing to a higher population density. One prevalent concern is the uncertainty surrounding the legal status of land and housing in MUAs, which poses

potential obstacles to development and resource allocation. Moreover, the overall level of sanitation in MUAs is noted to be low, indicating insufficient access to essential services and facilities. This deficiency can have cascading effects on public health and the general well-being of the residents. In essence, the analysis underscores the multifaceted challenges faced by MUAs, highlighting the urgent need for comprehensive and targeted interventions to address housing, infrastructure, education, and legal uncertainties to uplift the living standards of the affected populations.

According to the Atlas of Marginalized Urban Areas [14], the MUAs are poorly equipped with urban utilities compared to the rest of the settlements: 30% of households are not connected to the water supply network (compared to 6.3% at national level in urban areas), 33% of households are not connected to a sewage system (compared to 6.9% at national level in urban areas), and 4.1% of households do not have electricity (compared to 0.4% as the national urban average). The majority of the population has utility debts (electricity, water, sewerage, waste collection), and in many cases, they have been disconnected from these utilities [14].

The first level of the analysis of LDSs involved scrutinizing the challenges and requirements concerning waste management within the MUA territory, based on the needs and the problems of the population and the SWOT analysis. It has been determined that all MUAs are confronted with at least one of the following situations:

1. Inadequate sanitation levels are observed in commune spaces and basements of apartment buildings, along with deficiencies in the green areas and vacant lots. Additionally, in certain instances, rainfall exacerbates the issue by carrying household waste from neighboring areas upstream.
2. MUAs exhibit a reduced level of connectivity to sanitation services compared to other parts of the city, attributed to several contributing factors:
 - The absence of public sanitation services within the MUAs, which contributes to a lower degree of connection to a formal sanitation infrastructure.
 - The limited number of contracts with sanitation operators, primarily due to the low-income levels of the population residing in the MUAs. A small percentage of residents in these areas hold permanent employment, with the majority often engaged in precarious work as daily laborers or in informal, non-contractual positions. Their economic reliance is often tied to social benefits for sustenance.
 - The sanitation service faces interruptions stemming from accumulated debts related to the payment of sanitation taxes. In the MUAs of 67% of the analyzed LDSs, where data were available, the population experiences utility debts exceeding the national average, as highlighted in [53].
 - The absence of land or housing title deeds poses a significant challenge as it renders residents unable to enter into contracts for utilities, including sanitation services.
 - Access to certain MUAs, which is impeded by inadequate, unpaved, and/or extremely narrow roads, hindering the passage of sanitation vehicles.
3. Absence of hygiene education and cleanliness practices within both homes and the community, leading to instances of litter being discarded out of windows, near garbage bins, or in the immediate living areas.
4. Shortcomings in waste collection include inadequate and/or improvised bins coupled with prolonged collection periods.
5. The absence of segregated waste collection persists despite some MUA residents generating income through the sale of recyclable materials. Unfortunately, non-valuable fractions are often indiscriminately mixed with other waste.
6. Use of waste for heating homes. In 74% of the analyzed LDSs where data were available, the percentage of inadequately heated dwellings in these areas exceeds the national average [53].

7. The presence of illegal landfills, including within sanitary protection zones, contributes to environmental pollution, heightens the prevalence of illnesses among the local population, and sustains the unfavorable image associated with the ZUMs.
8. Global studies show a direct link between poor waste management and an increased incidence of disease [21]. The increased occurrence of chronic diseases among MUA residents is attributed, on the one hand, to improper waste management practices, such as incineration and dumping. On the other hand, poor housing conditions, poverty, and hunger also play a role in exacerbating health issues.

Although all the analyzed strategies signal issues related to waste and sanitation in the MUAs, only two strategies (Alba Iulia and Câmpulung Muscel) include a specific objective related to waste management (the second level of the analysis).

As for the action plan (the third level of the analysis), 21 LDSs (57%) have prioritized measures and interventions related to waste management. The 21 strategies have one or two measures primarily focusing on public education for cleanliness, community involvement in sanitation efforts, and the organization of voluntary selective waste collection campaigns for residents. Only four LDSs have measures related to the development of waste storage and collection systems, including the establishment of waste collection platforms. None of the strategies include measures concerning illegal waste dumps. The detailed breakdown of measures and interventions in the action plan of LDSs is presented in Figure 4.



Figure 4. Prioritized measures and interventions related to waste management in LDSs.

The limitation on measures aimed at enhancing waste management in MUAs could be linked to the funding structure of projects within LDSs through only two operational programs: the Regional Program and the Human Capital Program. Projects targeting other aspects of waste management would need to secure funding from internal sources or alternative operational programs. In the case of five strategies, priority measures are financed from internal sources, primarily focusing on educating the population, engaging them in greening initiatives, and establishing collection platforms.

Inadequate sanitation in MUAs not only leads to their negative characterization but also causes health issues among the population and adds to environmental pollution. Surprisingly, waste management is not prioritized by the LAGs responsible for developing the LDSs. This finding directly responds to the research question (a).

3.2. Monitoring of Illegal Waste Deposits with Remote Sensing Techniques

The applied method for the remote monitoring of illegal waste deposits led to attainable results obtained at each phase of the methodology, results which will be detailed in the following sections. The study was conducted in a specific urban area, namely Turda Municipality. This site was selected on the basis of the information on waste management in the MUAs analyzed in the LDS, one of the 37 endorsed LDSs. The presence of slums in

the Atlas with the confirmation of illegal waste deposits and MUAs in the LDS determined two specific locations (Section 3.2.1.): in the area of the Margaretelor MUA, where we established the East Study Area, and in the area of the industrial MUA, where we established the South Study Area, as it is reflected in Figure 5.

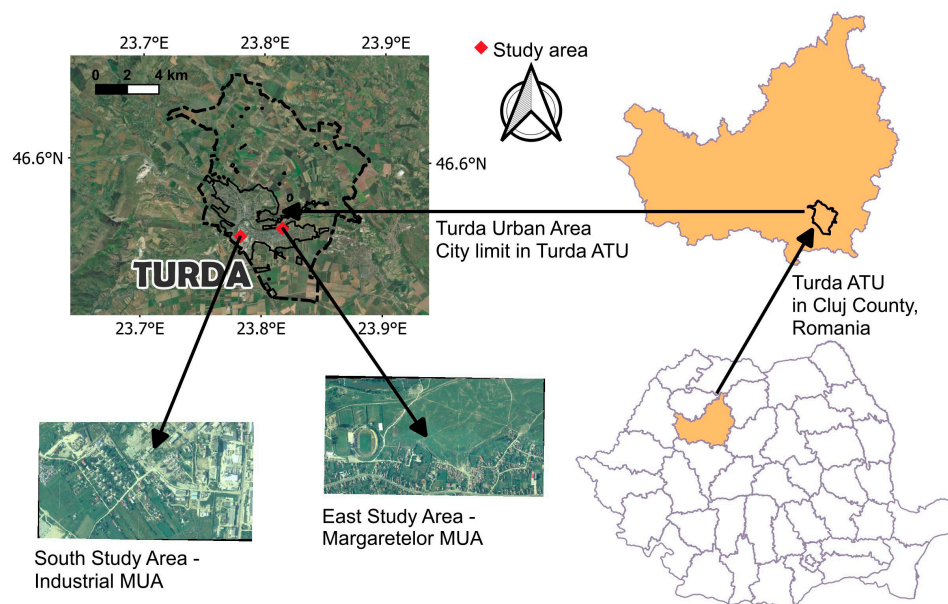


Figure 5. The East and South Study Areas in Turda Municipality, Cluj County, Romania. Source: adapted by the authors based on the data from [34,51,54,55].

3.2.1. Characterization of the Study Area

Turda is a city situated in the North-West Region of Romania, which is identified by the Atlas of Urban Marginalized Communities in Romania [14] to be one of the cities to include such MUAs, with the spatial footprint determined based on the census sectors. The LDS for Turda (elaborated by LAG “Urban Turda” and updated in 2020) [56] identifies five MUAs, which overlap with one or more identified census sectors as marginalized in the Atlas [14]: MUA 1 (Margaretelor) in the eastern extremity of the city, MUA 2 (bloc ELTA) in the south-east of the city (near Youth Park), MUA 3 (Victoriei) in the east city, MUA 4 (Industrial) in the southern part of the city (south of the Arieș River), and MUA 5 (Barbu Lăutaru) to the north near the city center, towards Turda Salt Mine. We identified that only MUA 1 and MUA 4 intersect the slum-type areas identified in the Atlas, as we show in Figure 6.



Figure 6. MUAs identified in the Atlas of urban marginalized communities in Romania, MUAs identified in Turda’s LDS, and the MUAs of their intersected areas. Source: accentuated and adjusted by the authors based on [14,34,37,56].

3.2.2. Production of the Prioritization Map

The social and economic key factors were identified in the two selected MUAs in Turda, based on the diagnostic analysis of the needs, resources, and problems of the population of the SDL territory in Turda [56]. In relation to the employment, economic environment, and social protection, the unemployment rate is about 30% in both MUAs, almost ten times larger than the national average in 2021, and as for the working population in the MUAs, they were employed with the minimum wage. We designed the prioritization model established on the basis of the DEMATEL analysis which assesses the criticality of each factor, and it is detailed in Table 3 with the following priority sequence:

Table 3. The prioritization matrix of the five categories of critical factors influencing the presence of illegal dumps in Turda.

Factor Criticality	Description of Spatial Identification
1. Environment	The presence of industrial areas; the sports ground was included in this category due to the impact of a big construction land not so frequently used at the outskirts of the city [48]
2. Infrastructure	The presence of available roads and railways and the remoteness of illegal waste disposal possible locations due to the slum areas' location at the city's outskirts [48]
3. Social	The two types of slums (slum areas of houses and/or improvised shelters) since these communities, which include Roma and non-Roma demographics, tend to consist of large families. Also, the lack of identity and property documents are indications of conduct inclined toward the sociocultural acceptability of illegal waste disposal [14,38,56]
4. Economic	The two types of slums—slum areas of houses and/or improvised shelters, since these communities have an extremely poor population [14,42,56]
5. Landscape	The presence of water and the presence of forest, especially the presence of the Arieş river, which introduces a difference in the level of terrain, while the forestation area is very small [48]

The geospatial analysis was associated with the DEMATEL matrix through the assignment of the spatial GIS buffer layers obtained via geoprocessing to the critical factors introduced in Table 3: the industry and sports ground layers were considered to pertain to the Environment factor, the railway, roads and street layers to pertain to the Infrastructure factor, river and forest layers to pertain to the Landscape factor, and finally the MUAs layer to pertain to both the Social and the Economic factors, as illustrated in Table 4.

Table 4. Spatial layers of representation of the critical factors introduced in the DEMATEL analysis and the prioritization model.

Critical Factor	Spatial Representation
Environment	industry and sports ground layers
Infrastructure	railway, roads and street layers
Social	MUA layer
Landscape	river and forest layers
Economic	MUA layer

These five critical factors were also spatially identified in Turda, based on the description in Tables 3 and 4, and are presented in Figure 7.

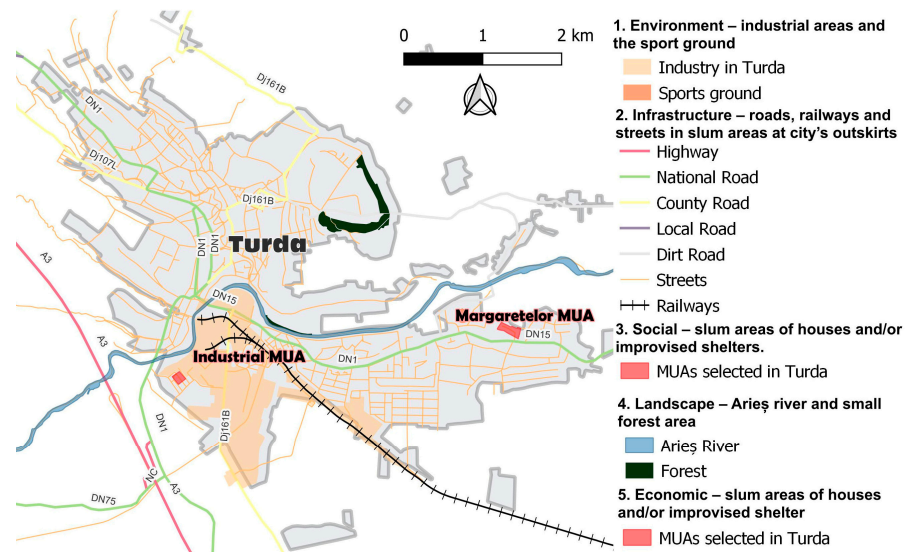


Figure 7. Spatial distribution of the five categories of critical factors influencing the presence of illegal dumps in Turda. Source: elaborated by the authors based on [34,37,56].

The distance for each buffer is expressed in meters and the resulting buffer areas were obtained by means of conducting a geo-analysis with the employment of geoprocessing tools, as indicated in Figure 8.

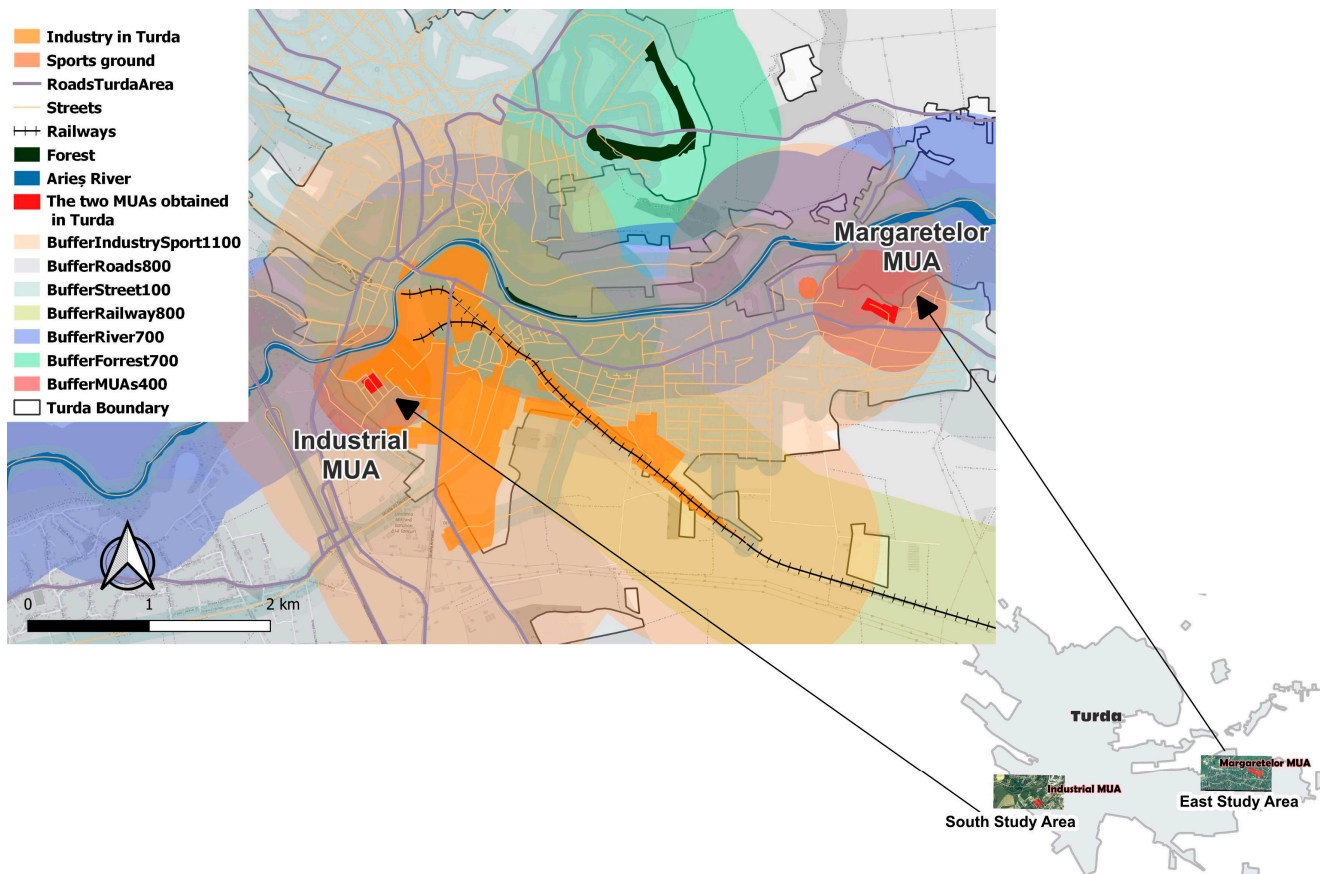


Figure 8. The seven buffer areas around the spatial factors identified as critical based on the geography of illegal waste deposits. Source: elaborated by the authors.

The prioritization method consisted of the geospatial analysis performed using geoprocessing tools to intersect the MUAs' buffer area with the other remaining six spatial buffers ordered in the prioritization sequence of the model in Table 4 and thus obtaining the areas with a high possibility of illegal waste disposal. The intersection geo-algorithm with each of the other buffer layers was performed on the MUAs' buffer area as it is considered the generating focal spot since the mean value of relation in the DEMATEL analysis pertains to the Social factor. These operations resulted in the identification of two priority areas with a high possibility of illegal waste disposal: the South Priority Area (SPA) and the East Priority Area (EPA), as shown in Figure 9.

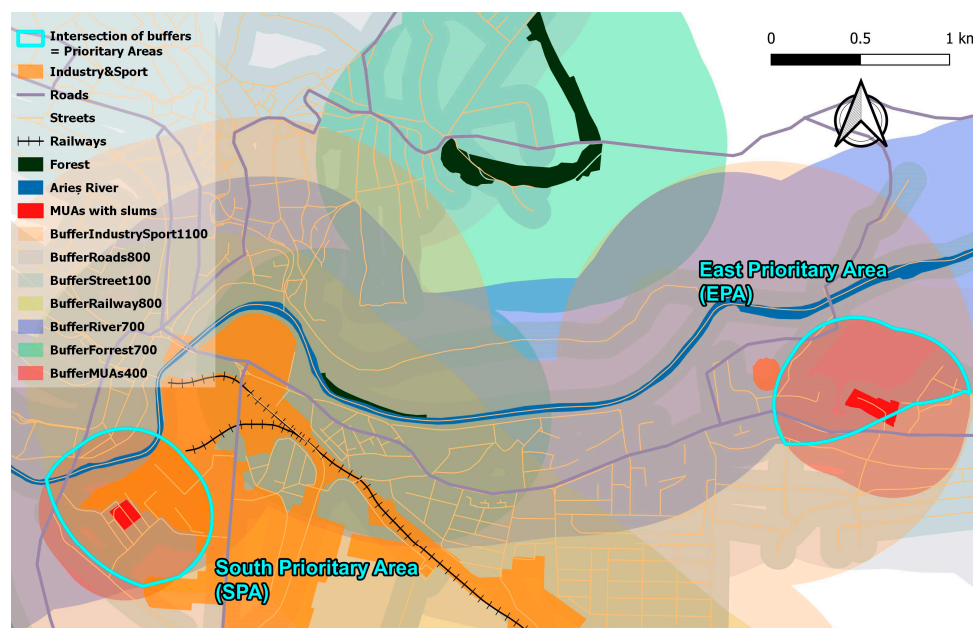


Figure 9. The prioritization map -the two priority areas with a high possibility of illegal waste disposal resulting from the prioritization method after the intersection of the spatial buffers. Source: elaborated by the authors.

3.2.3. Map of Identified Illegal Landfills

To obtain and georeference the Hi-res imagery, we accessed The National Registry (RENNS) orthophotoplans inventory covering the city of Turda, containing the images sensed during the years presented in Figure 10:

The orthophotoplans were sensed with a time-lapse of approximately 5 years. The images were downloaded or acquired from the RENNS web interface and georeferenced for the two prioritized locations: SPA and EPA. The first stage of analysis of the orthophotoplans consisted of the identification of the potential illegal waste dumpsites based on visual interpretation of the georeferenced imagery. Based on the last six reports of the Environmental Protection Agency of Cluj county, the administrative unit that includes Turda Municipality [57–62], we averaged the percentual composition of the household waste generated in this area for six years in a row (2016–2021), and after the exclusion of the biodegradable fraction, which usually has less longevity in illegal waste deposits, we observed that the largest percentages of waste are represented by plastic, paper/cardboard, and other debris (which also includes fabric materials), as shown in Figure 11. Thus, the visual features of illegal waste disposal sites in the images are specific to plastic, paper/cardboard, and fabric debris, together with a great portion of rubble from construction and demolition waste, since only an average of 3.8% of the total waste collected in the county [57–62] is represented by the C&D debris, while the World Bank's estimate of the global average generation rate is around 8.84% [63], which means that around 5% of the C&D waste could be illegally disposed.

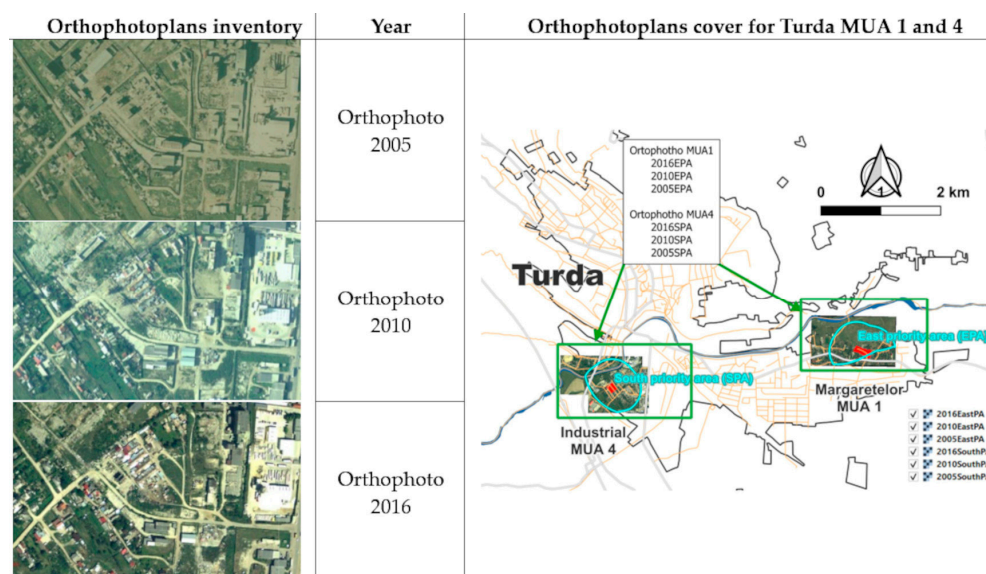


Figure 10. The National Registry (RENNs) orthophotoplans inventory by year. Source: elaborated by the authors.

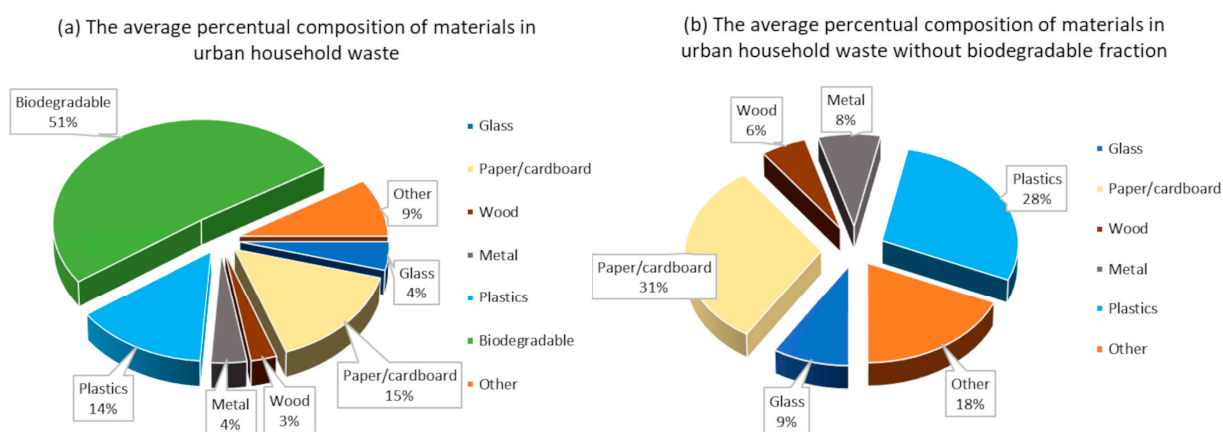


Figure 11. (a) The average percentual composition of materials in urban household waste in Turda's county (Cluj) between 2016 and 2021. (b) The average percentual composition of materials, except biodegradable, in urban household waste in Turda's county (Cluj) between 2016 and 2021. Source: adapted by authors from the 2018–2023 Environmental reports [57–62].

We present in Figure 12 a typical example of an illegal waste deposit representing municipal domestic waste situated in the EPA of Turda. The key interpretive features used to identify these illegal dumps were characterized by the small size and complex spatial pattern of land cover and the variety of materials and colors; the same technique can be used with satellite images with high resolutions as [27] 1 m to 0.3 m per pixel.

The visual evaluation performed via the expert-knowledge interpretation resulted in the vectorial layer with the land cover of the actually existing waste disposal sites, determined based on boundaries, which were determined with the help of their envelope curve, resulting from the employment of the Convex Hull geo-algorithm in QGIS. The resulting layers are displayed in Figure 13.



Figure 12. Identification, selection, and validation of the presence of an illegal dumpsite in the Margaretel MUA, East Priority Area, based on the expert-knowledge analysis of the orthophotoplans and confirmed in situ. Source: adapted by the authors based on the RENNS orthophotoplans [64] and local drone video capture [65].

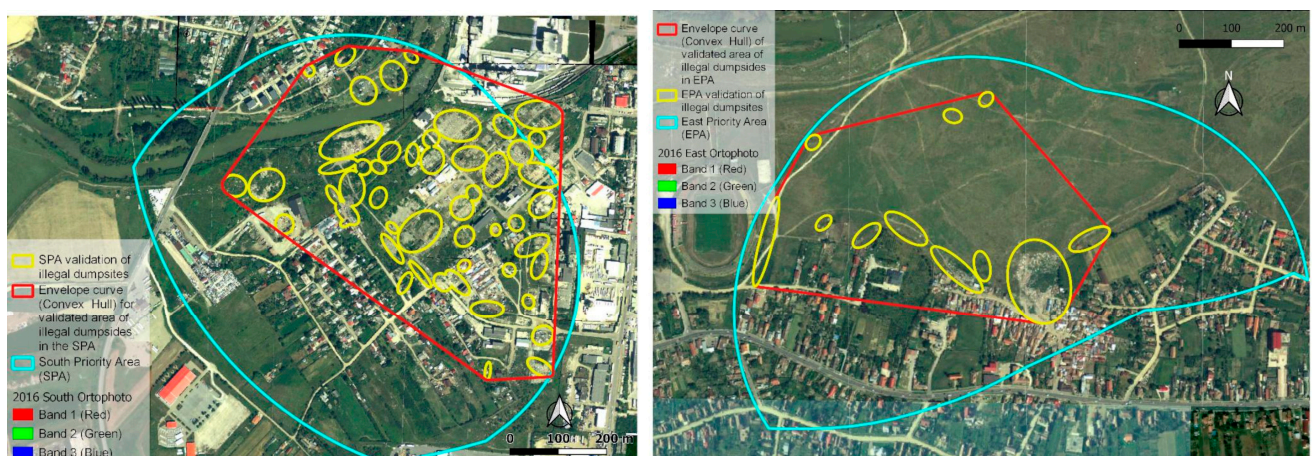


Figure 13. The envelope curves (Convex Hull) resulting from the geoprocessing of the validated clusters containing illegal dumpsites in the EPA and SPA are to a great extent overlapping with the surfaces of each of the South and East Priority Areas.

Since the envelope curves resulted from the validated illegal dumpsites overlap the coverage of the EPA and SPA in a major proportion, we achieved our goal to find, in a fast way, the priority areas with high degrees of illegal dumping rates.

The systematic monitoring and improvement of waste data must be performed with regularity. Consequently, the periodic documentation of the evolution of the areas of high priority can be performed on time-series aerial imagery, an analysis that we carried out on for our case study based on Turda. The resulting evolution is presented in Figure 14. The dynamics of the locations did not vary significantly, maintaining a few focal zones. One important observation is that the illegal waste deposits maintained their evolution predominantly inside the boundaries of the priority areas we identified based on the decade-long coverage of the available orthophotoplans.

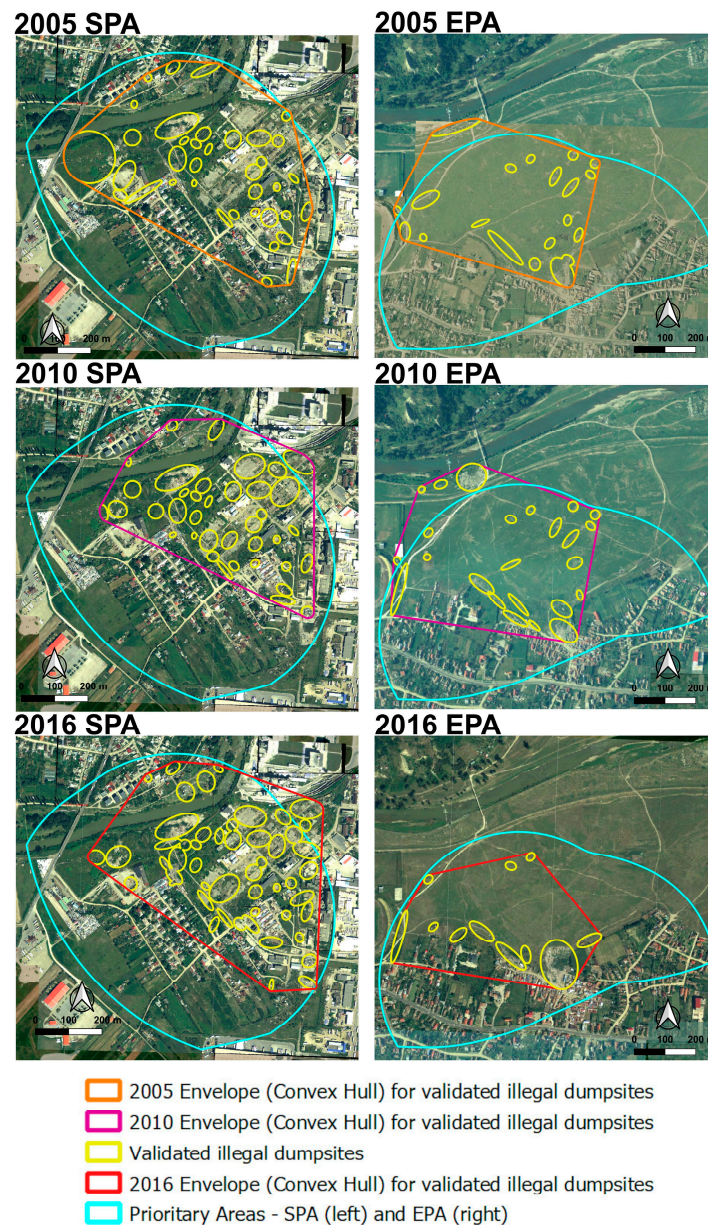


Figure 14. Map of the remote monitoring timeline. The chronological evolution of the illegal dumpsites in the two priority areas.

3.2.4. Extract Landcover of Illegal Landfills (Optional)

The European Space Agency [66] offers immediate access to open and free Earth observation images from the Copernicus Sentinel satellites. The most suitable mission is Copernicus, which offers a reprocessing level—L2A. Sentinel-2 provides images in the visible and infrared wavelengths with a spatial resolution of 10 m to 60 m (depending on the wavelength), meaning that only objects larger than 10 m to 60 m can be observed. The imagery's full global coverage has been available since March 2017. The illegal waste deposits may be a few centimeters in size; thus, very high-resolution (VHR) imagery is necessary [36]. Based on the analysis of their suitability in demonstrating the presence of illegal waste deposits, as presented in Figure 15, we concluded that they cannot momentary be used in monitoring the illegal waste deposits due to their resolution, which is too low for our objective, though they have the highest resolution among the open data satellite coverage images.

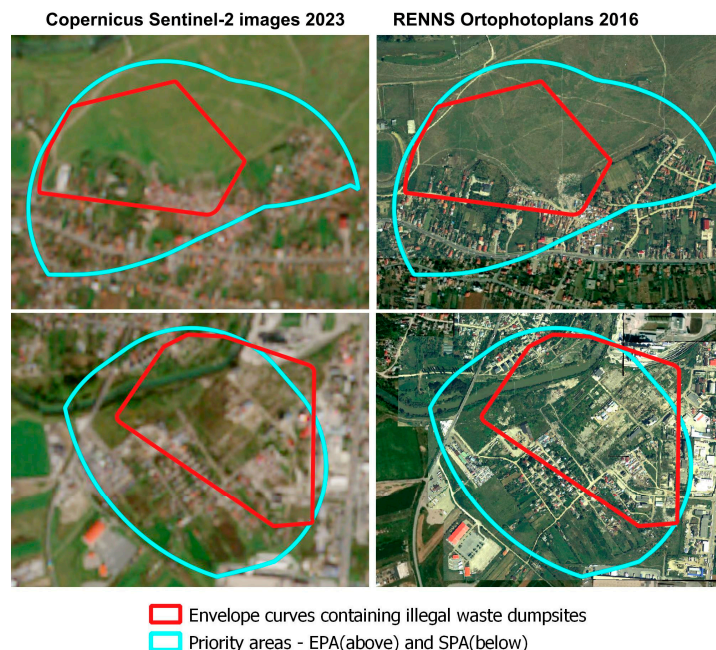


Figure 15. Copernicus Sentinel-2 imagery with a spatial resolution of 10 m vs. the RENNS orthophotoplans. Source: elaborated by the authors.

The final spatial prioritization model for the monitoring system included steps 1–3 and step 5; step 4 is optional due to the low resolution of the open data satellite images, which makes the illegal waste deposits non-discernible, but can become sustainable for future open data satellite images with higher resolution or simpler algorithms; thus, our methodology corresponds to the aim of being flexible, integrative, and sustainable.

3.2.5. Validation. Production of the Monitorization Map Analyzing

The resulting layers obtained from the visual inspection of the potential illegal waste deposits were confronted with the layer obtained for the priority areas, spatially identified based on the intersection of the buffer layers resulting from the geography of the distribution of the factors of influence. In Figure 16, it can be seen that the results are successful since the coverage of the priority areas predominantly overlaps with the footprints of the remotely identified potential illegal waste deposits.

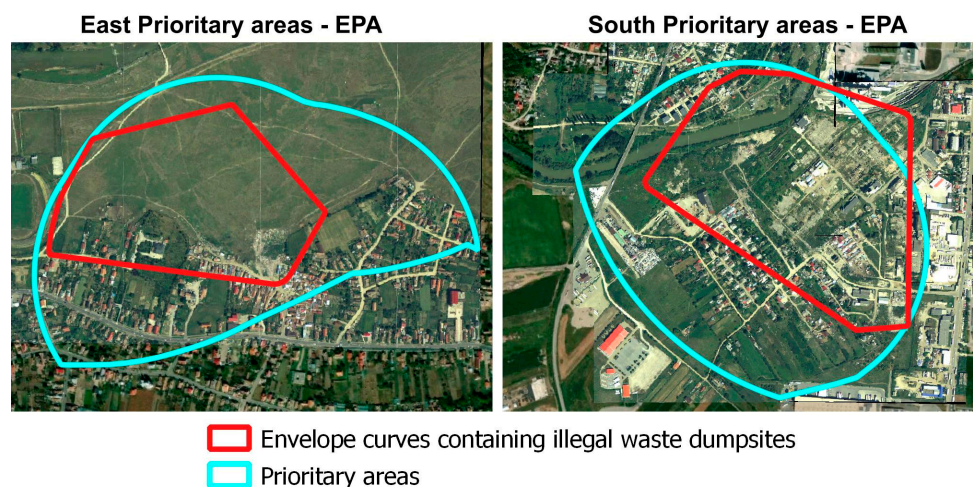


Figure 16. The coverage of the priority areas partially overlaps with the footprints of the remotely identified potential illegal waste deposits. Source: elaborated by the authors.

Regarding the in situ validation process, the verification was carried out based on the illegal waste information documented in the Turda LDS [56] and confirmed with the in-situ corroboration based on remote street view platforms or drone captures and photographs; as shown in Figure 12, Section 3.2.3, we have determined that the identified areas indeed contain illegal waste deposits. For the Margaretelor MUA situated in the East Priority Area of Turda, the SDL mentions that in the pasture in the central area of this slum, there is “a pile of garbage”. Also, for the Industrial MUA, identified in our study in the South Priority Area (SPA) of Turda, the SDL mentions that the area is dirty and that there are various types of waste—industrial, household garbage, toxic waste, rubble, and tanks still filled with toxic liquids.

In Figure 17, we present a typical example of an illegal waste deposit representing municipal domestic waste mixed with C&D debris situated in the South Priority Area (SPA) of Turda.



Figure 17. Examples of in situ photos for corroboration with the ortophotoplans to demonstrate the validation process. Source: modified by the authors based on various ortophotoplans, drone captures, and photographs. (a,b) Illegal C&D debris, SPA [64], (c,d) C&D debris [65], and (e–h) industrial area, old dismantled chemical factories’ area, SPA, Turda, Romania [64,67–69].

The LDS for Turda [56] mentions the MUA 1 in the East Priority Area as a housing mix between ordinary lasting houses with fenced yards and small houses closely built and stuck

to each other or short-lived shacks. The majority of housing is clustered at the far end of Margaretelor Street, which becomes narrower, reaching only footpaths to the community's outskirts. "The pasture in the central area of the community is a pile of garbage". While most homes lack bathrooms, sanitation and public services cover the area.

The MUA4, comprising the Industrial Zone communities, is isolated from the rest of the city. The concrete road is severely deteriorated with deep holes, making it challenging to travel. The sewerage system is also degraded, and there are gravel and dirt roads and paths throughout the area. The housing comprises former office buildings, temporary modular housing, blocks of flats, individual houses, shacks, and barracks, along with extensions of these constructions. The majority of houses are significantly deteriorated, physically worn out, and lack bathrooms; instead, courtyards often house toilets secured with padlocks. While the sewage system is present, it is not functional due to blockages and degradation. Sanitation services and garbage containers are available, though they do not cover the entire community. The area is marked by its uncleanness, filled with household waste, as well as various other types of deposits, such as industrial, household, toxic, and industrial rubble. Numerous areas are designated for waste disposal, and there are tanks filled with liquid toxic substances [56].

Thus, based on the data presented in the LDS and confirmed with the in situ verification or remotely using street view platforms, we have determined that the identified areas indeed contain illegal waste deposits.

We can assert that employing spatial and remote monitoring proves to be an effective approach to the monitorization of illegal deposits in the MUAs, addressing the research question (b).

4. Conclusions

Upon scrutinizing waste management in the analyzed LDSs, it became evident that widespread issues plague all MUAs, encompassing concerns about cleanliness, waste collection, and illegal waste disposal. Unfortunately, waste management in MUAs does not occupy a prioritized status within the purview of the local action groups formulating the LDSs or the broader authorities. The measures and interventions proposed in these strategies are regarded as insufficient to comprehensively tackle the sanitation challenges confronting these communities. This points to a substantial gap in the attention and resources allocated to waste management, further amplifying the enduring problems within these areas. This conclusion aligns with our primary research objective. Nevertheless, further research is essential, particularly in light of the submission of new LDSs seeking financing through the CLLD instrument for the upcoming programming period. This can be combined with research on the consolidation of diverse strategies that can be brought together in a unified framework.

Relying on the information provided in the LDS and further validated through on-site inspections or remote assessments using street view platforms in Turda MUAs, we have reached the conclusion that the identified areas contain illegal waste deposits. This assertion is based on the consistency between the documented data and the real-world verification, both on-site and through remote sensing observations, confirming the presence of unauthorized waste deposits in the specified locations, highlighting the pressing need for targeted interventions and improved waste management practices in these areas. The utilization of spatial and remote sensing monitoring demonstrated effectiveness in monitoring illegal landfills within the MUAs, thus successfully fulfilling the second research objective.

The monitorization should continue in the priority areas, with the support of newer aerial imagery or through services available as plugins of the QGIS 3.28.15-Firenze software, which can provide newer images—the monitorization of the priority areas with the OpenLayers plugin visualizing the Microsoft Bing Aerial map using an Airbus image from 2023, for example. The presence of illegal waste disposal sites in the images may, in future research, integrate sustainable remote sensing techniques and algorithms based

on automatic/semi-automatic methods of interpretation that employ the supervised or unsupervised classification of aerial imagery or very high-resolution satellite imagery.

The research limitations primarily stem from the reliance on data derived from LDSs approved in 2017, considering that circumstances may have changed since then. Hence, direct conversations with LAGs are essential for obtaining updated insights. Furthermore, it is important to note that the data extracted from the analyzed strategies may not always be comprehensive or uniform, introducing potential inconsistencies in the research.

The authors can draw broader theoretical conclusions about the necessity of adopting circular and carbon-neutral waste management practices in marginalized urban areas for environmental sustainability and public health. The findings suggest that strategies for waste management should be an integral part of Local Development Strategies for these areas. The methodology employed for the studied areas in Turda, including a geospatial analysis, can be applied to other territories facing similar challenges, emphasizing the potential transferability and scalability of the approach. The study underscores the broader importance of aligning waste management practices with sustainable development goals, especially in areas that are often overlooked or marginalized.

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