Analysis of mixed municipal waste in selected municipalities and towns in Slovakia

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Summary

This article analyses mixed municipal waste in 31 municipalities in the Slovak Republic, focusing on the differences between apartment buildings, single-family houses, large cities and small towns. The unit of analysis used is 5% of the total number of mixed waste collection bins in use in the area of interest. Based on the results, it was possible to determine the amount of each type of waste in the mixed municipal waste. By analysing the waste in 31 cities and municipalities in Slovakia, we obtained a cumulative 15135.69 kg of mixed municipal waste, which contained 12 waste components in the municipalities of interest. We sought to demonstrate the difference in the amount of recyclable components of municipal waste obtained from town and village, as well as the difference in the representation of recyclable components of municipal waste originating from individual housing developments and complex housing developments. Statistical processing did not show a difference in the percentage composition of mixed municipal waste between the village and the town. The proportion of plastic and kitchen bio-waste was statistically significantly higher in complex housing and the proportion of garden bio-waste was statistically significantly higher in individual housing. In the mixed municipal waste of the selected municipalities, we found the following shares of individual waste types in Slovakia in 2020: paper 6.28%; plastic 10.49%; glass 5.10%; metal 2.55%; multi-layer combined material 0.92%; kitchen bio-waste 13.69%; garden bio-waste 25.37 %; textiles and footwear 4.34%; nappies 6.09%; hazardous waste 0.98%; construction waste 1.95 %; mixed municipal waste 22.23%. In the current climate of climate change, unsorted mixed waste is a significant problem and is traditionally landfilled or incinerated. Recycling is one of the solutions to reduce mixed municipal waste, but before that, it is necessary to understand what the composition of mixed municipal waste is and why different types of waste are treated in this way. Our work can help to introduce new waste sorting practices and thus contribute significantly to efficient waste management.

***Keywords**: waste, analysis, municipal waste, municipalities, cities*

Introduction

Waste management practices are changing and adapting rapidly in many countries as legislative and economic factors encourage more sustainable options such as reducing landfilling and recovering valuable resources. Accurate knowledge of the composition and generation of waste is needed to set realistic and achievable waste strategy targets, including recycling rates[1]. Municipal waste management schemes, recycling charges, waste separation and subsequent recycling are effective tools for reducing the amount of mixed municipal waste. The effectiveness of different municipal waste management tools has been demonstrated in many works[2,3,4]. The literature agrees that several measures need to be used in parallel to reduce landfilling. The search for mechanisms aimed at achieving long-term sustainable development plays an increasingly important role in the implementation of various strategies. Therefore, along with climate change, waste has become one of the biggest global challenges[5].The composition of municipal solid waste provides a description of the components of waste and varies widely from place to place[6]. The most striking difference is the difference in organic matter content, which is much higher in low-income areas than in high-income areas, while paper and plastic content is much higher in high-income areas than in low-income areas. In higher income areas, disposables and packaged food are used in greater quantities. For lower income areas, the use of fresh vegetables is much higher compared to packaged food. This results in a waste composition that has high moisture content, high specific gravity and low calorific value[7,8]. Many works use waste analysis in introducing appropriate internetions to reduce mixed municipal waste[9,10,11]. The authors suggest that there is an increasing trend in municipal waste generation in Slovakia, especially since 2016[12]. In the long term, the largest volume of municipal waste is produced in Bratislava and Nitra municipal regions. The lowest values were recorded in Trenčín, Prešov and Košice regions. The authors further note that the largest value of municipal waste production increases towards the west of Slovakia. Specifically, European directives state that only 10% of waste can be landfilled from 2035 onwards[13]. Approximately two thirds of municipal waste in Slovakia ends up in landfills. Recycling rates in Slovakia are below average compared to other EU countries[14]. The main objective of the Slovak Republic's waste management by 2025 is to move away from landfill disposal, especially for municipal waste[15]. Identifying the composition of waste is therefore critical to achieving this goal. It is necessary to know the composition of mixed municipal waste, to identify the shortcomings and causes that lead to its generation and to implement measures to reduce its quantity. In this article, we attempt to increase the knowledge on the composition of municipal waste.

The main objective of this paper was to conduct an analysis of mixed municipal waste in 31 Slovak cities and municipalities in 2020 and to confirm or refute the hypothesis that the representation of recyclable waste components in municipal waste is higher in cities than in villages.We also wanted to verify the hypothesis that in individual housing construction there will be a higher representation of the monitored recyclable components of municipal waste compared to complex housing construction. The exact socioeconomic status of the residents of the study sites was not available, so we did not assess it in the analyses.

The analysed data can be used to develop local waste measures and also as baseline data for comparing the effectiveness of individual measures to reduce the amount of mixed municipal waste.

Material and Methods

Our analysis was based on the legislative guidance of the Ministry of the Environment of the Slovak Republic, which according to § 105 (3) (a) of Act No. 79/2015 Coll. on Waste and on Amendments and Supplements to Certain Acts provides in § 1 Methodology for the analysis of mixed waste. This measure entered into force on 1 July 2020. The analysis of municipal mixed waste (MMW) is its detailed examination in terms of its composition. The aim of the analysis is to determine the representation of the different waste components still present in the mixed waste after the separation of the waste components. The sample size of the mixed waste shall be set at between 5% and 10% of the total number of mixed waste collection bins in use in the area of interest.

The bins shall not come from a single location in the area of interest, for example from a single street, street block, housing estate or urban area, the sample shall be from as large an area of interest as possible, unless the analysis is aimed at analysing the composition of mixed waste from only one location.

In selecting the collection receptacles to be sampled, receptacles containing sub-standard waste or any of the waste components in sub-standard quantities shall be excluded. Data on the weight of the waste components sorted shall be entered in a table by individual waste component sorted in kilograms and the weight of each waste component shall be indicated as a percentage of the total sample.

Our analyses were determined from 5% of the total number of collection bins for mixed waste in 31 towns and municipalities in the Slovak Republic.

The waste bins were randomly selected from the residents of the village and all those involved in carrying out the waste analysis were thoroughly trained on how to sort the waste. The waste sampling took place early in the morning on the day of the waste collection, which is provided for the municipalities by a contracted waste collection company. The survey was carried out between March and October 2020.

The presented research work was focused on the quantitative assessment of the content of the composition of mixed municipal waste. We focused on monitoring the content and quantity of 12 components of mixed waste.

In Figure 1 we present the 31 municipalities in which we carried out analyses of mixed municipal waste, where in some municipalities (11), we distinguished the analysis of waste from individual housing construction (IHC) and complex housing construction (IHC and CHC). We divide individual municipalities into villages (24) and towns (7), with towns (cities) having at least 5000 inhabitants and villages (villages) having less than 5000 inhabitants (Law No. 369/1990 Coll.).

After waste analysis, the sorted waste was handed over to the collection yard and placed in the appropriate sorted waste container. Some specific waste components (rubber, ash, wood) were included under mixed waste. Electrical appliances and small electrical waste were included under hazardous waste.

The dataset obtained from the waste analyses was subjected to statistical evaluation. The parametric T-test, we used only when there was a normal distribution of data in both groups. Nonparametric test (Mann-Whitney U-test), we used only when there was no normal distribution of data in both groups. We set the significance level of statistical tests at 0.05 for a statistically significant difference and 0.001 for a highly significant difference between the data being compared.

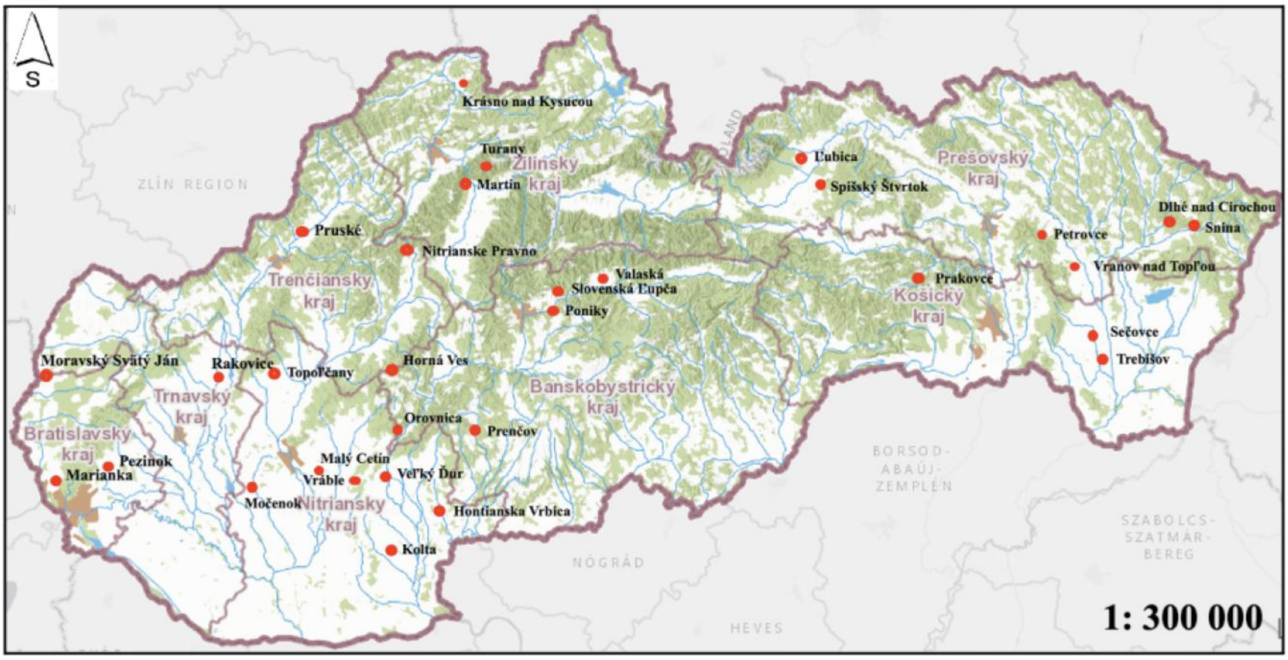


Figure 1: Study area

(Note: Modified map using the map base August, 2023, from https://www.google.com/maps)

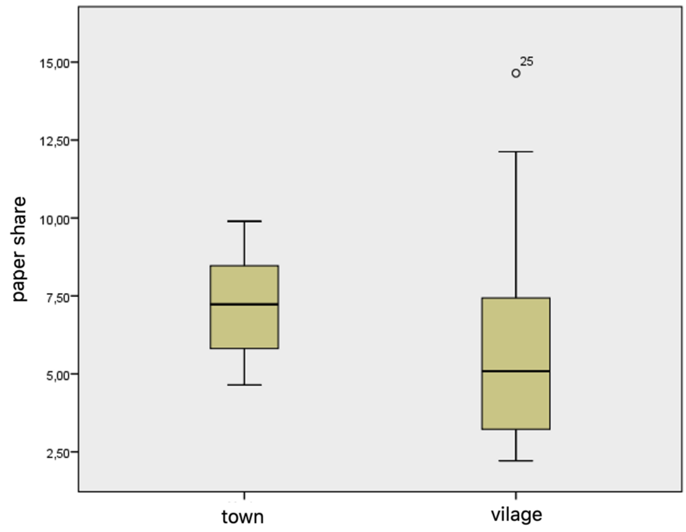
Results

Table 1 shows the amount of mixed municipal waste in kilograms collected from the 31 monitored municipalities. In some municipalities, we distinguished between analyses of waste from individual housing construction (IHC) and complex housing construction (CHC), the quantities of which we also report in the table.

Table 1: Study areas and amount of waste

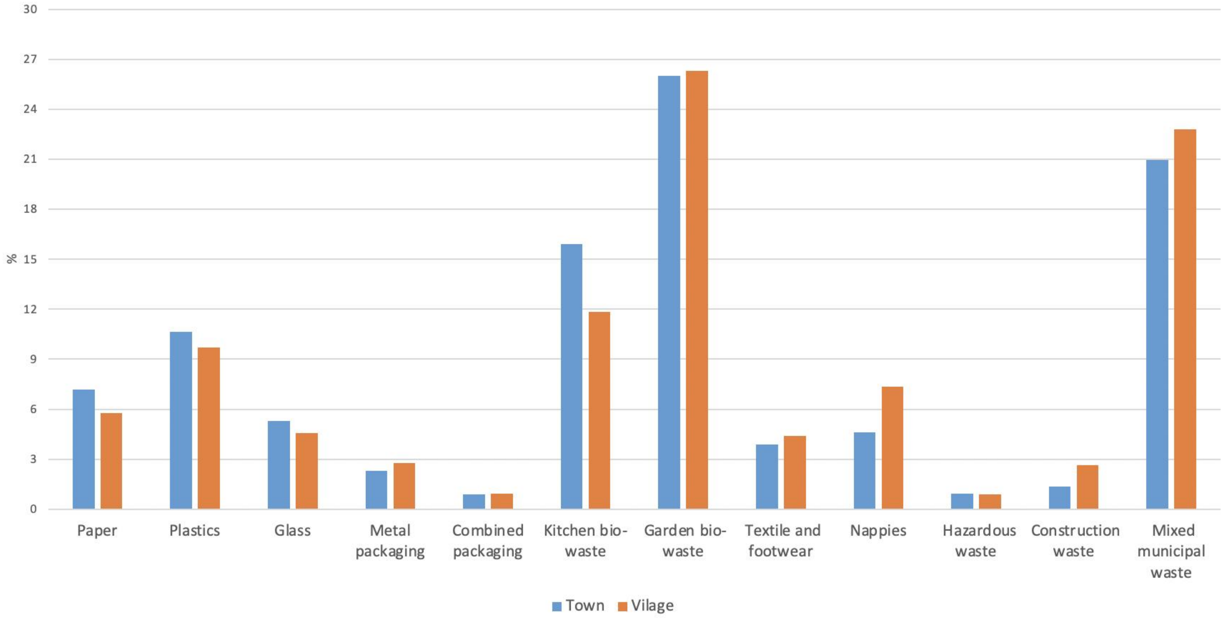
	Village/ Town	MMW [kg]	IHC [kg]	CHC [kg]
Marianka	village	588.45		
Pezinok	town	361.70	223.20	138.50
Rakovice	village	364.50	221.50	143
Moravský Svätý Ján	village	474.78		
Pruské	village	287.20		
Nitrianske Pravno	village	382.90		
Hontianska Vrbica	village	147.80		
Veľký Ďur	village	562.50	523.50	39
Vráble	town	1068.92	648.80	420.12
Malý Cetín	village	232.98	158.18	74.80
Kolta	village	211.24		
Močenok	village	391.90	235.50	156.40
Topoľčany	town	1341.18	174.31	1166.87
Krásno nad Kysucou	town	374		
Bystrička	village	179.39		
Turany	village	164.02		
Poniky	village	182.33		
Slovenská Ľupča	village	447.38	263.68	183.70
Prenčov	village	162.50		
Valaská	village	242.57	40.80	201.77
Petrovce	village	87.17		
Orovnica	village	248.09	167.86	80.23
Horná Ves	village	242.30		
Ľubica	village	218.86		
Spišský Štvrtok	village	104.30		
Dlhé nad Cirochou	village	579.67	324.79	254.88
Snina	village	1247.90	682.30	565.60
Vranov nad Topľou	town	1448.48	984.78	463.70
Prakovce	village	682		
Trebišov	town	909.30	279.50	629.80
Sečovce	town	1199.38	372.38	827
Total	-	**15135.69**	**5301.08**	**5345.37**

In a detailed evaluation of the observed waste components using a non-parametric U-test, we did not find a statistically significant difference in the percentage of any of the observed components between urban and rural areas ($p \geq 0.05$). In the case of paper (Graph 1), the significance level was closest to the statistical significance level ($p = 0.098$).



Graph 1: Evaluation of the difference in the percentage of paper share in municipal waste from the city and the municipality

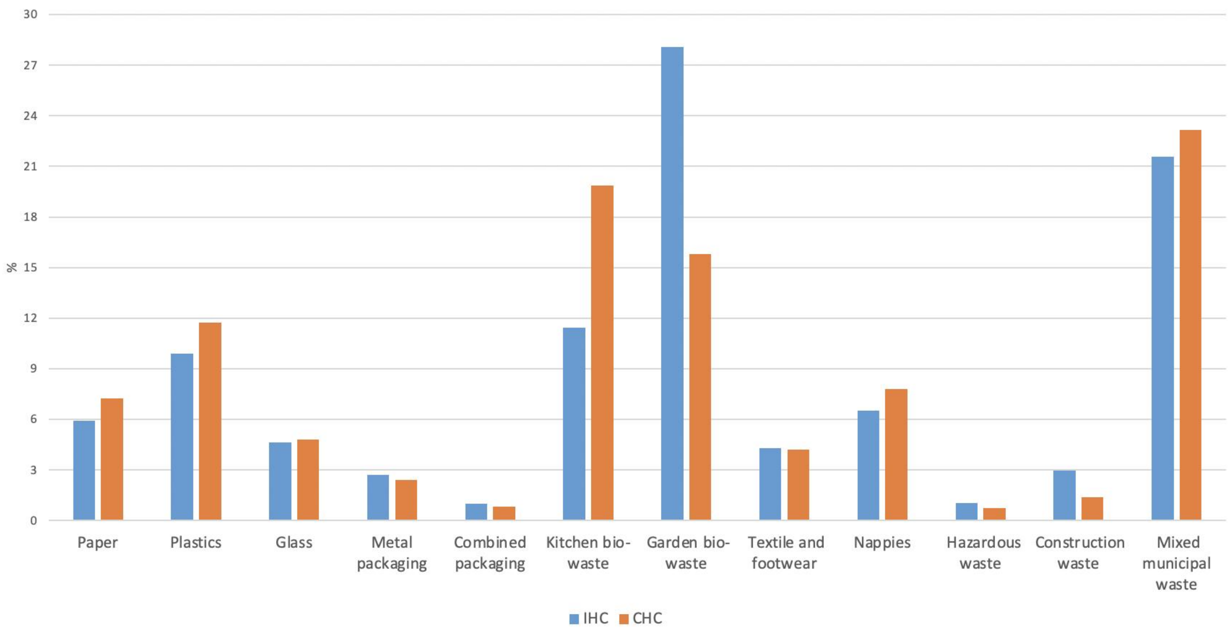
From the analyzed data, we created a cumulative graph comparing the composition of waste in the city and the municipality (Graph 2).



Graph 2: Comparison of waste composition in the city and the municipality

Using the same procedure, we analysed the difference in the shares of the observed waste components in individual housing developments and complex housing developments in 11 municipalities. By parametric T-test we did not show a statistically significant difference in the proportion of glass ($p= 0.795$) and combined packaging ($p= 0.312$). For the proportion of paper, textiles and footwear, nappies, metal packaging, hazardous and construction waste and mixed municipal waste, a U-test was used for the analyses. However, the latter showed no statistically significant difference between IHC and CHC when comparing any of these components ($p \geq 0.05$).

There was a statistically significant difference in the percentage of plastic ($p= 0.048$), kitchen waste ($p= 0.032$) and garden waste ($p= 0.032$). The percentage of plastic kitchen bio-waste is statistically significantly higher in CHC and the percentage of garden bio-waste is statistically significantly higher in IHC. From the analyzed data, we created a cumulative plot comparing the composition of waste in for IHC and CHC (Graph 3).



Graph 3: Comparison of waste composition between IHC and CHC

Discussion

By analysing waste in 31 towns and municipalities in Slovakia, which contained 12 waste components, we showed no difference in the percentage composition of mixed municipal waste between municipalities and towns. The proportion of plastics and kitchen bio-waste was statistically significantly higher in complex housing developments and the proportion of garden bio-waste was statistically significantly higher in individual housing developments. A high proportion of separable components in waste in the municipalities of Sady nad Torysou, Jasenie and Klenovec was also demonstrated by authors[16].The authors further demonstrated that a high proportion of mixed municipal waste is biodegradable waste, which confirms our findings. The comparative analysis showed that bio-waste accounted for approximately 36% of the total amount of mixed waste that ends up in landfill without further use. This trend is not unique. Similar conclusions were reached by authors in Poland[17]. In Polish cities, the annual production of household waste ranges from 238 to 309 kg per capita. Biodegradable waste is a significantly predominant component of household waste in Polish cities, followed by paper/cardboard and plastics. In the Czech Republic, the results of study showed that the average Czech consumer throws away 0.566 kg of food waste per week, which amounts to 29.4 kg per year[18]. People most often throw away bread and pastries, ready meals and fresh fruit. The results of further analysis in Denmark showed that household residual waste mainly contains food waste[19]. The amount of biodegradable waste is expected to increase in the next 25 years due to economic and population growth. It is reported that the annual amount of urban biodegradable waste in Asian countries could increase from 278 to 416 million tonnes from 2005 to 2025. A similar trend is expected in Europe and other parts of the world[20]. For example, waste in Abu Dhabi City contains approximately 50% of food waste[21].

Efficient waste management is the basis for improving services to citizens as well as environmental impact[22]. Approximately 1,4 billion hectares of productive land (28% of the world's agricultural area) is used for food production annually and is being lost or wasted. In addition to wasting food and soil resources, it is estimated that the carbon footprint of food waste contributes to greenhouse gas emissions, releasing approximately 3.3 billion tonnes of CO_2 into the atmosphere annually. Commonly, this food waste, which is part of municipal solid waste, is incinerated[23,24,25]. Meanwhile, the high rate of landfilling can be reduced through concerted action by the state, municipalities and the citizens themselves. Ljubljana is the so-called first "zero waste" city in Europe. 15 years ago it was one of the biggest polluters, with residents producing high amounts of unrecycled waste that went to landfill. Today, less than 5% of the waste produced goes there and 68% of the waste is recycled[26]. A similar trend was observed in the study where authors found that in the municipality of Jasenie, waste production decreased and residents' interest in waste sorting increased after identifying deficiencies in the waste sorting system[16]. By properly setting up a waste collection and sorting system, it is possible to reduce the costs incurred by the municipality for the disposal of mixed waste[16].

One of the options to reduce the amount of waste as well as to increase the separation of individual components is the introduction of quantitative collection for municipalities and the implementation of waste sorting analyses. In addition, other factors, such as the frequency of waste collection, also influence waste reduction and have an impact on sorting rates and waste production. The waste generation rate may increase with increasing income[27]. Other research for example, has shown differences in municipal waste production and separation between different age groups[28]. Technical conditions in the household, such as sufficient space for sorting in the kitchen, is an important factor[29]. Furthermore, it is important to inform and reassure citizens that their efforts are meaningful and that the waste they sort is actually used for its declared purpose and does not end up in a landfill or incinerator[30]. Door-to-door collection system increases the level of waste separation by up to 40% compared to the nest collection system[31]. Municipal waste generation is lower in municipalities that have some form of fee in place than in municipalities that have a flat fee[29]. If the infrastructure is available and there is sufficient frequency of collection container exports to allow for easy separation, people are willing to invest more effort and time in these activities[32]. After food waste sorting system is in place, it is important for policy makers to ensure the availability of containers for sorting and to motivate households to sort food waste by raising environmental awareness, providing financial incentives, and minimizing the barriers associated with sorting food waste[33].

Conclusion

By analysing waste in 31 cities and municipalities in Slovakia, we obtained a cumulative 15135.69 kg of mixed municipal waste, which contained 12 waste components in the monitored municipalities.

We were unable to confirm the hypothesis that cities produce higher proportions of recyclable components in municipal mixed waste than municipalities. Neither did we confirm the hypothesis that the proportion of the observed components in mixed waste from individual housing developments would be lower than that from conplex housing developments. The statistical differences found are isolated. The proportion of plastic kitchen bio-waste was statistically significantly higher in complex housing developments and the proportion of garden bio-waste was statistically significantly higher in individual housing developments.

Overall, we found high proportions of recyclable components in all the samples we monitored, the average values were as follows: paper 6.28%; plastic 10.49%; glass 5.10%; metal 2.55%; multilayer combined material 0.92%; kitchen bio-waste 13.69%; garden bio-waste 25.37%; textiles and footwear 4.34%; nappies 6.09%; hazardous waste 0.98%; construction waste 1.95%; mixed municipal waste 22.23%. From the above results it follows that the waste sorting system in the Slovak Republic is inadequate and requires an increase in the sorting rate.

For example, biological waste consists of cumulatively amounted to about 36% of the total mixed waste. The amount of biodegradable waste is expected to increase in the next 25 years due to economic and population growth. So its consistent sorting is necessary, as well as the separation of recyclable waste components.

Our analysis can provide the necessary information for future evaluation of the effectiveness and implementation of different practices to minimise the production of mixed waste.

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Analýza zmesového komunálneho odpadu vo vybraných obciach a mestách na Slovensku

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Souhrn

Tento článok sa zaoberá analýzou zmesového komunálneho odpadu v 31 samosprávach v Slovenskej republike, pričom sa zameriavame na rozdiely medzi bytovými domami, rodinnými domami, veľkými mestami a malými mestami. Ako jednotka analýzy sa používa 5 % z celkového počtu zberných nádob určených na zmesový odpad, ktoré sa používajú v záujmovom území. Na základe výsledkov bolo možné určiť množstvo jednotlivých druhov odpadu v zmesovom komunálnom odpade. Analýzou odpadu v 31 mestách a obciach na Slovensku sme získali kumulatívne 15135,69 kg zmesového komunálneho odpadu, ktoré obsahovali 12 zložiek odpadu v sledovaných samosprávach. Snažili sme sa preukázať rozdiel v množstve recyklovateľných zložiek komunálneho odpadu získaného z mesta a dediny, ako aj rozdiel v zastúpení recyklovateľných komponentov komunálneho odpadu pochádzajúceho z individuálnej bytovej výstavby a komplexnej bytovej výstavby. Štatistickým spracovaním sme nepreukázali rozdiel v percentuálnom zložení zmesového komunálneho odpadu medzi obcou a mestom. Podiel plastov a kuchynského bioodpadu bol štatisticky významne vyšší v komplexnej bytovej výstavbe a podiel záhradného bioodpadu bol štatisticky významne vyšší v individuálnej bytovej výstavbe. V zmesovom komunálnom odpade vybraných samospráv sme zistili tieto podiely jednotlivých druhov odpadu na Slovensku v roku 2020: papier 6,28 %; plast 10,49 %; sklo 5,10 %; kov 2,55 %; viacvrstvový kombinovaný materiál 0,92 %; kuchynský bioodpad 13,69 %; záhradný bioodpad 25,37 %; textil a obuv 4,34 %; plienky 6,09 %; nebezpečný odpad 0,98 %; stavebný odpad 1,95 %; zmesový komunálny odpad 22,23 %. V aktuálnej dobre klimatických zmien predstavuje netriedený zmesový odpad významný problém, ktorý sa tradične skládkuje alebo spaľuje. Recyklácia predstavuje jedno z riešení zníženia zmesového komunálneho odpadu, no predtým je potrebné pochopiť, aké zloženie predstavuje zmesový komunálny odpad a prečo sa s jednotlivými druhmi odpadu zaobchádza práve takýmto spôsobom. Nami realizovaná práca môže pomôcť pri zavádzaní nových postupov triedenia odpadu a tým významne napomôcť k efektívnemu nakladaniu s odpadom.

Klíčová slova: *odpad, analýza, komunálny odpad, samosprávy, mestá*