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GIS AND LINEAR PROGRAMMING IN WASTE MANAGEMENT SYSTEM PLANNING

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ABSTRACT
Population growth, economic development and higher standards of living lead to increased production of waste, but efficient waste management is becoming a major challenge faced by local communities in developing countries. The application of Geographic Information System (GIS) and mixed integer linear programming in planning of municipal waste management system is the subject of the work. The observed waste management system is based on the construction of waste transfer stations - facilities for temporary storage, preparation and reloading of waste for transport to a landfill. Problem of determining the optimal number and locations of waste transfer stations can be solved using two-stage methodology: Phase 1- selection of suitable area and Phase 2 - determination of optimal number and micro-locations of waste transfer stations. This paper discusses Phase 1 and includes the development, adaptation and application of GIS in order to determine area suitable for the location of waste transfer stations from spatial, environmental and social point of view. The problem is solved by using MapInfo Professional 11.0, cartographic software for visualization and analysis of the relationship between data and geographic space. Troubleshooting was performed on the selected area of research - the Herzegovina-Neretva Canton in Bosnia and Herzegovina.
Keywords: Waste management planning, GIS, Linear programming, Waste management system modeling

1. INTRODUCTION

Selection of the optimal number and location of waste management system infrastructure facilities requires an extensive evaluation process, in order to identify the best available location. In addition to being in accordance with the requirements of legislation in force, potential sites must at the same time satisfy the spatial, environmental and social factors. A final decision on the site selection is important and challenging task, which needs to be the result of a comprehensive and detailed analysis and evaluation of several acceptable options, with the continued involvement of all stakeholders. When making a decision on the site selection it is necessary to balance between economic, environmental and social interests that emerge in these areas in order to meet long-term goals and needs of nearby settlements, the region and beyond [1].

In dealing with such complex and sensitive social issues, a key factor is the "space", which implies the entire area of research, i.e. the area where the problem needs to be addressed. In order to ensure an objective and impartial decision-making, it is necessary to analyze the entire area of research in the same way. Such an open decision-making process in waste management assumes multiple and iterative analysis. Today, this process can be facilitated by the help of effective tools for the management and processing of spatial information. One of these tools is Geographic Information System (GIS), which enables display and processing of spatial data for solving complex analysis and planning problems. Environmental spatial analysis allows understanding and addressing complex environmental problems, such as the selection of waste transfer stations (WTSs). When analyzing such issues, merging of spatial, environmental and other data and information from many different sources, in different formats and from a multidisciplinary perspective is of great importance, and GIS system can provide that.

In addition to spatial, environmental and social considerations to be taken into account when evaluating potential sites, a very important criterion that ensures the viability of the whole system is the economic criteria, which, in this case, refers to the reduction of the cost of the system. Method of Linear Programming (LP) and its variation - a method of Mixed Integer Linear Programming (MILP) is an effective tool for finding solutions related to the selection of the optimal number and location of WTSs. Therefore, by using the MILP, the number of WTSs as well as the best location will be selected from a number of proposed WTS sites in a way that minimizes the cost of the overall system.

Problem of determining the optimal number and locations of waste transfer stations can be solved using two-stage methodology:

Phase 1- Selection of area suitable for the location of waste transfer stations

Phase 2 - Determination of optimal number and micro-locations of waste transfer stations.

This paper is focused on Phase 1.

2. METHODOLOGY FOR SELECTION OF AREA SUITABLE FOR THE LOCATION OF WASTE TRANSFER STATIONS

The main goal of identifying areas suitable for the location of WTSs is to ensure that transfer stations are located in the area that has the least impact on the environment and population. This area is determined by the procedure of eliminating areas that are not suitable for the location of WTSs, taking into account the criteria of exclusion, i.e. elimination criteria. This procedure results in positive territory, or area suitable for the location of WTSs. This area is determined by subtraction of the eliminated area from the total area of research [6].

$$P_S = P - P_e$$

Where: P - Total area of research, P_S - Area suitable for the location of WWTs, P_e- Eliminated area, i.e. area not suitable for the location of WWTs.

The area that is not suitable for the location of WWTs is determined by eliminating all areas that do not satisfy the elimination criteria.

$$P_e = \bigcup_{i=1}^{i=n} P_{ei}$$

$P_{e1}, P_{e2}, P_{e3}, ..., P_{en}$ – Areas eliminated according to elimination criteria, n – Number of elimination criteria.

Basic operations in GIS, which allow the determination of areas suitable for the location of WTSs are:

- Buffering and
- Overlay.

Buffering implies creating polygons around points, lines or polygons by locating their boundaries at a certain distance. This operation creates two areas: one located within a certain distance of selected real features and the other area outside. The area that is within the specified distance is called buffer. Buffers are created based on the elimination criteria:

- Spatial - Roads and railroads, Airports, Agricultural areas, Zones planned for special purposes
- Environmental - Natural protected areas and areas with valuable flora and fauna, Surface and ground water areas, Floodplains, Steep slopes and unstable areas
- Social - Urban areas, Drinking water sources, Cultural-historical areas

Each buffer is determined based on the elimination criteria and stored in a separate thematic layer. By overlaying all the layers that contain information about the buffer zones, two types of areas are identified (i) areas that meet all the required criteria and (ii) areas that do not meet the criteria. All areas outside the zone of influence (buffer zone) are considered suitable for the location of WTSs.

3. APPLICATION TO THE AREA OF RESEARCH

Herzegovina-Neretva Canton is located in the southern part of Bosnia and Herzegovina and occupies the area of 4,401 km². It consists of nine municipalities: Konjic, Jablanica, Prozor-Rama, Citluk, Capljina, Neum, Stolac, Ravno i Grad Mostar. Waste management is the responsibility of municipalities and public utility companies whose owners are municipalities. The regional sanitary landfill that will have the capacity to serve all nine municipalities is currently under construction. WTSs will have a special role in the overall waste management system, as they will serve as a liaison between the municipalities, i.e. waste generation source and the landfill. The primary reason for the establishment of WTSs is to reduce the cost of waste transport from the source of its generation to the landfill.
Analysis is performed on the basis of available maps and other relevant information. For elimination of the area that is not suitable for the location of WTSs the elimination criteria presented in Table 1 were used. Width of buffer zones is determined on the basis of literature data.

Table 1: Elimination criteria and buffer zones

Elimination criteria / buffer zone		
Spatial	Environmental	Social
▪ Roads and railroads / 200 m for the main roads, 100 m for other roads ▪ Airports / 3 km ▪ Agricultural areas / min. 500 m ▪ Outside zones planned for special purposes	▪ Natural protected areas and areas with valuable flora and fauna / min. 500 m ▪ Surface and ground water areas / min. 500 m ▪ Outside floodplains ▪ Steep slopes and unstable areas / min. 200 m for unstable areas, min. 100 m for conditionally unstable	▪ Urban areas / min. 1 km for the larger settlements, min. 500 m for the smaller settlements ▪ Drinking water sources / min. 1 km ▪ Cultural-historical areas / min. 100 m

By application of GIS operation – buffering, a corresponding area for each criterion is determined. Overlaying all buffer areas enables determination of the total eliminated area by all elimination criteria (orange area in Figure 1). Area suitable for location of WTSs from spatial, environmental and social aspect is defined by subtracting the eliminated area from total area of research (blue area in Figure 1).
The area defined in the Phase 1 is the input for the Phase 2 which implies the application of MILP for determination of optimal number and microlocation of waste transfer stations by minimizing total costs of the system:

$$Min\,Z = \sum F + \sum V + \sum T$$

where: ***F*** - Fixed costs, ***V*** - Variable costs, ***T***- Transport costs. The Phase 2 is not discussed in detail.

4. CONCLUSIONS

This paper discusses the application of GIS and MILP in the waste management system planning. Selected concept of the system is based on the construction of WTSs. Problem of determination of optimal number and locations of WTS is solved through a systematic approach. The goal of this approach is to select the "most acceptable option" based on the characteristics of the waste management system, the available data, and set of criteria and constraints. GIS has proven to be a valuable tool that can facilitate the decision making process of selecting the suitable area for new WTSs and reduce the time and cost of the selection process. The wider area determined by application of GIS is the input for application of MILP which provides possible process of selecting the optimal number and micro-locations for WTSs by minimizing the total cost of the system.

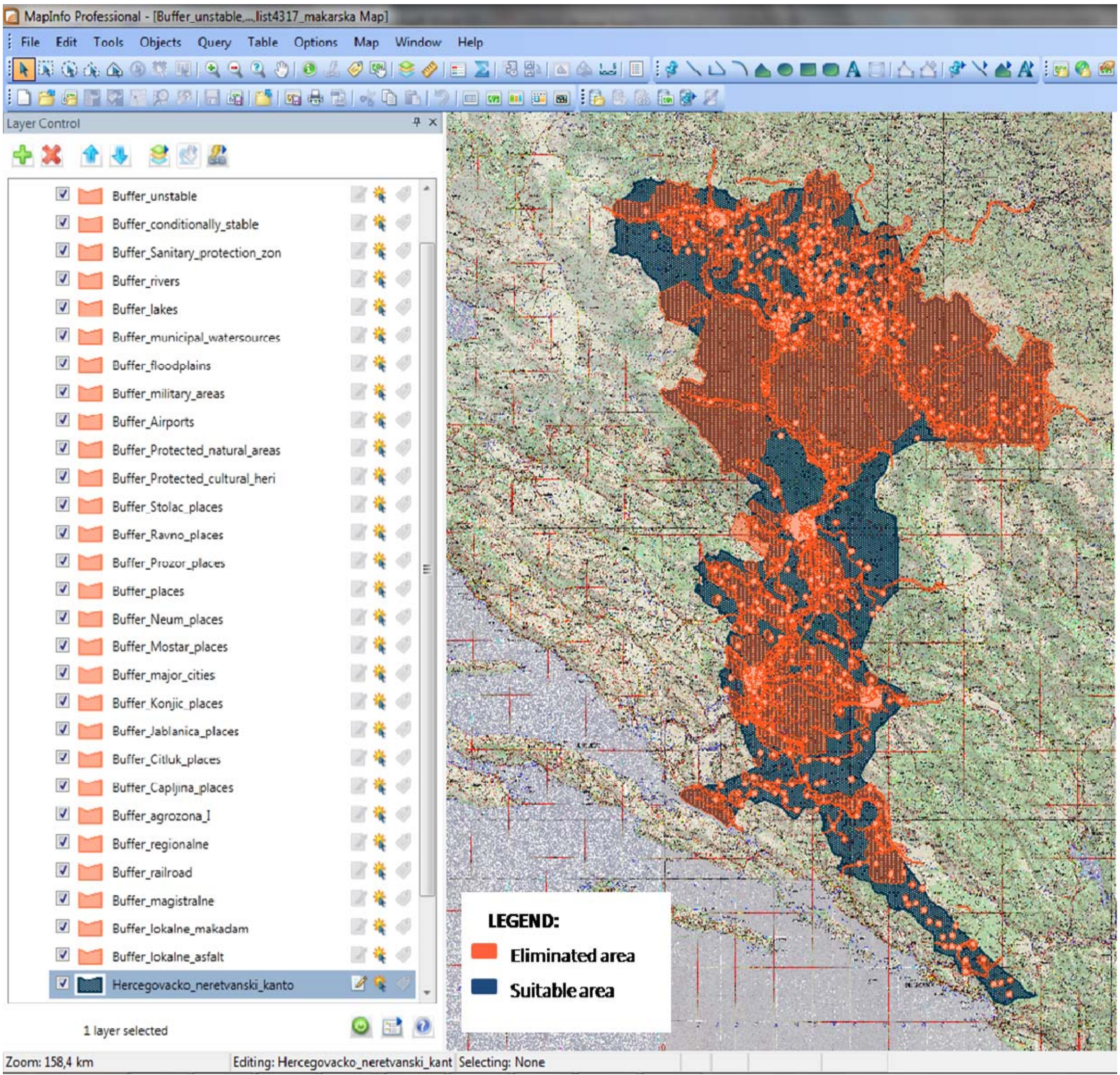

Figure 1. Eliminated area and area suitable for location of WTSs

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