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LANDFILL RECLAMATION USING THE EXAMPLE OF THE MUNICIPAL WASTE DISPOSAL PLANT IN PUŁAWY – A CASE STUDY

Karol Głażewski[1], Magdalena Daria Vaverková[1, 2]✉

[1]Institute of Civil Engineering, Warsaw University of Life Sciences – SGGW, Warsaw, Poland
[2]Faculty of AgriSciences, Mendel University in Brno, Brno, Czech Republic

ABSTRACT

Landfilling remains a dominant method of waste disposal worldwide, largely due to inadequate waste management frameworks, despite efforts to promote recycling and reuse. As populations and consumption levels grow, waste generation continues to increase, highlighting the need for effective waste management solutions. Landfills are sites where waste undergoes various physical, chemical and biological transformations, making the implementation of safety measures, leachate collection and gas recovery systems critical. This article presents a case study of the reclamation of the Puławy municipal landfill, which has been in operation since 1998. The reclamation process involved extensive steps such as forming the landfill body, securing the slopes, constructing a degassing layer, implementing a sealing layer and applying a cover layer. These measures were crucial in mitigating the negative environmental impact of the landfill, reducing harmful emissions and improving local groundwater quality. The results of the Puławy municipal landfill reclamation include reductions in leachate and gas emissions, improvements in air/groundwater quality and the transformation of the site into a green space that provides recreational opportunities for the community. This reclamation project serves as a model of responsible waste management and community involvement, demonstrating how degraded landfills can be transformed into valuable public resources. The article also discusses the broader implications of landfill reclamation, noting both the positive and negative aspects. Benefits include environmental protection, resource recovery, enhanced biodiversity and improved quality of life for local communities. However, challenges such as the long-term monitoring and maintenance of reclaimed sites and the financial costs associated with reclamation efforts are also considered. This study also emphasises the importance of landfill reclamation in the process of shaping and promoting environmental sustainability, as well as addressing modern waste management challenges.

Keywords: waste management, landfill, reclamation, sustainability

INTRODUCTION

Landfilling is a common method of waste disposal worldwide, and countries such as the United States, China and India are the largest producers of municipal solid waste (Sabour, Alam & Hatami, 2020; Zoungrana, Hasnine & Yuan, 2022; Wang et al., 2024). As the human population and consumption both grow, the amount of waste generated continues to increase, creating an urgent need for humanity to effectively manage the problem (Chen, Bodirsky, Krueger, Mishra & Popp, 2020; Shah, Srivastava, Mohanty & Varjani,

Magdalena Daria Vaverková https://orcid.org/0000-0002-2384-6207
✉magdalena.vaverkova@mendelu.cz; magdalena_vaverkova@sggw.edu.pl

2021). Despite efforts to promote recycling and reuse of waste materials, landfilling remains a common practice due to inadequate waste management frameworks in many countries (Sabour et al., 2020; Osazee, 2021). Landfills act as ecological reactors where waste undergoes various transformations, highlighting the importance of critical factors such as landfill safety, leachate collection and gas recovery systems (Ilahi & Agnihotri, 2021; Nanda & Berruti, 2021; Mondal, Choudhury, Kundu, Dutta & Samanta, 2023). With the increasing challenges of environmental pollution and waste management, landfill remediation is becoming an indispensable part of today's society (Koda et al., 2021a; Koda et al., 2021b; Koda et al., 2023; Wen, Zhao, Guan & Zhang, 2023).

Modern society is increasingly aware of the need to protect the environment and ensure sustainability for future generations (Kumar & Agrawal, 2020; Rajadesingu, Deepankara, Dowlath, Karuppannan & Arunachalam, 2021). In this context, landfill reclamation is not only an integral part of waste management strategies, but also symbolises a commitment to environmental protection and concern for public health and community welfare (Zorpas, 2020; Khan, Anjum, Raza, Bazai & Ihtisham, 2022).

Landfill reclamation is a process that involves various techniques, such as sealing the landfill, improving drainage, stabilising waste and restoring natural ecosystems (Koda, Podlasek, Osiński, Markiewicz & Vaverková, 2021a; Koda et al., 2023; Wen et al., 2023). Successful remediation can turn formerly contaminated sites into valuable resources for local communities, providing new recreational opportunities, green spaces and contributing to improved air and groundwater quality (Reddy, Janga & Kumar, 2024). The example of a reclaimed landfill in the Municipality of Puławy demonstrates how responsible waste management and community engagement can transform problematic sites into valuable public spaces that serve both people and nature.

Landfill reclamation is the process of restoring land that has been used as a landfill to a useful or environmentally acceptable condition (Madadian, Haelssig & Pegg, 2020; Jakimiuk, 2022). Reclamation is carried out according to the schedule of landfill reclamation activities. The reclamation process is carried out in a way that protects the landfill from its harmful effects on surface and groundwater and air. The entire process should aim to integrate the landfill into the surrounding environment. Landfill reclamation has both positive and negative aspects. On the positive side, reclamation projects can significantly improve environmental quality (Nai et al., 2021) by reducing leachate and gas emissions, thereby protecting groundwater and air quality (Majewski, 2021; Kumari, Ahirwal & Maiti, 2022; Tan et al., 2022). These projects can transform run-down areas into green spaces that provide recreational opportunities and enhance the aesthetic value of the community (Artuso, Cossu, He & She, 2020; Koda et al., 2021b). In addition, reclaimed landfills can be repurposed for a variety of uses, including industrial, commercial or residential development, contributing to local economic growth (Ospanbayeva & Wang, 2020; Wenhong, Ridong & Jiayi, 2021). On the negative side, landfill reclamation can be costly and resource-intensive, requiring significant financial investment in site preparation, waste stabilisation and long-term monitoring (Titova, Shmandiy, Kharlamova, Rygas & Malovanyy, 2022; Sternik & Andrianova, 2023). The process can also present technical challenges, such as managing residual contamination and ensuring the stability of the reclaimed site (Majewski, 2021; Jakimiuk, 2022; Koda et al., 2023). There is also the risk of unforeseen environmental impacts, such as the re-release of contaminants during excavation and treatment. Despite these challenges, the long-term benefits of landfill reclamation often outweigh the drawbacks, making it an important strategy for sustainable waste management and environmental remediation.

This article highlights the importance of landfill reclamation in the context of today's environmental challenges and discusses key aspects of the process, its goals, methods and benefits to society and the environment. By exploring this topic through the example of a reclaimed landfill in the Municipality of Puławy, it is possible to explain why landfill reclamation is not only a necessity, but also an opportunity to create a more sustainable and environmentally friendly future.

MATERIAL AND METHODS

Landfill description

The facility is located on the premises of the municipal waste disposal plant (MWDP) in Puławy, at Dęblińska 96 (Fig. 1), approximately 6.7 km northwest of the centre of Puławy (GPS coordinates of the landfill: 51°28′02.0″N 21°56′10.0″E), along the National Road 801 (Warsaw–Otwock–Karczew–Wilga–Maciejowice).

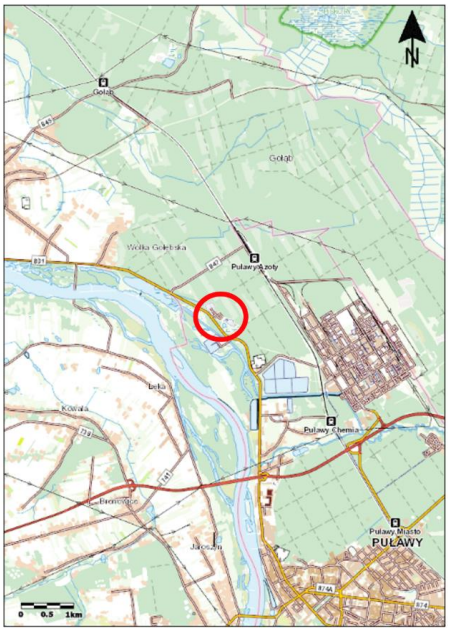

Fig. 1. Landfill site location

Source: https://www.geoportal.gov.pl.

The landfill is surrounded on three sides by forests managed by the Puławy Forestry Commission. On the south-eastern side are the remaining installations and facilities of the MWDP (Fig. 2).

The landfill is an existing facility, built in 1996 and has been in operation since 1998. It has the characteristics of a sub-level landfill, consisting of two sub-quarries. The sub-quarries store the waste of the group separately:
– 17 – wastes from construction, renovation and demolition of buildings and roads;
– 19 – wastes from waste disposal and neutralisation facilities and wastewater treatment and water management;
– 20 – municipal solid waste.

The area of the landfill calculated along the outer contour of the crown is 27,685 m^3, while the total area occupied by the landfill is 3.17 ha. The target maximum ordinate of the waste crown is 135 m above sea level, and the total geometric capacity of the landfill is about 0.3 million m^3. In accordance with Article 103(2) of the Waste Act of 14 December 2012 (consolidated text Dz.U. 2023 poz. 1587), the landfill located on the premise MWDP in Puławy is a landfill for non-hazardous and inert waste.

The following materials have been used to prevent leachate from entering groundwater: (i) bent mate made of VOLCLAY type sodium bentonite in a propylene matrix (with the ability to self-seal in case of puncture), with a filtration coefficient of 10–11 $m \cdot s^{-1}$; (ii) AGRU PEHD geomembrane.

Fig. 2. Satellite aerial view of landfill in Puławy

Source: https://mapy.cz.

The geomembrane is protected from mechanical damage by a 40-centimetre-thick drainage protection layer with a 2/16 grain size. The drainage pipes are laid on a 4/8 gravel bed, which also protects the geomembrane from damage caused by the impact of coarser fractions of the filter layer (16/32). On top of the drainage protection layer, above the drainage pipes, a 400 g·m^{-2} geotextile is laid in 2,100-millimetre-wide strips.

Due to the profiling of the bottom of the basin with a bilateral slope to the north and south, there are two drainage basins. The theoretical daily leachate volume for average annual rainfall is 10.3 m^3 per day. The drainage network consists of four Ø200 mm pipelines laid along the longitudinal axis of the landfill. Leachate from the pipelines is collected in wells located outside the embankment of the landfill, four on the northern side of the basin and two on the southern side. From the wells, leachate is pumped to the pumping station and from there to a 162 m^3 leachate tank located on the southern slope of the landfill. Through the pumping station, the leachate from the tank is directed to the biofraction production process, which is carried out on the biofraction preparation line, a part of the MWDP plant. The unused amount of leachate is pumped out of the reservoir by a septic tank truck and directed to the wastewater treatment plant (WWTP). The groundwater monitoring system consists of five piezometers, while the landfill gas collection system is equipped with six degassing wells. A view of the landfill prior to reclamation is shown in Figure 3.

Fig. 3. Landfill in Puławy before reclamation – view from the south

Source: own work.

RESULTS

Activities related to the reclamation of the landfill

Pursuant to the regulations of the Waste Act of 14 December 2012, the Head of the Province issues a decision on the closure of a landfill and post-operational activities consisting of the reclamation of the site. In the case of the Municipality of Puławy, the decision was issued on 15 May 2019, clearly specifying the date of ending the dumping of waste and the stages of technical closure of the landfill. According to the above-mentioned decision, the process of the landfill closure and reclamation was divided into the following stages: (1) forming the body of the landfill, including the removal of depressions, delaminations and gaps by moving waste within the quarters and, if necessary, backfilling with materials or waste; (2) protection of the slopes and top from wind and water erosion; (3) construction of a degassing layer with a minimum thickness of 15 cm after compaction; (4) construction of a sealing layer of highly insulating materials, such as clay and clayey soils (a layer of 30 cm thickness in two stages of 15 cm each with compaction each time); (5) construction of a topsoil covering layer of 90–110 cm of material or waste; (6) seeding of grass mixture and planting of shrubs and maintenance treatments. The decision also includes a schedule of rehabilitation activities, as detailed in Table 1.

Table 1. Schedule of activities related to the reclamation of a part of the landfill

Scope of work	Completion deadline
Technical reclamation	
Cessation of waste acceptance	by 30 June 2019
Securing the landfill to prevent waste deposition	by 5 July 2019
Cleanup work around the landfill cell	by 15 July 2019
Clearing of fire roads, protective vegetation belts and cleaning and unclogging of perimeter ditches	by 15 July 2019
Grading work	by 31 July 2019
Inspection of degassing wells and securing materials for chimney extensions	by 31 July 2019
Protection of slopes and surfaces from wind and water erosion	by 31 July 2019
Installation of gas drainage	by 30 September 2019
Installation of sealing layer	by 15 November 2019
Biological reclamation	
Installation of covering layer with grass seeding	by 30 April 2023
Supplementary grass seeding	by 15 May 2023
Plantings	by 31 October 2023
Maintenance of plantings	by 30 April 2024

Despite these advanced construction activities, no construction permit is required for the closure and operation of the landfill. According to the Construction Law (consolidated text Dz.U. 2024 poz. 725, 834), construction work is defined as the building, installation, repair or demolition of a structure. Since landfill reclamation does not fall under any of the above categories, it does not require a separate construction permit. It is based solely on the decision of the provincial head.

Reclamation process of the landfill

The work on the already closed landfill was carried out according to the schedule established by the decision of the Head of the Lublin Province.

Protection of slopes and top against wind and water erosion

The process of securing the slopes and top of the landfill against wind erosion primarily consists of eliminating all cracks and natural water runoff from the landfill roof area. Additionally, any waste on the slopes that could interfere with the proper embankment of the slopes should be removed. Furthermore, the top of the landfill should be compacted using suitable equipment to achieve the highest possible compaction ratio.

Implementation of the gas drainage

The purpose of the gas drainage layer is to separate the waste from the reclamation layers, so it is necessary to compact the topsoil in such a way as to create a homogeneous, level layer (with no voids or holes) that provides an even base for the next layer. A gas drainage system of filter sand (river or mine sand) is laid on top of the landfill to remove landfill gases. Sand mixed with clay is allowed to increase the stability of the slope. It is assumed that the thickness of the degassing drainage layer after compaction will not be less than 15 cm. The execution and final result of this phase are shown in Figure 4. As part of this reclamation, a passive degassing system for the existing biogas extraction wells is planned. At this stage, the degassing column should be filled with aggregate to a level not lower than the designed ordinate of the sealing layer (i.e., at least 60 cm above the levelled drainage).

Fig. 4. Landfill during the construction of the layer separating the waste from the subsequent reclamation layers (left) and the final result (right) – view of the landfill entrance

Source: own work.

Implementation of the sealing layer

The sealing layer is designed to protect the landfill from the infiltration of rainwater and melted snow. The thickness of the sealing layer over the entire surface of the landfill embankment is 0.3 m. The sealing layer is made of a material with a high insulation coefficient, such as clayey or loamy soils.

Construction of a layer to protect the sealing lay

The topsoil layer is designed to protect the liner from erosion caused by excessive desiccation or rainwater runoff. If biological reclamation is not expected to occur quickly, this layer will also provide a place for plant growth and development.

Figure 5 illustrates a cross-section of the landfill, highlighting the current waste level in comparison to the designed final level. The diagram provides a detailed view of the various layers involved in the reclamation process. The cross-section through the layers of the reclaimed landfill depicted in the illustration showcases the original waste level and subsequent marked reclamation layers. At the top, there is a 0.15-metre erosion protection layer providing stability and protection. Below lies the sealing layer, aimed at preventing leachate from reaching the soil and groundwater. Next is the gas drainage system, designed to remove gases accumulated within the waste. Successive reclamation layers depict the gradual transformation of the landfill into an environmentally friendly area, enhancing its stability and minimising adverse impacts on the surroundings.

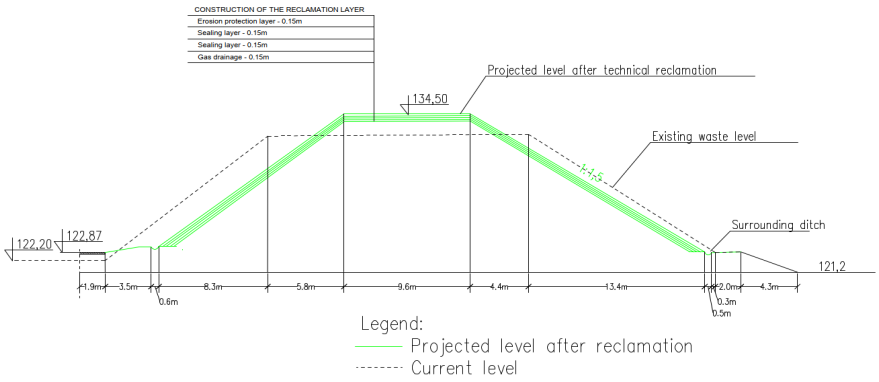

Fig. 5. Cross-section of the landfill showing the waste level and the designed level along with the reclamation layers

Source: own work.

Figure 6 shows a top view of the reclaimed landfill, illustrating the geometry and location of the degassing wells. Figures 7 and 8 depict the landfill in the Municipality of Puławy after recultivation, showcasing the transformation of the former landfill area into a sustainable green space.

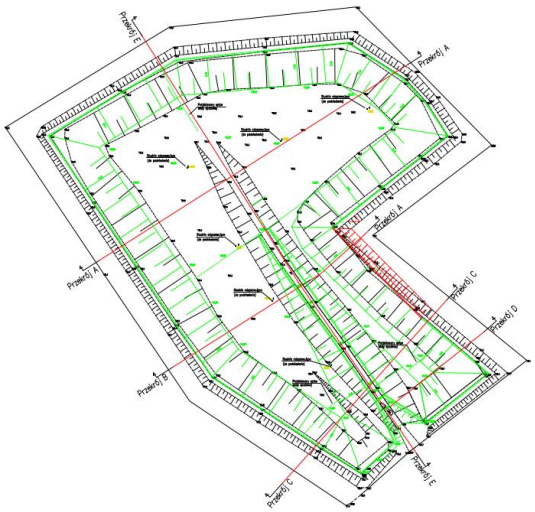

Fig. 6. Top view considering the geometry of the landfill in Puławy

Source: own work.

Fig. 7. View of the waste landfill in the Municipality of Puławy after recultivation – view from the east

Source: own work.

Fig. 8. View of the waste landfill in the Municipality of Puławy after recultivation – view from the south-eastern slope

Source: own work.

DISCUSSION

Landfill reclamation is an organised process aimed at mitigating the environmental impacts of waste disposal (Koda et al., 2021a; Koda et al., 2021b; Koda et al., 2023). Landfills, even when properly managed, can still pose a risk of contamination, making the reclamation of contaminated sites critical, as discussed in Liu et al. (2023). In countries such as India, where open dumping (non-sanitary landfills) is common, landfill reclamation (GHGs) using methods such as bio-mineralisation is critical to reduce greenhouse gas emissions, leachate pollution and land reclamation for sustainable reuse, as highlighted in Mohan and Joseph (2020). Overall, landfill reclamation is a multifaceted process that involves various strategies to minimise environmental degradation and maximise resource recovery.

The results of the reclamation of a waste landfill in the Municipality of Puławy indicate a significant impact of this process on the environment and the local community. First, recultivation activities significantly reduced the negative impact of the landfill on the environment, including contamination of ground and surface waters and the emission of harmful gases into the atmosphere. The technologies used, such as geomembranes and drainage systems, effectively protect the area against further degradation. Moreover, the reclamation of the Puławy landfill was carried out meticulously and according to schedule, ensuring comprehensive protection against wind and water erosion. Through the implementation of gas drainage and sealing layers, the site was effectively transformed into a sustainable green space that blends seamlessly into the surrounding environment.

To increase the broader applicability of this study, it is beneficial to compare the landfill reclamation project in Puławy with similar initiatives. Such comparisons can provide a broader understanding of the remediation of old landfills. For example, the reclamation of the Fresh Kills Landfill in New York transformed one of the world's largest landfills into a public park, highlighting the potential for large-scale ecological restoration (Klenosky, Snyder, Vogt & Campbell, 2017; Wilczkiewicz, 2017; Melosi, 2018). Similarly, the reclamation of the Tel Aviv Hiriya landfill in Israel shows how former landfills can be transformed into vibrant ecological parks and showcases innovative waste-to-energy technologies (Limor-Sagiv & Lissovsky, 2023; Limor-Sagiv et al., 2024). At the national level, the Radiowo landfill reclamation in Poland demonstrates effective methods for transforming landfills into green spaces that provide community benefits and improve environmental health (Koda et al., 2021b). Including these comparative examples not only broadens the context, but also illustrates different approaches and outcomes in landfill reclamation.

Reclamation has also contributed to the restoration of land degraded by landfill activities, which is particularly important in the context of urbanisation and the needs of local communities (Ospanbayeva & Wang, 2020; Kumari et al., 2022). Reclaimed land can be used for recreational purposes (Koda et al., 2021b), which improves the quality of life for residents and for agricultural or industrial purposes, which supports the local economy.

The reclamation process in Puławy is also an example of the effective recovery of raw materials from waste, which promotes the sustainable use of natural resources. Thanks to sorting and proper waste management, it was possible to recover valuable raw materials that can be reused in various sectors of the economy.

Landfill reclamation also has a positive impact on biodiversity (Vaverková et al., 2022). The restoration of natural ecosystems in landfill areas promotes the recovery of habitats for many plant and animal species, which is crucial for the preservation of biodiversity (Koda et al., 2021b; Winkler et al., 2021; Vaverková et al., 2022).

Another important aspect of reclamation is improving the image of the local community. Caring for the natural environment and the health of residents builds trust in the local government and strengthens the sense of community. Reclamation projects often involve local residents, which builds ecological awareness and promotes responsible attitudes toward environmental protection. Research in Indonesia has shown that reclamation projects in regions such as Bangkalan Regency have engaged coastal communities, including fishermen, in the management of reclaimed land, leading to increased community well-being and economic opportunities (Dewi & Turisno, 2020). In addition, effective reclamation programmes can create employment

opportunities, increase local economic activity and boost merchant income, ultimately contributing to the overall image and well-being of the community (Pambudi, Utomo, Soelarno & Takarina, 2023).

Landfill reclamation can have long-term economic benefits (Ospanbayeva & Wang, 2020; Yu et al., 2020; Titova et al., 2022). Although the initial costs associated with landfill reclamation are high, in the long run, it can lead to a reduction in landfill management costs and the treatment of environmental impacts, benefiting both the municipal budget and residents. The Puławy example shows that landfill reclamation is a process with multiple benefits, including environmental protection and improvement of the quality of life for the local community. The long-term effects of land reclamation contribute to sustainable development, which is crucial in the face of today's waste management and environmental challenges. Further research is needed to examine the extended long-term effects and global comparisons to improve their applicability and relevance in different contexts and other similar sites.

CONCLUSIONS

Landfill reclamation is an integral part of today's waste management strategies. In the face of growing environmental and waste management challenges, remediation offers not only solutions to environmental problems, but also opportunities to create a more sustainable future. The example of a landfill in the Municipality of Puławy shows that responsible waste management and community involvement can transform problematic sites into valuable resources that serve both people and nature.

Benefits of landfill reclamation:

1. Environmental protection: reclamation reduces the negative impacts of landfills on soil, water and air, helping to protect the natural environment and public health.
2. Land reclamation: restoring land to a condition usable by the local community can allow it to be used for recreational, agricultural or industrial purposes.
3. Resource recovery: the reclamation process can recover valuable materials from waste, contributing to the sustainable use of natural resources.
4. Biodiversity restoration: restoring natural ecosystems promotes the reestablishment of plant and animal habitats, helping to preserve biodiversity.
5. Improved community image: landfill reclamation can improve the image of the local community by demonstrating concern for the environment and the health of local residents.
6. Reduce long-term costs: although the cost of landfill reclamation can be high, it can be cost-effective in the long run by reducing the costs associated with landfill management and pollution-related health problems.

The example of the landfill in the Municipality of Puławy demonstrates the multifaceted benefits of landfill reclamation, from environmental protection and resource recovery to community enhancement and economic savings.

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Author's contributions

Conceptualisation: K.G. and M.D.V.; methodology: K.G.; validation: M.D.V.; formal analysis: K.G.; investigation: K.G.; resources: K.G.; data curation: K.G.; writing – original draft preparation: K.G. and M.D.V.; writing – review and editing: M.D.V.; visualisation: K.G.; supervision: M.D.V.

All authors have read and agreed to the published version of the manuscript.

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REKULTYWACJA SKŁADOWISKA ODPADÓW NA PODSTAWIE GMINY MIASTO PUŁAWY – STUDIUM PRZYPADKU

STRESZCZENIE

Składowanie odpadów pozostaje dominującą metodą ich utylizacji na całym świecie, głównie z powodu nieodpowiedniej ramowej polityki zarządzania odpadami, pomimo wysiłków na rzecz promowania recyklingu i ponownego użycia. Wraz ze wzrostem populacji i poziomu konsumpcji rośnie ilość wytwarzanych odpadów, co podkreśla potrzebę skutecznych rozwiązań w zakresie gospodarki odpadami. Składowiska odpadów to miejsca, w których odpady ulegają różnym przemianom fizycznym, chemicznym i biologicznym, co sprawia, że wdrożenie środków bezpieczeństwa, zabezpieczanie odcieków i stosowanie systemów odzyskiwania gazu mają kluczowe znaczenie. W niniejszym artykule przedstawiono studium przypadku rekultywacji składowiska odpadów komunalnych w Puławach, eksploatowanego od 1998 roku. Proces rekultywacji obejmował rozległe etapy, takie jak: formowanie bryły składowiska, zabezpieczenie skarp, wykonanie warstwy odgazowującej, wykonanie warstwy uszczelniającej oraz nałożenie warstwy przykrywającej. Działania te miały kluczowe znaczenie dla złagodzenia negatywnego wpływu składowiska na środowisko przyrodnicze, ograniczenia szkodliwych emisji i poprawy jakości lokalnych wód gruntowych. Rezultaty rekultywacji składowiska w Puławach obejmują zmniejszenie emisji odcieków i gazów, poprawę jakości powietrza i wód gruntowych oraz przekształcenie terenu w zieloną przestrzeń, która zapewnia możliwości rekreacyjne dla społeczności. Projekt rekultywacji służy jako model odpowiedzialnego gospodarowania odpadami i zaangażowania społeczności, pokazując, w jaki sposób zdegradowane tereny można przekształcić w cenne zasoby publiczne. W artykule omówiono również szersze implikacje rekultywacji składowisk odpadów, zwracając uwagę zarówno na pozytywne, jak i negatywne aspekty. Korzyści obejmują ochronę środowiska przyrodniczego, odzyskiwanie zasobów, zwiększoną bioróżnorodność i poprawę jakości życia lokalnych społeczności. Do wyzwań należy zaliczyć długoterminowe monitorowanie i utrzymanie zrekultywowanych terenów oraz koszty finansowe związane z wysiłkami rekultywacyjnymi. W tym badaniu podkreślono również znaczenie rekultywacji składowisk odpadów w procesie kształtowania i promowania zrównoważonego rozwoju, a także w rozwiązywaniu współczesnych wyzwań związanych z gospodarką odpadami.

Słowa kluczowe: gospodarowanie odpadami, składowisko odpadów, rekultywacja, zrównoważony rozwój