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Mapping of solid waste pollution in Zakarpattia region

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SUMMARY

Within the framework of the presented study, the authors carried out cartographic modeling of the pollution of the territory of Zakarpattia region with solid household waste (SHW) according to certain parameters. The analysis of available data made it possible to identify spatial disparities in the load on the environment within Zakarpattia region, to identify areas of excessive SHW accumulation and environmentally vulnerable communities. The methodological basis of the study is the analysis of the morphological composition of waste, demographic indicators, the cluster structure of SHW management, and infrastructure data. The results of the study include the analysis of cluster models that ensure logistical efficiency, environmental safety, and a 35% reduction in waste disposal volumes. One of the results is a proposal to integrate new cartographic materials into the regional waste management plan to create a more balanced solid waste management system within Zakarpattia region.

Keywords: solid household waste; mapping; clustering; Zakarpattia region; environmental impact; waste management; landfills.

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Introduction

As a border region with a predominantly rural population, Zakarpattia region faces the problem of uneven distribution of solid waste sources and limited infrastructure for their treatment. The lack of modern landfills, sorting stations, composting systems, and a large-scale centralized collection of hazardous substances and waste leads to their accumulation in places not designated for this purpose. This leads to the emergence of unauthorized spontaneous landfills, often on river banks. According to the Regional Waste Management Plan (Zakarpattia, 2025), only three landfills in Zakarpattia region comply with state building standards, and most landfills operate without project justification. The problem of land scarcity in the mountainous areas of Zakarpattia region, in particular in Rakhiv and the northern part of Tyachiv districts, complicates the creation of new landfills, which necessitates the optimization of the existing solid waste management system.

A regional analysis of the problem of solid waste pollution in Zakarpattia region was carried out using a cartographic research method, which allows visualizing the spatial aspects of pollution, identifying imbalances in the environmental load, and localizing ecologically vulnerable areas of individual communities, districts, or parts of Zakarpattia region. Cartographic modeling ensures the integration of multi-component data — morphological, demographic, infrastructural — into a single analytical system, which is critically important for management decision-making, particularly at the regional level.

The aim of this study is to map the pollution of Zakarpattia region with solid waste and analyze the cluster management model, taking into account morphological, demographic, infrastructural, and geoecological factors.

Method and Theory

The methodological basis of the study involves a comprehensive approach to assessing the pollution of Zakarpattia region with solid household waste (SHW) using geoinformation technologies, cluster analysis, technical and economic justification, and environmental expertise. The study is divided into several stages. The first stage involves the collection and systematization of statistical data on the generation of SHW within the territorial communities of Zakarpattia region. Next, an analysis of the morphological classification of waste is carried out based on regional passports and field surveys. Cartographic modeling of pollution by individual parameters is implemented by integrating data from an interactive map of landfills, dumps, and riverbed clearing sites (Google My Maps, 2025), as well as materials from the environmental passport of Zakarpattia region, which classifies objects according to their level of environmental hazard. Cluster analysis of the solid waste management structure was carried out using different models, where each cluster covers a group of communities with similar morphological, logistical, and infrastructural characteristics. Particular attention was paid to the K4 model, which provides for the integration of sorting stations, composting, and centralized collection of hazardous components. The assessment of logistical accessibility to solid waste management facilities was based on an analysis of transport infrastructure, terrain, and distance to the nearest landfills. Critical areas were identified where the distance to the facility exceeds 50 km, which creates an additional burden on the environment and the community budget.

All stages of the study were implemented using ArcGIS and Excel software, which ensured a high level of accuracy of cartographic models and consistency with official regional planning data.

In geo-ecological studies, mapping serves not only to visualize, but also to spatially analyze environmental risks, predict pollution scenarios, and assess the effectiveness of management measures. In particular, an interactive map of landfills, dumps, and riverbed clearing sites in Zakarpattia region (Google My Maps, 2025) made it possible to identify critical areas where the distance to these sites exceeds 50 km, creating an additional burden on the environment and community budgets.

The pollution of Zakarpattia region with solid waste is not only local but also transboundary in nature, particularly in the upper reaches of the Tisa River basin. As the authors of the article (Khilchevskyi et al., 2022) note, the chemical composition of water is influenced by anthropogenic factors, among which the unauthorized accumulation of solid waste plays a significant role. Another study focuses on the importance of developing a network of monitoring stations to assess the impact of pollution on surface waters in cross-border areas, which is critical for the environmental assessment of Zakarpattia region as a whole (Leta et al., 2022).

Results

The results of the study revealed significant spatial disparities in the environmental load in Zakarpattia region, caused by the uneven distribution of solid waste sources and limited infrastructure.

A K4 cluster model was developed, covering four integrated zones, taking into account the morphological composition of waste, logistical accessibility, and the environmental vulnerability of the territories. The model allows the optimization of transport routes, reduction of maintenance costs, and ensuring environmental safety.

Areas of excessive load have been identified, particularly in Berehove and Tyachiv districts, where the number of waste disposal sites exceeds permissible limits, and the lack of sorting stations contributes to the accumulation of waste in unauthorized places, which are often located on river banks without appropriate barriers to retain waste during floods and thus prevent pollution of watercourses in Zakarpattia region.

An analysis of the morphological composition of solid waste showed that organic components account for about 35% of the total volume, which opens up prospects for the introduction of composting systems. At the same time, valuable fractions (plastic, glass, metal) remain insufficiently covered by separate collection systems in general in the communities of Zakarpattia region.

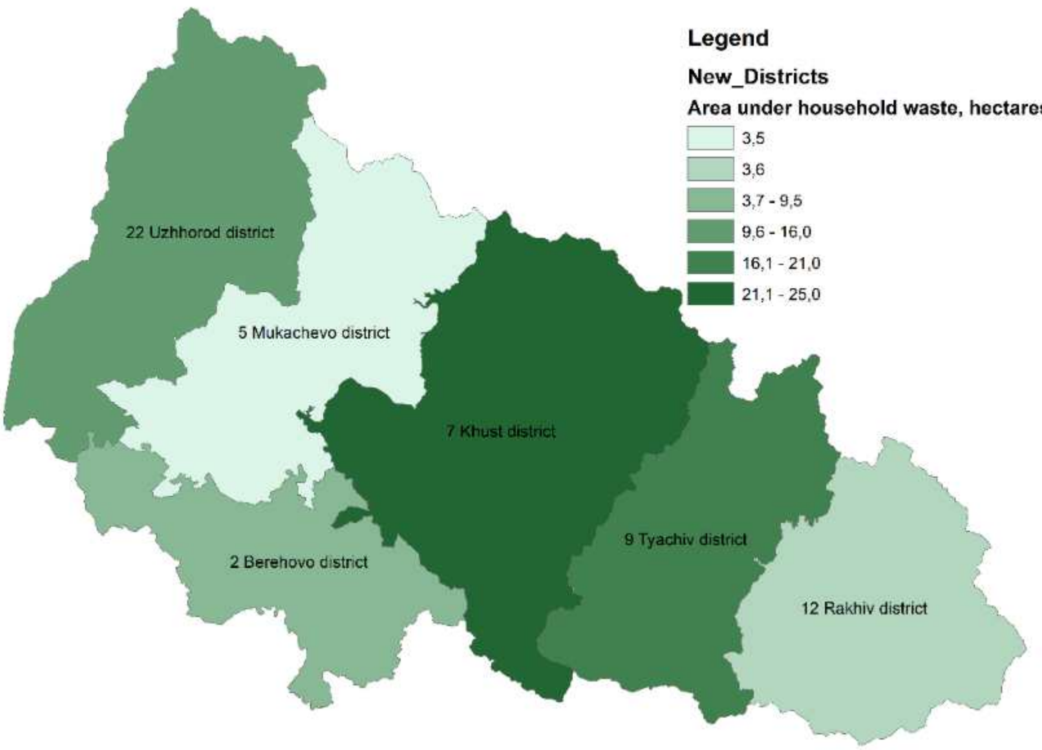

Figure 1. *Map showing the number and area of landfills and waste disposal sites in Zakarpattia region*

The cartographic model of pollution in the region (Fig. 1) visualizes the distribution of landfills and dumpsites, their area, and environmental status. The highest concentration of objects is observed in Uzhhorod district (23 units, 25 ha), while other districts show an unbalanced structure.

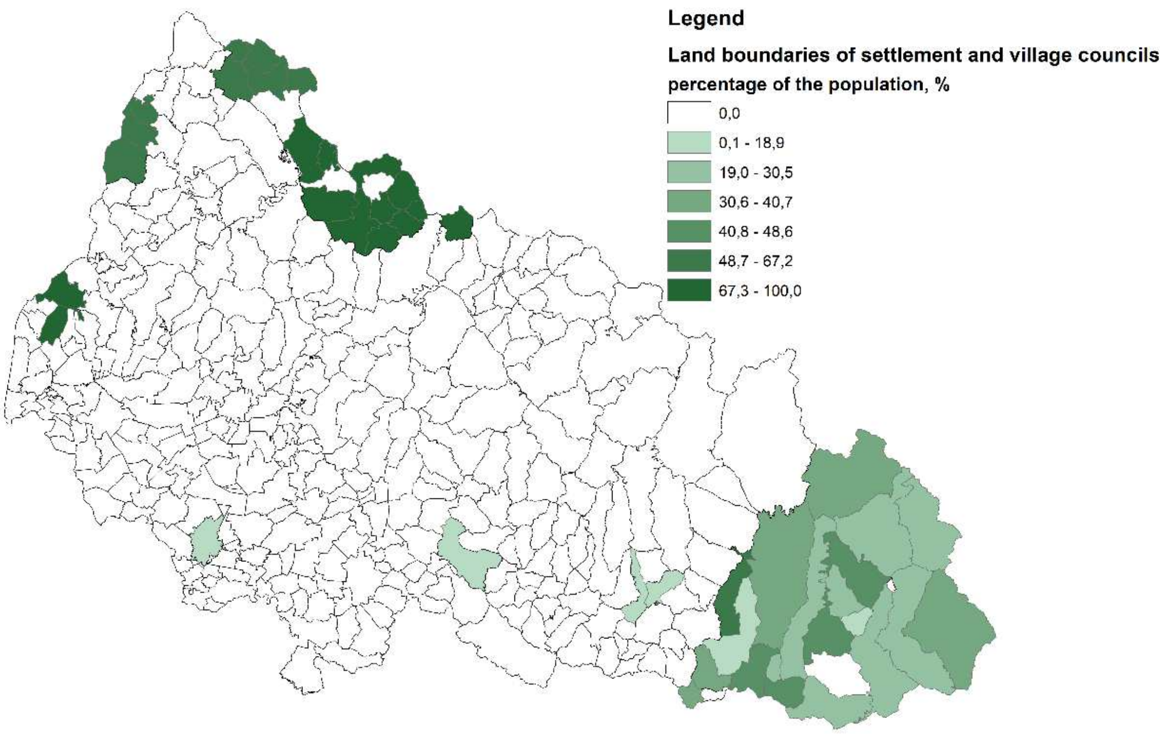

***Figure 2**. Map showing the percentage of the population covered by separate household waste collection, %*

Identification of environmentally vulnerable communities with limited access to solid waste management infrastructure, low sorting coverage, and high risk of water pollution. At the same time, it should be noted that as of 2021, there is a lack of data on the majority of communities in Zakarpattia region regarding the population covered by separate household waste collection (marked in white on the map (Fig. 2). Berehove City Community, Roztoky Village Community Verkhnye Vodyane Village Community, Bilyn Village Community, Yasinya Village Community, Vilkhovetska Village Community, Neresnytsya Village Community, and Khust City Community have low percentages of the population covered by separate household waste collection—less than 20%. It is recommended that these communities be included in the priority areas for environmental monitoring.

Conclusions

Mapping the pollution of the Zakarpattia region with solid waste allowed us to identify spatial disparities, environmentally vulnerable communities, and justify a cluster management model. The proposed K4 model ensures logistical efficiency, environmental safety, and infrastructure integration, taking into account the morphology of solid waste. A projected 35% reduction in landfill volumes is possible with the implementation of a cluster management model, infrastructure modernization, and intensified educational campaigns on waste management.

The results obtained can be integrated into the Regional Waste Management Plan of Zakarpattia region until 2034, as well as serve as a basis for strategic planning, environmental monitoring, and cross-border cooperation in the Tysa River basin.

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