Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.20614

91 (2017) 395–401
October

Spatial assessment of landfill sites based on remote sensing and GIS techniques in Tagarades, Greece

Mohamed Elhag*, Jarbou A. Bahrawi

Department of Hydrology and Water Resources Management, Faculty of Meteorology, Environment & Arid Land Agriculture, King Abdulaziz University, Jeddah 21589, Saudi Arabia, email: melhag@kau.edu.sa (M. Elhag), jbahrawi@kau.edu.sa (J.A. Bahrawi)

Received 28 November 2016; Accepted 18 February 2017

ABSTRACT

Remote sensing techniques and geographic information system (GIS) are employed in investigation of the environmental criteria for assessing the study area sustainability for hosting a landfill. The designated area is 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, as 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 considered in the weighted overlay analysis tool; then the weights were assigned under GIS environments. Moreover, the constraints were merged in one Boolean layer. Compiling both the factors map and the constraint map resulted in a map of suitable areas classified into three 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 8,895 ha with latitude 40°27′44.78″ N and longitude 23°2′30.20″ E. This study can be further used for assessing the sustainability cost for optimizing the landfill site by applying social and economic criteria.

Keywords: Fuzzy membership; Landfill; Multi-criteria analysis; Spatial assessment; Suitability analysis; Sustainability

1. Introduction

Waste is generated universally as a direct consequence of all human activities. It can be loosely defined as any material that is of no further use to the owner and is, hence, discarded [1]. Landfilling is the lowest-ranking waste management option in the waste hierarchy but remains dominant method used in Europe. 57% of the municipal waste in Western Europe and 83.7% in Central Eastern Europe were landfilled [2].

The landfill has been defined according to Common Ministerial Decision [3] 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 may be used for another purpose’ [4]. Although landfill site selection analyses have been carried out since the end of the last century [5,6], this problem is still addressed by the literature related to waste management [7].

Multi-criteria evaluation (MCE) techniques and/or multi-criteria analysis integrated with geographic information systems (GIS) were and are also, in the present, widely used for solving spatial problems and elaborated in the literature. GIS-based 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 [8,9].

Landfill siting is one complex spatial problem because its solution requires a large amount of environmental, social, economic, and engineering data. Many of the attributes

---

* Corresponding author.

Presented at the 13th IWA Specialized Conference on Small Water and Wastewater Systems & 5th IWA Specialized Conference on Resources-Oriented Sanitation, 14–16 September, 2016, Athens, Greece.

1944-3994/1944-3986 © 2017 Desalination Publications. All rights reserved.

involved in the process of sanitary landfill sites selection have a spatial representation, which has motivated the predominance of geographical approaches that allow for the integration of multiple attributes using GIS [7,10–13].

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 are integrated [14]. Some differences compared with the classical GIS–MCE integration show that the approach, which 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 was more efficient to address the problem [15].

According to Gemitzi et al. [16], the most suggested criterion as a constraint regarding the surface hydrology is the 500-m distance from springs, wells, drinking, and irrigation water sources. Another recommended distance is 50 m [15]. 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 and drinking water [16]. 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 [11] or 1 km from water bodies, flooding areas, and water flows [15]. In absence of hydrological measurements, like the type of aquifer, groundwater flow direction, and flow velocity, general buffer distances should be 500 m as an adequate and 1,000 m as a conservative [1].

Based on a recent scholarly work of Demesouka et al. [17], landfill site selection utilizing incorporated GIS-multiple-criteria decision analysis techniques has been comprehensively discussed over the last 3 decades by several authors [9,18]. Moreover, the consideration of multicriteria-spatial decision support system is well cited in [16,19,20]. According to Demesouka et al. [21], there are four categories of the decision rules implementations surmised and cited as following: First, weighted linear combination has six different criteria weight elicitation methods: not available [22]; equal importance [23]; ratio [24]; analytic hierarchy process [25]; fuzzy analytic hierarchy process [26]; and analytic network process [27]. Second, multiattribute utility theory has one criterion weights elicitation method, which is ratio [28]. Third, compromise programming has two different criteria weight elicitation methods: equal importance [29] and analytic hierarchy process [21]. Fourth, ordered weighted average has one criterion weight elicitation method, which is the analytic hierarchy process [30].

The aim of the current research is to train the sustainability concept towards a wider application of the GIS and remote sensing techniques by presenting their significant helpfulness in solving the general spatial problem of landfill sites.

2. Materials and methods

2.1. Study area

The 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 an average elevation of 597.76 m and latitude 40°27′19″ N and longitude 23°02′59″ E (Fig. 1). Recently, more than 6 million tons of urban wastes have been disposed of in the area. Landfill leachates are collected in the adjacent lagoon. The area is characterized with small settlements positioned in the mountainous regions in the north and southeast. 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 was 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 olive cultivations as well as annual crops [31,32]. The designated study area was specifically selected due to urgent quest to have another landfill site after the firebreak incident that took place in the existed landfill. Moreover, the walls of the existed lagoon were eventually bent. The firebreak led to an excess of 1,500 m^3 of leachates to be released into a local stream network and contaminated the surrounding area of 800 ha, and land owners noticed that leachates remained for roughly 10 months [32].

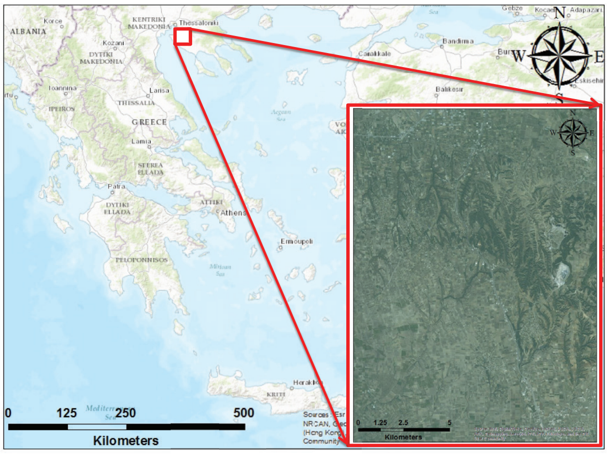

Fig. 1. Location of the study area.

2.2. Input data set

Four topographic maps were registered and georeferenced to the GCS WGS 1984 coordinate system and 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.

Watershed characterization is based on the independent analysis of ASTER GDEM data (30 m). Under ArcGIS environment, Arc Hydro tools were specifically used. The Arc Hydro tools were used to derive several data sets that collectively describe the drainage patterns of a catchment. Raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. These data are then used to develop a vector representation of catchments and drainage lines. Using this information, a geometric network is constructed [33].

Remote sensing data was obtained from Landsat Operational Land Imager (OLI-8), which was acquired on June 10, 2013. Typical atmospheric and radiometric corrections and spatial resolution enhancement were implemented for each band individually. Furthermore, supervised classification was implemented using support vector machine classifier for better classification results [34]. The final step in the digital image analysis is the evaluation of the accuracy of the computer-derived classification of results. These results often expressed in tabular form, known as a confusion matrix [35].

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 is 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, which 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. The 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 a sustainable landfill location. The background of criteria for selecting a landfill location was carried out following World Bank [36]. In accordance with the environmental and economic criteria selection, different digital map layers were created using the map layer analysis functions provided under GIS environment. The economic criteria were taken into consideration in the determination process of the environmental criteria in term of constraints/factors selection [20].

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
1,000 m buffer around intermittent or permanent streams, water bodies, and wetlands
5,000 m distance from utility corridors (electrical, water, sewer, and communication)
2,500 m distance from schools, hospitals, and churches
Factors
Landfill site with 50 ha surface (30–50 years lifespan)
1,000 m distance from motorways, city streets, residential area, and sensitive area
Geological structure of the study area (classified)
6,000 m distance from archaeological sites
Outside areas with more than 30% slope

2.3.1. Environmental criteria

- Highest seasonal groundwater table (10-year height), to be below any planned excavation of the landfill construction.
- Permeability of the soils above the groundwater table, preferably <10^{-6} cm/s when undisturbed.
- Environmentally significant wetlands of reproductive and biodiversity value, not to be present in the potential landfill area unless capable of absorbing the anticipated pollution.
- 10-year water recharges area for existing or pending water supply development, to be out of the landfill boundary.
- Public or private drinking, irrigation, or livestock water supply wells, down-gradient of the landfill boundary should be outside the site boundary unless readily and economically available alternative water supply sources or written consent of the owner.
- Endangered species breeding areas or protected areas, to be outside the landfill boundary
- Protected forests, to be at minimum distance of 0.5 km of the landfill area.
- Major infrastructure lines crossing the landfill site, like electricity, water, sewer, or gas lines are to be avoided or rerouted if economically feasible.
- Porous bedrock formations, like limestone or carbonate, are to be avoided.
- Outside 10-year flood boundary, if the site is within 100-year flood boundary, risk of washout should be eliminated.

2.3.2. Economic criteria

- Site area and volume, to meet the needs for the projected landfill lifetime of minimum 10 years for justifying the infrastructural costs.
- Within 30 min drive from the waste generation area, for waste collection operations to be economic. If the distance is >30 min, investment is needed in larger collection vehicles (more than 5 t load) or transfer stations (at least 20 t capacities).
- Within 2 h drive from the transfer stations (if exist).
- Accessibility the distance from the public road to the site should be <10 km when large landfills serving metropolitan areas and <1 km when small landfills serving secondary cities.

2.4. Analyses

The sustainable framework perspective of the selected criteria/constraints led to 26 GIS layers in total used for the analysis as it is summarized in Fig. 2. A 1,000-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 5,000 m was also applied to the layers: water bodies, permanent streams, intermittent streams,

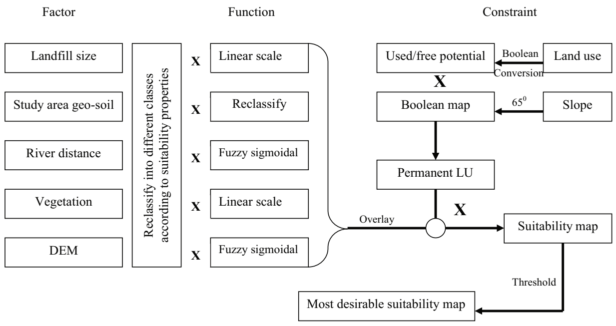

Fig. 2. Sustainable landfill sites selection framework.

Table 2
Elevation classes

Elevation (m)	Class	Suitability	Area (ha)	Total area (%)
<600	1	Least suitable	7,092	79.72
>600 and <629	2	More suitable	1,651.52	18.56
>629 and <726	3	Most suitable	152.96	1.72

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

wells, piped wells, and water pumps. A buffer of 2,500 m was applied to churches and schools. Around the channels of up to 5, 5–10, and over 10 m width, a buffer of 1,000 m was applied. After the buffering, these were converted into raster files with a cell size of 30 m and used further in the analysis as constraints or factors.

The rest of the GIS layers are digital elevation model, slope, land cover, and geology. The elevation of the study area ranges from 584 to 726 m a.s.l. To reduce the transportation expenses as well as CO_x and NO^x emissions due to the heavy transportation, the landfill should not 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 risk reduction of the flooding and the existing high groundwater table, the DEM map was classified for different levels of suitability showed in Table 2. No elevation values were excluded; the highest was assigned with value of 3 as the most suitable and the lowest with value of 1 as the least suitable.

Regarding the slope, its maximum value across the study area is 31.17%. According to Chang et al. [15], 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).

The layer's 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 into raster files with a cell size of 30 m using this field class. Consequently, geology and land cover each with three new classes were used further in the analysis.

The CORINE land cover map was also classified in three classes. According to Gemitzi et al. [16] and Delgado et al. [7], 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

Table 4
Geological classes

Deposits	Class	Suitability	Area (ha)	Total area (%)
Diluvium-proluvial	1	Unsuitable	368.16	4.1
Alluvium	2	More suitable	8,114.4	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

Table 5
Land cover classes

Land cover	Class	Suitability	Area (ha)	Total area (%)
Non-irrigated arable land; permanently irrigated land	1	Unsuitable	7,425.12	83.5
Broad-leaved forest; complex cultivation patterns; land principally occupied by agriculture, with significant areas of natural vegetation; pastures	2	More suitable	1,079.04	12.1
Discontinuous urban fabric; transitional woodland-shrub	3	Most suitable	396	4.4

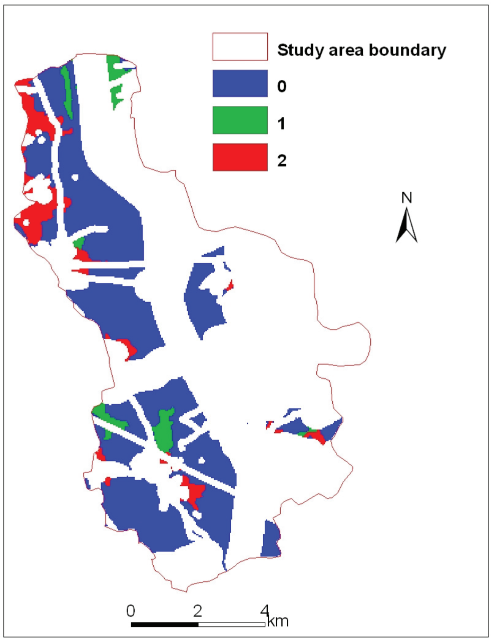

Fig. 3. Weighted overlay – resulting map (masked) of Agia Paraskevi (classes 0, 1 and 2 correspond to classes 0, 1 and 2 in Table 7).

are not mountainous (Table 5). Noticeably, most of the area (over 95%) is agricultural land.

3. Results and discussion

The factors put together in the weighted overlay analysis tool 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' scored with 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' scored with 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 as 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 (Fig. 3). 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 into two groups of factors and constraints to build up the final suitability map (Table 6).

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 [37].

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 [38]. 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 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	1,000 m buffer
Manufacturing buildings	1,000 m buffer
Industrial area	1,000 m buffer
Local roads (connecting villages)	1,000 m buffer
Path – buffered	1,000 m buffer
Undefined roads	1,000 m buffer
b-Constraints	Buffered
Regional roads	1,000 m buffer
Channel – up to 5 m wide	5,000 m buffer
Channel – 5–10 m wide	5,000 m buffer
Channel – over 10 m wide	5,000 m buffer
Wells	5,000 m buffer
Piped wells	5,000 m buffer
Water bodies	5,000 m buffer
Water pumps	5,000 m buffer
Permanent stream	5,000 m buffer
Intermittent stream	5,000 m buffer
Local roads – inside the village	1,000 m buffer
Schools	1,000 m buffer
Residential area	1,000 m buffer
Villages	1,000 m buffer

Table 7
Weighted overlay resulting classification

Description	Class	Area (ha)	Total area (%)
Unsuitable	0	2,614.88	29.39
More suitable	1	366.56	4.12
Most suitable	2	47.82	0.53

The biggest suitable areas are overlaid on the layer's regional roads and local roads (connecting villages). The area of 48 ha seems to be the most suitable for a landfill (Fig. 4) because it is close to the 100 ha factor and close to regional as well as the local road of connecting villages [39,40].

4. Conclusions

The produced results suggested the optimal 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

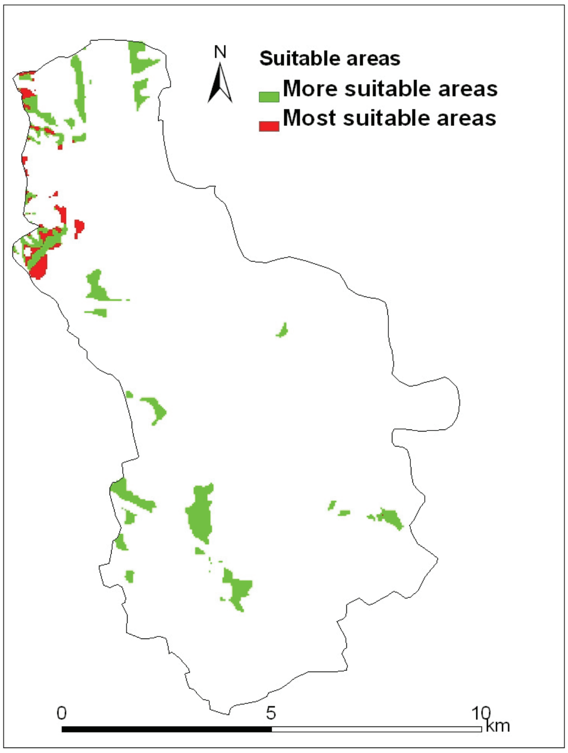

Fig. 4. Suitable areas (classes 1 and 2 from Table 7) of Agia Paraskevi area.

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 application of the current landfill location assessment is for 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.

Acknowledgement

This article was funded by the Deanship of Scientific Research (DSR) at King Abdulaziz University, Jeddah. The authors, therefore, acknowledged with thanks DSR for technical and financial support.

References

[1] R. Taylor, A. Allen, Waste Disposal and Landfill: Potential Hazards and Information Needs, World Health Organization, Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources, 1995.

[2] Environmental Protection Agency (EPA), Toxicological Review of Hydrogen Sulfide in Support of Summary Information on Integrated Risk Information System (IRIS), National Center for Environmental Assessment, Washington, D.C., EPA/635/R-03/005, 2003.

[3] Common Ministerial Decision (CMD), Methods, Terms and Conclusion for the Use of Sewage Sludge in Agriculture That Comes from Domestic and Urban Treated Wastes, 80568/4225, 1991, pp. 463–467.

[4] K. Westlake, Sustainable landfill – possibility or pipe-dream? Waste Manage. Res., 15 (1997) 453–461.

[5] M.Z. Siddiqui, J.W. Everett, B.E. Vieux, Landfill siting using geographic information systems: a demonstration, J. Environ. Eng., 122 (1996) 515–523.

[6] R. Batstone, J.E. Smith Jr., D. Wilson, The Safe Disposal of Hazardous Wastes, The Special Needs of Developing Countries, The World Bank Technical Paper Number 93, Vol. 3, Washington, D.C., 1989.

[7] O.B. Delgado, M. Mendoza, E.L. Granados, D. Geneletti, Analysis of land suitability for the siting of inter-municipal landfills in the Cuitzeo Lake Basin, Mexico, Waste Manage., 28 (2008) 1137–1146.

[8] J. Malczewski, A GIS-based approach to multiple criteria group decision making, Int. J. Geogr. Inf. Sci., 10 (1996) 955–971.

[9] J. Malczewski, Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis, Int. J. Appl. Earth Obs. Geoinf., 8 (2006) 720–277.

[10] G. Zalidis, S. Stamatiadis, V. Takavakoglou, K. Eskridge, N. Misopolinos, Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology, Agric. Ecosyst. Environ., 88 (2002) 137–146.

[11] T.D. Kontos, D.P. Komilis, C.P. Halvadakis, Siting MSW landfills with a spatial multiple criteria analysis methodology, Waste Manage., 25 (2005) 818–832.

[12] B. Sener, M.L. Süzen, V. Doyuran, Landfill site selection by using geographic information systems, Environ. Geol., 49 (2006) 376–388.

[13] M.A. Nwachukwu, H. Feng, J. Alinnor, Assessment of heavy metal pollution in soil and their implications within and around mechanic villages, Int. J. Environ. Sci. Technol., 7 (2010) 347–358.

[14] S.J. Carver, Integrating multi-criteria evaluation with geographical information systems, Int. J. Geogr. Inf. Sci., 5 (1991) 321–339.

[15] N.-B. Chang, G. Parvathinathan, J.B. Breeden, Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region, J. Environ. Manage., 87 (2008) 139–153.

[16] A. Gemitzi, V.A. Tsihrintzis, E. Voudrias, C. Petalas, G. Stravodimos, Combining geographic information system, multicriteria evaluation techniques and fuzzy logic in siting MSW landfills, Environ. Geol., 51 (2007) 797–811.

[17] O.E. Demesouka, A.P. Vavatsikos, K.P. Anagnostopoulos, GIS-based multicriteria municipal solid waste landfill suitability analysis: a review of the methodologies performed and criteria implemented, Waste Manage. Res., 32 (2014) 270–296.

[18] A. P. Vavatsikos, Decision Support System Development in GIS Environment Using Fuzzy Multicriteria Decision Making Methods, PhD Thesis, Department of Production Engineering and Management, Democritus University of Thrace, Komotini, Greece, 2008, pp. 68–84.

[19] M.L. MacDonald, A multi-attribute spatial decision support system for solid waste planning, Comput. Environ. Urban Syst., 20 (1996) 1–17.

[20] M.A. Sharifi, V. Retsios, Site selection for waste disposal through spatial multiple criteria decision analysis, J. Telecommun. Inf. Technol., 3 (2004) 1–11.

[21] O.E. Demesouka, A.P. Vavatsikos, K.P. Anagnostopoulos, Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system: method, implementation and case study, Waste Manage., 33 (2013) 1190–1206.

[22] J.J. Kao, H.Y. Lin, Multifactor spatial analysis for landfill siting, J. Environ. Eng., 122 (1996) 902–908.

[23] A.K. Dikshit, T. Padmavathi, R.K. Das, Locating potential landfill sites using geographic information systems, J. Environ. Syst., 28 (2000) 43–54.

[24] B. Nas, T. Cay, F. Iscan, A. Berktay, Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation, Environ. Monit. Assess., 160 (2010) 491–500.

[25] V. Yildirim, Application of raster-based GIS techniques in the siting of landfills in Trabzon Province, Turkey: a case study, Waste Manage. Res., 30 (2012) 949–960.

[26] Y.O. Ouma, E.C. Kipkorif, R. Tateishi, MCDA-GIS integrated approach for optimized landfill site selection for growing urban regions: an application of neighborhood-proximity analysis, Ann. GIS, 17 (2011) 43–62.

[27] A.A. Isalou, V. Zamani, B. Shahmoradi, H. Alizadeh, Landfill site selection using integrated fuzzy logic and analytic network process (F-ANP), Environ. Earth Sci., 68 (2013) 1745–1755.

[28] D. Geneletti, Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites, Waste Manage., 30 (2010) 328–337.

[29] K. Vatalis, O. Manoliadis, A two-level multicriteria DSS for landfill site selection using GIS: case study in Western Macedonia, Greece, J. Geogr. Inf. Decis. Anal., 6 (2002) 49–56.

[30] S.P. Gbanie, P.B. Tengbe, J.S. Momoh, J. Medo, V.T.S. Kabba, Modelling landfill location using geographic information systems (GIS) and multi-criteria decision analysis (MCDA): case study Bo, Southern Sierra Leone, Appl. Geogr., 36 (2013) 3–12.

[31] G.C. Zalidis, M.A. Tsiafouli, V. Takavakoglou, G. Bilas, N. Misopolinos, Selecting agri-environmental indicators to facilitate monitoring and assessment of EU agri-environmental measures effectiveness, J. Environ. Manage., 70 (2004) 315–321.

[32] M. Elhag, J.A. Bahrawi, Consideration of geo-statistical analysis in soil pollution assessment caused by leachate breakout in the municipality of Thermi, Greece, Desal. Wat. Treat., 57 (2016) 27879–27889.

[33] M. Elhag, Characterization of a Typical Mediterranean Watershed Using Remote Sensing Techniques and GIS Tools, Hydrol. Curr. Res., 6 (2015) 197–204.

[34] A. Psilovikos, M. Elhag, Forecasting of remotely sensed daily evapotranspiration data over Nile delta region, Egypt, Water Resour. Manage., 27 (2013) 4115–4130.

[35] M. Elhag, A. Psilovikos, M. Sakellariou, Detection of land cover changes for water recourses management using remote sensing data over the Nile delta region, Environ. Dev. Sustain., 15 (2013) 1189–1204.

[36] World Bank (WB), Solid Waste Landfills in Middle- and Lower-income Countries, A Technical Guide to Planning, Design, and Operation, World Bank Technical Paper No. 426, ISBN 0–8213–4457–9, 1999.

[37] N. Kazakis, A. Pavlou, G. Vargemezis, K. Voudouris, G. Soulios, F. Pliakas, G. Tsokas, Seawater intrusion mapping using electrical resistivity tomography and hydrochemical data: an application in the coastal area of eastern Thermaikos Gulf, Greece, Sci. Total Environ., 543 (2016) 373–387.

[38] V.R. Sumathi, U. Natesan, C. Sarkar, GIS-based approach for optimized siting of municipal solid waste landfill, Waste Manage., 28 (2007) 2146–2160.

[39] N. Kazakis, K. Voudouris, G. Vargemezis, A. Pavlou, Hydrogeological regime and groundwater occurrence in the Anthemountas River basin, northern Greece, Bull. Geol. Soc. Greece, XLVII/2 (2013) 711–720.

[40] B. Jiang, Head/tail breaks: a new classification scheme for data with a heavy tailed distribution. Prof. Geogr., 65 (2013) 482–494.