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Odor-aided analysis for landfill site selection: Study of DOKAP Region, Turkey

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Abstract

In our world, with the increase of factors such as the rapid and irresponsible consumption of natural resources, man-made environmental disasters, global warming, and pollution of water resources, solid wastes have to be stored or disposed of more effectively. The presentation of the data required to solve spatial problems such as storage, management, and location selection can be carried out extensively and effectively using geographic information systems (GIS). On the other hand, the unsatisfactory results obtained with GIS recently have made it mandatory to use spatial multiple-criteria decision-making (S-MCDM) methods that include the decision-makers in the process. In this study, RSWSA site selection was carried out in eight cities under the responsibility of the Eastern Black Sea Project Regional Development Administration (DOKAP). A combination of GIS and S-MCDM was used in this site selection process. A total of eight data layers were used in the site selection application. Afterwards, storage areas determined as suitable via GIS analysis underwent additional evaluation, taking into account geological, seismic, and environmental factors as well as transportation costs. In addition to these multi-component evaluations, odor analyses were carried out on the proposed storage areas using the prevailing wind direction.

Keywords: Solid waste landfill; site selection; odor mapping; GIS; S-MCDM; AHP

1. Introduction

The amount of solid waste generated as a result of the growing population, increases in purchasing power, and technological developments continues to rise. This increase in the amount of solid waste elicits the need for sustainable and integrated waste management (Ministry of Environment and Urbanisation 2017). The increasing volume and complexity of waste associated with the modern economy poses a serious risk to ecosystems and human health. Every year, an estimated 11.2 billion tons of solid waste are collected worldwide (UNEP 2020). In the absence of effective waste management, the disposal of these collected wastes becomes more and more difficult day by day. Urban solid waste disposal causes problems such as soil erosion, air pollution, and greenhouse gas emissions. The degradation in the organic ratio of solid wastes accounts for about five percent of global greenhouse gas emissions (Farahbakhsh and Forghani 2019; UNEP 2020). The dispersal of solid waste debris threatens ecosystems. Moreover, this situation puts pressure on city residents and environmental health. In addition, unhealthy open storage areas can contaminate drinking water and create an environment for the emergence of infectious diseases (UNEP 2020).

Within waste management systems, various disposal approaches can be used to prevent these and similar problems. The landfill method is a waste management approach that is frequently used in addition to recycling processes, biological waste treatment, incineration, and gasification methods. Studies on the subject report that landfill is the most common method used to eliminate urban solid wastes in developing countries. However, they state that this method creates environmental and health problems (Kapilan and Elangovan 2018; Mussa and Suryabhagavan 2019; Gautam et al. 2020; Karakuş et al. 2020). In a similar manner, Turkey benefits from the landfill method of urban waste disposal.

According to data published by the Turkish Statistics Institute (TUIK), of the 32.1 million tons of municipal waste collected in the country in 2018, 11.9% of this waste was sent to recovery facilities and 67.2% to regular storage facilities. Although the rate of unregulated dumping has been decreasing from year to year, within the scope of established waste strategies, 20.2% of municipal waste is stored in this way (TUIK 2020a). Sustainable development data from the United Nations Sustainable Cities and Communities project indicate that the ratio of solid wastes collected regularly to the total amount of solid waste reaches 78.6% (TUIK 2020b).

Global and national targets regarding waste management include increasing recycling practices and preventing environmental damage at the source. However, safe disposal in landfills is one of the least preferred methods in the waste management hierarchy (Directorate for EU Affairs 2020). The absence of a landfill poses a major problem in many of Turkey's cities. In order to solve this problem, efforts to expand recycling practices throughout the country continue. The strategy document published by the Ministry of Environment and Urbanization states that by 2023 it aims to comply with the environmental policies of the European Union by providing regular solid waste services to all citizens. It also states that in order to minimize solid waste environmental pollution, the technologies most suited to the conditions in the country will be chosen for the construction of infrastructures and operation of the facilities (Ministry of Environment and Urbanisation 2016). According to the management strategy established in Turkey, planned landfills will prevent waste pollution, provide environmental awareness, and improve the quality of life in cities without such facilities.

Many factors such as the economy, the environment, land management, and sustainability should all be taken into consideration when planning the facility. When site selection applications around the world are examined, geographical information systems (GIS)-based location selection is commonly encountered (Kapilan and Elangovan 2018; Khodaparast et al. 2018; Yildirim et al. 2018; Farahbakhsh and Forghani 2019; Mussa and Suryabhagavan 2019; Gautam et al. 2020; Karakuş et al. 2020; Umar and Naibbi 2020). However, the inadequacy of the results obtained with GIS alone has mandated the use of spatial multi-criteria decision-making (S-MCDM) methods that include the decision-makers in the process. A combination of GIS with different MCDM methods can be used in the selection of suitable sites. The GIS-based analytic hierarchy process (AHP) offers valuable feedback for decision-makers (Baser 2020). Today, sanitary landfill location problems can be solved with GIS-based S-MCDM integration. This study aimed to build a model prepared by integrating GIS and S-MCDM methods, to test it using field studies, and to prove its usability. Therefore, as one of the most frequently used MCDM methods in the literature, the AHP was selected for the site selection study.

In the study, GIS technologies were used in the selection of the most suitable landfill sites for the provinces in the Eastern Black Sea Region. A total of 42 suitable landfill sites that comply with national and international legislation and meet environmental and sociological criteria were identified in the region. Two areas among the eight provinces in the region were studied in detail, along with the appropriate cost values. In this context, the opinions and suggestions of the relevant institutions and organizations and external stakeholders were also taken into consideration. In the final stage, seismicity, seismic, environmental, and geological studies were conducted for 14 of the sites determined as most suitable for the region and transportation, access, and odor analyses were then carried out using technological methods.

2. Material and methods

Within the scope of this study, regular solid waste storage area (RSWSA) location selection was carried out in eight provinces in the study region. In this context, factors affecting location selection were evaluated separately. The location selection process was handled in two stages. In the first stage, the laws and regulations in force concerning solid waste landfills in Turkey (Official Gazette 2010, 2011, 2015) and environmental action plans and strategy documents (Ministry of Environment and Urbanisation 2016, 2017) were taken into account. Turkey is among the countries that are candidates for membership in the European Union (EU) and negotiations between the parties are ongoing. For this reason, the criteria of the EU regarding solid waste landfill site selection were also considered in this study (EU 1999). Moreover, the factors to be used within the scope of the study were determined by considering the studies conducted by the World Health Organization (WHO 2000) and the criteria discussed by world-renowned environmental organizations (EPA 1997).

The second stage involved academic studies and practices in national and international fields regarding the determination of sanitary landfills and reports published by governmental and non-governmental organizations. The location selection criteria were then determined using the obtained values (Table *1*). These factors may differ depending on the regions where solid waste landfills are to be built. For this reason, the criteria obtained from academic studies were taken as a basis for the analyses carried out in the study and the existing factors throughout the region were determined and used in the analyses.

Table 1. Main criteria used in landfill site selection

S/N	Factors	Sources
i	Slope	(Al-Jarrah and Abu-Qdais 2006; Sener et al. 2006; Akbari et al. 2008; Sumathi et al. 2008; Chang et al. 2008; Sharifi et al. 2009; Wang et al. 2009; Moeinaddini et al. 2010; Nas et al. 2010; Şener et al. 2010; Aragonés-Beltrán et al. 2010; Ekmekçioĝlu et al. 2010; Gorsevski et al. 2012; Kemal Korucu and Erdagi 2012; Arkoc 2014; Kapilan and Elangovan 2018; Khodaparast et al. 2018; Mussa and Suryabhagavan 2019; Umar and Naibbi 2020)
ii	Land Use	(Cheng et al. 2003; Al-Jarrah and Abu-Qdais 2006; Sener et al. 2006; Sumathi et al. 2008; Chang et al. 2008; Sharifi et al. 2009; Wang et al. 2009; Moeinaddini et al. 2010; Nas et al. 2010; Şener et al. 2010; Ekmekçioĝlu et al. 2010; Eskandari et al. 2012, 2015; Gorsevski et al. 2012; Arkoc 2014; Beskese et al. 2015; Khodaparast et al. 2018; Kapilan and Elangovan 2018; Karakuş et al. 2020; Umar and Naibbi 2020)
iii	Geology	(Al-Jarrah and Abu-Qdais 2006; Sener et al. 2006; Sumathi et al. 2008; Sharifi et al. 2009; Wang et al. 2009; Şener et al. 2010; Moeinaddini et al. 2010; Eskandari et al. 2012, 2015; Arkoc 2014; Beskese et al. 2015; Kapilan and Elangovan 2018; Mussa and Suryabhagavan 2019; Karakuş et al. 2020)
iv	Streams	(Cheng et al. 2003; Al-Jarrah and Abu-Qdais 2006; Sener et al. 2006; Akbari et al. 2008; Sumathi et al. 2008; Chang et al. 2008; Sharifi et al. 2009; Wang et al. 2009; Moeinaddini et al. 2010; Şener et al. 2010; Aragonés-Beltrán et al. 2010; Ekmekçioĝlu et al. 2010; Gorsevski et al. 2012; Kemal Korucu and Erdagi 2012; Eskandari et al. 2012, 2015; Arkoc 2014; Beskese et al. 2015; Mussa and Suryabhagavan 2019; Karakuş et al. 2020; Umar and Naibbi 2020)
v	Soil classification	(Al-Jarrah and Abu-Qdais 2006; Chang et al. 2008; Beskese et al. 2015; Eskandari et al. 2015; Kapilan and Elangovan 2018; Mussa and Suryabhagavan 2019; Karakuş et al. 2020)
vi	Main arterial roads	(Akbari et al., 2008; Al-Jarrah and Abu-Qdais, 2006; Aragonés-Beltrán et al., 2010; Arkoc, 2014; Beskese et al., 2015; Chang et al., 2008; Cheng et al., 2003; Ekmekçioĝlu et al., 2010; Eskandari et al., 2015, 2012; Farahbakhsh and Forghani, 2019; Gautam, 2020; Gorsevski et al., 2012; Karakuş et al., 2020; Khodaparast et al., 2018; Moeinaddini et al., 2010; Mussa and Suryabhagavan, 2019; Nas et al., 2010; Sener et al., 2006; Şener et al., 2010; Sharifi et al., 2009; Sumathi et al., 2008; Umar and Naibbi, 2020; Wang et al., 2009)
vii	Surface waters	(Akbari et al., 2008; Al-Jarrah and Abu-Qdais, 2006; Aragonés-Beltrán et al., 2010; Beskese et al., 2015; Chang et al., 2008; Cheng et al., 2003; Ekmekçioĝlu et al., 2010; Eskandari et al., 2015, 2012; Gautam, 2020; Gorsevski et al., 2012; Kapilan and Elangovan, 2018; Karakuş et al., 2020; Kemal Korucu and Erdagi, 2012; Khodaparast et al., 2018; Moeinaddini et al., 2010; Sener et al., 2006; Şener et al., 2010; Sharifi et al., 2009; Sumathi et al., 2008; Umar and Naibbi, 2020; Wang et al., 2009)
viii	Landslide sites	(Ekmekçioĝlu et al. 2010; Eskandari et al. 2012; Kemal Korucu and Erdagi 2012)

2.1. Cost surface map produced via Multi-Criteria Decision Making (MCDM)

2.1.1. Multi-criteria decision-making (MCDM) method

The MCDM methods are interactive and flexible tools for analyzing the complexity between alternatives with different environmental and socioeconomic effects. The combination of GIS and MCDM techniques facilitates the evaluation of various alternatives to criteria and objects with multiple and complex structures. This method ensures the integration of information by proportioning and comparing alternatives in line with the selected criteria. This situation means that because many criteria are related to space and attribute, a large number of variables are analyzed, and at the same time are managed jointly in a coordinated manner (Anavberokhai 2008; Yildirim 2009). The MCDM method can be used to identify the single most preferable option, enumerate options, select a limited number of options for the next detailed assessment, or separate acceptable from unacceptable possibilities (Sener 2004).

Considering the literature studies in general, the MCDM methods are quite diverse. Among these methods, the AHP, simple additive weighting (SAW), ELECTRE, and TOPSIS are used frequently in location determination studies. In this study, the AHP method, which provides more advantages to the user, was applied in the site selection studies.

2.1.2. Multi-criteria decision-making (MCDM) method

The AHP method is one of the most frequently used MCDM methods in the literature. The method was developed by Thomas L. Saaty in 1977.

The AHP is a powerful and easy-to-understand method that allows groups and individuals to combine qualitative and quantitative factors in the decision-making process (Saaty 1994). It uses a hierarchical model of purpose, criteria, possible sub-criteria levels, and options for each problem. It is a general method for complex, obscure, or non-structural problems and is based on three basic principles:

i. Creation of hierarchies

ii. Determination of advantages

iii. Logical and numerical consistency

All parts of the hierarchy are related to each other, and it is easy to see how a change in one factor affects other factors. With this method of decision making, many types of data can be brought together, differences in performance levels can be adjusted to each other, and comparisons between objects that look different can be made. In the AHP method, there is an objective at the top of the hierarchy, and under this goal, there are criteria, sub-criteria, and options, respectively.

The AHP method, as one of the MCDM methods, was used in the study because it enables the decision-maker to reach a solution for complex problems easily and is a simpler method to apply compared to other methods.

The AHP was the method used to determine the weights of the criteria for the selection of the landfill site and to produce the cost surface map to be used in decision making. This method was used to determine the effectiveness of the criteria in site selection and the degree to which the analysis would be affected at the factor weight point.

The AHP method starts with the first step of determining a problem that is aimed to produce a solution. In the second step, a hierarchical structure is created by determining the criteria and sub-criteria to be used in the solution of this problem. A hierarchical structure is created using these criteria and sub-criteria to be used in the solution of this problem. In the third step of the method, comparative decision making and preference matrices are produced using the paired comparison method for the criteria. In the fourth step, the weight vector is calculated as a result of the operations performed on the binary comparison matrix. After determining the weights, a cost surface map is created using Equation (1) and the decision-making process is performed using this map.

$$A_{AHP} = \sum_{j}^{n} a_{ij} w_j \ , i = 1,2,3, \dots , m \qquad (1)$$

According to Equation (1) (Saaty 1980):

a_{ij} is the value of option i by the criterion j, and w_j expresses the weight of criterion j determined by binary comparison (Ozturk and Batuk 2010).

3. Theory and calculation

3.1. Study area

The region covering the study area is located in northeastern Turkey along the coast of the Black Sea. The area of approximately 49,000 km^2 covers eight provinces (Samsun, Ordu, Giresun, Trabzon, Rize, Artvin, Gümüşhane, and Bayburt) and is under the responsibility of the Eastern Black Sea Project Regional Development Administration (DOKAP), which operates to accelerate development of the region and implement development projects (Fig *1*).

Fig 1. Study area

3.2. Datasets and spatial database design

Each of the factors that affect the landfill site selection process corresponds to a spatial dataset. Especially in developing countries such as Turkey, these datasets are produced by different agencies in different formats and then stored. In some cases, the same datasets are produced by different institutions with different methods and at different scales. This situation creates significant problems in the organization of spatial data. Moreover, data collected via different methods are used in solving the daily problems of the institutions and the spatial information produced is not involved in future planning. As a result, spatial data are obtained using different coordinate systems and standards, making them unsatisfactory for GIS studies (Yomralioglu et al. 2002).

The spatial data and maps regarding the administrative boundaries, geology, soil class, and land cover factors of the study area were produced by public institutions responsible for the production of data. Relevant spatial data (at a scale of 1 / 25,000) and maps were obtained from these institutions. The data provided with the map purchases were integrated with the database and data items were organized in layers.

The datasets representing the topography of the provinces in the study were produced from 1 / 25,000 scaled digital contour data. In the spatial data management, in order to avoid any difficulties in data processing, the contour data of the provinces in the study were integrated into separate files according to the 1 / 100,000 scaled layout sheets. Data for the basins, rivers, roads, tourism areas, conservation areas, erosion areas, lakes, forests, etc. covering the entire DOKAP region were also requested from the relevant institutions and after being prepared in the office, added to the database. At this stage, the data regarding residential areas were determined by the digitization process carried out on satellite images.

The spatial data obtained from all institutions were brought together within the framework of a common standard and then integrated into the system in a controlled manner. The inaccuracies and incompatibilities were corrected for all of the data, which was then designed, arranged, and added to the database in a single format using the same projection system. During this process, many digitization and reproduction studies were carried out along with data collection from the field.

After all the data were integrated into the database, the projection transformation process was performed in order to analyze the data in a single coordinate system. For this purpose, the projection that best represented the study area was determined. Because the region is laid out on a west-east axis, it was decided that the Lambert conformal conic projection was the most appropriate and this was created by determining the necessary parameters for the region. All data were transformed into this projection, added to the database, and made ready for analysis.

The data in the database were divided into five feature datasets: A, B, C, D, and E. The dataset and database designs are shown in Fig *2*. Accordingly, the data in the A dataset was converted to raster format via the Euclidean distance method and the data in the B dataset was converted to raster format using the vector-to-raster operation. First, the TIN data were obtained using the contour lines in the C dataset. The TIN data were then converted to raster format via the TIN-to-raster and used to obtain slope data. The D dataset containing the settlement data was interpolated with the Kriging method to obtain a raster map. The meteorology data in dataset E were used only in the odor analysis. Raster maps were produced from the data contained in the datasets using the above-mentioned methods. These raster maps were then reclassified, after which a cost surface map was prepared for the landfill facilities using MCDM methods. After the cost was determined on the surface map and the opinions from the relevant institutions were received, the results were subjected to geological, geoseismic, and seismicity analyses followed by odor analyses. As a result of these evaluations, the areas deemed to be the most suitable for regular solid waste storage facilities were revealed.

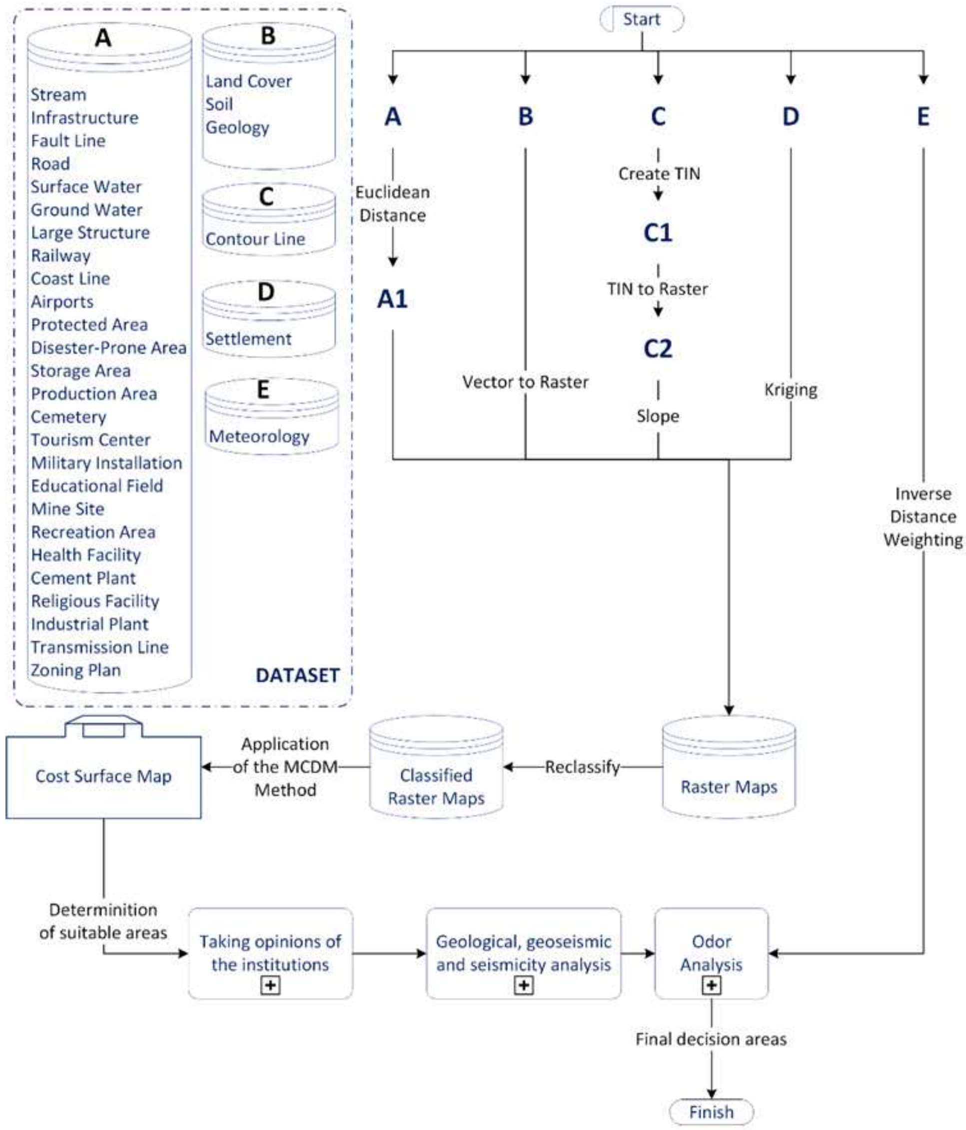


Fig 2. Datasets and spatial database design

3.3. *Factor weights for study area*

In determining suitable locations for landfills, layers were established based on the eight provinces that make up the study area. These layers are shown in Table 2 together with their weights, sub-factors, and suitability classifications.

The conformity classification process of the sub-factors was performed over the values given from 1 to 10. In the table, factors defined as definite obstacles are represented by ∞. A value of 1 corresponds to the most suitable areas and a value of 10 to the least suitable areas. For the determination of these weights, the study used the work of (Yildirim et al. 2018) on solid waste landfill site selection using MCDM-supported GIS. In addition to this study, the sensitivities of the Eastern Black Sea Region and the problems currently experienced in solid waste storage were included in the process. The factors and sub-factors affecting the location selection of solid waste storage areas are shown in Table 2. According to this table, areas defined as definite obstacles include:

i. 300 m from infrastructures such as energy transmission lines and sewerage,

ii. 500 m from railway routes, coastal lines, school and hospital areas, ports and natural resource areas,

iii. locations at a distance of 1000 m from fault lines, flora/fauna reserves, aquifers, and conservation areas

With these buffer distances defined as definite obstacles, the aim was to prevent adverse environmental and sociological effects that may be caused by regular solid waste landfills.

In addition, the suitability classifications of the sub-factors were determined based on the slope, geology, streams, soil classification, main arterial roads, surface waters, and landslide area data, as weighted in Table 2. These classified factors used in the production of the cost surface map can be seen in *Fig 3*.

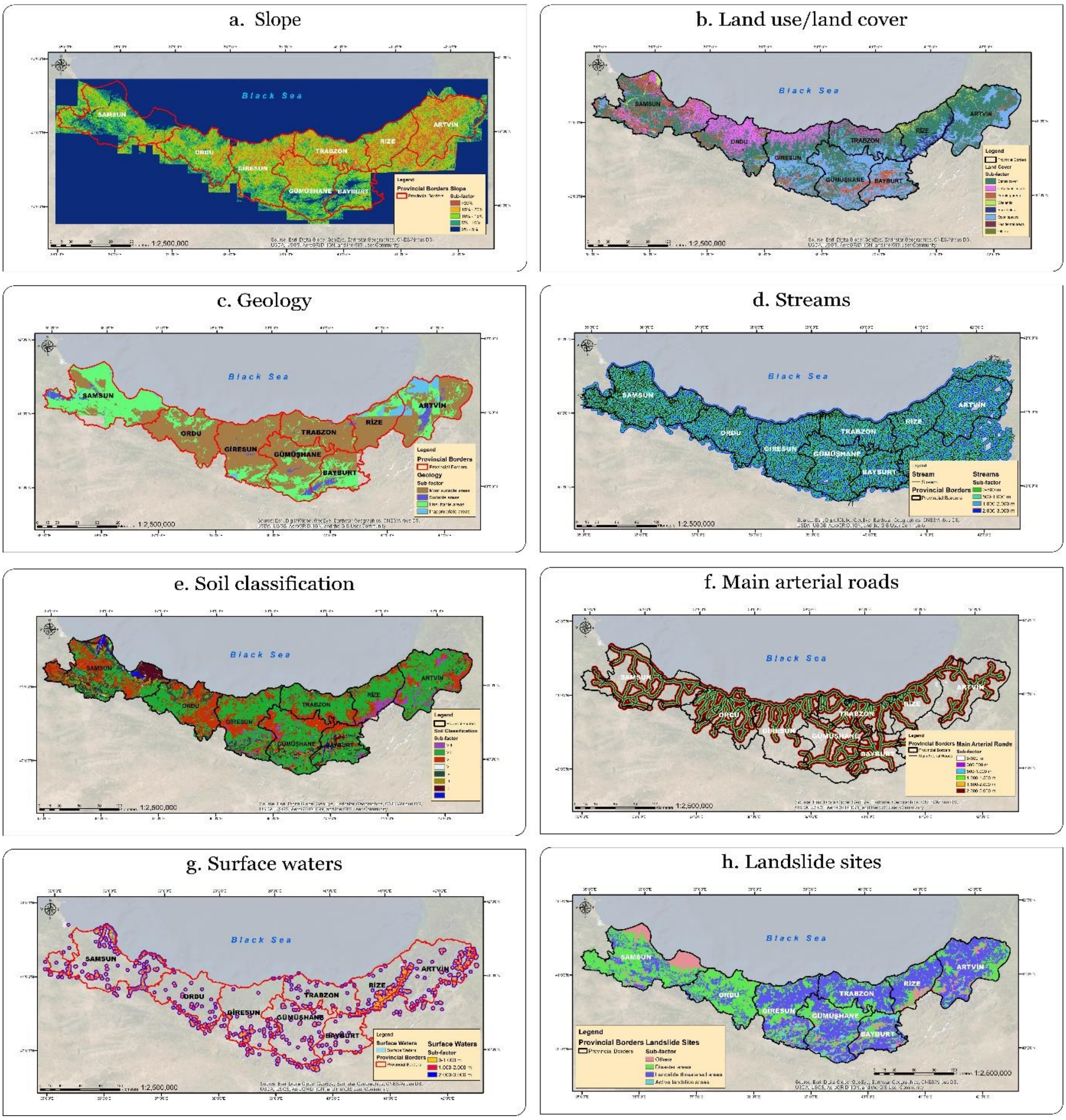


Fig 3. Classified factors used in cost surface map generation

Table 2. Factor weights

Factors	Weights	Sub-factors	Score	Factors	Weights	Sub-factors	Score
Slope	**0.10**	0-5	1	Soil	**0.10**	I (The best quality soil)	∞
(Degree)		5-10	3	classification		II	10
		10-15	6			III	9
		15-20	8			IV	7
		>20	10			V	6
Land use/	**0.15**	Dense forest	∞			VI	5
Land cover		Crop substitution	9			VII	2
		Farming areas	10			VIII (The worst quality soil)	1
		Wetlands	∞	Main	**0.10**	0-300 m	∞
		Rock fields	6	arterial		300-500 m	1
		Open spaces	5	roads		500-1000 m	3
		Residential areas	∞			1000-1500 m	5
		Others	1			1500-2000 m	7
Geology	**0.10**	Most suitable areas	1			2000-5000 m	9
		Suitable areas	5			>5000 m	10
		Unsuitable areas	10	Surface	**0.20**	0-1000 m	∞
		Inappropriate areas	∞	waters		1000-2000 m	10
Streams	**0.20**	0-500 m	∞			2000-3000 m	6
		500-1000 m	10			>3000 m	∞
		1000-2000 m	9	Landslide	**0.05**	Active landslide areas	∞
		2000-3000 m	5	Sites		Landslide threatened areas	10
		>3000 m	1			Disaster areas	9
Population	**-**	0-1000	1	Railways	**-**	0-500 m	∞
		1000-5000	6			>500 m	1
		5000-25000	7	Coastline	**-**	0-500 m	∞
		25000-50000	8			>500 m	1
		50000-100000	9	Education	**-**	0-500 m	∞
		>100000	10	centers		>500 m	1
Infrastructures (Pipelines, Energy Transmission Lines, Sewerage)	-	0-300 m	∞	Healthcare facilities	-	0-500 m	∞
		>300 m	1			>500 m	1
Fault Lines	-	0-1000 m	∞	Ports	-	0-500 m	∞
		>1000 m	1			>500 m	1
Flora and Fauna Reserves	-	0-1000 m	∞	Conservation areas	-	0-1000 m	∞
		>1000 m	1			>1000 m	1
Acquifer Fields	-	0-1000 m	∞	Natural resource areas (Water, Energy, etc.)	-	0-500 m	∞
		>1000 m	1			>500 m	1

3.4. *Cost surface map*

The AHP method was used in the determination of solid waste disposal sites in the study area. The data were scored with the values shown in Table 2 and factor weights were determined by creating pairwise comparison matrices. The data used in the study were converted into raster format and prepared for analysis. After the the factors were converted into raster format, the conformity classification process was carried out. The obtained factor weights were then used in the raster surface analysis and the solid waste storage areas belonging to each were determined.

The raster data model is the most useful data format for performing arithmetic operations between pixels of the same layer or pixels in different layers in the same geographic location. Today, because of the advantages of the raster data format, certain functions of GIS software are used extensively, such as surface analysis, determination of minimum cost routes, creation of arithmetic operations between layers, and determination of the most suitable locations (Yildirim 2009). The cost surface map created in the study was obtained using AHP, one of the MCDM methods. When the generated cost surface map is examined, the suitable and unsuitable points for solid waste site selection can be identified. In the generated cost surface map, pixels with low numerical values indicate the most suitable points for solid waste disposal sites and the areas with pixel values shown in green indicate the most suitable points for solid waste storage, whereas pixels in red show areas that are not suitable for storage (*Fig 4*).

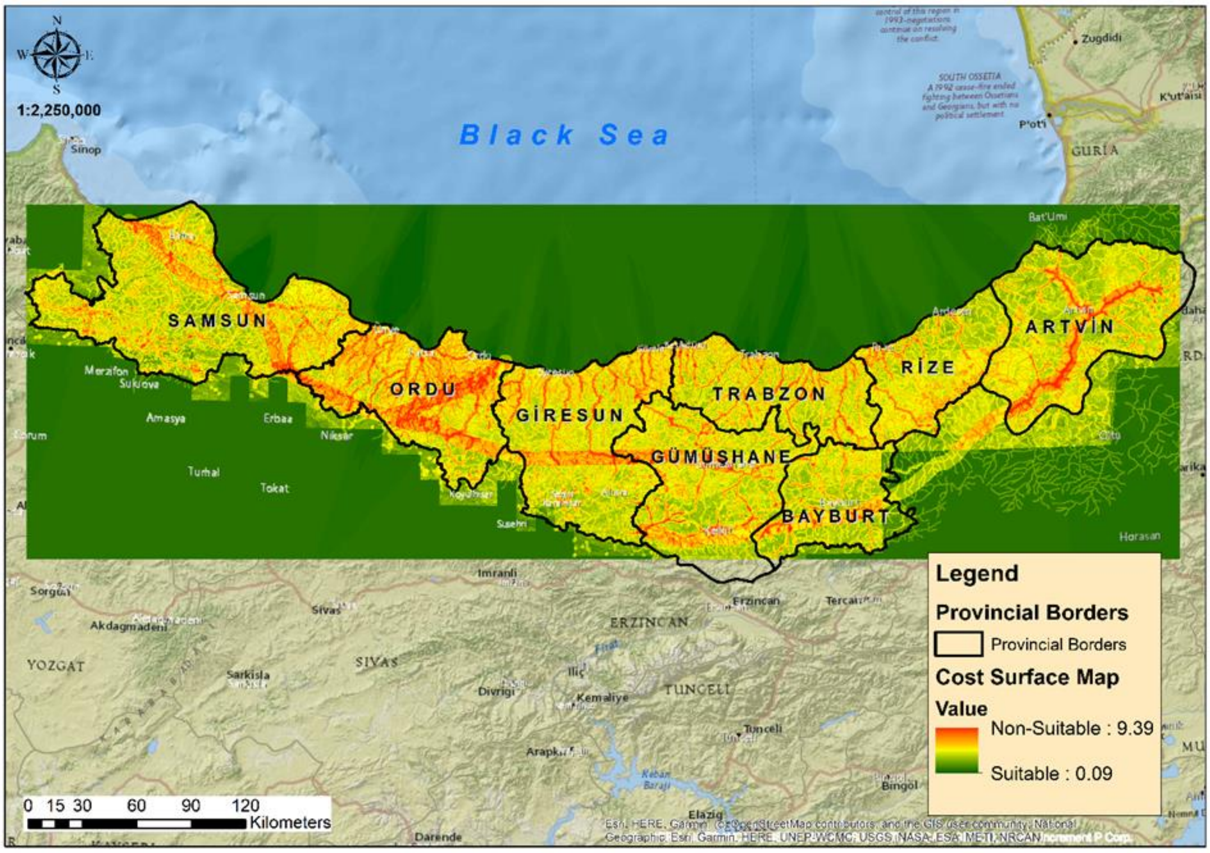


Fig 4. Solid waste landfill cost surface map

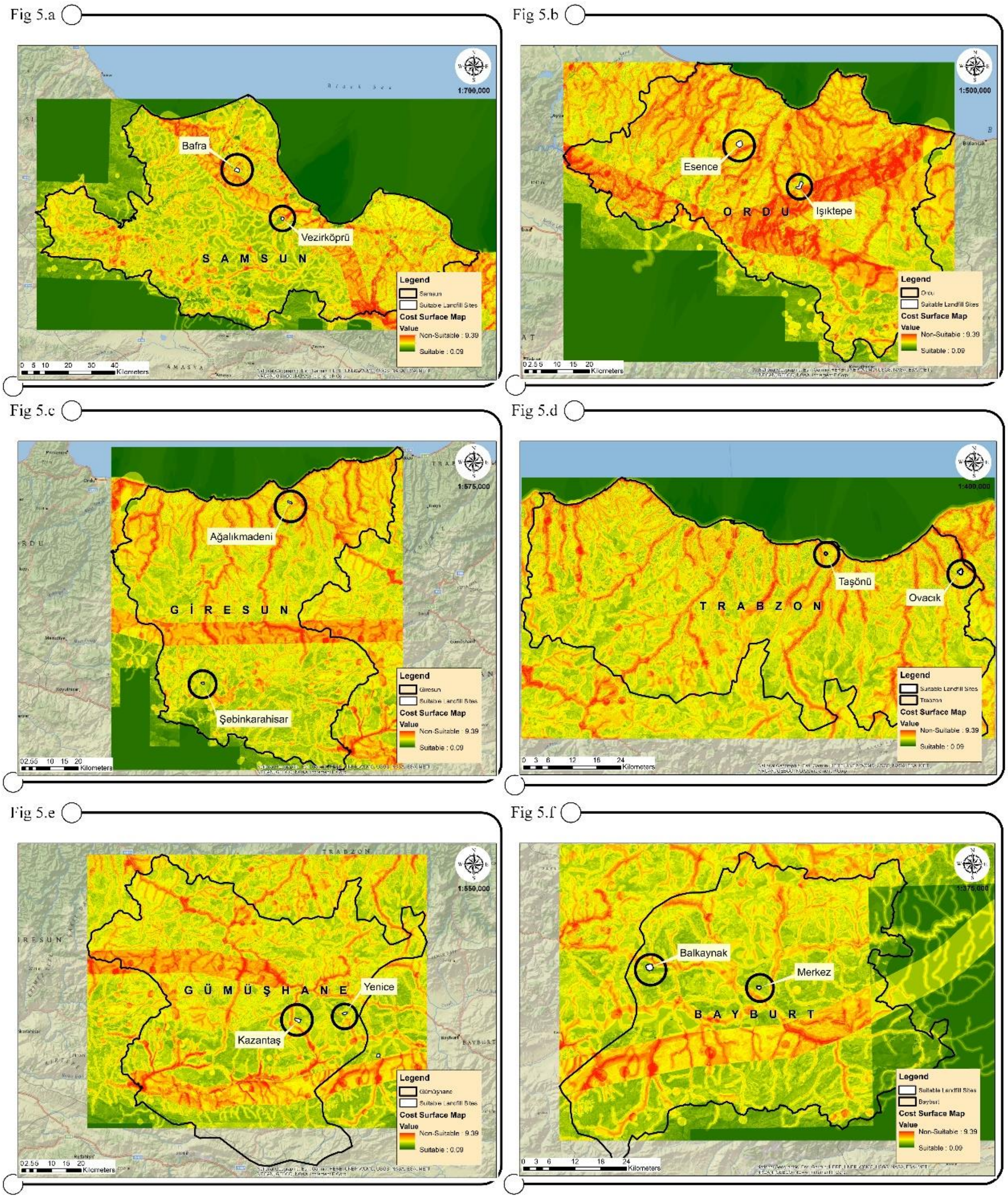
When an evaluation was conducted on a provincial basis, the number of areas on the cost surface map deemed suitable for solid waste storage facilities were ten in Samsun, five in Ordu, eight in Giresun, seven in Trabzon, four in Gumushane, five in Bayburt, and three in Artvin. However, these potential points are DOKAP areas. Two important solid waste points were determined for each province. Meetings held with the relevant institutions, meetings of the working team, and the evaluation of the land conditions all contributed to the determination of the points where drilling / geological / seismic measurements and evaluations would be carried out. The pixel-based suitability values obtained from the cost surface map were interpreted in the process.

4. Results

4.1. The most suitable solid waste landfill sites for the Eastern Black Sea Region

In the study, the areas having the potential for solid waste sites in each province were determined using the raster-based cost surface map produced to identify the possible solid waste disposal areas. The suitable and most suitable areas for each province were determined on the DOKAP cost surface map created for the study area. When the evaluation was made in the context of all provinces, a total of 42 solid waste disposal points were found. Among these 42 areas, 14 of the most suitable areas were studied in detail (*Fig 5*). For these areas, geological, seismicity, seismic, environmental, transportation, access, cost, etc. analyses were carried out comprehensively (Table 3).

At this stage of the study, each solid waste disposal site was also evaluated statistically to provide an additional perspective to the decision-making phase. The factors used in choosing the most suitable sites and additional assessment aspects were also considered, including average distance from settlements, average distance from streams, average distance from main arterial roads, average slope, forest areas, and distance from tourism areas. Evaluations made on the basis of these factors are presented in *Table 4*. As a result of these controlled evaluations, the areas identified from the cost surface map were found to be the healthiest in terms of landfill areas.



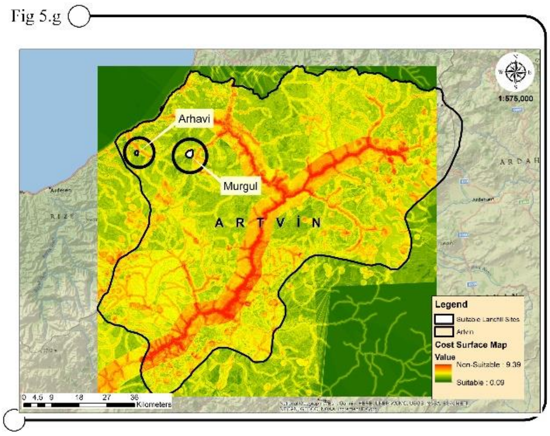


Fig 5.a Two suitable landfill sites determined for Samsun
Fig 5.b Two suitable landfill sites determined for Ordu
Fig 5.c Two suitable landfill sites determined for Giresun
Fig 5.d Two suitable landfill sites determined for Trabzon
Fig 5.e Two suitable landfill sites determined for Gümüşhane
Fig 5.f Two suitable landfill sites determined for Bayburt
Fig 5.g Two suitable landfill sites determined for Artvin

Fig 5. Suitable landfill sites determined for DOKAP region

Table 3. Final assessment of suitable areas for landfill sites

S/N	Province-District	Field	Figure 4	Area (ha)	Average Pixel Value	GIS Analysis	Geological Analysis	Seismic Analysis	Environmental Analysis	Transport Cost Analysis
i	Artvin-Murgul	Baskoy	4.g	443.20	2.3503	Very Suitable	Suitable	Partially Suitable	Suitable	Suitable
ii	Artvin-Arhavi	Gurgencik		129.69	2.5664	Very Suitable	Suitable	Partially Suitable	Suitable	Suitable
iii	Bayburt-Merkez	Balkaynak	4.f	208.08	2.3915	Very Suitable	Suitable	Not Suitable	Suitable	Suitable
iv	Bayburt-Merkez	Merkez		65.97	2.4153	Very Suitable	Very Suitable	Suitable	Suitable	Suitable
v	Giresun-Sebinkarahisar	Ovacık	4.c	70.43	2.6265	Very Suitable	Suitable	Suitable	Suitable	Suitable
vi	Giresun-Espiye	Agalikmadeni		92.50	2.7314	Very Suitable	Partially Suitable	Partially Suitable	Suitable	Suitable
vii	Gümüshane-Merkez	Yenice	4.e	100.71	2.3225	Very Suitable	Suitable	Suitable	Suitable	Suitable
viii	Gümüshane-Merkez	Kazantas		198.94	2.5430	Very Suitable	Suitable	Suitable	Suitable	Suitable
ix	Ordu-Kumru	Esence	4.b	285.01	3.4100	Very Suitable	Very Suitable	Suitable	Suitable	Suitable
x	Ordu-Gurgentepe	Isiktepe		256.13	3.6736	Very Suitable	Suitable	Very Suitable	Suitable	Suitable
xi	Samsun-Vezirkopru	Avdan	4.a	111.66	2.6593	Very Suitable	Very Suitable	Suitable	Suitable	Suitable
xii	Samsun-Bafra	Aktekke		483.98	3.4788	Very Suitable	Very Suitable	Not Suitable	Suitable	Suitable
xiii	Trabzon-Arakli	Tasonu	4.d	39.48	2.9506	Very Suitable	Very Suitable	Very Suitable	Suitable	Suitable
xiv	Trabzon-Of	Ovacik		127.17	2.9655	Very Suitable	Very Suitable	Suitable	Suitable	Suitable

Table 4. Geo-statistical evaluation of solid waste landfill sites

S/N	Province-District	Field	A	B	C	D	E	F	G	H
i	Artvin-Murgul	Baskoy	0.82	0.03	1.28	384.98	166.60	12	South-east	VI
ii	Artvin-Arhavi	Gurgencik	0.55	0.41	0.41	122.79	150.38	17	South	VI
iii	Bayburt-Merkez	Balkaynak	1.09	0.64	0.77	0	76.20	9	South-east	VII
iv	Bayburt-Merkez	Merkez	3.18	1.83	1.83	0	94.58	6	South-west	VII
v	Giresun-Sebinkarahisar	Ovacık	0.44	0.42	13.95	30.70	3.62	9	South	VI
vi	Giresun-Espiye	Agalikmadeni	1	0.56	1.84	16.14	24.36	17	South-east	VII
vii	Gumushane-Merkez	Yenice	0.65	0.45	1.10	0	65.53	9	South	VII
viii	Gumushane-Merkez	Kazantas	0.59	0.97	1.02	17.71	49.45	4	South	VII
ix	Ordu-Kumru	Esence	0.06	0.90	0.81	149.66	53.22	15	South	VII
x	Ordu-Gurgentepe	Isiktepe	0.09	0	0	125.74	53.22	11	South	VII
xi	Samsun-Vezirkopru	Avdan	0.98	0.53	1.88	0	3.84	5	South	IV
xii	Samsun-Bafra	Aktekke	0.54	0	1.90	0	1.41	6	South	III
xiii	Trabzon-Arakli	Tasonu	0.30	0.64	0.72	0	38.41	5	South-west	VI
xiv	Trabzon-Of	Ovacik	0	0.32	1.34	0	71.60	11	South	VII

A: Distance from residential areas (km), **B**: Distance from the middle line of the stream (km), **C**: Average distance from the main roads (km), **D**: Area within forests (ha), **E**: Distance from tourism areas (km), **F**: Average slope (%), **G**: Aspect (orientation), **H**: Soil classification (Soil quality values between 1-8; the best quality soil is 1st class soil)

Table 3 can be summarized as follows:

i. Murgul-Baskoy was determined as a suitable area for Artvin Province. However, as a result of the seismic analysis, it was emphasized that a landslide hazard might be present in some parts of this area and additional preventive measures should be taken, whereas the remaining parts would be more suitable for waste storage.

ii. The Center area was determined as the most suitable for Bayburt Province. The second area studied for Bayburt Province was the Balkaynak area; however, it was not considered suitable for storage because groundwater was detected.

iii. Ovacık was determined as the most suitable area for Giresun Province. As the second area studied for Giresun Province, Agalikmadeni had a landslide risk. When the area concerned was evaluated seismically, only a part of it was considered as possibly suitable. It was concluded that the relevant part would be suitable for use if necessary measures were taken to construct structures against landslides.

iv. Both Yenice and Kazantas were identified as very suitable areas for Gumushane Province.

v. Both Esence and Isiktepe were identified as very suitable areas for Ordu Province.

vi. Avdan was determined as the most suitable area for Samsun Province. On the other hand, the Aktekke area was considered to be unsuitable in terms of the the ground features and the possibility of a vertical progressive fault line passing through the region.

vii. Tasonu was determined as the most suitable area for Trabzon Province. Apart from this area, Ovacik area was also determined as usable.

viii. For Rize Province, no solid waste storage area that met the first-degree criteria was identified.

4.2. Odor analysis for suitable solid waste landfill sites

The odor analysis stage revealed the areas in each province where solid waste disposal sites may be affected by emission of bad odors. At this stage, the basic data required for odor analysis included the prevailing wind direction and intensity of the wind related to that direction. For this reason, the daily maximum wind strength and direction data were obtained from the General Directorate of Meteorology for 20 stations in the region. These data were examined and generalized as required and prevailing wind directions and related wind intensities were determined on a monthly basis.

Using the interpolation method of inverse distance weighting (IDW), a distribution map was created for monthly wind intensity and direction for the relevant 20-station data. A network of rectangular cells was generated by projecting points at 500-m intervals to represent the region. At these points, direction and intensity data were added from the wind distribution maps created using IDW. Thus, at the request of DOKAP, areas were identified that would be affected by the odors emitted from the solid waste storage points of the Tasonu (Trabzon-Arakli) area. The odor analysis for this area is shown in *Fig 6*.

Fig 6.a The prevailing wind direction in January and the odor distribution

Fig 6.b The prevailing wind direction in March and the odor distribution

Fig 6.c The prevailing wind direction in April and the odor distribution

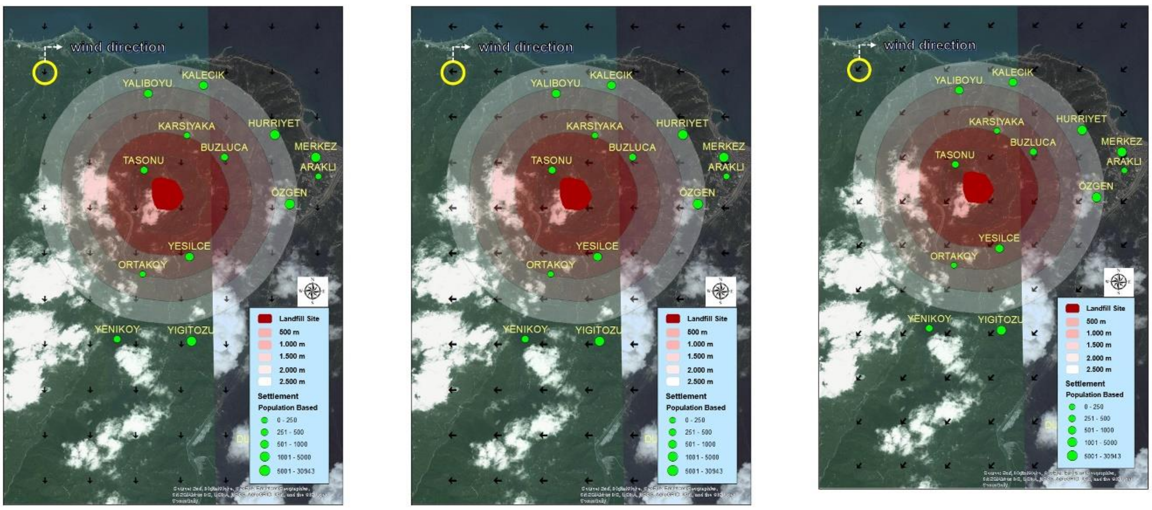


Fig 6. Odor analysis example for Tasonu area (Trabzon-Arakli)

5. Discussion

One of the most important problems seen in residential areas is ensuring that the waste produced is managed in the most environmentally friendly manner. Various disposal methods are used in the field of waste management around the world. The disposal method that has been the most highlighted recently is recycling. On the other hand, considering the work and investment costs required for recycling and recovery methods to become widespread, cities currently are in need of landfill facilities. In addition, when waste management approaches are examined, it is seen that regular landfills are necessary to minimize environmental problems. In addition, conducting studies on the location of solid waste storage sites will help to prevent all manner of prospective problems.

An examination of the studies conducted regarding the choice of sites for solid waste storage revealed that GIS and S-MCDM methods were frequently used. The AHP method was used in this study because it provided an easy solution for complex problems and because although it was simpler to apply compared to other methods, it offered a more qualified decision-making ability. The factors that facilitated the production of an effective solution were determined by considering national and international legal regulations, academic studies, and waste management plans. Afterwards, these factors were weighted and brought together in a common format to enable analyses to be carried out that were then presented in the form of a raster-based cost surface map.

As a result, the study identified a total of 42 suitable landfill sites in the application area that comply with national and international legislation and meet environmental and sociological criteria. From each of the eight provinces in the region, two areas exhibiting appropriate cost values were studied in detail. In this context, the opinions and suggestions of the relevant institutions, organizations, and external stakeholders were also considered. In the last stage, seismicity, seismic, environmental, and geological studies were performed for the most suitable 14 areas determined for the region. In addition, odor analyses were also carried out for the determined suitable areas. The people living in the region are not foreseen to remain indifferent towards solid waste storage facilities. In this sense, public awareness can be raised and trust in the State can be further increased by producing correct solutions in the light of scientific criteria for management of these sites, in addition to developing policies to prevent leakage, odor, and environmental damage, and supporting studies based on scientific findings. One of the most important advantages of the study for the region is that a holistic spatial database was created for eight provinces under the responsibility of DOKAP. With this database, an analysis of all projects envisaged for the region can be conducted with accuracy and consistency and much more rapidly. The created spatial database can provide an important spatial information infrastructure for future projects (e.g., for the tourism, energy, environmental, health, education, transportation, agricultural, and planning sectors) to be carried out by DOKAP in the region.

Each of the factors that affect the landfill site selection process corresponds to a spatial dataset. On the other hand, the use of spatial data on the local, regional, national, and international scale has become an important requirement. In the spatial database design carried out in this study, the standards set forth by the process of Turkey’s adaptation to the European Union guidelines were also taken into consideration. In line with these requirements and in order to increase the effectiveness of the created model, factors affecting site selection and sub-factors expressing the transition difficulties for these factors were created according to the relevant standards. Many related laws/regulations, academic studies, reports, etc. were examined when determining these factors. The contributions of these factors towards the target within the scope of the project and the methods used to determine the weight values were then decided. As a result of this study and the advantages provided by the model, the applicability of the model to other regions of Turkey has also been proposed.

6. Conclusion

Using holistic and alternative approaches, this study aimed to determine the most suitable landfill sites in the area covering Samsun, Ordu, Giresun, Trabzon, Rize, Artvin, Gumushane, and Bayburt Provinces under the responsibility of DOKAP. This study is one of the biggest ever carried out on behalf of the DOKAP region, with the field covered by the study including many features such as the occupational disciplines and working stakeholders. In order to implement waste management approaches, suitable sites for landfill facilities in the region were identified with this study. As a result, suitable areas were determined in terms of establishment activities.

The AHP method was used in weighting the factors used to determine the most suitable areas. Multiple criteria were weighted with a binary comparison-based approach and analyzed in raster format. The regular solid waste storage areas were produced alternatively. Two areas for each of eight provinces in the region, underwent additional analyses and were studied in detail with appropriate cost values. The GIS and S-MCDM, seismicity, seismic, geological and geotechnical, environmental, and access/transportation/cost analysis results were evaluated together. With the advantages of the method used in the production of the cost surface map, this study yielded very positive results.

The combination of GIS technologies supported by S-MDCM methods has become the most important solution technique for the selection of environmentally friendly solid waste storage sites and for a sustainable management approach to a permanent solution. By taking into account environmental sensitivities, the solid waste landfills provided for the provinces included in the study will contribute positively to the environment and public health. In this regard, it is very important to conduct an odor analysis on candidate landfill sites. In light of current academic studies on the subject, the odor analysis carried out in this study will add a different dimension to landfill site selection studies.

In summary, this study can be seen as a guide for other studies because it included multidisciplinary studies, considered international criteria in the environmental context, covered a large study area, and used nearly 30 factors in the decision-making phase.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The data that support the findings of this study are available from Eastern Black Sea Project Regional Development Administration (DOKAP) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Eastern Black Sea Project Regional Development Administration (DOKAP).

Competing interests

The authors declare that they have no competing interests" in this section.

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Authors' contributions

VY: Conceptualization, Methodology, Project administration, Funding acquisition. **BU**: Supervision. **TMK**: Investigation, Writing- Reviewing and Editing. **FT**: Software, Formal analysis, Data curation. **BAA**: Validation, Resources, Visualization, Writing- Original draft preparation.

All authors read and approved the final manuscript.

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Figures

Figure 1

Study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

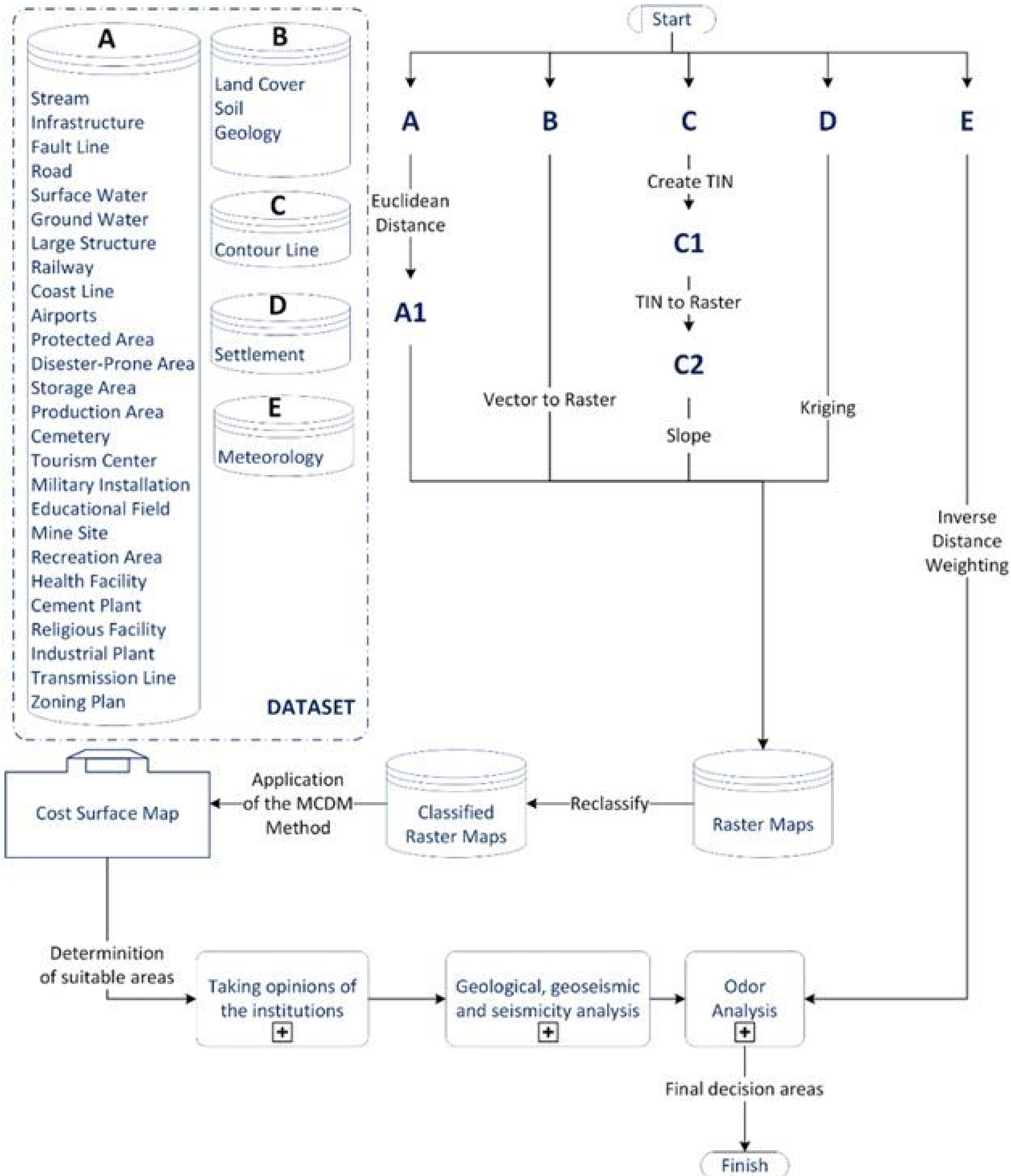

Figure 2

Datasets and spatial database design

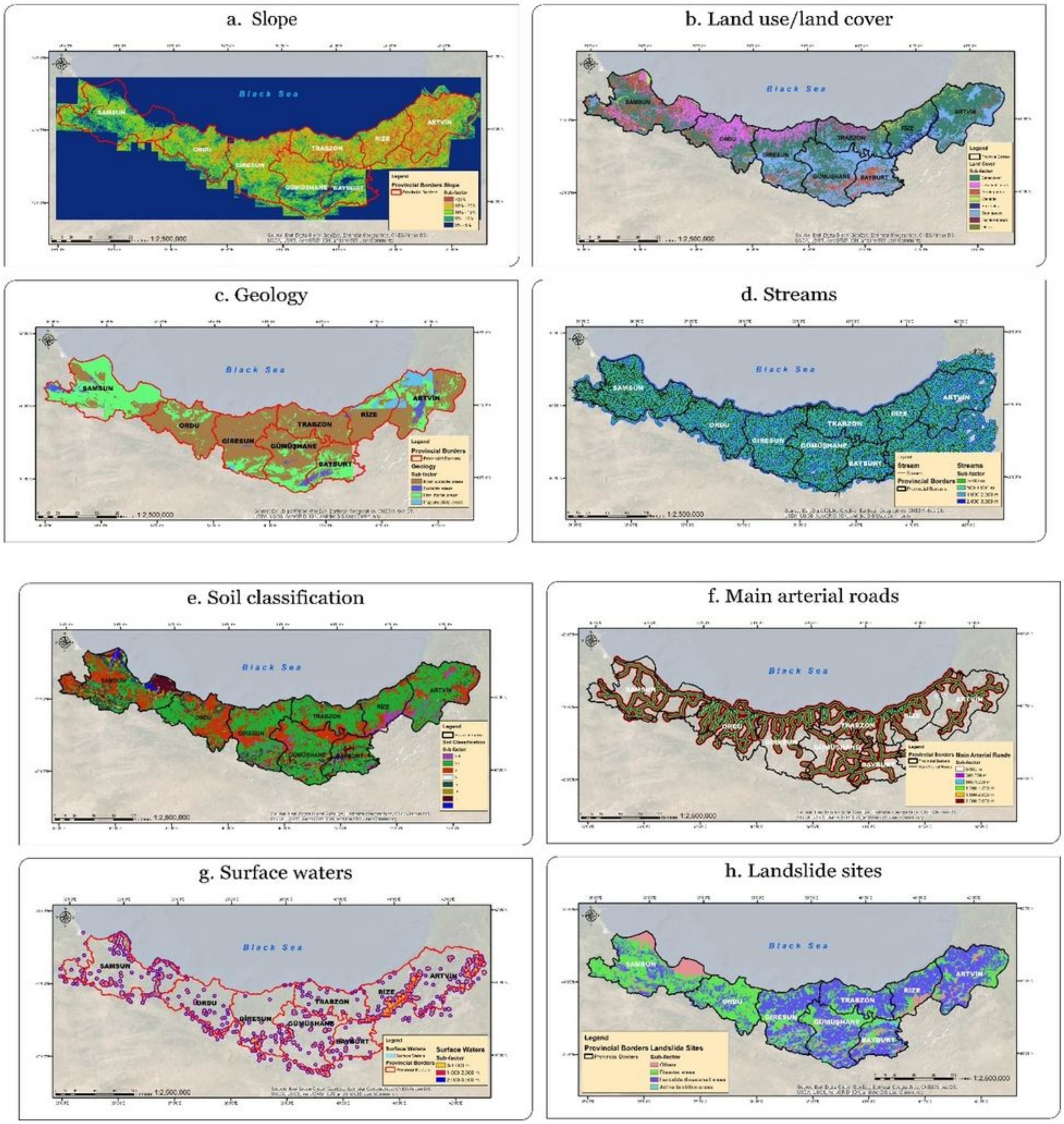

Figure 3

Classified factors used in cost surface map generation Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

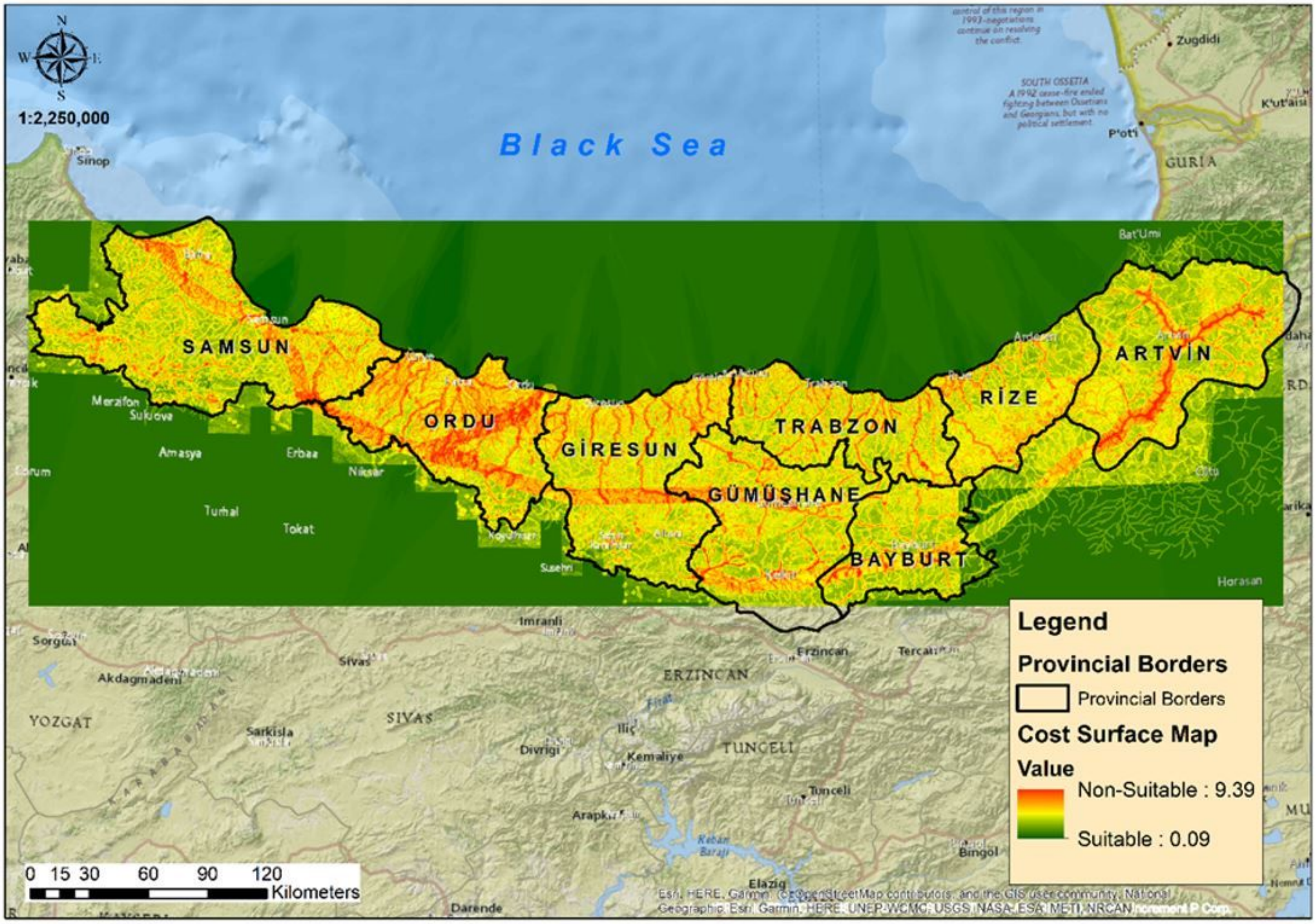

Figure 4

Solid waste landfill cost surface map Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

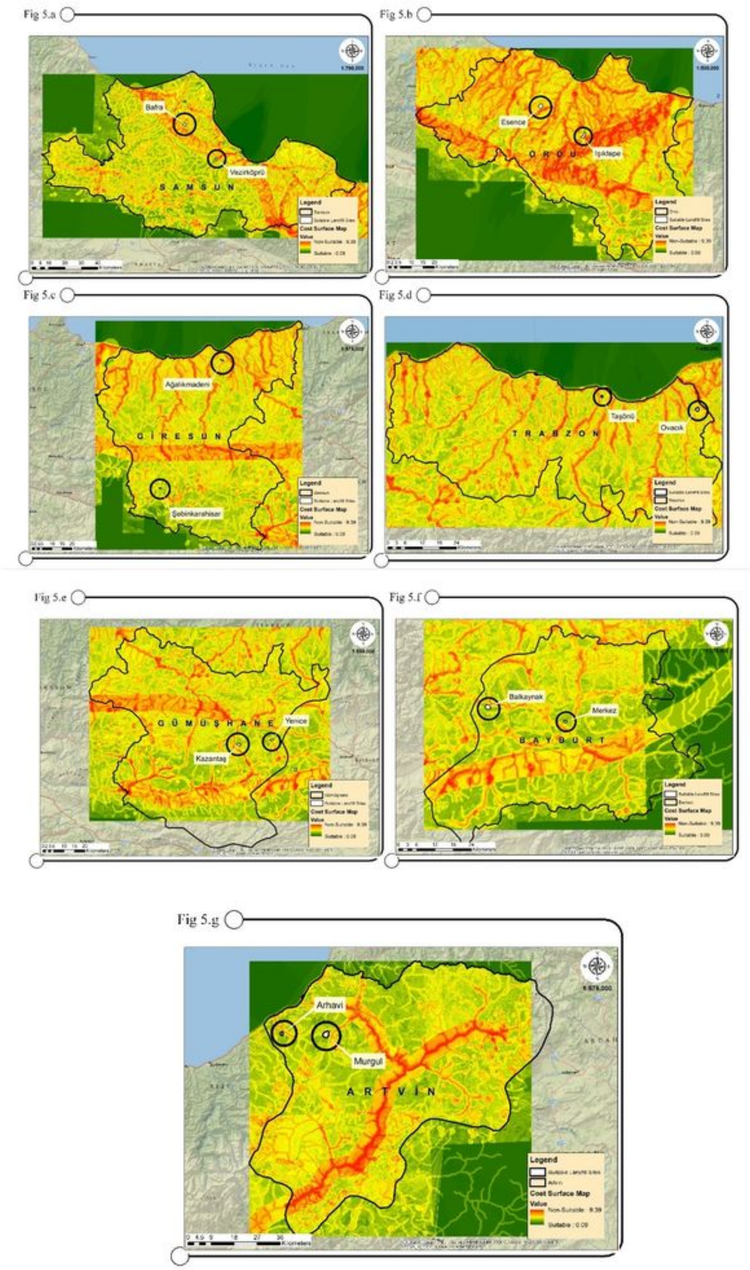

Figure 5

Suitable landfill sites determined for DOKAP region Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

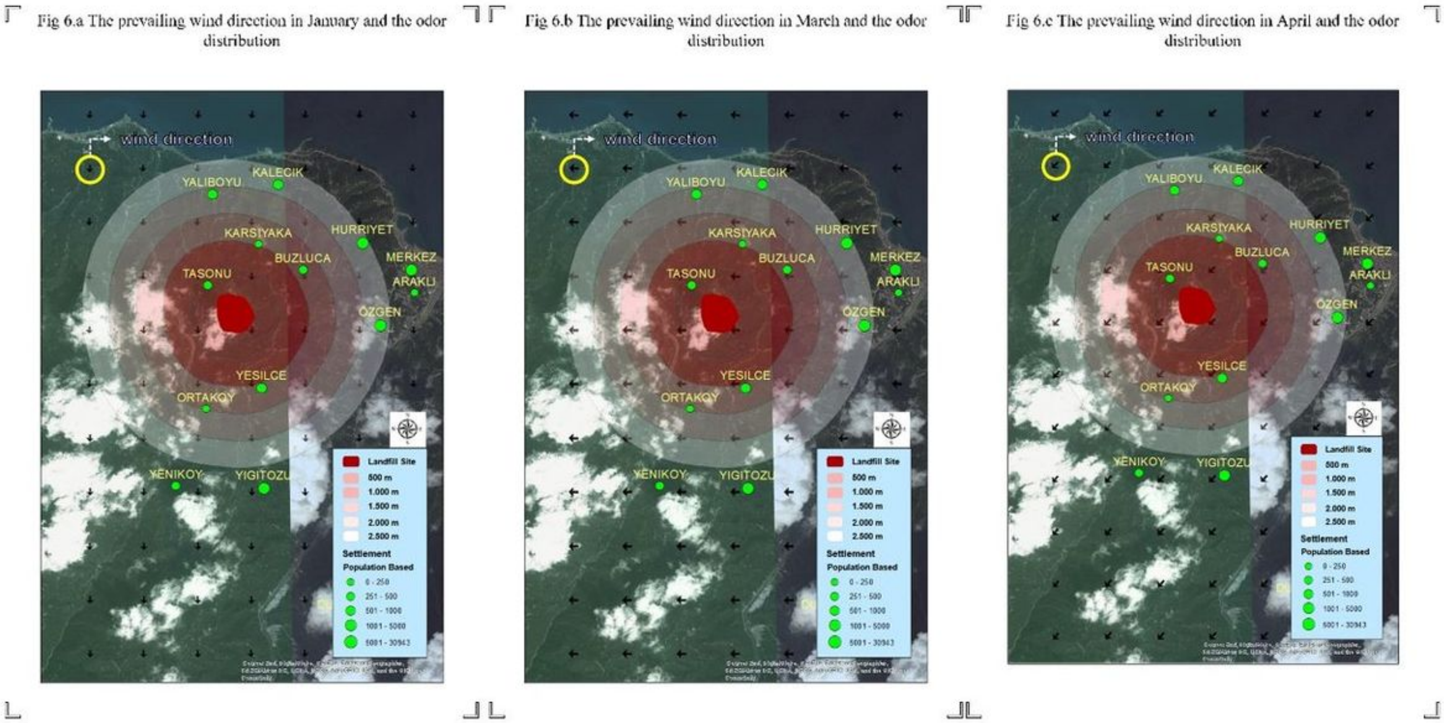

Figure 6

Odor analysis example for Tasonu area (Trabzon-Arakli) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.