

# MICRO-LOCATION ANALYSIS IN MUNICIPAL SOLID WASTE MANAGEMENT – COMPREHENSIVE USE OF GIS IN THE SERBIAN VILLAGES

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**ABSTRACT:** The problem of waste management in rural areas in Serbia has not been the subject of detailed specific researches, since most of the research has been directed towards the study of means, mechanisms and procedures of waste elimination in urban settlements. The reason for the reduced scope of research in this field occurs in the fact that rural settlements can not be considered as adequate subjects due to usual deficiency of specific data (population number, fluctuations, quantities of waste, waste composition, methods of eliminating waste, etc.). In addition, for several decades villages in Serbia have eliminated waste primarily spontaneously. This has proven difficult to research because of the variations of methods applied to each specific locale, and the different environmental variables. Unlike the existing, plan-based criteria for defining locations for waste elimination (i.e. hypsometry, slope angles, distance from water-reservoirs, watercourses, infrastructure, natural and cultural assets, etc.), in villages these criteria are based on the patterns of behavior, customs and habits of the local population, as well as participation of local stakeholders in waste management. On the other hand, there is a significant problem in the absence of the Serbian and European legislation in this field. This paper will point to the possibility of changing the common practice in selection the location for waste management in rural areas, as well as some new methodological procedures (socially based GIS). The European theory and practice recognize new concepts of landfill sites selection in rural areas based on interdisciplinary research using multi-criteria analysis and model-based approaches to site selection, based on pre-defined location criteria and parameters (geographical, geomorphologic, hydrological, etc.). This paper will present the results of a research conducted in rural communities located in the Stara Planina Mt. Nature Park in Serbia. Through testing the initial hypothesis on the differences, but also correlations, between the criteria of open landfills created in rural areas and the location conditions given by theoretical parameters, as well as scientific bases (deterministic model), a location-specific model, corresponding to the research polygon, has been created for the simulation and evaluation using the GIS environment and with the support of the AHP and SAW methodologies. The research has been conducted using the ArcGIS Spatial Analyst software with the aim to stress the importance of using mathematical and geo-statistical analysis in the planning practice.

*Keywords: multi-criteria decision analysis; location theory; GIS; Stara Planina Mt. Nature Park; Serbia*

## 1. INTRODUCTION

The increasing number of theoretical studies in the domain of environmental planning are precisely directed towards finding adequate solid waste management systems and waste planning methods, which are primarily used in large urban centers. On the other hand, in smaller communities, such as rural areas, the research activities that are carried out in the field of municipal solid waste management are considerably smaller in scope, or are, like in Serbia, practically neglected. Nevertheless, certain results of the research on this problem in urban areas can also be directly used for rural settlements (e.g., in determining set of criteria for selecting solid waste disposal sites/landfills) (Vinti, Vaccari, 2022) (Taboada et al, 2011) (Patwa et al., 2020) (He, 2021). Structural differences in demographic and economic characteristics, in the behavioral model (behavioral patterns of the local population), in the environmental premises in the towns and villages, also condition different inputs in determining the methods and locations for elimination of municipal solid waste.

Having in mind those differences, theoretical and methodological approach and frameworks applied to urban and rural settlements should necessarily be separated and improved.

The recent methodology used for determination of the location for the waste elimination represents the new contemporary concept based on the GIS instruments and AHP and SAW methods. This concept is based on a multiple and interdisciplinary research (versus previously one-sided deterministic one) (Achillas et al, 2013) (Demesouka, et.al ,2014) as well as on the analysis and definition of multi-criteria model-based approach to selecting landfill sites based on predefined location criteria and parameters. Considering the analyses of recent studies in the field of solid waste management (Ferronato, Toeertta, 2019), (Guerrero, et al 2013), (He, 2021), the issue of including the social aspect in the said problem area has been actualized through taking into account affinities, behavioral patterns and interests of local population as highly ranked criteria for selecting solid waste disposal sites and methods. Further-more, the studies of the abovementioned theoreticians indicate a considerable shift in the current methodology which has previously been based on only AHP (Analytic Hierarchy Process) and SAW (Simple Additive Weighting) methods used in decision-making theories, as well as recent methodological assumptions which more significantly rely on the GIS tools. Namely, over the past twenty years, with the development of GIS tools as a decision support system, many researchers (Higgs, 2006), (Vucijak, et al, 2016), (Khan, Samadder, 2014), (Mikusova, et al 2019) (Dutta, Goel, 2017) have started using the GIS instruments as a major tool in the landfill site selection in a one-sided and theory-based manner. Criticism (Malczewski, 2004) (Nenkovic-Riznic, 2012) addressed to this methodology is based on the fact that geospatial systems could be used only as an instrument in the analysis, and not as a single methodological framework in the location analysis.

Therefore, it has been necessary to define an innovated methodological procedure for selecting landfill sites in rural settlements which would only rely on GIS instruments or AHP and SAW methodology (Guiquin et al, 2009) (Mokthari et al, 2016) as well as newly introduced socio/psychological location criteria.

## 2. MATERIALS AND METHODS

### 2.1 Methodological framework – history, analysis, studies

In the last decade of 20th and first decade of 21st century, the problem of selecting the location factors and methodological framework for determining the solid waste management method and potential landfill sites (areas) in settlements has been studied by many European and world researchers (Achillas, et al, 2013), (Mwangi, Thuo, 2014), (Ferronato, Torreta, 2019), (Guerrero, et al. 2013), (He, 2021) (Pongracz, et al., 2004)

The criteria for locating the solid waste disposal facilities (or sites) have been studied, along with the standards relative to the so-called techno-economic criteria (engineering and geological ground

conditions, property-legal relations, local population projections, harmonization with laws and higher-level plans and programs, economic efficiency, etc.). On the other hand, in parallel with landfill sites created according to the mentioned theoretically based criteria, local citizens were forming open landfills (also in theory can be found as - unplanned landfills, open dumps). Location criteria for illegal dumps have originated directly from the local people, their behavioral patterns, affinities, etc. (the so-called criteria of spontaneously created landfills or socio/psychological criteria). These criteria have neither been in focus in contemporary theory research nor have they been taken into account in the landfill site selection. The mentioned view-point is a result of a previous comprehensive research on contemporary theoretical and research assumptions in the field of solid waste management. Furthermore, the current practice (at world level) does not sufficiently take into account the social/psychological criteria as the relevant ones.

Thus, a new field of research has been opened with the aim to determine correlations between technoeconomic and socio/psychological criteria/conditions. These new criteria taken into account in creating open landfills are based on behavioral models of local population, their habits, affinities of different interest groups to which the population belongs, as well as on visual assessment and location criteria/conditions that are a result of theoretical checks, scientific foundation, as well as research with clearly predefined methodology, which has actually been taken as a basis for this research study.

The entire methodology has primarily been based on a comparative analysis of different case studies (examples) conducted by the world researchers in the sphere of the GIS application in landfill site selection in rural settlements (Greece, China) (Kontos et al, 2005), (Guiquin et al, 2009) and other countries (Demesouka et al, 2014), (Patwa, et al, 2020), (Anwar et al, 2018), (Santos et al, 2021), (Ishizaka, Nememry, 2024), (Milutinovic et al, 2014) (Vucijak et al, 2016). It has also been based on the establishment of joint location criteria which could be taken into account as the general, techno-economic criteria, as well as on predefined multi-criteria analyses (through modified and, for the needs of this research, adapted AHP and SAW methods and methods of socially-based multi-criteria analysis), and techno-economic criteria for the landfill site selection in a pilot area in Serbia (villages of the Stara planina mountain Nature Park) (PPSPA, 2008), as supplemented for the needs of this research.

On the other hand, research has incorporated multi-criteria analysis of open landfills based on socio/psychological criteria. Furthermore, the degree of concordance between locations obtained through the analysis of techno-economic and socio/psychological criteria have been determined once again through a comparative analysis, whereby conclusions in research have been drawn. All of the mentioned phases have also relied on a direct application of GIS technologies in the analysis, which has implied the creation of geospatial databases used for detailed visualization of results. In this way, a model has been created which, adapted to local conditions, can be used for the landfill site selection in rural settlements with different geographic, demographic, engineering geological characteristics, etc. These methods have been monitored in all phases both through survey method and through regression analysis of data (in order to identify attitudes of local people on the selection of methods and sites for solid waste management purposes, as well as to define specific socio/psychological criteria).

Methodology used within this research represents a consolidation of the existing methodological frameworks used for the landfill site selection, also supplemented with the analysis using the geospatial databases (GIS methodology).

Considering that landfill site selection is also influenced by the type of settlement, as well as solid waste disposal method planned for a certain territory, through examples of foreign practice (Demesouka et al, 2014), (Patwa, et al, 2020), (Anwar et al, 2018) and successful scenarios (Kontos et al, 2005), (Guiquin et al, 2009), it has been necessary to also define the general criteria for implementation of such projects in Serbia.

## **2.2. Pilot area- villages of Stara planina Nature park**

The area of three villages located in the Stara planina Mt. Nature Park in South-east Serbia were chosen as pilot area for testing the main hypothesis (Picture 1). The reason for choosing these villages is the availability of planning documentation and studies (PPSPA, 2008), (PPSPA, 2022), as well as the

fact that they are in the nature protection regime, which can represent an additional aggravating elimination criterion. Consequently, the research has gained greater relevance (taking into consideration additional technoeconomic criteria).

Also, significant degree of strong behavioral habits related to waste management was observed in these villages.



Picture 1. Nature park Stara planina, Republic of Serbia

Source: PE "Srbijašume", Serbia

Overall methodological procedure has been divided into 5 phases as follows:

Phase I – Multi-criteria analysis and the GIS as a decision support tool for the landfill site selection

Over the past fifteen years, multi-criteria analysis, social multi-criteria analysis, AHP method and other methods found a fruitful realization with their incorporation into the geographic information systems (GIS). The GIS combines spatial data (maps, ortho-images, satellite images) with qualitative and quantitative data, as well as descriptive databases.

The GIS represents a practical visualization of multiple-criteria decision analysis (MCDA) and, as such, (Milutinovic, et al. 2014), (Goulart Coleho et al., 2017) (Huang et al, 2011) (Dias et al., 2019) (Cegan et al., 2017), (Bhagat et al., 2016) it has become an integral component of regional and urban planning, and also environmental planning. GIS is becoming more and more helpful in all of the location studies.

Considering that a combination of multi-criteria and GIS method has recently mainly been used in the existing research in the sphere of waste management, this combination has also been used for this specific research.

Phase II – Selecting the location criteria

After location analysis methodology selection, it was necessary to establish evaluation criteria, based on predefined methodologies.

As previously mentioned, the location-specific requirements, or factors, depend on various parameters linked to site-specific natural conditions: hypsometry, inclination angles (slope), terrain exposition, presence of ground and surface waters, water accumulations, soil, flora, fauna, previous protection, geomorphology, geology, seismic, flood-proneness, soil engineering, geologic conditions, etc., as well as on certain economic factors such as location availability, property-legal relations, costs of preparation, connection with surroundings/transport costs, problem of parcel revitalization, etc.

Some of these factors have also been a result of a field survey and deliberation on the importance of locating new landfills in villages as formulated by local population. In addition to natural and technoeconomic aspects, it is important for the location to also take into account aesthetic aspect, which has a key role in location for open landfills. Finally, it has also been necessary to take into consideration the planning aspect which implies the existing and planned land use, existing and planned distribution of population and settlements in the subject area, existing and planned amount of generated waste, etc. On the other hand, local population tends to have more location criteria directly associated with behavioral patterns and affinities of local people (socio/psychological criteria). For the purpose of this research, these criteria have been classified into: free space criterion (ownership over the land, location availability); distance from housing groups in the village; terrain configuration (geomorphologic criterion); visual effects (aesthetic criterion); behavioral patterns (models) – habits; consent of inhabitants of rural settlements (public participation).

This set of criteria has also been supplemented with opinions of local populace from several villages on the territory of the Republic of Serbia (total amount of 120 citizens), which have been formulated through various field surveys and interviews.

#### Phase III– Evaluating the criteria

The evaluation process implies a selection of a greater number of man-made and natural location factors, their ranking set by weighting their importance for certain areas. Criteria weighting is based on the analysis and expert opinion. Thus, this evaluation can also be considered as a quantitative classification of location factors. After the classification of location factors, as well as based on theoretically and empirically predefined levels of importance of certain location factors for a specific problem, the suitability limit values have been defined within each individual evaluation criteria (or location factor). Namely, quantitatively and qualitatively verifiable parameters of each of the location factors have got its land capacity value (qualitative determinant of suitability) relative to the considered problem, thereby the suitability is given the value expression (1-5, 1-10 or classification into suitable, conditionally suitable and unsuitable) related to the land use.

#### Phase IV– Integrating multi-criteria analysis within the GIS framework

Cartographic diversification of observed territory, depending on suitability degree of the location relative to the previously established location criteria, has been carried out using the geographic information systems (GIS) within the ArcGIS (Spatial Analyst) software package. Based on examples of research mentioned in this chapter, it may be concluded that this methodology has contributed not only to easier geospatial consideration of locations, but has also enabled the creation of more accurate, mathematics-based waste disposal sites in rural settlements using complex mathematical procedures. Calculations have been performed mathematically using the ArcGIS Spatial Analyst software package for performing not only mathematical calculation of the most suitable location, but also for its visualization. The research has been conducted through creating a raster of specific zones or line directions of constraints distribution and their later reclassification relative to suitability criteria (suitable, unsuitable, and conditionally suitable). Thus, a clear idea in zoning certain location criteria has been obtained. Through overlapping the degree of suitability of different location criteria and their recalculation using this software package, absolutely accurate mathematically calculated locations have been created that are directly related to previously established weights and location criteria. The obtained results have been graphically expressed as dots or zones which may be considered the most suitable according to the predefined weights.

Phase V – A comparison between locations obtained using model-based approach (with technoeconomic criteria) and open landfills (with socio/psychological criteria)

In this phase, the existing open landfills have been compared with locations obtained through developing a specific model for research needs (technoeconomical model). Introduction of socio/psychological criteria of location in the technoeconomical model-based approach changed the position of the locations determined by the technoeconomical approach and the locations have come closer to those defined through the behavioral patterns of the local population

### 3. RESULTS

In order to define the method and system for municipal solid waste disposal in the territory of rural settlements in Serbia, as well as to use previously elaborated methodology, it has been necessary to determine main input parameters including:

- data on spatial coverage of settlements (topographic features, development of traffic, water resources and energy infrastructure, existing waste management system, locations closest to the existing/planned landfills),
- population data (demographic structure and projections of the resident population, disposition of settlements),
- data on the amount and structure of municipal solid waste in rural settlements and
- data on the existing methods waste management

After creating the database on the abovementioned parameters, it has been necessary to carry out the GIS mapping, through determining exact locations of rural settlements, existing waste disposal sites, existing and planned land use, existing and planned protection zones of natural and cultural assets, as well as possible geo-morphologic/hydrogeological barriers in the terrain (water accumulation protection zones, infrastructure corridors, etc.) and spatial distribution of land users (based on projected population) (National census, 2022) All mentioned multi-criteria analyses have been conducted using the ArcGIS (Spatial Analyst) software package, and based on own elaborated methodology,. All mentioned parameters have primarily been necessary for defining the waste collection method in a given territory, but also to tentatively define locations and outlines of recycling yards/transfer stations, landfill capacity and/or capacity of the waste processing facility in villages of Stara planina. The research activities have encompassed the determination of techno-economic, deterministic criteria used in the landfill site selection (such as geological, hydro-geological, geomorphological, seismic, climatic criteria, existing and planning methods of land use, ecological criteria, criteria for the protection of natural and cultural historical assets, existing infrastructure, etc.). On the other hand, from the aspect of determining the potential landfill sites, it has been necessary to conduct additional analyses, based on the behavioral patterns of the local inhabitants of Dojkinci, Senokos and Gostuša).

Altogether 18 different criteria have been determined according to which the most suitable locations for newly planned landfill sites in villages have been determined using the multicriteria decision analysis methodology. (Figure 1).

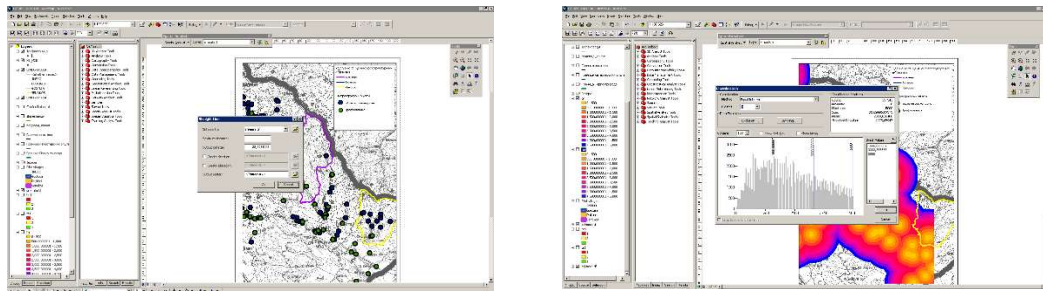
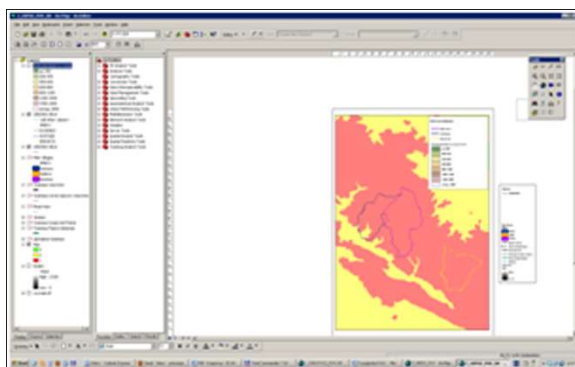


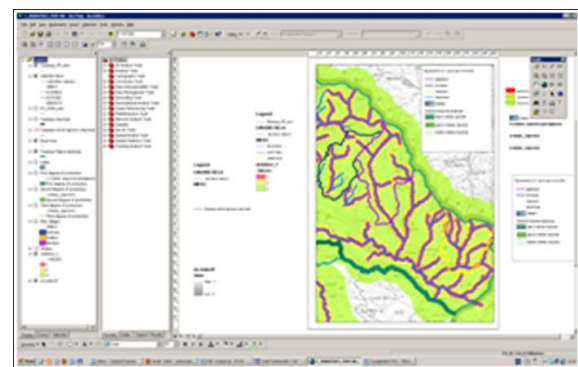
Figure 1. Initial analysis of the suitability criteria

They have been additionally evaluated through phase III and IV of the proposed methodology by using geospatial database and then graphically presented.

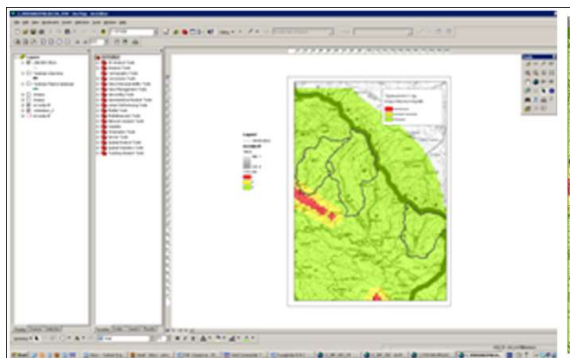
The most suitable locations have been denoted by the green color, the conditionally suitable ones by yellow color, while unsuitable sites according to these criteria have been denoted by red color. It is interesting to note that the research has been based only on three quantitative suitability ranks (suitable, conditionally suitable and unsuitable) considering that this is a common classification in the Serbian planning practice.



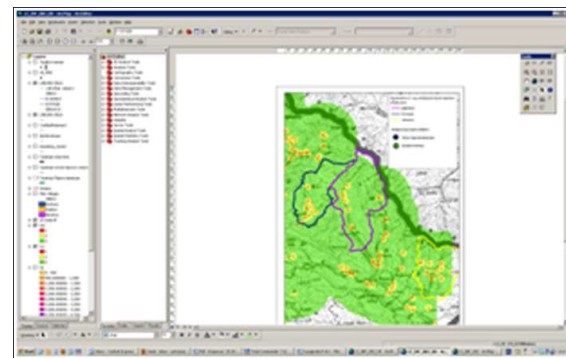
(a)



(b)



(c)



(d)

Figure 2. Geospatial analysis of the area of 3 villages in the Stara planina mountain relative to: a) hypsometry of the area, b) distance from watercourses, c) distance from infrastructure facilities d) distance from water accumulation

Figure 2 (a,b,c,d) depicts analyses of certain rural settlements which have been included in the analysis). These are only some of the analyses (out of the total of 18 ones) as shown on Figure 2. Other analyses have comprised suitability analyses relative to locations of existing settlements, climatic parameters, distance from state roads of the first and second category, etc.

Locations obtained through the analysis are a direct reflection of predefined techno-economic criteria, which can also be determined with a higher level of accuracy through an additional, more detailed, analysis. (Figure 3a.) After that, and in parallel with this analysis, the analysis for identifying the existing

landfill sites has also been conducted in the chosen pilot area of villages in the Stara planina mountain Nature Park (Figure 3b). In order to prove initial assumptions on the significance of socio/psychological criteria in selecting waste disposal sites in rural settlements, an additional criterion – social acceptance (level of public participation, behavioural models), has been included in the originally realized techno-economic model, and a new set of locations, territorially considerably closer to open landfills, have been determined through additional analyses (Figure 3c).

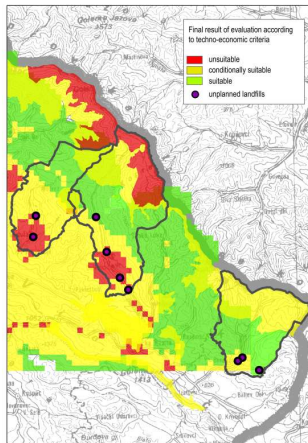


Figure 3a) Final result of evaluation according to techno-economic criteria in ARCGIS software package

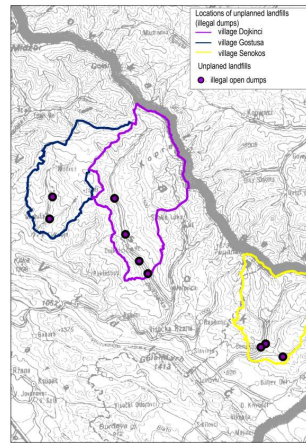


Figure 3b) Dotted distribution of open landfills in one of the analyzed localities (Stara planina Mt. Nature Park)

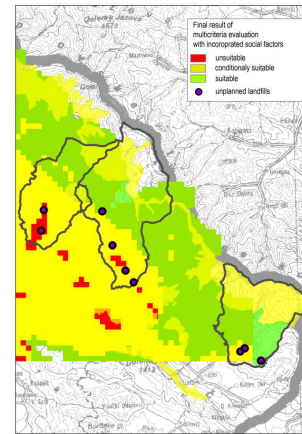


Figure 3c) Result of multi-criteria analysis with additional rank of social acceptance for the site (with existing landfill sites)

#### 4. DISCUSSION

Based on comparative representations of the existing open landfills (formed based on the socio/psychological criteria), as well as locations obtained through technoeconomical model-based approach, it may be concluded that the degree of success in solid waste management through construction of landfills/transfer stations/recycling yards in rural settlements primarily depends on the degree of local population participation in the decisions-making process in the sense of taking into account their attitudes in making decisions and, what is even more important, the degree to which habits and behavior of local population in the multi-criteria analysis has been taken into account.

Although these parameters have not been analyzed in detail, but have been taken into consideration as results of population surveys, they represent important implications in planning and creating models for locating any activity in space.

According to the research results, technoeconomical model-based approach in landfill site location, should be accompanied by a social/psychological analysis, as well as demographic characteristics of the area. This guarantees a successful realization of adequate waste management system adapted to the local conditions.

Survey of the local population, carried out for the purposes of this research, has revealed that open landfills' locations in the pilot area have been chosen according to the criterion of a free spaces, i.e., sites for which property-legal relations have been unknown (in cases of waste dumping into river beds, traffic corridors), aesthetic criterion ("if you can not see it, it is not there"), or behavioral criterion (transgeneration inherited waste disposal habits).

The survey results have shown that local population currently disposing their waste in illegal dumps,



would be ready to sort waste not only because of evident financial compensation, but also because of the „possibility to do something useful and to occupy their free time “.

This clear cause-and-effect relation that exists in human behavior models, demographic structure and habits and way of life, on the one hand, and waste disposal, on the other hand, indicate that individual interests of local population and their personal preferences, are a major factor in selecting waste disposal sites.

Also, rural life with the lack of continuous social engagement opens new field of stimulation of the local population for actions on collecting and separating waste within the village territory.

In the context of decision-making, it may be concluded that, although the technoeconomic model-based approach is more relevant from the viewpoint of spatial/urban planning, some new criteria for better understanding of participative planning in waste management are occurring. Thereby, it has been confirmed that for accurate selection of landfill and/or transfer station sites in rural areas it is also necessary to include habits, behavioral patterns and affinities of local population in decision-making process.

The new, combined technoeconomic and socio/psychological GIS methodology used in this research may, with partial changes, also be used for selecting sites for other, potentially ecologically hazardous purposes. By changing the number of criteria, as well as their rank in the model, the research can gain new perspectives and achieve higher level of objectivity.

## **5. CONCLUSIONS**

The research of the existing waste disposal methods in villages in Serbia, as well as proposed guidances for their improvement can have significant impact on the quality of environment and life of local population. Through specific research of the existing waste disposal sites (based on the preferences of the local inhabitants) on the research polygon, as well as through determining technoeconomical model-based locations for waste disposal it can be concluded that any research on these subject must have stronghold in public participation.

The locations of the landfills that were chosen based on the techno-economic model were significantly different from the locations of the spontaneously created landfills. However, the inclusion of socio/psychological factors in the overall multi-criteria analysis brought the locations closer together in a territorial manner. Having this in mind, it can be concluded that for all analyzes of locations for objects/purposes that will directly enable people for different activities in space, it is necessary to incorporate the socio/psychological factor.

Created GIS model used for ranking the location suitability after further elaboration (by increasing or reducing the number of criteria, depending on a specific research) may serve for diverse multi-criteria location analyses that are not directly associated with the waste management. Thus, the model also finds multiple application in different location studies in spatial planning.

More relevant research results have been achieved using the GIS instruments in combination with standard AHP and SAW analyses, achieving a higher degree of objectivity in specific research. This emphasizes importance of inclusion of GIS instruments in spatial location analysis which provide more accurate models that find multiple application in environmental planning.

## **ACKNOWLEDGEMENTS**

Funds for the realization of the research presented in this paper were provided by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, registration number: 451-03-68/2023-14/ 200006.

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