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Using Geographic Information Systems (GIS) to Optimize Positioning of a Waste Transfer Station in Cephalonia Island, Greece

Abstract

Choosing optimal locations for Waste Transfer Stations (WTS) is a decision that requires extensive environmental assessment, because site selection depends on different factors and regulations. Environmental factors are crucial as WTS facilities may significantly impact the environment and the ecology of the surrounding area. Here, we explore the use of Geographical Information Systems (GIS) and Linear Programming to identify suitable sites for setting up a WTS in Cephalonia Island, Greece. We used GIS in conjunction with multi-criteria analysis to identify both suitable and inappropriate areas. We used a combination of Linear programming and heuristic algorithm (p-median) analysis to minimize the average travel distance to the WTS, thus optimizing the possible position in terms of transportation costs from the settlements of the island. We used ArcGIS 10.1 and its extensions, Spatial and Network Analyst; the former extension to perform the suitability analysis using multi-criteria analysis and the latter to obtain the optimum position. To identify areas suitable for the WTS in Cephalonia we digitized various geographical, hydrological, and other spatial data. Input map layers include distance from the urban areas, hydrographic networks, and archaeological sites; transportation networks; land use/land cover; and Natura 2000 network areas. We created a map for each suitability criterion and a final composite map by simply overlaying the individual maps. The map identified 54,60 km^2 of the island to be the most suitable. At the end of the analyses, one candidate site near Prokopata village was determined to be the most suitable for the WTS placement.

Key-words: Waste transfer stations, multi-criteria analysis, linear programming, Geographical Information Systems, Cephalonia island

Introduction

The selection of suitable locations for setting up Waste Transfer Stations (WTS) requires extensive environmental parameter assessment to identify the best available spatial location

(Bovea, et al., 2007). The location of urban waste management sites should take into account a wide range of environmental, hydrological, and spatial criteria in order to reduce the negative impact on the environment and society (Chang, et al., 2008). A given position must thus comply with the requirements of existing laws and regulations, simultaneously minimizing economic, environmental, health, and social costs.

The selection process also requires consideration of multiple alternatives and evaluation of location-specific criteria by field research. Many of the features involved in the site selection process have a spatial dimension, meaning that the selection process can be expedited through the use of Geographic Information Systems (GIS) if good quality spatial data for the study area is available. If spatial data used to select sites are not sufficiently well resolved, the resulting WTS will have adverse effects on the environment and lower levels of social acceptability (EPA, 2002).

The advantages of using GIS for the selection of appropriate waste management sites, such as WTS or Landfill Sites, have been highlighted by several researchers. Jensen and Christensen (1986) demonstrated the utility of GIS for the selection of suitable solid and hazardous waste disposal sites, while GIS have also been used by Fatta, et al., (1998) for the selection of industrial waste sites. The use of GIS for the localization of the landfill sites and WTS has been particularly prevalent in Greece (Chrysostomou, 2012; Chatzipanayiotou, et al., 2014; Kontos, et al., 2003). Siddiqui (1996) presents a methodology that identifies and classifies potential landfill sites for site pre-assessment.

More recently, several publications have focused on the specific application of GIS-based multiple-criteria analysis or approaches using smart-systems to optimize the location of landfills, waste transfer stations, etc. (Chatzipanayiotou, et al., 2014; Kibetu & Muchiri, 2016; Kontos, et al., 2003; Kontos, et al., 2005; Panetsopoulos, 2015). This methodology is mainly used for spatial planning, where appropriate areas in a given study area are initially highlighted using GIS-based multiple-criteria analysis (Kontos, et al., 2005; Malczewski, 2004). A key feature of this approach is their binary nature; the final result is a split of the study area into appropriate or inappropriate areas. Other spatial techniques combine multi-criteria analysis and GIS (Kontos, et al., 2003; Minor & Jacobs, 1994; Tseronis, 2011). Appropriate mapping for this approach involves the processing of a variety of data to which weights can be assigned depending on specific geographic criteria. Data is often input into a Geographic Information System, which combines potentially unrelated data in an effective way.

The use of GIS has also been combined with the theory of multi-criteria analysis and fuzzy sets. Kontos, et al. (2005) describe a spatial method incorporating multi-criteria analysis, GIS, hierarchical analysis, and spatial statistics to evaluate a site for a waste management plant. To definitively find the appropriate location and optimize the entire system, Kontos et al. (2005) use linear network algorithms.

The aim of this study was to use GIS to find the most environmentally and socially acceptable position for a WTS on Cephalonia island, Greece. To do so, we employ multi-criteria analysis for separation of suitable and unsuitable areas, and a heuristic algorithm to minimize the mean travel distance, and thus obtain the best possible position as a function of the cost of waste transport from the island's settlements to the WTS.

Study area

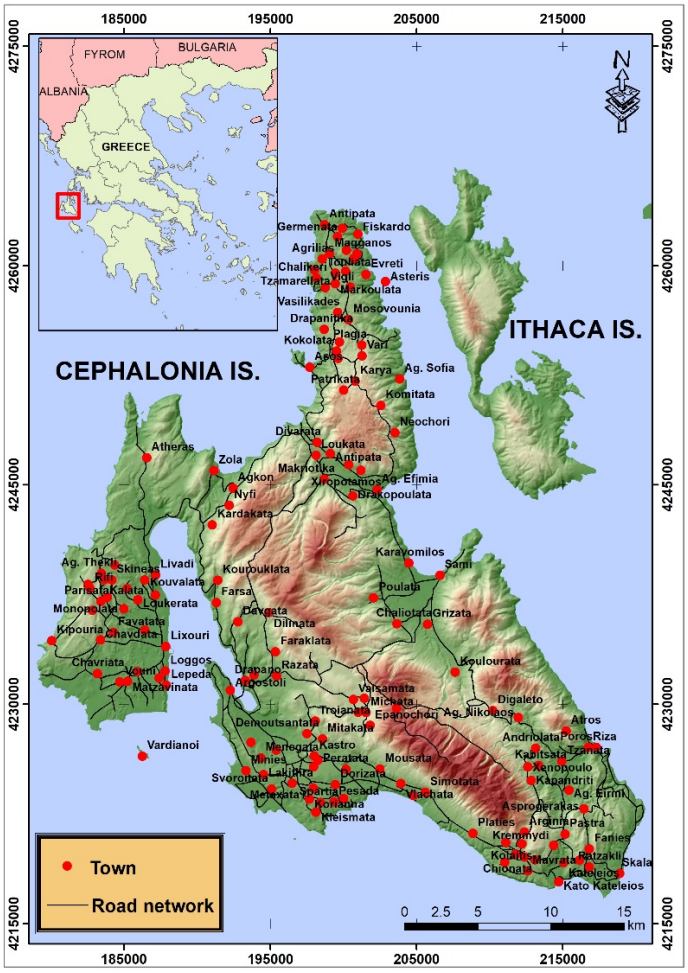

Figure 1. The island of Cephalonia with its road network and settlements.

Cephalonia island, which is the largest island of the Ionian islands region in Greece (Figure 1), has an administrative area covering 78,660 ha and a population of 35,803. The daily average waste collection on Cephalonia is about 67 tons, which yields about 24,500 tons of waste annually. The amount of municipal waste per capita is approximately 1.40 kg per annum. Municipal solid waste is mostly composed of domestic residues, not hazardous and commercial waste (Fratzis & Associates, 2016). The current open-dump site is located about 15 km Northwest from the Argostoli capital, in Kritonou area (WGS 84 - E 20°26’35.75”, N 38°18’35.24”).

Methodology

To optimize the placement of the WTS on Cephalonia island, we have defined various environmental, spatial, and hydrological criteria based on existing legislation, to exclude areas where environmental degradation is likely to occur. We also took into account the spatial distribution of existing urban waste management infrastructure. Specifically, we excluded areas around settlements, the network of rivers and streams, natural monuments, archaeological sites, and other protected areas. The aim of the methodology was to ensure social acceptance and to minimize the impact on the environment. The criteria used in this study are given in Table 1.

Following the exclusion of these areas, we are left with a map of appropriate areas for setting up a WTS. To optimize the location choice within this area, we carried out a center-gravity analysis of the road network, so that the urban waste would be transported at the lowest possible cost and in the shortest possible time.

Table 1. Selection criteria applied in the present study to delineate the location of the Waste Transfer Station defined by Mandylas, et al, (2013).

Criteria for exclusion of area from Waste Transfer Station location	**Distance from area**
Environmental	
Areas of NATURA 2000 network, Wildlife reserves, National Parks	-
Aesthetic Forests and UNESCO World Heritage Sites	-
Natural/Cultural monument areas	>500 m
Forest areas, high agricultural productivity areas, wetlands, and residential areas, as well as transport infrastructure (Rail lines)	-
Hydrological	
Water Systems: lakes, rivers	>300 m
Water abstraction points: springs, drilling	>600 m
Spatial	
Towns, cities, architecture and traditional settlements.	> 300 m of settlement boundaries <2,000 inhabitants and city boundaries > 500 m from the boundaries of traditional settlements > 800 m from the center of uninhabited settlements
Archaeological sites	-
Archaeological monuments and cultural heritage areas	>500 m
Coastline and tourist areas	>1,000 m

The next step in the analysis was to use the 'fishnet' method in the GIS environment to find the appropriate location on Cephalonia island in which to set up the WTS. The primary input data for the fishnet approach is derived from the earlier parts of the analysis. The areas defined as appropriate for WTS placement were divided into a 360-m grid. The footprint of the WTS considered would be approximately 13 ha (Panoutsopoulos, 2015).

For this study, we used the p-median heuristic algorithm with ESRI's Network Analyst 10.1 software. The algorithm is derived from graph theory and is mainly used in problems where the number of nodes is known. The algorithm finds the optimal locations for a given

number of facilities in order to minimize the total distance to distributed population demand points.

Each demand unit—settlements in the current study—can be weighted within the algorithmic calculation, which in the current study is the size of the population. This represents a demand for waste collection and transfer services that is directly proportional to settlement size. Thus, the goal of the p-Median algorithm is to find the appropriate location for the WTS to minimize the total travel time for waste trucks serving each of the settlements.

The final level of the analysis is the implementation of the p-median algorithm in a GIS environment. The Network Analyst extension for ESRI ArcGIS version 10.1 was used. Data was first processed by creating the appropriate linear network defined by the island's road system, to which the algorithm was then applied.

The population of island's settlements estimated by the 2011 census was used to calibrate the existing demand. This demand was then allocated by the algorithm to the prospective WTS facility locations derived from the earlier analysis. The algorithm minimizes the distance traveled from settlements (demand units) to WTS locations (facilities), with travel constrained by the island's road network. The final choice of the appropriate location was based on the suggestions put forth by from the waste management plan of the Ionian islands.

Results and Discussion

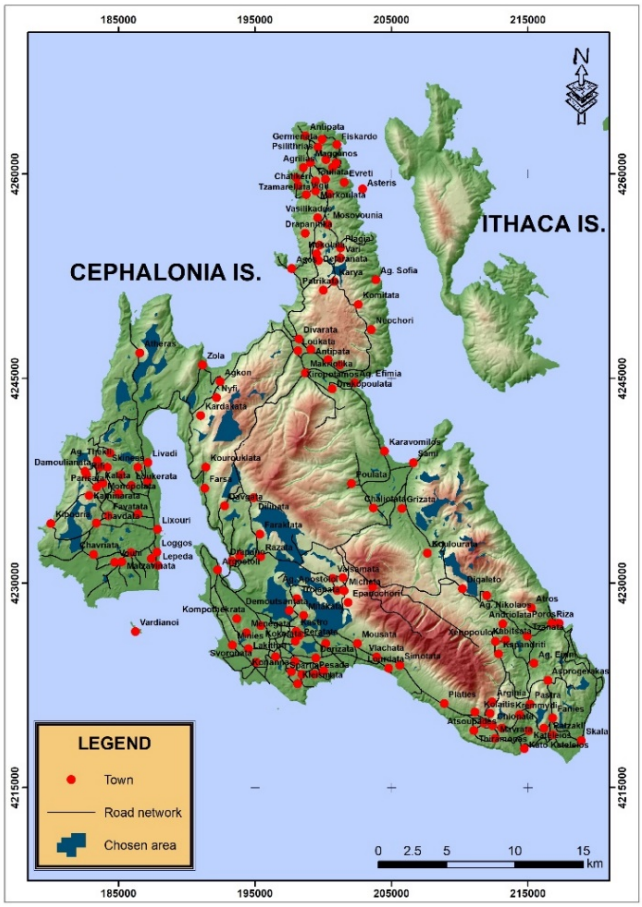

Figure 2. The calculated suitable locations (blue area) for the Waste Transfer Station placement.

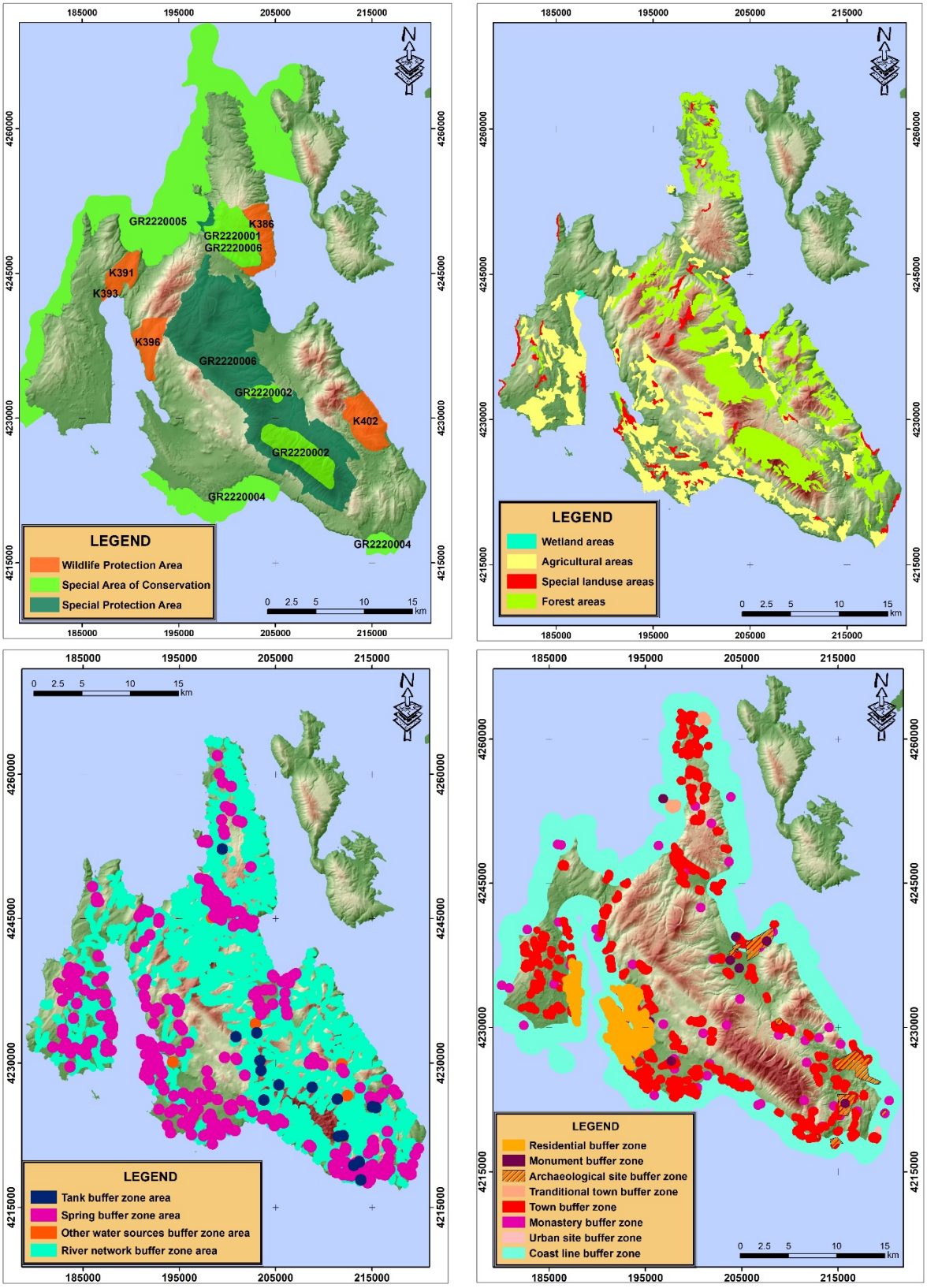

Figure 3. Visualisation of the environmental, spatial, hydrological criteria in the GIS maps.

To optimize the site selection for a WTS on Cephalonia island, a multi-criteria analysis was performed based on the criteria defined in Table 1 using ArcGIS version 10.1. The final

selected areas, resulting from the interplay of the various shape-files produced, depict the favorable areas for the location of the WTS on the topographic map of the island (Figure 2). Figure 3 shows the mapped criteria across the island.

The final number of the suitable locations for the placement of a WTS was 1,122, based on the calculation of the centroids of each square grid. These points were then used as the input data for the p-median algorithmic analysis. The output from the algorithm minimizes the distance of the settlements to the WTS, based on the existing road network of the island.

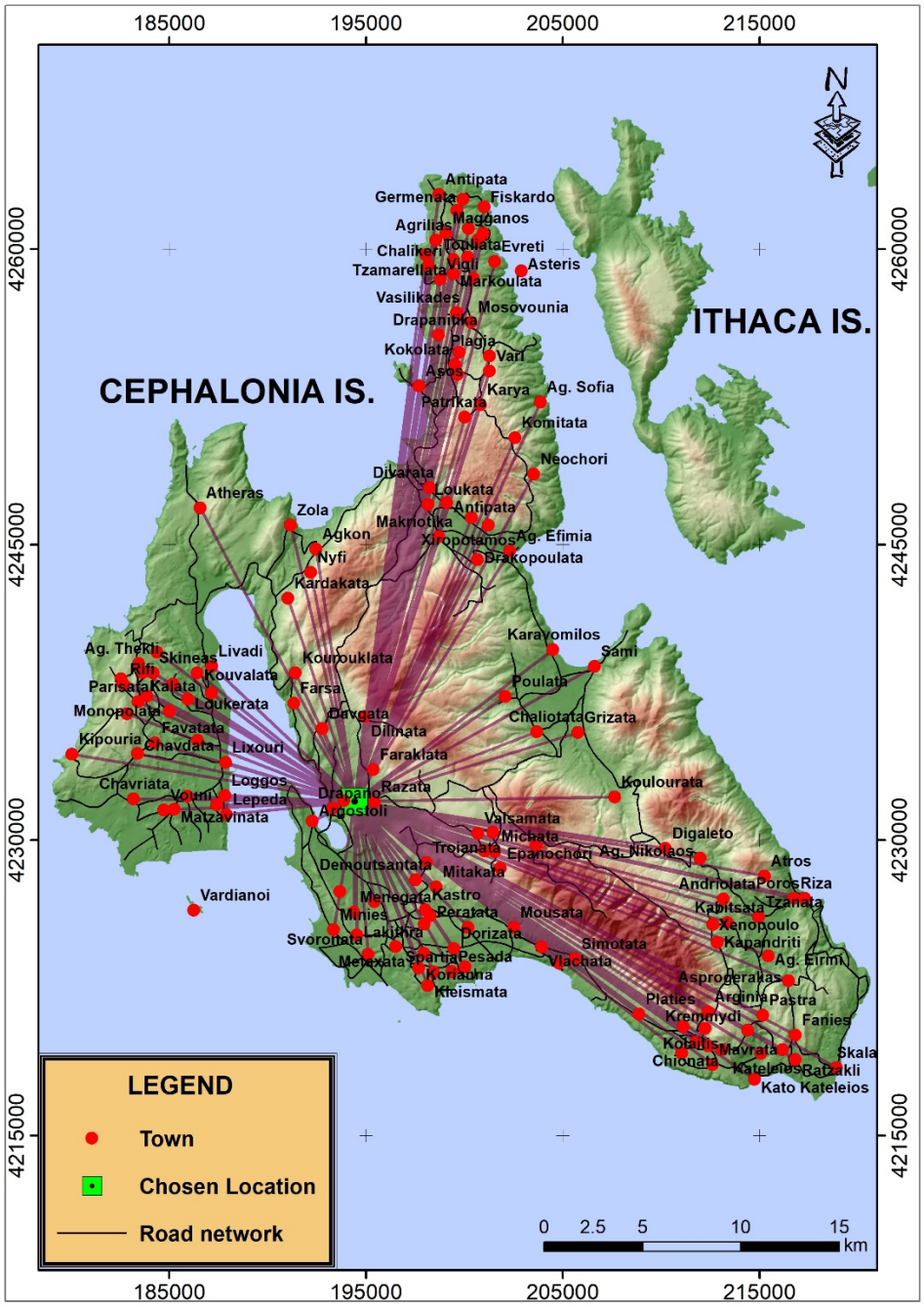

Figure 4. Showing the optimized location for the Waste Transfer Station on Cephalonia island resulting from the p-median algorithmic analysis.

Based on the results of the GIS analysis and application of the p-median algorithm, the optimized location for the WTS is near the town of Prokopata (Figure 4) (Greek Geographic Projection System X: 194,440.404, Y: 4,231,960.509).

In this study, we solved the problem of optimal site selection for setting up a Waste Transfer Station (WTS) on the island of Cephalonia using a combination of GIS, multi-criteria analysis, and heuristic algorithms. This supports the waste management plan for the Ionian islands (Fratzis & Associates, 2016), in which a proposal for a WTS in South Cephalonia was suggested. Our analysis objectively determines the suitable location for a WTS.

With these suitable areas identified, we optimized the placement of the WTS based on the criteria of minimizing travel time along the existing road networks for waste collection and transfer services. These results demonstrate that modern tools can be used to objectively assess large areas to find optimized hypothetical locations for technical facilities such as Waste Transfer Stations.

Acknowledgements

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References

Bovea, M. D., Powell, J. C., Gallardo, A. & Capuz-Rizo, S. F. (2007). The role played by environmental factors in the integration of a transfer station in a municipal solid waste management system. Waste Management, 27(4), 545-553.

Chang, N. B., Parvathinathan, G., & Breeden, J. B. (2008). Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. Journal of Environmental Management, 87(1), 139-153.

Chatzipanayiotou, M., Oikonomidis, D., & Voudouris, K. (2014). Placement of Suitable Landfill Site using G.I.S.: Application on Zakynthos Island. Thessaloniki. Proceedings of the 10th Interantional Congress of Hellenic Geographical Society (In Greek).

Chrysostomou, V. (2012). Criteria for Landfill placement, Thessaloniki: Unpublished dissertation (In Greek).

EPA, (2002). Waste Transfer Stations: A Manual for Decision-Making, Washington: United States Environmental Protection Agency.

Fatta, D., Saravanos, P., & Loizidou, M. (1998). Industrial waste facility site selection using geographical information system techniques. International Journal of Environmental Studies, 56(1), 1-14.

Fratzis & Associates (2016). Review of the Regional Waste Management Plan of Ionian islands – Final Report. p. 775 (In Greek).

Jensen, J. R. & Christensen, E. J. (1986). Solid and hazardous waste disposal site selection using digital geographic information system techniques. Science of the Total Environment, 86, 265-276.

Kibetu, D. & Muchiri, D. (2016). Using GIS to Select Ideal Sites for Municipal Wastes Transfer Station: Case Study of Embu. International Journal of Science, Technology and Society, 4(2-1), 1-7.

Kontos, T. D., Komilis, D. P., & Halvadakis, C. P. (2003). Siting MSW landfills in Lesvos island with a GIS-based methodology. Waste Management Resource, 21(3), 262-277.

Kontos, T. D., Komilis, D. P., & Halvadakis, C. P. (2005). Siting MSW landfills with a spatial multiple criteria analysis methodology. Waste Management,25, 818-832.

Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. Journal Evaluation and Program Planning, Τόμος 62, 3-65.

Minor, D. & Jacobs, T. (1994). Optimal land allocation for solid and hazardous waste landfill siting. Journal of Environmental Engineering, 120(5), 1095-1108.

Panoutsopoulos, Th. (2015). Placement of Solid Waste Management Units in the Peloponnese Region, Volos: University of Thessaly (In Greek).

Mandylas, C., Papavasileiou, G., Panagou, M., Brabetc – Venieri, K., Badeka, E., Moulatsioti G., Trakos, N. (2013). Study on the creation of Waste Transfer Stations of Gortynias Municipality. Mytilini: “Oikosfairiki”, Christoforos N. Mandylas & Associates (In Greek).

Siddiqui, M. Z. (1996). Landfill siting using geographic information systems: a demonstration. Journal of Environmental Engineering, 122(6), 515-523.

Tseronis, K., (2011). Optimal site selection of municipal solid waste treatment plant combined with landfill site, Patra: Unpublished dissertation (In Greek).