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Compost Plant Site Selection for Food Waste Using GIS Based Multicriteria Analysis

Sedat Yalcinkaya[1,a,*], Sevin Uzer[2,b], Hasan İhsan Kaleli[2,c], Fatih Doğan[2,d], Mert Kayalık[3,e]

[1]Department of Civil Engineering, Faculty of Engineering and Architecture, Izmir Katip Celebi University, 35620, Izmir, Turkey
[2]Department of Urban Regeneration, Graduate School of Natural and Applied Sciences, Izmir Katip Celebi University, 35620, Izmir, Turkey
[3]Department of Geomatics Engineering, Graduate School of Natural and Applied Sciences, Izmir Katip Celebi University, 35620, Izmir, Turkey
[*]Corresponding author

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A B S T R A C T

Marketplace waste collection is one of the crucial services provided by the district municipalities in Turkey. A significant amount of food waste is periodically collected from marketplaces. However, an important opportunity for recycling and mitigation climate change is missed because these waste are sent to landfills. Composting, one of the waste management technologies applied to organic waste to reduce greenhouse gas emissions and produce compost, is often preferred for the management of marketplace waste. This study aims to determine suitable locations for compost facilities to manage marketplace waste with the help of GIS considering economic, environmental, and topographic factors in Izmir, Turkey. There are 199 marketplaces in Izmir and each has at least one market a week. Each marketplace was weighted by means of population served by using location-allocation analysis since the amount of waste collected from the marketplaces is not known. First, an exclusion analysis was performed to remove limited use areas. Then, a preference analysis was performed. Factors affecting plant site selection process for composting marketplace waste, including marketplace locations and weights, were determined. Since all factors do not have equal importance, the analytical hierarchy process was used to determine weights for each factor based on their influence. The study area was spatially evaluated for each preference factor and a suitability map was created for each factor. Finally, a high-resolution final suitability map was obtained by combining each factor's suitability map along with their weights. Areas with a suitability index greater than 80% have been defined as suitable areas for compost facility installation. The results indicate that there are 323 potential locations suitable for compost facilities in Izmir.

[a] sedat.yalcinkaya@ikc.edu.tr https://orcid.org/0000-0003-3062-2698
[b] sevinuzer@gmail.com https://orcid.org/0000-0002-0125-1384
[c] hasanihsankaleli@gmail.com https://orcid.org/0000-0002-7221-9234
[d] fatih.dogan9696@gmail.com https://orcid.org/0000-0003-0430-8443
[e] kayalikmert@gmail.com https://orcid.org/0000-0002-1666-2215

Introduction

The world population is expected to be between 9.4 and 10.1 billion in 2050 (United Nations, 2019). Parallel to this increase, the global demand for food is predicted to be increased by 35-50% between 2012 and 2050 to feed the world population (Food and Agriculture Organization of the United Nations, 2018). As a result, food waste is expected to increase as well. Proper management of food waste is also seen as a way to contribute climate change mitigation by reducing greenhouse gas emissions. Food waste can be defined as the decline in the quantity or quality of food occurring from retail to the final consumption (Jenkins et al., 2016). Since food loss and waste have several impacts at the global level, Committee on World Food Security recommended the 'food use-not-waste' hierarchy to reduce food loss and waste (Food and Agriculture Organization of the United Nations, 2014). Composting, one of the steps in the hierarchy, is an important alternative for organic waste within the integrated solid waste management strategy that can be implemented to municipal solid waste (MSW) or separately collected food waste (Hocking, 2006). Determining the methodology and standardization for the use of products obtained from compost facilities as soil improver on degraded lands is one of the action plans for the prevention, reduction and management of food losses and waste in Turkey (Food and Agriculture Organization of the United Nations, 2020).

MSW is a multidisciplinary activity that includes collection, transportation, processing, treatment, recycling, or disposal of waste materials (Das and Bhattacharyya, 2015; Höke and Yalcinkaya, 2021; Kutlu and Mutlu, 2021; Mutlu, 2021; Rada et al., 2013; Yalçınkaya, 2020). Collection and transportation of solid waste is the first step in the MSW system and causes significant transportation costs and exhaust gas emissions. For optimum planning, distance between the waste recycling, treatment and disposal facilities, and waste sources must be minimized. Since marketplaces are geographically dispersed, siting compost facilities becomes an important aspect of food waste management system. Many criteria play a role in the selection of compost facility location and most of them are spatially variable. Therefore, geographic information system (GIS) is utilized in site selection process. Since site selection is also a multi-criteria decision making (MCDM) process, MCDM methods; such as the Analytic Hierarchy Process (AHP), are often used (Saaty, 2002).

Most of the site selection studies in the MSW management system are on landfill siting. The traditional approach, by integrating AHP and GIS, has been applied in most studies for different study areas (Chabuk et al., 2017; Güler and Yomralıoğlu, 2017; Hazarika and Saikia, 2020; Kamdar et al., 2019; Khodaparast et al., 2018; Uncumusaoğlu and Mutlu, 2019; Kilicoglu et al., 2020; Kükrer and Mutlu, 2019; Mutlu, 2019; Randazzo et al., 2018; Tokatlı et.al., 2021; Tüdeş and Kumlu, 2017; Yalcinkaya, 2020a; Yalcinkaya and Kirtiloglu, 2021;). In the aforementioned studies, criteria are divided into the basic contexts, namely environmental, morphological and economic. For example; Barzehkar et al. (2019) determined the most suitable location for a MSW landfill by comparing fuzzy logic and boolean logic. Ecological and socioeconomic criteria were considered by using GIS and MCDM methods together. Also, Yildirim et al. (2018) used TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions) technique and GIS to determine alternative locations for MSW landfills in Bursa, Turkey. Sadhasivam et al. (2020) applied GIS-based MCDM techniques to determine optimum landfill sites in Thiruverumbur taluk in Tiruchirappalli district, India. In addition, GIS and remote sensing techniques were used to process the geographic database in this study. In the end, a suitability index was created to identify candidate landfill sites. Chabuk et al. (2017) proposed an approach combining AHP and Simple Additive Weighting to obtain potential landfill sites.

While most of the site selection studies in MSW management have focused on landfill siting, some researchers have also focused on other waste management facilities. In the study carried out by Yalcinkaya and Kirtiloglu (2021) a model was developed based on fuzzy AHP and GIS to site an incineration plant in Izmir, Turkey. This study involved a pre-screening process to exclude unsuitable areas and a preference analysis to spatially scale the study are for each preference factor. Babalola (2018) used the weighted linear combination approach that MCDA applied for the procurement of suitability maps to site anaerobic digestion facilities for food and biodegradable waste. Khan et al. (2018) conducted a combined GIS and AHP method for siting waste conversion facilities including biofuel facilities, electricity facilities, composting, and anaerobic digestion facilities.

This study aims to determine suitable locations for compost facilities to manage marketplace waste with the help of GIS considering economic, environmental and topographic factors in Izmir, Turkey. So that marketplace waste can be recycled and greenhouse gas emissions from improper management and transportation of marketplace waste can be reduced. Economic, environmental, and topographic factors were evaluated spatially and the most suitable locations for compost facilities were determined by performing a GIS based MCDM approach.

Materials and Methods

The methodology of the study can be summarized as follows: Firstly, criteria and related factors were determined. Then, the weights of the marketplaces based on population served were determined. For this purpose, Location-Allocation analysis was carried out that reveals which marketplace serves which neighborhood and the number of the population served. In the continuation of the study, exclusion analysis was done by taking into account legal obligations and other studies. Later on, ten factors were weighted via AHP under the three main criteria. Then, preference analysis was performed to evaluate spatial suitability degree of each criterion. The final suitability map was produced by weighted summing each preference map based on their AHP weight.

Study Area

Izmir is the most developed city on the Aegean coast of Turkey. Izmir is located in the middle of the Aegean Region and around Izmir Bay. The territory of the province lies between 37° 45' - 39° 15' north latitudes and 26° 15' - 28° 20' east longitudes. Its area is approximately 12,000 km^2. The population of Izmir is 4,394,694 people which makes it the 3rd most populous city in Turkey (Turkish Statistical Institute, 2021). The city has 30 districts and 1,295 neighborhoods. The location of the study area is presented in Figure 1.

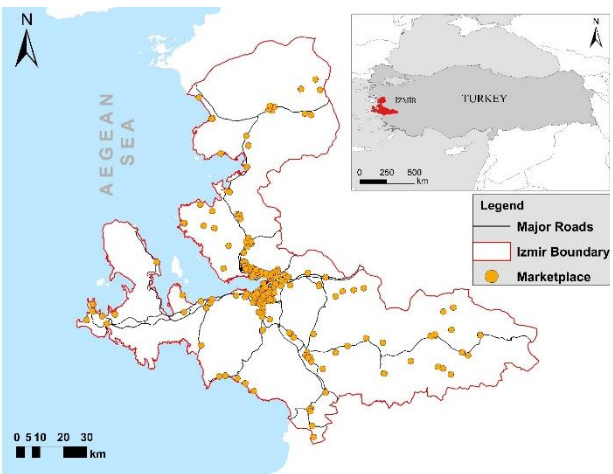

Figure 1. Map of the study area illustrating market areas, neighborhoods, and major roads.

Selection and Preparation of Criteria

In the study, 10 factors based on 3 criteria were identified (Table 1). Resource availability factor, which is one of the economic criteria, reflects the availability of marketplace waste that will form raw materials for the compost plant. Distance to wastewater plants and agricultural lands were considered as economic factors since wastewater to be formed in the compost plant may require treatment and compost can be used as soil improver at agricultural lands. Distance to the major roads is also an important economic. Because the transportation possibilities of both the source to be used and the products to be formed depend on this factor. Distance to protected areas, touristic places, water bodies and settlements factors, which constitute the environmental criteria, have been determined considering the human and environmental helth, and aesthetics. Under the topography criteria, slope and surface area requirement were evaluated.

Table 1. Preference factors, rasterization techniques to drive factors, minimum and maximum values for transformation functions, and AHP weights

Criteria	Factor	Rasterization	Min	Max	Weight
Economic	Resource availability	Inverse Distance Weighted	Min	Max	0.26
	Distance to major roads	Distance Accumulation	1000 m	30 m	0.14
	Distance to agricultural land	Distance Accumulation	2000 m	1000 m	0.09
	Distance to wastewater treatment plants	Distance Accumulation	Max	Min	0.06
Environmental	Distance to water bodies	Distance Accumulation	250 m	Max	0.12
	Distance to protected areas	Distance Accumulation	500 m	Max	0.11
	Distance to touristic areas	Distance Accumulation	500 m	Max	0.06
	Distance to settlements	Distance Accumulation	250 m	Max	0.04
Topographic	Slope	DEM to Slope	15 degree	0 degree	0.09
	Surface area	Polygon to Raster	1ha	10ha	0.03

Table 2. Data types and sources used in the study.

Data type	Source
Digital elevation model	NASA SRTM
Administrative boundaries	General Directorate of Mapping
Population	Turkish Statistical Institute (2021)
Landuse	Ministry of Environment and Urban Planning
Road network	OpenStreetMap
Neighborhood locations	Generated with Google geocode API and crosschecked with up-to-date Ministry of Interior neighborhood names list
Marketplace locations	Izmir Metropolitan Municipality

Table 2 presents the data and sources used in the study. Marketplace locations and related neighborhood populations were taken as reference for the resource availability factor, slope was derived from digital elevation model obtained from the NASA SRTM, road network was built by using openstreetmap data, and landuse data was obtained from the Ministry of Environment and Urbanization in vector format. Major roads data includes Motorway, Motorway_link, Trunk, Trunk_link, Primary, Primary_link classes in OSM. water bodies data includes lakes, ponds, dams, and streams. Protected area and touristic areas factors were derived from the landuse data. Protected areas include special environmental protection zones, natural parks, culture-tourism protection, and development zones. Touristic areas factor includes tourism center, beach, and tourism facility areas.

Location allocation analysis for weighting marketplaces

The weighting marketplaces step was conducted to estimate the weight for each marketplace based on population served. Addresses of the marketplaces were obtained in table form from the Izmir Metropolitan Municipality. In addition, 2020 population data of the neighborhoods was downloaded from the Turkish Statistical Institute (2021). The goal of location-allocation analysis is to locate the facilities in a way that supplies the demand points most efficiently. A location-allocation analysis was conducted to determine which marketplace serves which neighborhood and how much of the neighborhood population. The 199 marketplaces were divided into two groups as urban (99) and rural (100). Two different location-allocation analyses, LA_urban and LA_rural, were performed for these two separated groups.

In the LA_urban analysis, a maximum of 10 minutes driving time was chosen as the criterion, while in the LA_rural analysis, a maximum of 15 minutes driving time was chosen as the criterion. Maximize market share problem type was used in both analyses. 1,295 neighborhoods (demand points) were processed. 389 of them were assigned to urban marketplaces, and 497 neighborhoods were assigned to the rural marketplaces. 409 neighborhoods were not allocated to any marketplace within the given drivetime limits. Allocation of neighborhoods to the marketplaces is shown in Figure 2.

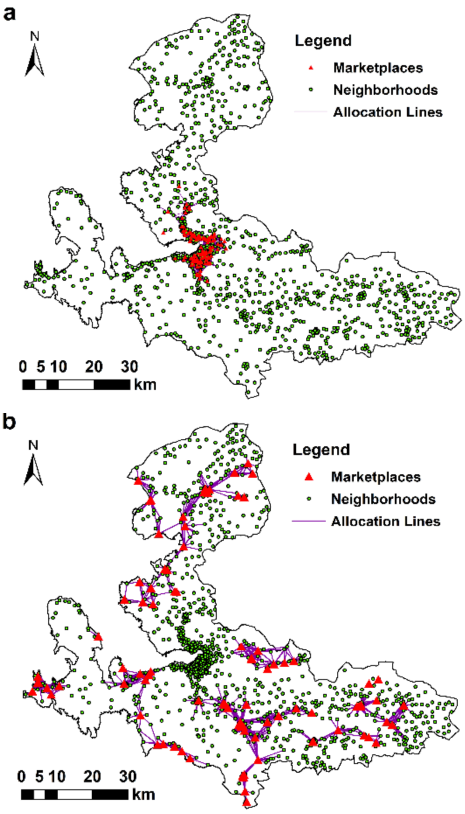

Figure 2. Allocation of neighborhoods to the a) urban marketplaces and b) rural marketplaces

Exclusion Analysis

Some areas should be excluded for compost plant siting. For this reason, exclusion analysis was carried out taking into account legally and technically limited use areas. Firstly, the areas to be excluded were determined (forest, industry and tourism regions, protected areas and prohibited military zones, etc.). The areas to be buffered within the excluded areas were determined as follows: 250 m buffer for settlements (Ministry of Environment and Urbanization, 2015), 10-30 m buffer for road network, 50-200 m buffer for water bodies, 500 m buffer for environmental protection areas (Sliz-Szkliniarz and Vogt, 2012; Sultana and Kumar, 2012). In the continuation of the study, the buffered areas were merged with the other unsuitable areas and excluded from the study area. The resulting area was defined as suitable.

Preference Analysis

The preference factors were compared among themselves according to the degree of importance and comparison matrices were created. While making this comparison, the criteria were scored according to the scoring table of Saaty (2002). According to the results obtained, final weight values were obtained for each criterion.

Each factor was derived from the base data in raster format to be used in suitability analysis. During this process, different rasterization methods were used for each factor (Table 1). Seven factors based on distance were rasterized by the distance accumulation method. For the resource availability factor, the marketplace demand weights obtained as a result of location-allocation were taken as a basis. These demand weights were rasterized by spreading over the entire study area using the inverse distance weighted interpolation method. The surface area factor was rasterized according to the polygon areas. Slope was produced using DEM in raster format.

Since the cell value units (meters, degrees, etc.) of the rasters produced for each factor are different, they cannot be used for suitability analysis. Proper functions, representing the suitability of a factor for siting compost plats were used to equalize each raster in a common scale. Thus, all rasters have been transformed between 1-10 by using linear functions with proper parameters (Table 1). For example, since proximity is taken as the basis for distance to major roads factor, the distance to give the maximum suitability value is 30 meters, while the distance to give the minimum suitability value is 1000 meters. Suitability value of 10 was assigned to areas 30 meters away, while suitability value of 1 was assigned to areas 1,000 meters away and above. It also scales areas between 30 and 1000 meters linearly and assigns intermediate values between 1 and 10. In the rasterization process, rasters with a cell size of 5 m, excluding the slope, were generated. Since there is no DEM data with sufficient resolution, a slope with a cell size of 30 m was generated.

Suitability Analysis

Firstly, all rasters produced for each factor were matched with AHP weights, and weighted summed to create the final suitability map in raster format with a cell size of 5 m. Weighted Sum overlays several rasters, multiplying each by their given weight and summing them together. The resulting suitability map was normalized to a scale between 1 and 10. Then, the regions with a suitability index value of 8 or more were separated and saved in vector format.

Results and Discussion

As a result of the exclusion analysis, an area of 7,153 km^2 within the borders of the mainland of Izmir, which has a total area of 11,970 km^2, has been remained. The excluded areas represent approximately 60% of the study area (Figure 3). Yalcinkaya and Kirtiloglu, (2021) excluded 97% of their study area for an incineration facility. It is estimated that the main reason for this difference is that agricultural lands were not excluded in the present study. Since the composts produced from organic wastes are used as fertilizer in the agricultural lands and also, agricultural lands can be evaluated as potential organic waste sources in the future, it is not restricted and proximity is preferred.

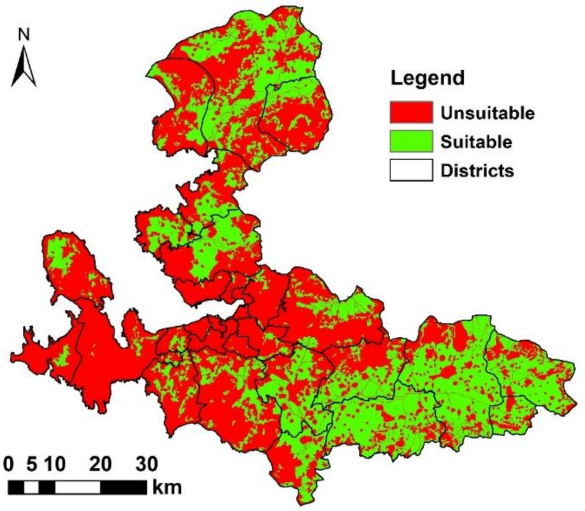

Figure 3. Excluded and suitable areas

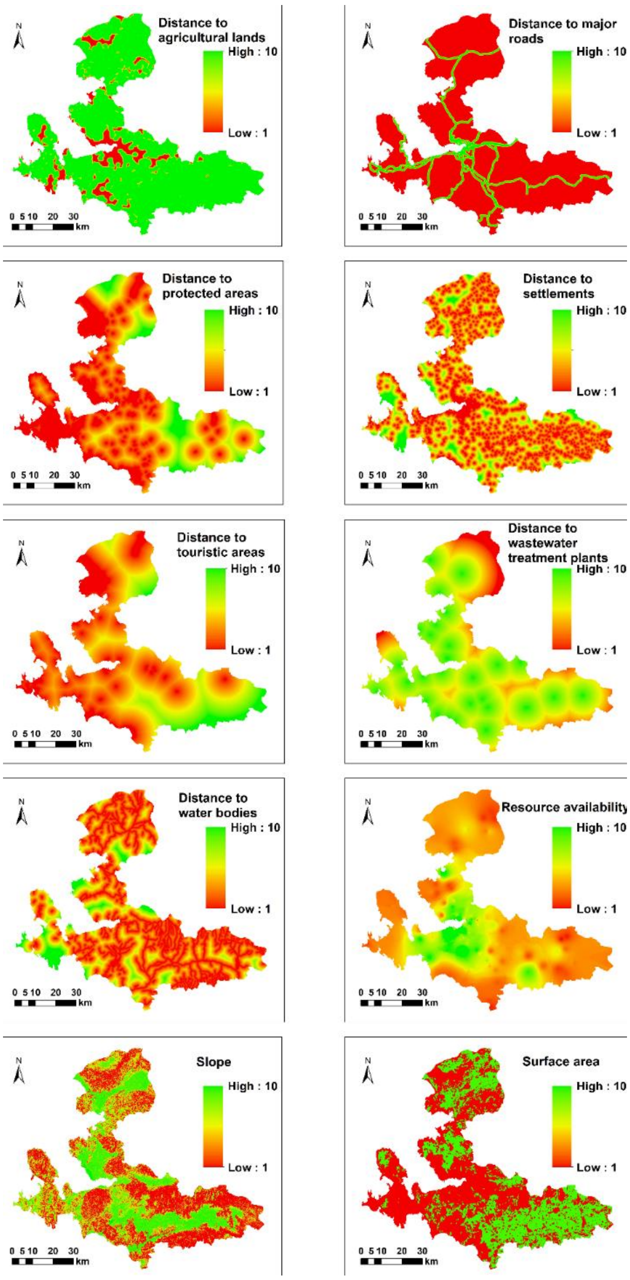

Figure 4. Transformed preference factors

Transformed preference factors were shown in Figure 4. Distance to water bodies, distance to protected areas, distance to settlements and distance to touristic places factors show a direct correlation between the distance and the degree of suitability, while there is an opposite relationship in the distance to major roads, distance to agricultural land and distance to wastewater treatment plants factors. Izmir Bay and its surroundings have scores for high resource availability due to high population density. Distance to major roads resulted as the most restricting factor, while distance to agricultural lands is the least. Distance to major roads, which is one of the economic factors, played a key role with the effect of having a narrow preferred area.

While determining the preferred factors and excluded area, it is aimed to provide an environmentally and economically sustainable management for marketplace waste. When the weights resulting from the AHP in Table 1 are examined, 12% of the total weight is composed of topographic criteria, 33% environmental, and 55% economic criteria. The dominance of economic sustainability is also reflected in the suitability result.

In Figure 5 blank areas are unsuitable areas. Areas with a suitable index of 3.23 represent the least suitable areas, and areas with 10 represent the most suitable areas. However, not every region with a high suitability index is a potential region for the location of a facility. In the literature, those who have a suitability index greater than or equal to eight ($SI \geq 8$) were considered suitable (Sultana and Kumar, 2012; Yalcinkaya, 2020b). For this reason, cell clusters with a suitability index greater than 8 and also wide enough to meet the facility area requirement (1-10 ha) were converted into vector format. 323 potential points were determined to be suitable for composting in Izmir (Figure 6). Potential points were searched in cell clusters with $SI \geq 8.5$ and $SI \geq 9$, but they did not show a balanced distribution as in Figure 6. This study, which is the first to determine the suitable places for compost facilities in the city of Izmir, can guide the waste management authorities for environmentally and economically sustainable management of marketplace waste.

Conclusion

Site selection/land suitability analyses are complex problems. In this study, 323 potential locations were determined for compost facility siting problem with GIS-based MCDM analysis. Marketplace waste are considered as the waste source, since they are periodically collected by separate waste collection trucks and sent to landfills in Izmir. As the number of preference factors increases, the sensitivity of the study increases and the area to be selected for the appropriate location narrows. In the following studies, vehicle routing problem analysis between the marketplaces and the potential compost facility sites ($SI \geq 8$) can be conducted to reduce the alternatives. Besides, transportation distances, fuel consumptions, exhaust emissions, and facility capacities can be determined via vehicle routing problem analysis. However, average waste amounts data for each marketplace must be available.

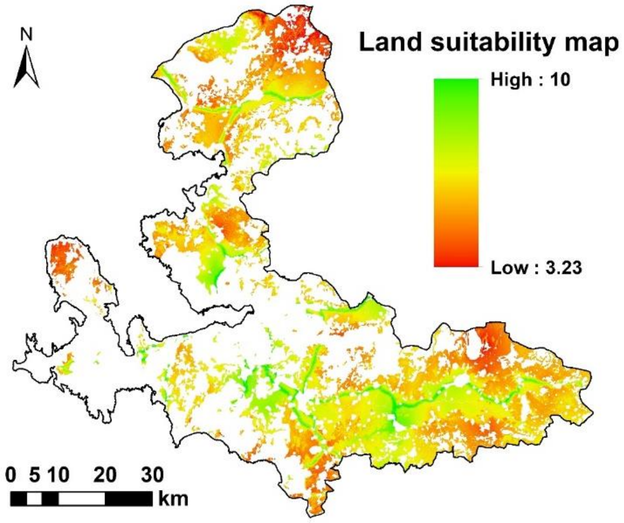

Figure 5. Land suitability map

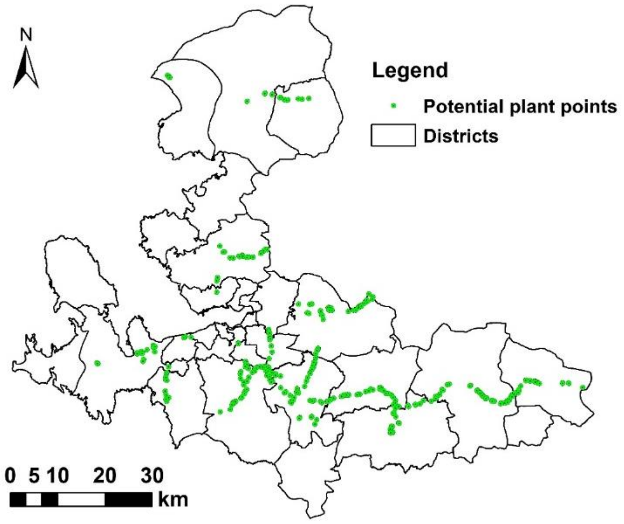

Figure 6. Suitable sites for compost facilities in Izmir

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