Spatial Assessment of Landfill Sites Based on Remote Sensing and GIS Techniques in Thermi, Greece

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Abstract

Remote Sensing techniques and Geographic Information System are employed in conducting an investigation of the environmental criteria for assessing the study area suitability for hosting a landfill. The designated area is located in the municipality of Thermi between the villages Trilofos, Agia Paraskevi and Tagarades, Prefecture of Thessaloniki in North Greece. In Greece, the overall waste management situation at the current time can be fairly characterized as underestimated, the main constraints being from technical and financial nature. Ten environmental criteria, five factors and five constraints, were applied. 26 GIS map layers were produced using topographic, geological and CORINE 2006 land cover maps as well as Landsat OLI-8 satellite images. The factors were input in the weighted overlay analysis tool and weights were assigned under GIS environments. The constraints were merged in one `0 layer`. Compiling both the factors map and the constraints map, resulted in a map of suitable areas classified in 3 classes according to the suitability - least suitable, suitable and most suitable. The suitable and most suitable areas represent 414.38 ha or 4.65 % of the total study area of 8895 ha with latitude 40°27'44.78"N and longitude 23° 2'30.20"E. This study can be further used for assessing the environmental cost for optimizing the landfill site by applying social and economic criteria.

Keywords: Fuzzy Membership, GIS, Landfill, Multi Criteria Analysis, Multi Criteria Evaluation.

1. Introduction

Waste is generated universally as a direct consequence of all human activities. It can be loosely defined as any material that is considered to be of no further use to the owner and is, hence, discarded (Taylor & Allen, 1995). Landfilling is the lowest ranking waste management option in the waste hierarchy, but remains dominant method used in Europe. Some 57 % of municipal waste in Western Europe and 83,7 % in Central Eastern Europe was landfilled in 1999 (EPA, 2003).

Landfill has been defined (CMD, 1991) as ‘the engineered deposit of waste onto and into land in such a way that pollution or harm to the environment is prevented and, through restoration, land provided which may be used for another purpose’ (Westlake, 1997). Although landfill site selection analyses have been carried out since the end of the last century (Siddiqui et al., 1996; Balstone et al., 1989), this problem is still addressed by the literature related to waste management (Delgado et al., 2007).

Multi-criteria evaluation (MCE) techniques or multi-criteria analysis (MCA) integrated with GIS were and are also in the present, widely used for solving spatial problems and elaborated in the literature. In an electronic search, 300 articles on GIS based multi-criteria decision analysis have appeared published in refereed journals from 1990 to 2004 (Malczewski, 2006).

GIS-based (or spatial) multi-criteria decision analysis can be defined as a collection of techniques for analyzing geographic events where the results of the analysis (decisions) depend on the spatial arrangements of the events (Malczewski, 1999).

Landfill siting is one complex spatial problem because its solution requires large amount of environmental, social, economic and engineering data. Many of the attributes involved in the process of selection of sanitary landfill sites have a spatial representation, which in the last few years has motivated the predominance of geographical approaches that allow for the integration of multiple attributes using Geographic Information Systems (GIS) (Zalidis et al., 2002; Kontos et al., 2005; Sener et al., 2006, Delgado et al., 2007; Nwachukwu et al., 2010).

The need for GIS-MCE integration is mainly led from the insufficiency of the both methods standing alone and the great results improvement when both methods integrated (Carver, 1991). Some difference compared to the classical GIS – MCE integration shows the approach that follows two-stage analysis, integrating thematic maps with chosen variables in the first stage and using fuzzy multi-criteria decision-making tool in the second (Chang et al., 2008).

The most suggested criterion as a constraint regarding the surface hydrology is 500 m distance from springs, wells, drinking and irrigation water sources (Gemitzi et al., 2007). Another recommended value is 50 m (Chang et al., 2008). Separately, the constraining distance values are 200 m for lakes, 100 m for rivers and 500 m for water supply sources, such as source used for irrigation, drinking water (Sumathi et al., 2007). Sites must be at a distance of 1 km downwards of the catchment areas of aquifers or drinking water reservoirs and 500 m distance from lakes, rivers, perennial flows and wetlands (Gemitzi et al., 2007), (Kontos et al., 2003) or 1 km from water bodies, flooding areas and water flows (Chang et al., 2008). In absence of hydrological measurements, like the type of aquifer, groundwater flow direction and flow velocity, general buffer distances would be 500 m as an adequate and 1000 m as a conservative (Taylor & Allen, 1995).

The aim of the thesis is to contribute towards wider application of the Geographic Information System and Remote Sensing techniques in the country by presenting their significant helpfulness in solving one specific spatial problem locating a landfill. In addition, this study should emphasize the existing problem of GIS data availability in the country.

2. Materials and Method

2.1. Study area

Study area is located in Thermi municipality in the vicinity of the villages Tagarades, Trilofos, and Agia Paraskevi, prefecture of Thessaloniki, in North Greece. The study area is located at average elevation of 597,76 m and latitude 40° 27' 19 N, longitude 23° 02' 59 E. Recently, more than 6 million tons of urban wastes have been disposed in the area. Landfill leachates are congregated in adjacent lagoon. The area characterizes with small settlements positioned in the mountainous regions in the north and south-east. The climate is moderate continental having Mediterranean and continental characteristics with an average annual precipitation of 500 mm. The average annual temperature is 14° based on 30 years measurements. The slope ranges from 0 to 31 %. The area of Thermi developed on Precambrian gneiss and schist and Paleozoic schist and granite. The designated area is principally used for agricultural activities, irrigated and non-irrigated annual crops. The agriculture activities comprise mainly olives cultivation as well as annual crops (Zalidis et al., 2004; Elhag and Bahrawi, 2016).

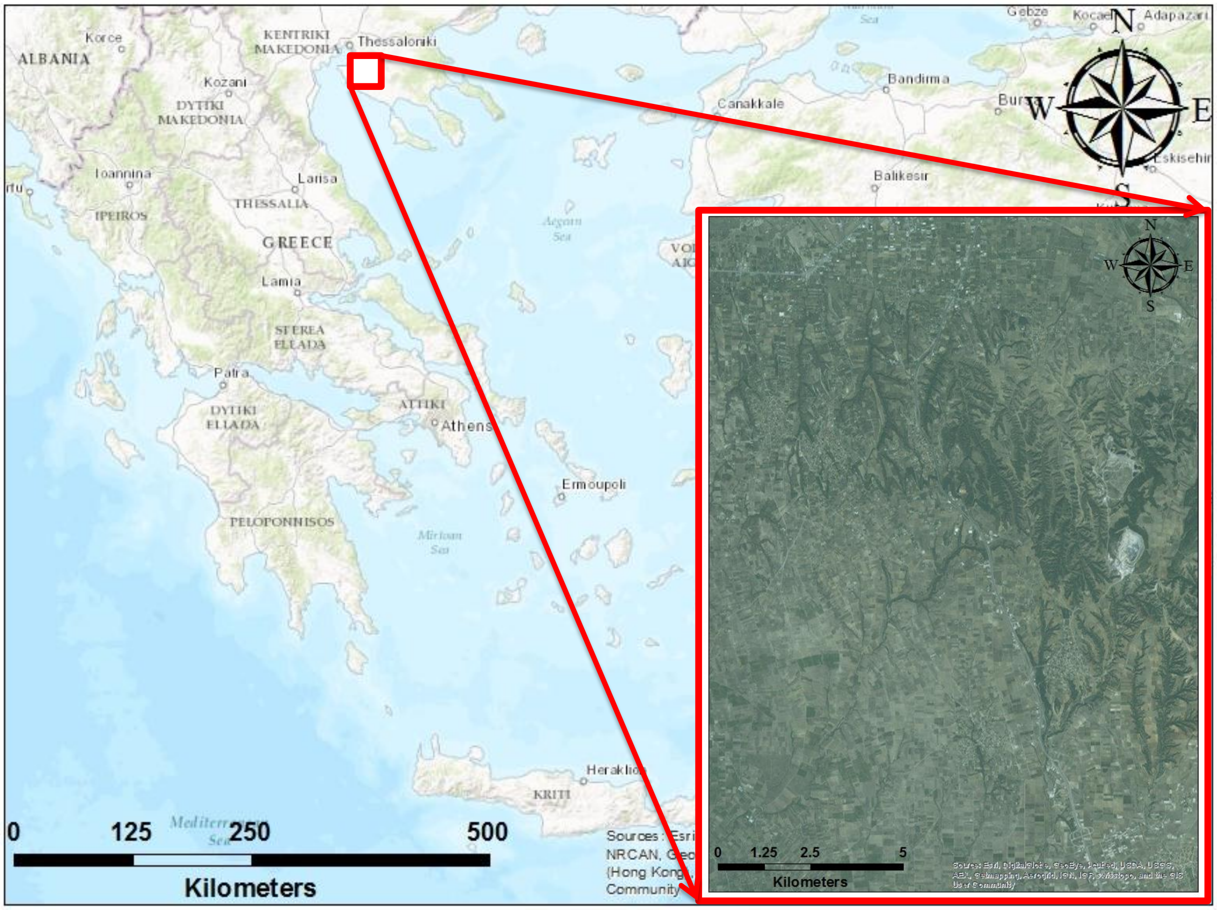

Figure 1. Location of the study area

2.2. Input Dataset

Four topographic maps were registered and georeferenced to the GCS WGS 1984 coordinate system they were used as input (under layer) in the process of digitizing the topographic features and producing vector digital data needed for the analysis. The topographic maps are in the scale of 1:25.000. They are published by the Hellenic Army Geographical Service, The Ministry for the Environment, Physical Planning and Public Works and from the Hellenic Forest Service. Landsat 8 satellite imagery was acquired on June 2013.

The reason for using and processing the Landsat 8 images was the need for registration of the topographic maps for the panchromatic band includes precision coregistration of images and developing more accurate classifications of land cover. OLI- 8 was also used for merging with the multispectral in order acquiring the best of 15 m spatial resolution and multispectral imaging.

The geological map used is in digital vector data format produced by digitizing a scanned paper geological map published by the Hellenic Army Geographical Service. It's in scale 1:100 000, projected to the same coordinate system as the complete data set – GCS WGS 1984. The study area presents six different soil deposits belonging to three different geological time periods.

CORINE Land Cover 2006 data set was used to reclassify the existing land cover into values of 0, 1, 2 and 3 were assigned to each class, where 0 designates land cover areas which are excluded from being potential landfill sites and 3 designates areas which are the most suitable. Value of 0 is assigned to the 'permanently irrigated arable land' as well as pastures, non-irrigated arable land, 'complex cultivation patterns' and 'land principally occupied by agriculture, with significant areas of natural vegetation'.

2.3. Applied criteria

The criteria listed in Table 1 were chosen as relevant for locating a landfill. The background of criteria for selecting a landfill location was carried out following WB (1999). In accordance with criteria selection, different digital map layers were created using the map layer analysis functions provided under GIS environment.

Table 1. Applied criteria in term of Constraints and Factors.

Constraints
Excluding aquifers, groundwater protection zones, watersheds and alluvial plains
Excluding national parks, historical areas, habitats of threatened and endangered species
1000 m buffer around intermittent or permanent streams, water bodies and wetlands
5000 m distance from utility corridors (electrical, water, sewer and communication)
2500 m distance from schools, hospitals, churches
Factors
Landfill site with 50 ha surface (30 to 50 years life span)
1000 m distance from motorways, city streets, residential area, and sensitive area
Geological structure of the study area (classified)
6000 m distance from archaeological sites
Outside areas with more than 30 % slope

2.4. Analysis

Applying the selected criteria and using the produced/preprocessed input data, 26 GIS layers in total were used for the analysis. A 1000 m buffer was applied to the data produced by digitizing: railways, regional roads, local roads (connecting villages), local roads (inside a village), undefined road, path, residential areas, villages, industrial areas, commercial buildings and manufacturing buildings. A buffer of 5000 m was also applied to the layers: water bodies, permanent streams, intermittent streams, wells, piped wells and water pumps. A buffer of 2500 m was applied to churches and schools. Around the channels of up to 5, 5-10 and over 10 m width a buffer of 1000 m was applied. After the buffering, these were converted into raster files with cell size 30 m and used further in the analysis as constraints or factors.

The rest of the GIS layers are: DEM, slope, land cover and geology. The elevation of the study area ranges from 584 to 726 m a.s.l.. In order reducing the transportation expenses as well as COx and NOx emissions due to the heavy transportation, the landfill shouldn't be located more than 300 m above the most elevated settlement. The most elevated settlement is the village Agia Paraskevi positioned between 617 and 623 m a.s.l. meaning that throughout the study area all the elevations are suitable for locating a landfill. For reducing the risk of flooding and existing a high groundwater table, the DEM map was classified as in Table 2. No elevation values were excluded; the highest was assigned a value of 3 as the most suitable and the lowest a value of 1 as the least suitable. The cell size is 30 m x 30 m.

Table 2. Elevation classes

Elevation (m)	**Class**	**Suitability**	**Area (ha)**	**Total area in %**
< 600	1	Least suitable	7092	79.72
> 600 and < 629	2	More suitable	1651.52	18.56
> 629 and < 726	3	Most suitable	152.96	1.72

Regarding the slope, its maximum value across the study area is 31. 17 %. According to Chang et al. (2008), slopes over 20 % should be excluded and slopes below 5 % are the most suitable for locating a landfill. Therefore, the slope was reclassified as in Table 3 using 4 classes, from 0 (representing the excluded area) to 3 (representing the most suitable area).

Table 3. Slope classes

Slope (%)	**Class**	**Suitability**
> 20 % < 32 %	0	Excluded area
> 15 % < 20 %	1	Least suitable area
> 5 % < 15 %	2	More suitable area
< 5 %	3	Most suitable area

The layers geology and land cover were first added a new field “*class*” in the attribute table, where values of 1 to 3 were assigned to the polygons as shown in Table 4. Thus, the layers were also converted in raster files with cell size 30 m using this field class. Consequently, geology and land cover each with three new classes were used further in the analysis.

Table 4. Geological classes

Deposits	Class	Suitability	Area (ha)	Total area in %
Diluvium-proluvial	1	Unsuitable	368.16	4.1
Alluvium	2	More suitable	8114.4	91.2
Quartz-sericite schist, muscovite chlorite schist and amphibole schist; Graphite schist and quartz-muscovite schist; Epidote-chlorite schist and amphibole schist; Mica schist and lepidolite.	3	Most suitable	416.64	4.7

The CORINE land cover map was also classified in three classes. According to Gemitzi et al. (2007) and Delgado et al. (2007), the mountainous forests should be classified as least suitable but not excluded. In this case, the broad-leaved forests were classified as more and not least suitable since are not mountainous (Table 5). Noticeably, most of the area (over 95 %) is agricultural land.

Table 5. Land cover classes

Land cover	Class	Suitability	Area (ha)	Total area in %
Non-irrigated arable land; Permanently irrigated land.	1	Unsuitable	7425.12	83.5
Broad-leaved forest; Complex cultivation patterns; Land principally occupied by agriculture, with significant areas of natural vegetation; Pastures	2	More suitable	1079.04	12.1
Discontinuous urban fabric; Transitional woodland-shrub.	3	Most suitable	396	4.4

3. Results and discussion

The factors were put in the weighted overlay analysis tool in under GIS environment. The layer slope was first converted from floating point to integer pixel type by reclassification in order to be used in the weighted overlay tool. The class 0 from the slope layer was designated as ‘restricted’ getting a value of -1, the minimum value in the weighted overlay analysis. The class 1 of the land use map representing the non-irrigated arable land and permanently irrigated land was also designated as ‘restricted’ getting a value of -1. The same was applied to the class 1 of the classified geology layer diluvium-proluvial deposits. At the end, the weights were assigned: 10 to the DEM and slope, 35 to the land use and 45 to the geology layer. All the constraints were merged and one mask layer - the ‘0 mask’ layer - was produced (Figure 2). It was created to be later used for producing the real ‘non 0’ mask needed for extracting the classified, non 0 values, from the resulting weighted overlay layer. All input data layers were divided in two groups of factors and constraints to build up the final suitability map (Table 6).

Table 6. Factors and Constraints suitability

a-Factors	**Classified or buffered**
Land cover – classified	Classified 1 - 3
Geology – classified	Classified 1 - 3
DEM – classified	Classified 1 - 3
Slope - classified	Classified 1 - 3
Commercial buildings	1000 m buffer
Manufacturing buildings	1000 m buffer
Industrial area	1000 m buffer
Local roads (connecting villages)	1000 m buffer
Path - buffered	1000 m buffer
Undefined roads	1000 m buffer
b-Constraints	**Buffered**
Regional roads	1000 m buffer

Channel – up to 5 m wide	5000 m buffer
Channel – 5 to 10 m wide	5000 m buffer
Channel – over 10 m wide	5000 m buffer
Wells	5000 m buffer
Piped wells	5000 m buffer
Water bodies	5000 m buffer
Water pumps	5000 m buffer
Permanent stream	5000 m buffer
Intermittent stream	5000 m buffer
Local roads – inside the village	1000 m buffer
Schools	1000 m buffer
Residential area	1000 m buffer
Villages	1000 m buffer

The selected suitable areas are located in different parts of the study area, in the north as well as in the south and mainly in the western parts of the area. The final map produced presents areas belonging to the three classes 0, 1 and 2, where 0 is the unsuitable area. The areas belonging to the class 1 satisfy the minimum criteria for locating a landfill and they are designated as more suitable (Voudouris and Kazakis 2011).

The areas of class 2 are more suitable than the areas of class 1 and are designated as the most suitable for locating a landfill (Voudouris and Kazakis 2011). In total, 4.12 % or 366.56 ha of the total study area is classified in class 1 and 0.53 % or 47.82 ha in class 2 (Table 7).

Table 7. Weighted overlay resulting classification

Description	Class	Area (ha)	Total area in %
Unsuitable	0	2614.88	29.39
More suitable	1	366.56	4.12
Most suitable	2	47.82	0.53

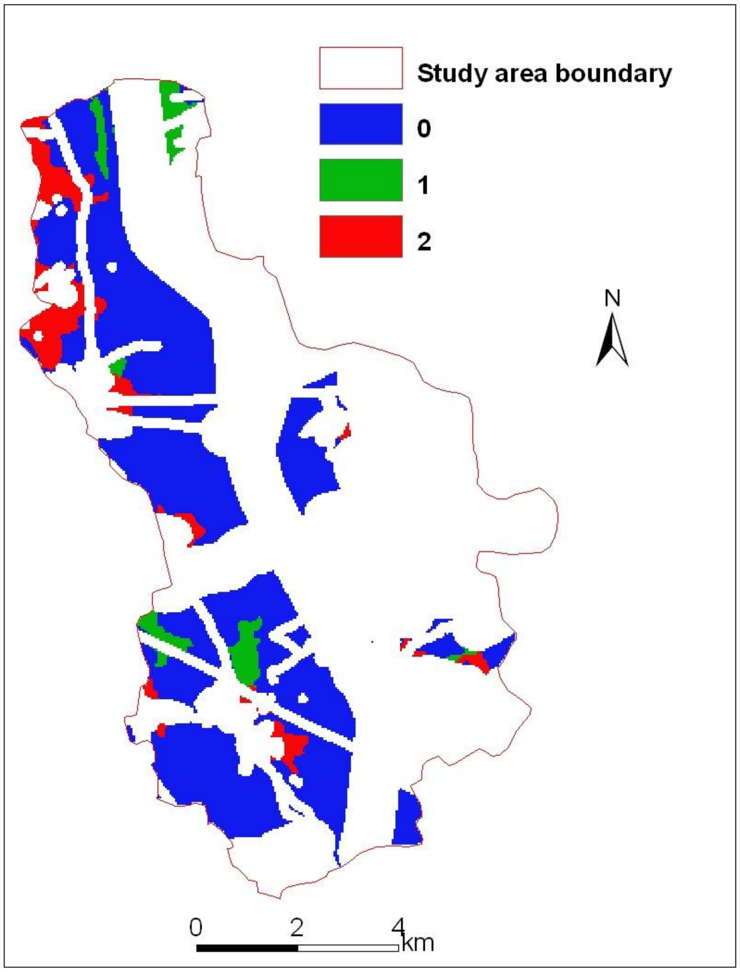

Figure 2. Weighted overlay - resulting map (masked) of Agia Paraskevi (classes 0, 1 and 2 correspond to classes 0, 1 and 2 in Table 7).

The biggest suitable areas are overlaid on the layers regional roads and local roads (connecting villages). The area of 48 ha seems to be the most suitable for a landfill (Figure 3), because it's closest to the 100 ha factor and close to regional as well as local road of connecting villages (Kazakis et al., 2013; Jiang, 2013).

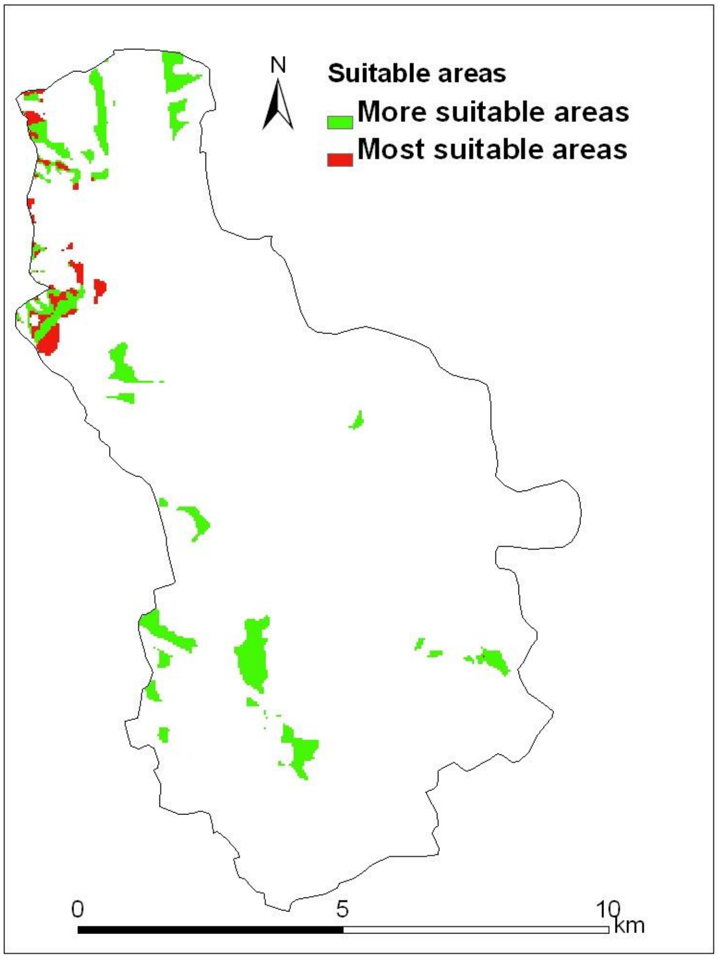

Figure 3. Suitable areas (class 1 and 2 from Table 7) of of Agia Paraskevi area.

4. Conclusions

The produced results suggest the best landfill location in terms of least negative environmental impacts. Further needed studies would examine the economic and social criteria for locating a landfill. Compiling these together would result in an optimal model for locating a landfill in the country. An interdisciplinary team of professionals would need to assess all the criteria. This work should represent the first step towards an analysis that would produce conclusions regarding the environmental cost to be paid for optimizing a landfill location economically and socially. Another usefulness of this partial landfill location assessment is the possibility of comparing the landfill costs between choosing the most environmentally sound landfill location and an economically and socially optimized landfill location. Examining the differences between a financially and economically optimized landfill location and a landfill location that is the most environmentally sound would also bring out the advantages and disadvantages of both locations.

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