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Technical assessment of the municipal waste management system and the design concept of the local landfill in the Ryki Commune

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ABSTRACT

Municipal waste management is a key element of the environmental policy of local government units in Poland. The aim of this study was to analyze the waste management system in the Ryki Commune in 2022–2024 and develop a concept for a local municipal waste landfill.. In 2024, a total of 4355.43 Mg of municipal waste was collected within the commune, of which 570.52 Mg was collected at the municipal waste management plant (PSZOK). The recycling rate reached 54.07%, while the landfill rate was 40.14%. A landfill concept was developed in Niwa Babicka, with an expected waste mass of 184163.76 Mg and an operational period of 12 years. The results indicate relatively high efficiency of selective collection, with a significant share of mixed waste sent to landfill. The proposed infrastructure solutions can improve system efficiency and reduce transportation and operating costs.

Keywords: waste management, municipality, project concept, landfill.

INTRODUCTION

Waste and its associated environmental threats constitute one of the most significant problems in contemporary environmental protection. Dynamic civilizational development, population growth, and rising consumption levels are leading to a systematic increase in the amount of waste generated, which poses both an organizational and technological challenge for municipal management systems. This increase in waste volume necessitates the implementation of modern waste management methods and the search for solutions consistent with the concept of a circular economy (CE) [1].

The development of waste management in European Union countries, including Poland, in recent years has been closely linked to the implementation of the circular economy concept, which aims to reduce waste through reuse, recycling, and energy recovery. Despite the implementation of new technologies and legal regulations, the problem of increasing waste volumes remains relevant, and waste disposal continues to have a negative impact on the natural environment, including through greenhouse gas emissions and soil and water pollution [1]. Economic and environmental efficiency are crucial elements of municipal waste management systems. Studies conducted for Polish cities have shown that the average efficiency level of municipal waste management systems remains moderate, indicating the need for further action to improve the organization of the systems and increase their environmental effectiveness [2].

At the same time, the social aspect of waste management systems is becoming increasingly important. The organization of waste collection and management directly impacts the quality of life of residents, the level of costs incurred by households, and the effectiveness of selective waste collection. Proper environmental education and social involvement are key elements in increasing the effectiveness of municipal waste management systems [3]. The waste management system in Poland is undergoing systematic changes resulting from the adaptation of national regulations to European Union requirements and the introduction of new technological and organizational solutions. Implementing innovations in waste management, including solutions based on intelligent management systems and reverse logistics, allows for increased efficiency of municipal systems and reduced their negative environmental impact [4]. At the local level, local government units play a key role in waste management, responsible for organizing the collection, transport, and management of municipal waste. The efficiency of the system depends on many factors, including technical infrastructure, the organization of the separate collection system, the level of environmental awareness of residents, and the municipality's financial capabilities. At the same time, the rising costs of operating waste management systems necessitate the search for new organizational and technological solutions to increase their efficiency [5]. The Ryki Commune, as an urban-rural unit, carries out tasks related to the organization of the municipal waste management system in accordance with applicable legal regulations. However, the operation of the local waste management system requires continuous monitoring and adaptation to changing legal, economic, and social conditions. Regular analysis of the system's operation allows for the identification of areas requiring improvement and the development of action plans to increase its efficiency. The aim of this study is to analyze the state of municipal waste management in the Ryki Commune, taking into account organizational, infrastructural, economic, and environmental aspects, and then develop a concept for improving the operation of the waste management system.

This study analyzes data on the quantity and structure of municipal waste generated, assesses the level of compliance with statutory obligations, and identifies possible directions for the system's development in line with current trends in waste management and the European Union's environmental policy.

MATERIALS AND METHODS

Research on the functioning of the municipal waste management system was conducted based on data covering the years 2019–2024. The analysis was conducted using statistical data and official documents regarding municipal waste management in the Ryki Commune. The primary data source was materials from the Ryki Municipal Office, specifically annual reports on the implementation of municipal waste management tasks, which included information on the amount of collected and managed waste, its fractional structure, and the costs of operating the system. The analysis also utilized statistical data published by the Central Statistical Office, which included information on the number of residents, the amount of municipal waste generated, and the recovery and recycling rates.

The scope of the analysis included an assessment of the functioning of the municipal waste management system, taking into account the following elements:

- the amount of municipal waste generated in the years 2019–2024,
- the fractional structure of municipal waste,
- the level of selective waste collection,
- the levels of preparation for reuse and recycling,
- the costs of operating the waste management system,
- changes in the number of residents covered by the waste collection system.

Statistical and comparative methods were used to analyze the data, enabling the assessment of changes occurring during the period under review. In particular, time trend analysis was used, which involved comparing the values of individual indicators in subsequent years of the analyzed period. Change dynamics were calculated for selected parameters, enabling the assessment of the rate of increase or decrease in the amount of waste generated and the level of selective collection. To assess the effectiveness of the municipal waste management system, a comparative analysis of the obtained results was conducted with the requirements specified in applicable national law and strategic documents regarding waste management. In particular, the levels of

preparation for reuse and recycling of municipal waste required by national law and European Union directives were taken into account. Based on the obtained results, an analysis of the functioning of the municipal waste management system in the Ryki Commune was conducted, and areas requiring improvement were identified. The results of the analyses formed the basis for developing a concept of actions aimed at improving the effectiveness of the municipal waste management system in the studied commune.

Characteristics of the study area

The study area covered the Ryki Commune, an urban-rural commune located in eastern Poland. Commune covers an area of 161.8 km² and serves as a significant administrative and economic center for the region. Geographically, the commune is located within the Żelechów Upland, partially in the Wieprz River valley and the Vistula River valley. The natural and geomorphological conditions of this area significantly influence spatial development, settlement structure, and the functioning of the municipal waste management system. The Ryki Zommune borders:

- to the east, the Ułęż and Nowodwór communes,
- to the south, the Puławy and Żyrzyn communes,
- to the southwest, the city of Dęblin and the Stężyca commune,
- to the north, the Kłoczew commune,
- to the northwest, the Trojanów commune (Masovian Voivodeship).

One of the significant factors influencing the functioning of the municipal waste management system is the number of residents covered by the waste collection system. Demographic changes have a direct impact on the amount of waste generated and the operating costs of the waste management system. During the analyzed period, a gradual decline in the number of residents of the Ryki Commune was recorded. In 2024, the population reached 19,878, a decrease of 380 residents compared to 2022. This trend is consistent with the nationwide depopulation trend observed in many urban-rural communes in Poland. An analysis of the population of the town of Ryki indicates a systematic decline in both permanent and temporary residents. In 2022, the town's population was 9,527, while in 2024 it decreased to 9,288. A similar trend was observed in the rural areas of the Ryki commune. In 2022, the rural population was 10,726, while in 2024 it decreased to 10,590. While this population reduction may reduce the amount of municipal waste generated, it may also lead to an increase in the unit costs of operating the waste management system. The Ryki commune has an urban-rural character, which means both dense urban development and scattered rural development. This spatial arrangement is crucial for the organization of the municipal waste collection and transport system, affecting logistical costs and the system's operational efficiency. The dispersion of development in rural areas necessitates the implementation of appropriate organizational solutions for waste collection, such as adjusting the frequency of waste collection and the location of selective municipal waste collection points. The municipal waste management system in the Ryki Commune is based on a decentralized model of waste collection and transfer to regional installations, in accordance with applicable national law and the provincial waste management plan [6,7]. A key element of the infrastructure is the source collection system, the municipal waste selective collection point (PSZOK), and the transport system to the waste treatment plant in Puławy. A unified system for selective municipal waste collection for households operates within the commune, in accordance with the Regulation of the Minister of the Environment of December 29, 2016 [8,9]. It covers five basic fractions:

- paper (blue containers),
- glass (green containers),
- metals and plastics (yellow containers),
- bio-waste (brown containers),
- mixed waste.

This system forms the basis for selective collection and enables the achievement of required recycling rates. According to data from the Central Statistical Office [10], this type of collection model is currently standard in most municipalities in Poland and is a key element in implementing a circular economy. A key infrastructure element is the PSZOK located in Ryki. This facility complements the collection system and allows residents to drop off problematic and bulky waste.

In 2024, the PSZOK accepted a total of 570.52 Mg of waste, including:

- construction and demolition waste – 254.56 Mg,
- bio-waste – 134.50 Mg,
- bulky waste – 106.42 Mg,

- waste electrical and electronic equipment – 13.09 Mg,
- used tires – 28.22 Mg.

The literature emphasizes that PSZOK is one of the key instruments for increasing the level of selective waste collection and limiting illegal waste dumping [11, 12]. Municipal waste is transported from the commune by an operator selected through a public tender [2]. The waste is directed to the regional municipal waste treatment facility in Puławy, in accordance with the assumptions of the provincial waste management plan [1]. In 2024, the total mass of collected waste amounted to 4,355.43 Mg, indicating the significant role of the transport system in the structure of the entire waste management system. The Ryki Commune lacks full-scale municipal waste treatment facilities, and the system relies on transferring waste to external facilities. In practice, this means dependence on regional facilities in Puławy and other treatment plants. According to the approach presented in the literature [13,14], this model is typical for urban-rural communes, but it limits the ability to fully control the waste stream and increases transportation costs. An analysis of the waste management infrastructure in the commune indicates:

- a well-developed selective waste collection system at source,
- a functional PSZOK with significant operational significance,
- a lack of local treatment facilities (dependence on the Puławy region),
- relatively high efficiency of problem waste collection.

According to Central Statistical Office reports [15], a similar infrastructure model is present in most municipalities in eastern Poland, where solutions based on outsourcing waste processing predominate. At the same time, literature indicates that the development of local infrastructure (e.g., composting plants or MBP installations) can significantly increase the system's efficiency and reduce logistics costs [16, 17].

CONCEPT OF A LOCAL LANDFILL PROJECT IN THE RYKI COMMUNE

An analysis of the waste management system in the Ryki Commune revealed that municipal waste generated within the commune is currently transferred to facilities located outside the commune. This solution generates high transport costs and increases pollutant emissions associated with transporting waste over long distances. Moreover, dependence on external installations limits the flexibility of the system and the possibility of its further optimization. In accordance with the principles of the circular economy, the development of local waste treatment and disposal infrastructure is one of the key elements of an effective waste management system [18, 19]. Therefore, a concept for the construction of a local municipal waste landfill serving the commune and potentially neighboring local government units was proposed.

Location and environmental conditions

The proposed location for the landfill was designated in the village of Niwa Babicka in the Ryki Commune (Figure 1). The selected area meets the basic location criteria specified in applicable laws and guidelines for landfill location. This area is located more than 500 meters from residential buildings and is separated from residential areas by a natural barrier in the form of a dense forest complex.

Based on the geological and hydrogeological analyses, a natural geological barrier approximately 1.2 m thick and with a filtration coefficient $k \leq 1.0 \times 10^{-9}$ m/s was identified. These conditions limit the migration of pollutants into the soil and water environment and meet the requirements for securing the landfill subsurface.

Waste volume forecast and landfill parameters

The forecast for the amount of municipal waste generated in the analyzed area was developed based on demographic data and waste accumulation rates. A 12-year landfill operation period and an average waste accumulation rate of 1 $m^3 \cdot M^{-1} \cdot year^{-1}$ were assumed. Based on the calculations, the total mass of waste deposited during the analyzed period was estimated to be approximately 184,000 Mg (Table 1). With an assumed waste density of 420 kg/m³ after compaction, the approximate volume of the landfill is approximately 438,000 m³.

Assuming a landfill height of 8 m, its base area is approximately 5.5 ha, while the total area including technical infrastructure has been

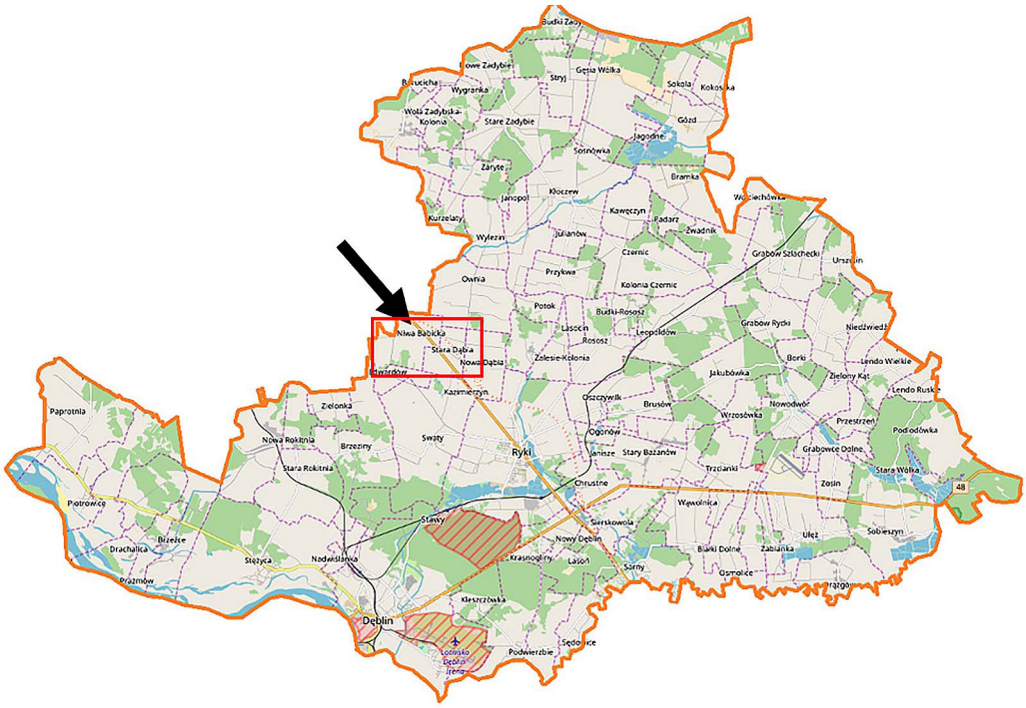

Figure 1. Location of the planned landfill in Niwa Babicka

Table 1. Estimated amount of waste generated in 2025–2036

Years	Number of inhabitants		Amount of waste from small towns and villages No. x waste density x accumulation rate [kg]	Amount of waste from large cities No. x waste density x accumulation rate [kg]	Total amount of waste per year
	Number of inhabitants of small towns and villages	Number of inhabitants of large cities			
2025	50400	21600	11088000	4752000	15840000
2026				4656960	15744960
2027				4564080	15622080
2028				4473360	15561360
2029				4384800	15472800
2030				4298400	15386400
2031				4212000	15300000
2032				4127760	15215760
2033				4039200	15127200
2034				3952800	15040800
2035				3866400	14954400
2036				3780000	14868000
Total waste after 12 years					184163760

estimated at approximately 10.7 ha. The planned landfill will divide the operational section into two sections, operated in phases.

Environmental protection system

To reduce the landfill's negative environmental impact, a multi-layer sealing system for the bottom and slopes, comprising mineral and synthetic layers, was designed. This system is supplemented by a leachate drainage system and a retention tank for periodic storage and transport to the wastewater treatment plant. The estimated annual leachate volume was estimated at approximately 4300 m³, which allowed for the selection of appropriate parameters for the drainage system and retention tank.

Degassing and energy recovery system

The concept also includes a degassing facility to collect biogas generated during the decomposition of organic waste. The estimated amount of biogas produced over the entire life of the landfill is approximately 22 million m³, which allows for its potential energy use. Biogas recovery is a significant element in reducing greenhouse gas emissions and aligns with the principles of a circular economy.

Benefits and limitations of the project

The construction of a local landfill can provide a number of environmental and economic benefits, including reduced waste transportation costs, increased independence of the waste management system, and the possibility of energy recovery from biogas. At the same time, this type of investment presents significant challenges, such as high implementation costs, the need to conduct an environmental impact assessment, and potential limitations resulting from public acceptance [4].

DISCUSSION

The analysis of the municipal waste management system in the Ryki commune indicates relatively high efficiency of selective collection and stable functioning of the organizational system, with a consistently high share of mixed waste sent for disposal. The obtained results are consistent with the observations presented in the literature on urban-rural municipalities in Poland, where despite the implementation of selective waste collection systems, mixed waste remains the dominant fraction [20, 21]. In 2024, the total mass of waste collected in the Ryki commune amounted to 4355.43 Mg, while the recycling level reached 54.07%. This value exceeds the required level of 45% specified in the national and EU law [22]. At the same time, the landfilling level of 40.14% indicates the still important role of disposal as the basic method of waste management. The literature emphasizes that achieving high recycling levels does not always translate into a significant reduction in landfilling, especially in systems dominated by mixed waste of low raw material value [23]. Similar relationships are observed in other municipalities in eastern Poland, where the morphological structure of waste limits the efficiency of material recovery [10]. An important element of the waste management system in the Ryki Commune is the PSZOK, which received 570.52 Mg of waste in 2024. The high share of construction waste (254.56 Mg) and biodegradable waste (134.50 Mg) confirms its key role in the waste management system. As Kozłowski et al. [24, 25] point out, the development of the PSZOK contributes to increased efficiency of selective waste collection and reduction of illegal waste abandonment, which is particularly important in municipalities with dispersed development.

From an infrastructure perspective, the Ryki commune operates under an outsourcing model, based on transferring waste to regional facilities. The lack of local treatment facilities results in dependence on external operators and increases transportation costs. As Bień and Korda (2020) point out, the development of local facilities, such as composting plants or MBP installations, can significantly improve the economic balance of the system and reduce transportation-related greenhouse gas emissions. The decline in the Ryki Commune's population between 2022 and 2024 (from 20,258 to 19,878 people) is consistent with this trend. in the nationwide trend of depopulation of urban-rural municipalities [10]. This phenomenon directly affects the unit costs of operating the waste management system, because maintaining infrastructure with a decreasing number of inhabitants leads to an increase in fixed costs per capita [3]. In accordance with the CE approach, the key direction of development of waste systems should be to reduce waste generation and maximize raw material recovery [26]. In this context, the commune demonstrates a moderately high level of adaptation to the requirements of the CE, however, reducing the mixed fraction sent to landfill remains a significant challenge.

CONCLUSIONS

Based on the analysis of the municipal waste management system in the Ryki Commune for the years 2022–2024, the following conclusions were drawn. The waste management system in the commune operates in accordance with applicable legal regulations and meets the recycling requirements set out in national and EU regulations. In 2024, a recycling rate of 54.07% was achieved, demonstrating the relatively high efficiency of selective municipal waste collection. Despite the high recycling rate, a

significant portion of waste (40.14%) still ends up in landfills, indicating the need for further optimization of the waste separation and processing system. The PSZOK plays a key role in the system, supplementing selective collection and enabling the management of problematic and bulky waste. The lack of local waste processing facilities results in the commune's dependence on external regional facilities, which increases transportation costs and limits the system's flexibility. The decline in the population between 2022 and 2024 may, in the long term, lead to an increase in the unit operating costs of the waste management system. In 2024, a total of 4355.43 Mg of municipal waste was collected within the commune, of which 570.52 Mg was collected at the municipal waste management plant. The recycling rate reached 54.07%, while the landfill rate was 40.14%. A landfill concept was developed in Niwa Babicka, with an expected waste mass of 184163.76 Mg and an operational period of 12 years. The results indicate relatively high efficiency of selective collection, with a significant share of mixed waste sent to landfill.

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