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ASSESSING SOLID WASTE MISMANAGEMENT IN TRIPOLI, LEBANON, USING GIS: A SPATIAL ANALYSIS WITH THE SWEPT MODEL

Abstract: This paper presents an in-depth analysis of solid waste management in Tripoli, Lebanon, using the SWEPT model a suitability model incorporating multiple criteria to assess potential sites for recycling and waste management initiatives. The SWEPT model considers socio-economic factors, waste characteristics, environmental pollution, and topographical conditions, assigning each location a suitability score that ranges from unsuitable to very high suitability. The model allows for a comprehensive evaluation of potential sites for recycling and waste management infrastructure in Tripoli, taking into account the complex urban and socio-economic conditions that affect the city's waste management system.

The model's validation is achieved through a matrix analysis, which compares the suitability of the selected sites for recycling with existing waste collection points. This approach ensures that the chosen sites are both strategically located and viable for implementation. By integrating GIS technology and spatial analysis, the study provides a clear visualization of the relationships between various urban planning challenges and waste management issues in Tripoli. Through these analyses, the paper offers evidence-based recommendations for improving waste management practices, enhancing the city's infrastructure, and addressing broader environmental concerns.

Keywords: GIS, SWEPT, Tripoli, Spatial Analysis, Pollution

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Introduction

In Tripoli – Lebanon, as in the rest of the Lebanese regions, the problem of waste management is preponderant in the absence of real sustainable solutions. The landfill and despite the presence of a waste sorting center near the landfill, it is not possible to solve this problem because of mismanaging and absent maintenance also the waste storing center is closed in 2019 (Tripoli Municipality union, 2019).

Tripoli city is home of the most important facilities in the country, such as the Port of Tripoli and the Spatial Economic Zone (Fig. 1). Unfortunately, the area also facing a significant problem with water pollution in the sea due to the mistreatment of water from the river. This pollution can have harmful effects on the marine ecosystem, as well as on human health and the local economy (Erdmann, 2011).

Fig. 1. The location of wastewater treatment plant and Landfill
Source: ESRI, 2022

The city suffers from many misery belts located around its periphery. The Tabbaneh area, Wadi al-Nahla neighborhood, Tanak area and Hosh al-Abaid in the port, and Wadi Mishmish in Abi Samra which lacks the lowest living conditions and infrastructure (Akbıyık & Çıralı, 2019). See also Fig. 2 and Fig. 3.

Fig. 2. The informal settlement in Tripoli El-Mina Hosh Abid, Haret Jdideh, Tanak
Source: own photos, 2019

Fig. 3. Waste in Tripoli from different area
Source: own photos, 2020

With all these kinds of problem in this small city a sustainable solution must be put forward in line like using of GIS, to provide a comprehensive understanding of the urban planning challenges in Tripoli. Specifically, GIS technology will be used to gather and analyze spatial data related to the waste problem in Tripoli, including population density, land use, and infrastructure. By integrating spatial data with other relevant data sources to applying the suitability Model "SWEPT".

Tripoli is a Lebanese city and the capital of the Northern Governorate, located at 34.43 latitude and 35.89 longitude, with a population of approximately 554,287 (UNOCHA, 2014). It is 80 km from the capital Beirut, with an area of approximately 24.7 km^2. It is bordered to the north by the district of Minieh-Denniyeh, to the south by Koura district, to the east by the district of Zgharta, and it benefits from a wide sea frontage to the west. The Abou Ali River crosses Tripoli, which divides it into two parts, connected by a bridge erected after the river flooded in 1956 (Dib & Krstić, 2020). See Fig. 4.

Research methodology and data

The SWEPT model is a comprehensive indexation framework developed to evaluate the suitability of waste management practices in Tripoli. It serves as a decision-support tool for identifying optimal sites for recycling facilities within urban areas. The model incorporates four key criteria: Social and Economic factors (S), Waste Characteristics (W), Environmental Pollution (EP), and Topography (T). These parameters collectively guide spatial analysis and ensure the integration of socio-environmental considerations in waste management planning.

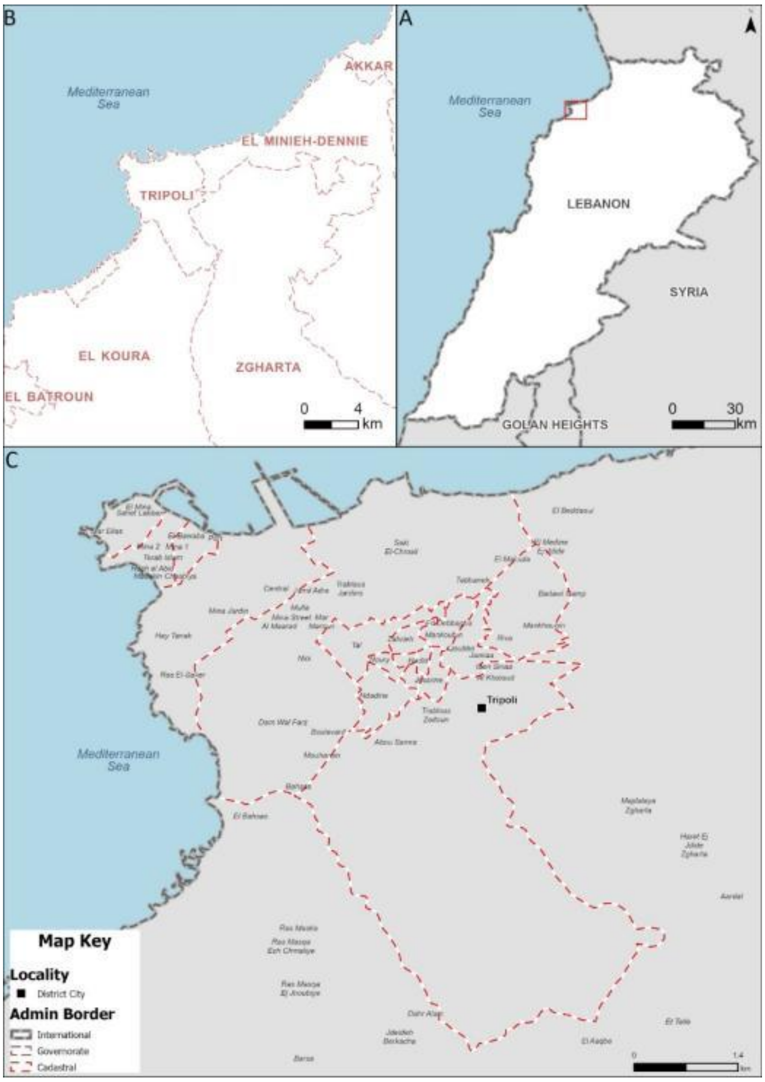


Fig. 4. The study area
Source: own study, 2024

During the data collection process, various types of data are gathered and categorized into two main groups: physical data and human data. Physical data includes information such as the location of drinking wells in Tripoli city obtained from NLWE, wind speed data extracted from the Global Wind Atlas, and slope, aspect, and elevation data derived from the ASTER digital elevation model with a 30-meter resolution. Human data comprises layers: roads extracted from OpenStreetMap (OSM) for Tripoli City, points of interest, and building layers obtained from Microsoft. Additionally, field data is directly collected, including the locations of unutilized buildings that can serve as waste collection points, points of aleatory dams, the number of waste containers and baskets, and data on waste generation and composition based on the 2021 report by Al Fayhaa Tafrouz Association.

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty (Saaty,1980), is a structured decision-making method used in the application of SWEPT. AHP facilitates decision-making by breaking a complex problem into a hierarchy of sub-problems, comparing them pairwise, and prioritizing them based on their relative importance.

In the SWEPT model, four main criteria are considered, each with sub-criteria, divided into physical and human aspects that influence the selection of recycling and sorting sites. For the physical criteria, environmental and topographic parameters are taken into account. In the study area, urban development occupies a significant portion of the city's space, leading to the disappearance of many soil and geological features, which are therefore not included in the analysis. For the human aspect, multiple sub-criteria are considered, such as road density, population, proximity to settlements, land cover, and waste characteristics (Table 1).

Table 1. Criteria and sub-criteria and cause of choosing of SWEPT model

Criteria L1	Sub – Criteria L2
Social and Economic	Road's density
	Population density
	Landcover
	Proximity to settlement
Waste Characteristic	Waste Generation
	Waste composition
Environment and Pollution	Wind speed m/s
	Proximity from water resources m
Topographic	Slope degree
	Aspect degree
	Elevation m

Source: own study, 2024

– Pairwise comparison: Each pair of criteria or alternatives is compared using Saaty's fundamental scale (Table 2), assigning numerical values to represent their relative importance.

Table 2. Fundamental scale for pair – wise comparisons in AHP

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two criteria contribute equally to the goal.
3	Moderate Importance	One criterion is slightly more favored.
5	Strong Importance	One criterion is strongly more favored.
7	Very Strong Importance	One criterion is significantly more favored.
9	Extreme Importance	One criterion is overwhelmingly favored.
2, 4, 6, 8	Intermediate Values	Compromise values for finer distinctions.

Source: Saaty, 1980

- Calculating weights: Eigenvalue computation generates weights that indicate the relative importance of each criterion or alternative.
- Consistency check: Ensures the reliability of pairwise comparisons by computing a Consistency Ratio (CR).

The Consistency Index (CI): To measure the consistency of the pairwise comparisons, the Consistency Index (CI) is calculated as:

$$\frac{CI = \lambda max - n}{n-1} \tag{1}$$

where:
λ max: The largest eigenvalue of the pairwise comparison matrix.
n: The number of criteria or elements being compared.

The Consistency Ratio (CR): To assess the consistency of the decision matrix, the Consistency Ratio (CR) is computed as (Table 3):

$$CR = \frac{CI}{RI} \tag{2}$$

where:
CI: Consistency Index.
RI: Random Consistency Index for the corresponding n.

Table 3. Random Consistency index Table

n (Matrix Size)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Random Consistency Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty, 1980

A CR value of 0.1 (10%) or less indicates acceptable consistency. Higher values suggest the need to revise the pairwise comparisons.

ArcGIS Pro 3.2 software was utilized to generate maps for road and population density, proximity to settlements, and other parameters. The natural breaks (Jenks) classification method was applied to classify each layer in the model. This method used in GIS-based decision-making and particularly effective when integrated into the AHP, minimizes within-class variance while maximizing between-class variance, thus identifying natural groupings within the data (Jenks, 1967). By enhancing the representation of data patterns, it ensures that classifications align with the dataset's intrinsic structure. Following the classification of each sub-criterion, the reclassification process in the AHP method was conducted using a five-point suitability scale ranging from "unsuitable" to "very highly suitable", forming the matrix for the SWEPT model (Table 4).

Table 4. Pairwise comparison matrix for the selected Criteria level 1 of SWEPT

Criteria	Social and Economic	Waste Characteristic	Environment Pollution	Topographic
Social and Economic	1	4/3	4/2	4/1
Waste Characteristic	3/4	1	3/2	3/1
Environment Pollution	2/4	2/3	1	2/1
Topographic	1/4	1/3	1/2	1

Source: own study, 2024

Normalize the matrix by dividing each element in a column by the sum of its respective column (Table 5).

Table 5. Normalized Matrix of the Criteria level 1 in SWEPT

Criteria	Social and Economic	Waste Characteristic	Environment Pollution	Topographic
Social and Economic	1.00/2.50=0.40	1.33/3.33=0.40	2.00/5.00=0.40	4.00/10.00=0.40
Waste Characteristic	0.75/2.50=0.30	1.00/3.33=0.30	1.50/5.00=0.30	3.00/10.00=0.30
Environment Pollution	0.50/2.50=0.20	0.67/3.33=0.20	1.00/5.00=0.20	2.00/10.00=0.20
Topographic	0.25/2.50=0.10	0.33/3.33=0.10	0.50/5.00=0.10	1.00/10.00=0.10

Source: own study, 2024

Calculate the average of each row in the normalized matrix to get the final weights (Table 6).

Table 6. Priority weights

Criteria level 1	Final Weight
Social and Economic	(0.40+0.40+0.40+0.40)/4=0.40
Waste Characteristic	(0.30+0.30+0.30+0.30)/4=0.30
Environment Pollution	(0.20+0.20+0.20+0.20)/4=0.20
Topographic	(0.10+0.10+0.10+0.10)/4=0.10

Source: own study, 2024

Weighted sum vector: Multiply the original matrix by the priority vector:

$$\text{Weighted Sum Vector} = \begin{bmatrix} 1\ , 1.33\ ,2\ ,4 \\ 0.75,1, 1.50,3 \\ 0.50, 0.67, 1, 2 \\ 0.25, 0.33, 0.50, 1 \end{bmatrix} [0.4,0.3,0.2,0.1] = [1.6,1.2,0.8,0.4]$$

Divide the weighted sum vector by the priority vector

$$\text{Ratio} = \left[\frac{1.6}{0.4}, \frac{1.2}{0.3}, \frac{0.8}{0.2}, \frac{0.4}{0.1}\right] = [4,4,4,4]$$

λmax = mean of ratios = 4

Calculate CI = $\frac{4-4}{4-1} = 0$

Calculate CR = $\frac{0}{0.9} = 0$

The Consistency Ratio (CR) is 0, indicating perfect consistency in the judgments.
To compute the weights for each sub-criterion (criteria level 2), we will distribute the weight of criteria level 1 among the sub-criteria proportionally to their relative importance.
Steps:

- Normalize the index values for each sub-criterion under a specific level 2 criterion.
- Multiply the normalized weights by the weight of the corresponding level 1 criterion to get the final weight for each sub-criterion (Fig. 5).

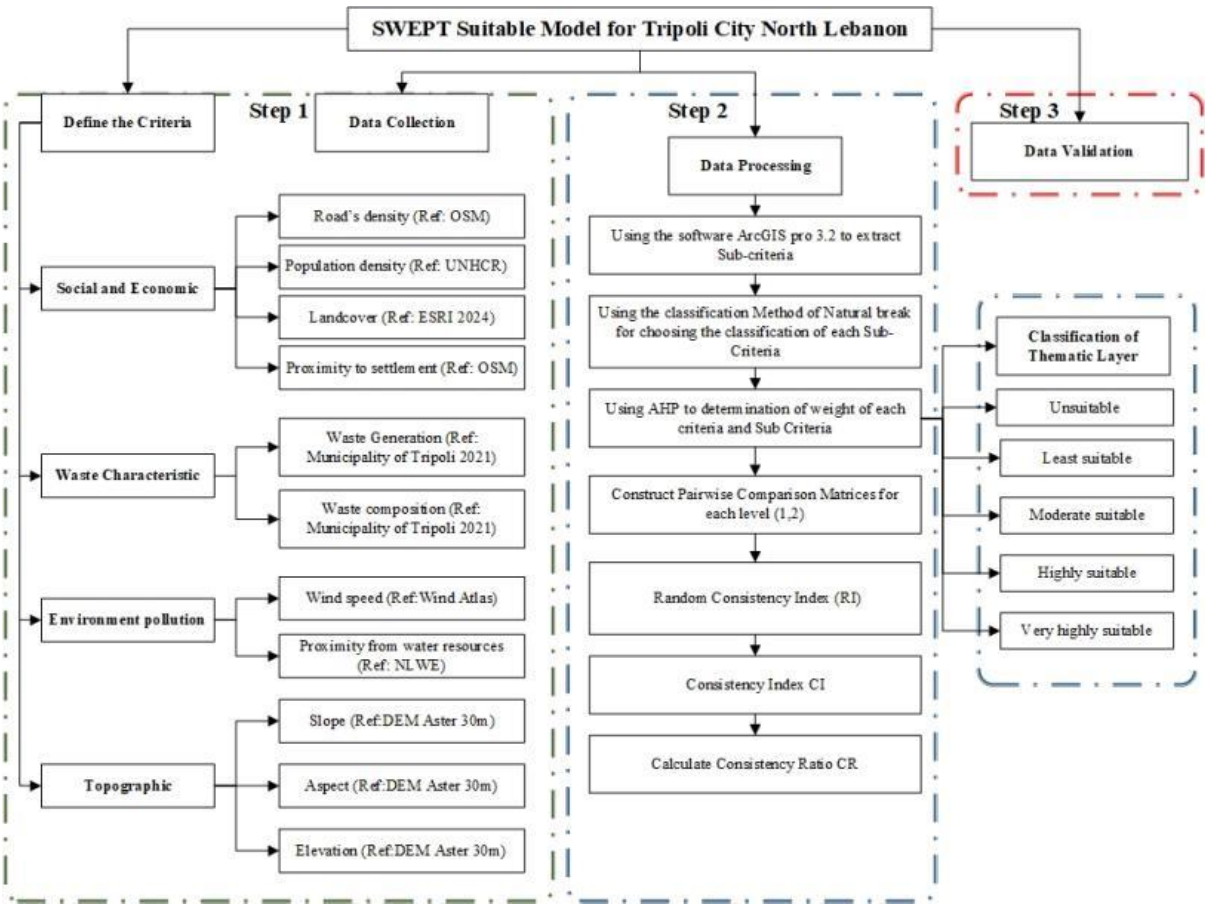


Fig. 5. The Steps to apply the SWEPT model
Source: own study, 2024

Results and discussion

The results of the SWEPT suitability model offer suitability map that highlights areas ranging from "Unsuitable" to "Very Highly Suitable" for waste management infrastructure sites. This approach not only ensures the sustainable utilization of land resources but also minimizes environmental impacts and aligns with socio-economic goals.

The result of SWEPT model divvied into 2 parts the first represent the analysis of each criterion (L1, L2) and after this the analysis of the suitability model result and the validation.

Social and economic:

- Roads Proximity: the proximity to roads directly impacts the efficiency and sustainability of the system. A spatial analysis of road proximity in the study area reveals a varied distribution across five classes, ranging from unsuitable to very high suitable road density. The southeastern part of the city is characterized by very low road density, covering an area of 6.65 km², which constitutes approximately 26.92% of the study area. In contrast, the central and coastal parts exhibit very high road density, with a value of 35.31 km², accounting for about 12.15% of the total area (Table 7, Fig. 6). Proximity to roads influences transportation costs, fuel consumption, and operational expenses, with areas of higher road density enabling smoother and faster waste collection, minimizing delays associated with difficult terrain (Asefa & Mindahun, 2019).

Table 7. The classification and weight of Road's density sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		index	Weight criteria L2	Area km²	% of Area
Social and Economic	0.4	Road's density km² 0.4	Unsuitable	0.0 – 8.83 km²	1	0.022	6.65	26.92
			Least suitable	8.84 – 17.66 km²	2	0.044	8.31	33.64
			Moderate suitable	17.67 – 26.49 km²	3	0.066	6.26	25.34
			Highly suitable	26.50 – 35.31 km²	5	0.111	3	12.15

Source: own study, 2024

This accessibility is critical for ensuring reliable waste management operations, reducing vehicle emissions, and achieving a balance between cost-effectiveness, operational efficiency, and environmental sustainability. The weight given to this sub-criterion was 0.4.

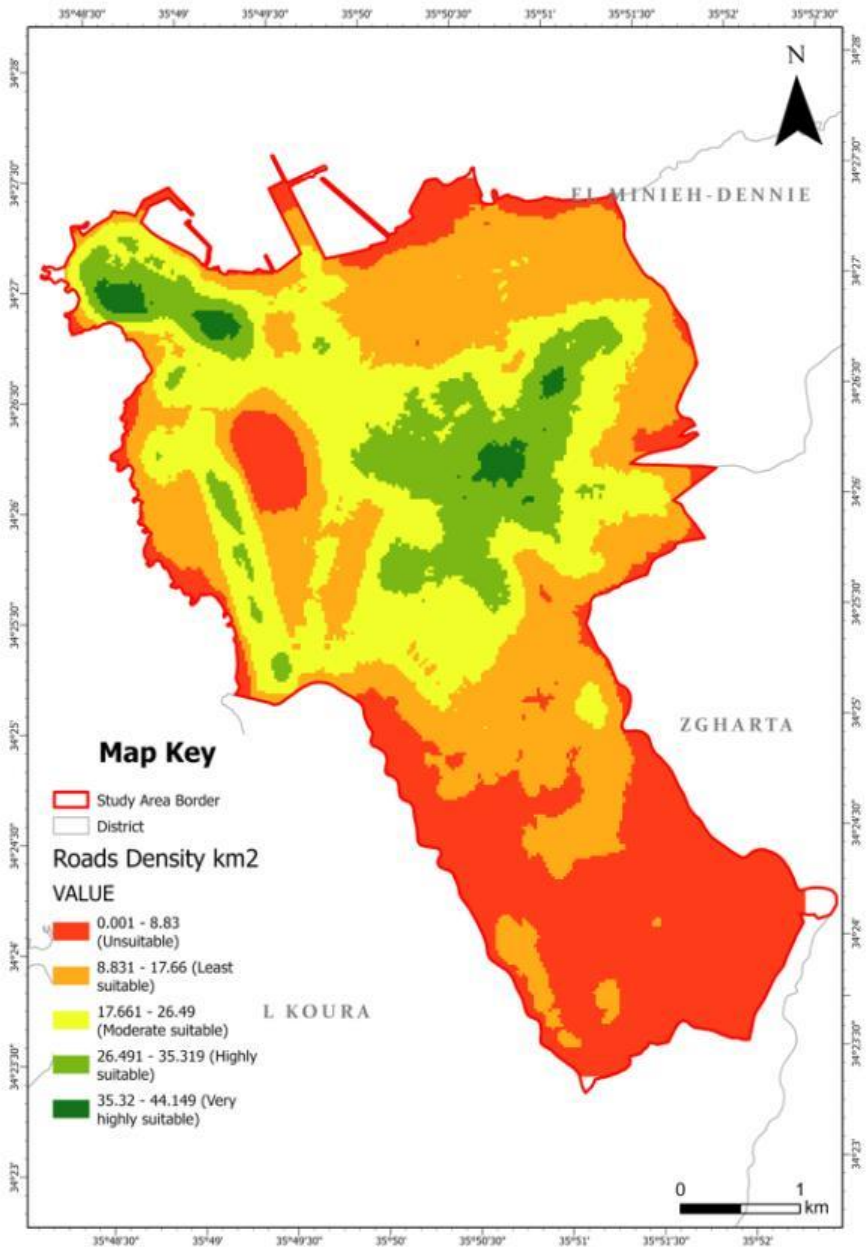


Fig. 6. Sub-criteria Road's density
Source: own study, 2024

- Population density: it affects the volume and complexity of waste generated. The analysis of population density shows that the southeastern part of the city is characterized by very low population density, with a value of 9195.88 inhabitants/km^2, covering approximately 85.02 % of the study area (Table 8, Fig. 7). low-density areas generate less waste but face higher transportation costs due to dispersed populations. In other hand, the central and coastal regions exhibit very high population density, with a value of 1620549.4 inhabitants/km^2, occupying about 2.71% of the total area.

Table 8. The classification and weight of population density sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		index	Weight criteria L2	Area km²	% of Area
Social and Economic	0.4	Population density Person/km² 0.3	Unsuitable	660220.30 – 1620549.4	1	0.016	0.67	2.71
			Least suitable	323204.82 –660220.29	2	0.033	0.83	3.36
			Moderate suitable	123346.11 – 323204.81	3	0.05	1.7	6.88
			Highly suitable	9195.88 – 123345.10	5	0.083	0.5	2.02
			Very highly suitable	144 – 9195.87	7	0.116	21	85.02

Source: own study, 2024

High-density areas generate larger volumes of waste, requiring more frequent collection and efficient management to prevent health hazards and environmental degradation. Conversely, incorporating population density into waste management strategies ensures tailored solutions that optimize resource allocation, enhance cost-effectiveness, and promote environmental sustainability for both urban and rural contexts (Matsunaga & Themelis, 2019).

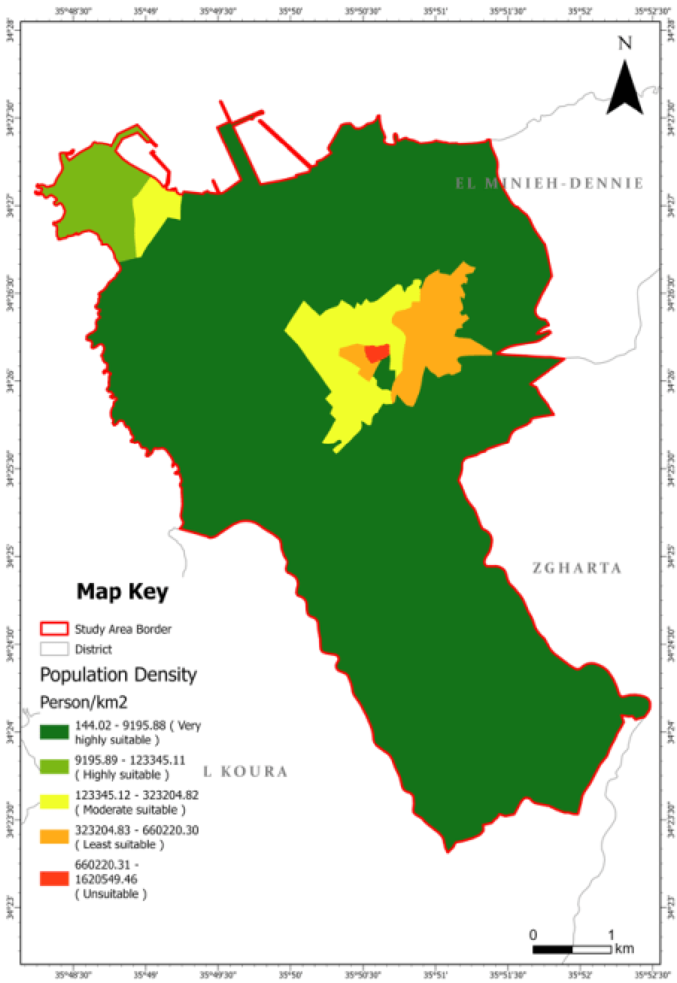


Fig. 7. Sub-criteria population density
Source: own study, 2024

- Landcover: it impacts the feasibility of waste treatment, storage, and disposal facilities. Tripoli has different types of land cover, built-up land occupied around 70.40% form the city's area, rangeland 11.74%, Bare ground 10.85%, determine the suitability of specific locations for waste management operations (Table 9, Fig. 8).

Table 9. The classification and weight of landcover sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		index	Weight criteria L2	Area km^2	% of Area
Social and Economic	0.4	Landcover 0.2	Unsuitable	Crops, water	1	0.011	1.09	4.41
			Least suitable	trees	2	0.022	0.64	2.59
			Moderate suitable	Built up area	3	0.033	17.39	70.40
			Highly suitable	Rangeland	5	0.055	2.9	11.74
			Very highly suitable	Bare ground	7	0.077	2.68	10.85

Source: own study, 2024

Moreover, land cover influences environmental risks, like water contamination. Understanding land cover aids in predicting the challenges of waste management logistics, such as accessibility and potential ecological impacts.

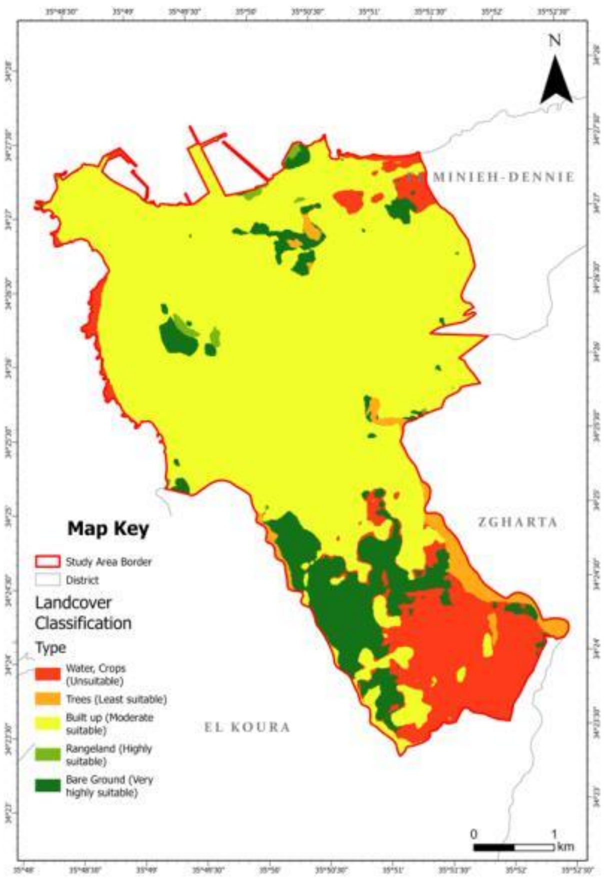


Fig. 8. Sub-criteria landcover
Source: own study, 2024

- Proximity to settlement: Proximity to settlements play an important role in minimize risks for example odors, noise, and potential health hazards. Maintaining an appropriate distance from residential areas helps mitigate concerns about air quality, waste visibility, and community objections. This approach strikes a balance between environmental protection, public health, and social acceptance while ensuring sites remain accessible for operational efficiency (Kator & Jakada, 2023). In the study area, the city center, which hosts the highest number of settlements, is classified as unsuitable for the construction of sorting and recycling facilities, covering approximately 22% of the total area. In other side, the southern part of the city, located over 2000 meters away from settlements, is classified as highly suitable for such facilities, encompassing 21.46% of the study area (Table 10, Fig. 9).

Table 10. The classification and weight of proximity to settlement sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		Index	Weight criteria L2	Area km²	% of Area
Social and Economic	0.4	Proximity to settlement m 0.1	Unsuitable	0 – 250	1	0.005	5.45	22.06
			Least suitable	250 – 500	2	0.011	6.51	26.36
			Moderate suitable	500 – 1000	3	0.016	4.69	18.99
			Highly suitable	1000 – 2000	5	0.027	2.75	11.13
			Very highly suitable	>2000	7	0.038	5.3	21.46

Source: own study, 2024

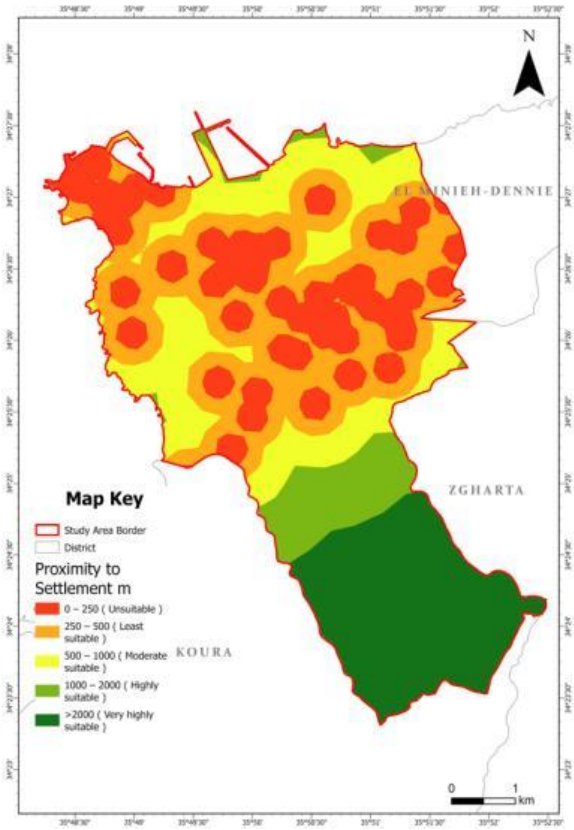


Fig. 9. Proximity to settlement
Source: own study, 2024

Waste characteristic:

Waste generation: and composition tow indicators to consider when developing solid waste management models. Understanding the types and quantities of waste generated in a given area is essential for effective planning and optimization of waste management systems. Waste generation refers to the amount of waste produced, which can vary widely based on factors like population size, economic activity, and lifestyle. In this study, waste generation was classified into five categories, ranging from unsuitable (10165 tons) to very highly suitable (225576.75 tons). Spatial analysis revealed that approximately 87.73% of the study area is classified as unsuitable for waste generation, while only 1.50% is considered very highly suitable (Table 11, Fig. 10).

Table 11. The classification and weight of waste generation sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		Index	Weight criteria L2	Area km²	% of Area
Waste charact e-ristic	0.3	Waste Generation t 0.65	Unsuitable	525 - 10165	1	0.036	21.67	87.73
			Least suitable	10165.1 - 52309	2	0.07	1.13	4.57
			Moderate suitable	52309.1 – 81460	3	0.108	0.8	3.24
			Highly suitable	81460.1 – 139089	5	0.180	0.73	2.96
			Very highly suitable	139089.1 – 225576.75	7	0.252	0.37	1.50

Source: own study, 2024

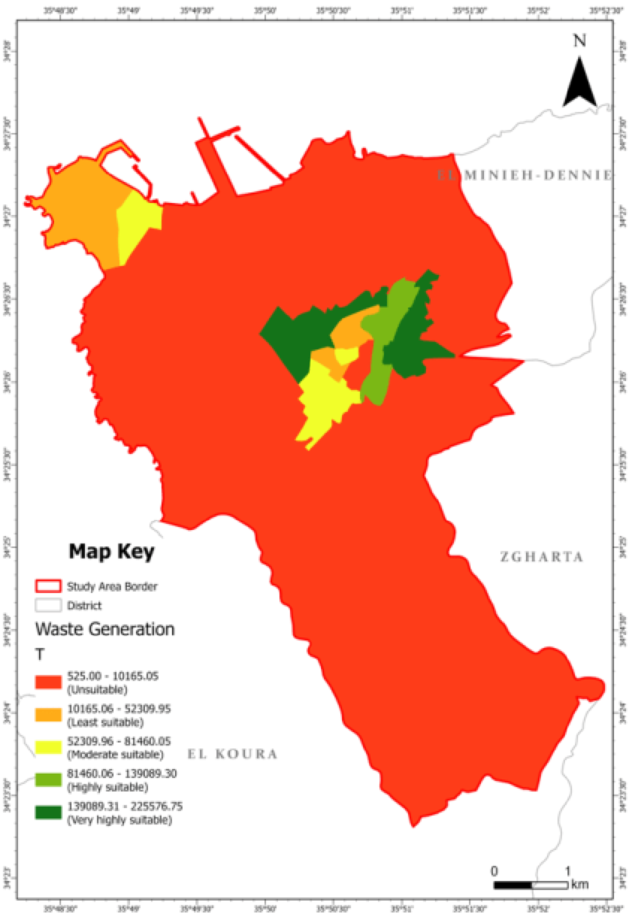


Fig. 10. Sub-criteria waste generation
Source: own study, 2024

Waste composition: focuses on the types of materials making up the waste, in the study area it is divided into 4 class (residual, reject, recyclable, organic). The characterization of waste helps in identifying which materials can be recycled or composted and which will require disposal in landfills or treatment facilities it is occupied 32.39% of the study area. This data is vital for effective decision-making and the selection of appropriate waste management technologies, as it allows for the estimation of recycling potential, the identification of disposal needs, and the planning for waste treatment and processing facilities (Table 12, Fig. 11).

Table 12. The classification and weight of waste composition sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		Index	Weight criteria L2	Area km²	% of Area
Waste characteristic	0.3	Waste composition 0.35	Unsuitable	Residual	1	0.020	16	64.78
			Least suitable	Reject	2	0.041	0.7	2.83
			Moderate suitable					
			Highly suitable	Recycle	5	0.102	6.9	27.94
			Very highly suitable	Organic	7	0.144	1.1	4.45

Source: own study, 2024

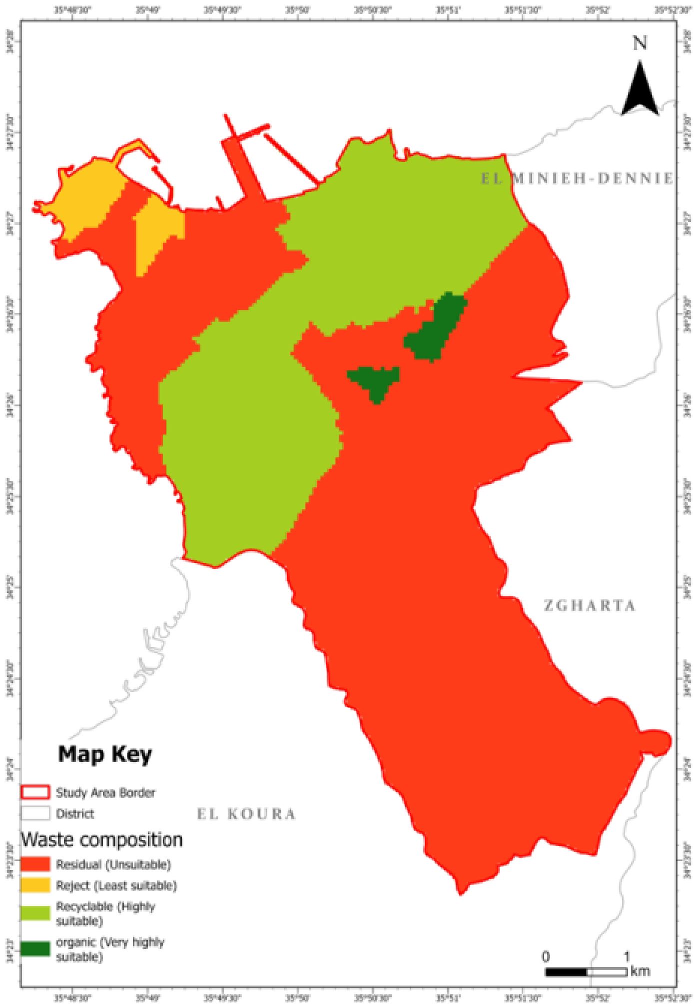


Fig. 11. Sub-criteria waste composition
Source: own study, 2024

Environnement pollution:

Wind speed: is important in determining the suitability of sites for waste management, particularly recyclable facilities. the analysis of wind speed value in the study area identifies that the southeastern part of the city is classified as very highly suitable and highly suitable for recyclable site development, with low wind speeds averaging around 1.882 m/s and 2.3 m/s. This zone covers approximately 49% of the study area and supports effective containment of odors and lightweight waste using basic strategies like fences or vegetation barriers. In other hand, the central and coastal regions, characterized by wind speeds of about 4 m/s, fall under the unsuitable category, occupying 6.28 % of the total area. In these high-wind zones, odors and waste dispersion pose greater challenges, requiring active management to prevent litter spread and minimize impact on surrounding areas (Table 13, Fig. 12).

Table 13. The classification and weight of wind speed sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		Index	Weight criteria L2	Area km²	% of Area
Environment pollution	0.2	Wind speed m/s 0.4	Unsuitable	3.435 – 4.404	1	0.022	1.55	6.28
			Least suitable	2.752 – 3.434	2	0.044	1.88	7.61
			Moderate suitable	2.315 – 2.751	3	0.066	9.15	37.04
			Highly suitable	1.823 – 2.314	5	0.111	10.34	41.86
			Very highly suitable	0.92 – 1.822	7	0.155	1.78	7.21

Source: own study, 2024

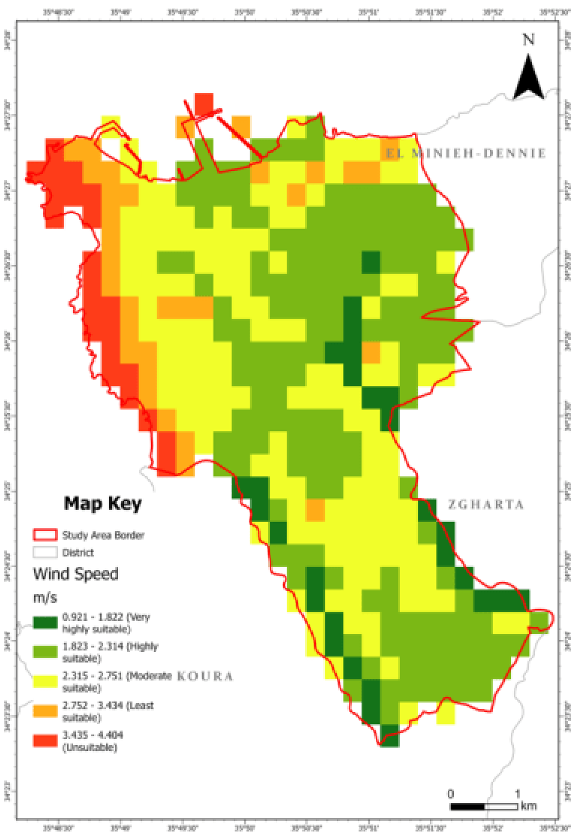


Fig. 12. Sub-criteria wind speed
Source: own study, 2024

Proximity from water resources: Sites located far more, as they significantly reduce the risk of leachate infiltration and contamination, provided proper waste management practices are implemented. The Spatial analysis reveals that the southeastern and northwestern parts of the city fall into this category, covering approximately 57% of the study area. In another part, the central region, with proximity values between 100 and 250 meters, is deemed unsuitable for waste site development. This zone occupies about 5% of the total area and poses higher risks of water pollution, requiring advanced engineering solutions such as impermeable barriers and leachate collection systems to mitigate contamination. Factoring proximity to water bodies into site selection ensures compliance with environmental regulations while minimizing potential impacts on water quality (Table 14, Fig. 13).

Table 14. The classification and weight of proximity from water resources sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		Index	Weight criteria L2	Area km^2	% of Area
Environm-ent pollution	0.2	Proximity from water resources m 0.6	Unsuitable	0 – 100	1	0.033	1.22	4.94
			Least suitable	101 – 250	2	0.06	1.76	7.13
			Moderate suitable	251 – 500	3	0.1	3.16	12.79
			Highly suitable	501 – 1000	5	0.166	4.46	18.06
			Very highly suitable	>1000	7	0.233	14.10	57.09

Source: own study, 2024

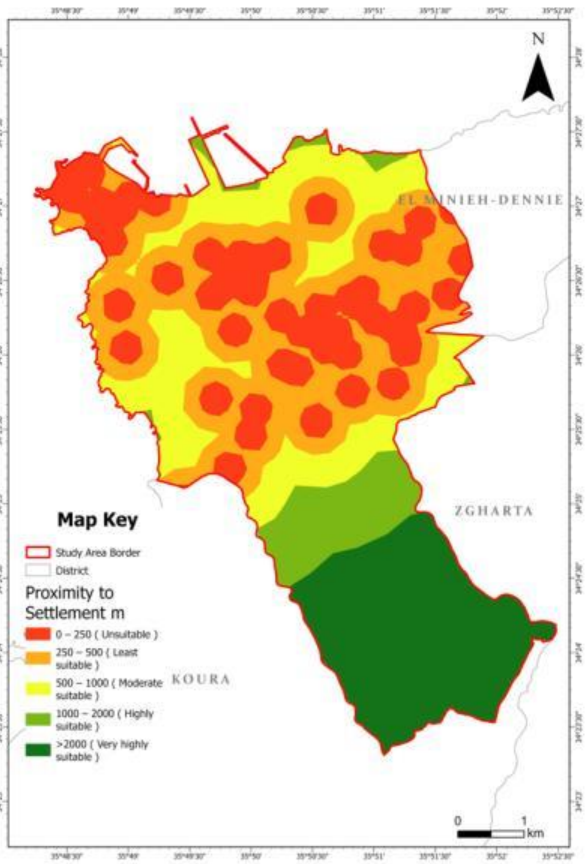


Fig. 13. Proximity from water resources
Source: own study, 2024

Topographic:

- Slope: Steep slopes 10.47 till 35.58 degree occupying around 3.40% from the study area can complicate drainage and leachate management, increasing the risk of contamination by allowing contaminated water to flow away from the site, potentially affecting nearby water sources. On such terrains, special measures, like leachate collection systems, become necessary to prevent environmental harm (Ouma & Tateishi, 2011). Additionally, steep slopes pose a higher risk of erosion, which can destabilize waste sites and lead to waste runoff during heavy rains. Furthermore, steep slopes can hinder operational efficiency by making access more difficult, requiring more infrastructure like roads for waste transportation and compacting. While flatter 0 till 5-degree land occupying 78% is generally preferred for ease of management and lower environmental risks, slopes can still be utilized effectively with the right engineering solutions. However, excessively steep sites are usually less suitable for waste management due to these operational and environmental challenges (Table 15, Fig. 14).

Table 15. The classification and weight of slope sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		Index	Weight criteria L2	Area km²	% of Area
Topogra-phic	0.1	Slope degree 0.35	Unsuitable	17.59 – 35.58	1	0.019	0.84	3.40
			Least suitable	10.47 – 17.58	2	0.038	1.48	5.99
			Moderate suitable	5.31 – 10.46	3	0.058	3.12	12.63
			Highly suitable	2.38 – 5.30	5	0.097	7.84	31.74
			Very highly suitable	0 – 2.37	7	0.136	11.42	46.23

Source: own study, 2024

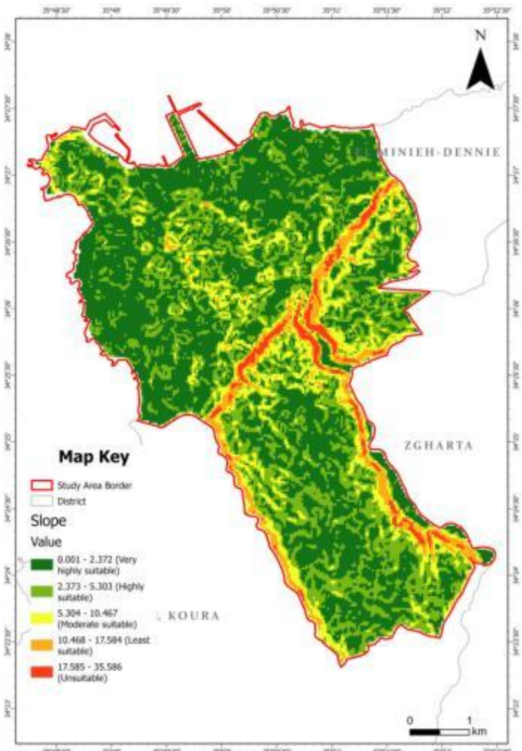


Fig. 14. Sub-criteria slope
Source: own study, 2024

- Aspect: The orientation of waste sites significantly influences waste drying, leachate production, and odor control. Southeast to Southwest slopes (135°–225°), which account for approximately 26% of the study area, are generally shielded from prevailing cold winds in most regions. These orientations provide balanced exposure to sunlight, which enhances waste drying, reduces leachate production, and minimizes odors. East- and West-facing slopes (90°–135° and 225°–270°), covering 21% of the study area, can also be effective. East-facing slopes benefit from morning sunlight, which accelerates drying processes, while West-facing slopes receive afternoon sunlight, which can aid waste evaporation depending on wind direction. Northeast-facing slopes (45°–90°), occupying 12% of the area, receive less direct sunlight, resulting in slower drying and decomposition of waste due to limited exposure. Northwest-facing slopes (270°–315°), which cover 16% of the area, are more exposed to stronger winds and prevailing wind directions, potentially increasing the spread of odors. Lastly, North-facing slopes (315°–45°), accounting for 23% of the area, receive the least sunlight. This leads to higher moisture retention, greater leachate production, and slower waste decomposition (Table 16, Fig.15).

Table 16:the classification and weight of Aspect sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		Index	Weight criteria L2	Area km²	% of Area
Topogra-phic	0.1	Aspect degree 0.35	Unsuitable	Flat, North	1	0.019	5.88	23.81
			Least suitable	Northwest	2	0.038	4	16.19
			Moderate suitable	Northeast	3	0.058	3.13	12.67
			Highly suitable	East, West	5	0.097	5.32	21.54
			Very highly suitable	Southeast to southwest	7	0.136	6.37	25.79

Source: own study, 2024

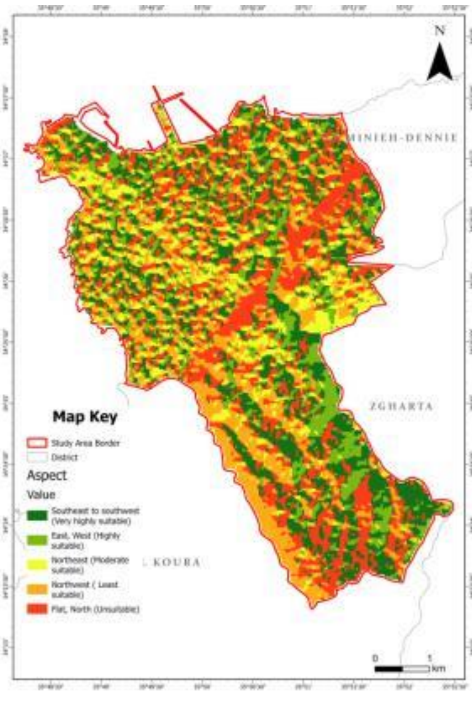


Fig. 15. Sub-criteria Aspect
Source: own study, 2024

- Elevation: Low-elevation areas (0–18 m) are typically flat, making them easier to develop and more accessible for waste transport and operational activities. These regions often benefit from better infrastructure, facilitating smoother logistics. They occupy approximately 40% of the study area. Slightly elevated areas (18–79 m) remain relatively accessible and manageable for construction, although they may involve minor additional costs. As elevation increases, the terrain becomes more challenging, leading to higher costs for waste transport and site preparation due to steeper slopes and reduced accessibility. This category covers about 12% of the study area. Areas with elevations between 110 and 140 m, which account for another 12% of the study area, are often associated with steeper terrain. This complicates waste transport and increases construction costs. Very high-elevation areas are more difficult to access, requiring substantial investments in infrastructure, while steep slopes add risks such as erosion and drainage challenges (Table 17, Fig. 16).

Table 17. Classification and weight of elevation sub-criteria

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		Index	Weight criteria L2	Area km²	% of Area
Topogra-phic	0.1	Elevation m 0.30	Unsuitable	102.1 - 140	1	0.016	3.03	12.27
			Least suitable	79.1 – 102	2	0.033	4.83	19.55
			Moderate suitable	49.1 - 79	3	0.05	3.82	15.47
			Highly suitable	19.1 - 49	5	0.083	3.07	12.43
			Very highly suitable	0 – 18	7	0.116	9.95	40.28

Source: own study, 2024

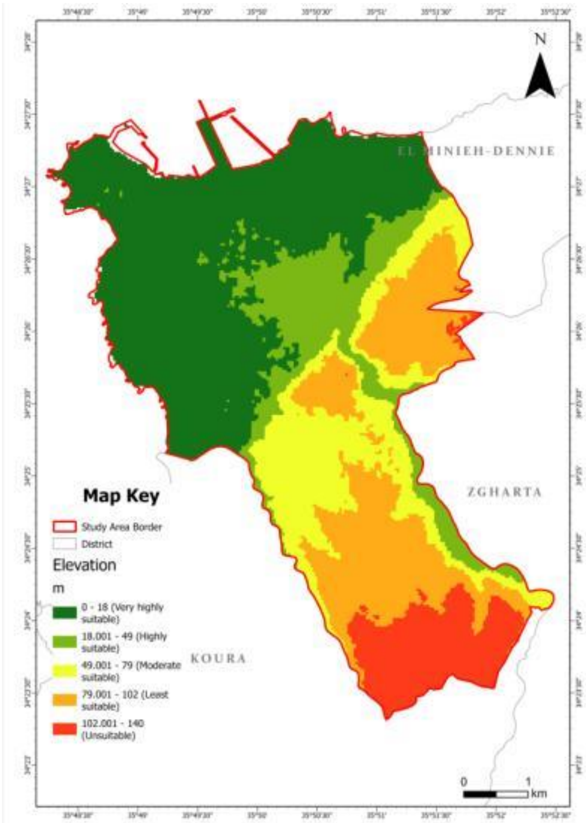


Fig. 16. Sub-criteria elevation
Source: own study, 2024

Table 18 presents suitability ranking index and weight of the criteria level 1&2 considered in this study.

Table 18. Suitability ranking index and weight of the criteria level 1&2 considered in study

Criteria Level 1	Weight criteria L1	Criteria level 2	Classification		index	Weight criteria L2	Area km^2	% of Area
Social and Economic	0.4	Road's density km^2 0.4	Unsuitable	0.0 – 8.83 km^2	1	0.022	6.65	26.92
			Least suitable	8.84 – 17.66 km^2	2	0.044	8.31	33.64
			Moderate suitable	17.67 – 26.49 km^2	3	0.066	6.26	25.34
			Highly suitable	26.50 – 35.31 km^2	5	0.111	3	12.15
			Very highly suitable	33.32 – 44.14 km^2	7	0.155	0.48	1.95
		Population density Person/km^2 0.3	Unsuitable	660220.30 – 1620549.4	1	0.016	0.67	2.71
			Least suitable	323204.82 –660220.29	2	0.033	0.83	3.36
			Moderate suitable	123346.11 – 323204.81	3	0.05	1.7	6.88
			Highly suitable	9195.88 – 123345.10	5	0.083	0.5	2.02
			Very highly suitable	144 – 9195.87	7	0.116	21	85.02
		Landcover 0.2	Unsuitable	Crops, water	1	0.011	1.09	4.41
			Least suitable	trees	2	0.022	0.64	2.59
			Moderate suitable	Built up area	3	0.033	17.39	70.40
			Highly suitable	Rangeland	5	0.055	2.9	11.74
			Very highly suitable	Bare ground	7	0.077	2.68	10.85
		Proximity to settlement m 0.1	Unsuitable	0 – 250	1	0.005	5.45	22.06
			Least suitable	250 – 500	2	0.011	6.51	26.36
			Moderate suitable	500 – 1000	3	0.016	4.69	18.99
			Highly suitable	1000 – 2000	5	0.027	2.75	11.13
			Very highly suitable	>2000	7	0.038	5.3	21.46
Waste characteri-stic	0.3	Waste Generation t 0.65	Unsuitable	525 - 10165	1	0.036	21.67	87.73
			Least suitable	10165.1 - 52309	2	0.07	1.13	4.57
			Moderate suitable	52309.1 – 81460	3	0.108	0.8	3.24
			Highly suitable	81460.1 – 139089	5	0.180	0.73	2.96
			Very highly suitable	139089.1 – 225576.75	7	0.252	0.37	1.50
		Waste composition 0.35	Unsuitable	Residual	1	0.020	16	64.78
			Least suitable	Reject	2	0.041	0.7	2.83
			Moderate suitable					
			Highly suitable	Recycle	5	0.102	6.9	27.94
			Very highly suitable	Organic	7	0.144	1.1	4.45
Environ-ment pollution	0.2	Wind speed m/s 0.4	Unsuitable	3.435 – 4.404	1	0.022	1.55	6.28
			Least suitable	2.752 – 3.434	2	0.044	1.88	7.61
			Moderate suitable	2.315 – 2.751	3	0.066	9.15	37.04
			Highly suitable	1.823 – 2.314	5	0.111	10.34	41.86
			Very highly suitable	0.92 – 1.822	7	0.155	1.78	7.21
		Proximity from water resources m 0.6	Unsuitable	0 – 100	1	0.033	1.22	4.94
			Least suitable	101 – 250	2	0.06	1.76	7.13
			Moderate suitable	251 – 500	3	0.1	3.16	12.79
			Highly suitable	501 – 1000	5	0.166	4.46	18.06
			Very highly suitable	>1000	7	0.233	14.10	57.09

Topograp-hic	0.1	Slope degree 0.35	Unsuitable	17.59 – 35.58	1	0.019	0.84	3.40
			Least suitable	10.47 – 17.58	2	0.038	1.48	5.99
			Moderate suitable	5.31 – 10.46	3	0.058	3.12	12.63
			Highly suitable	2.38 – 5.30	5	0.097	7.84	31.74
			Very highly suitable	0 – 2.37	7	0.136	11.42	46.23
		Aspect degree 0.35	Unsuitable	Flat, North	1	0.019	5.88	23.81
			Least suitable	Northwest	2	0.038	4	16.19
			Moderate suitable	Northeast	3	0.058	3.13	12.67
			Highly suitable	East, West	5	0.097	5.32	21.54
			Very highly suitable	Southeast to southwest	7	0.136	6.37	25.79
		Elevation m 0.30	Unsuitable	102.1 - 140	1	0.016	3.03	12.27
			Least suitable	79.1 – 102	2	0.033	4.83	19.55
			Moderate suitable	49.1 - 79	3	0.05	3.82	15.47
			Highly suitable	19.1 - 49	5	0.083	3.07	12.43
			Very highly suitable	0 – 18	7	0.116	9.95	40.28

Source: own study, 2024

Final output. The relative importance of different thematic layers and their corresponding classes were used to generate the map of potential zones of the recycling site. The rank and weight of different thematic layers is used to obtain the map of potential of recycling sites. The zonation map of the recycling site includes recycling zones, from unsuitable till very highly suitable (Table 19, Fig. 17).

Table 19. Final result of the application of SWEPT model

Scale	Index	Area km^2	%
Unsuitable	1	1.78	7.22
Least suitable	2	6.67	27
Moderate suitable	3	5.61	22.71
Highly suitable	5	8.78	35.54
Very highly suitable	7	1.86	7.53
Total		24.7	100

Source: own study, 2024

The zone with very highly suitable and highly suitable covering around 43% from the study area land and it is distributed in the central and the south of the city, this area categorize by lower population density that make the building for recycling sites more easier because we have the change to choose the sites from any empty area in another part in the old city of Tripoli where we have very high population density and a lot of economic activity at the north east direction the building of the sites might affected this activities also the area shows during the day a lot of traffic and people movement that elevate the cost of solid waste collection and elevate the consumption of fuel that affect also the environment. The moderate suitable area covering 22% from the study area and it is distributed in the north west of the city where we have the misery belt and the aleatory building. The unsuitable and least suitable area covering around 34% from the area it is distributed in the north east of the city and in the border where Abou Ali River pass, and a lot of drinking water wells was existed.

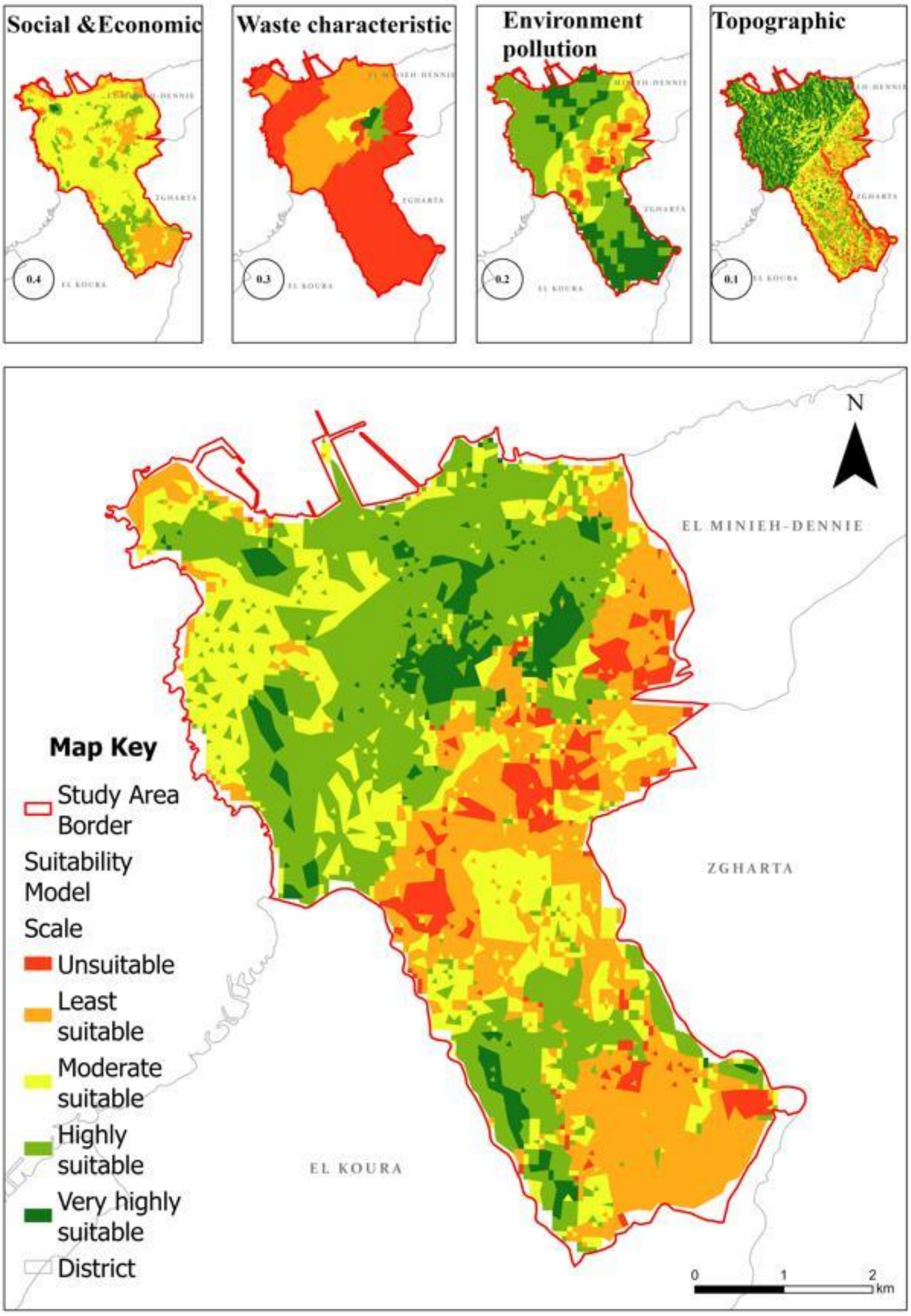


Fig. 17. SWEPT suitability model result
Source: own study, 2024

Model validation. For the validation of the model, a satellite image was used to gain an overview of the sites defined by the model and to identify potential areas for establishing recycling facilities for collected waste. These areas are located in the west and southwest of the city and are characterized by lower population density and higher road density. These factors facilitate the transportation of waste from the city to the sites, enabling sorting and recycling operations without adversely impacting the population or the environment (Fig. 18).

Fig. 18. The possible sites for recycling
Source: own study, 2024

The selected sites for building recycling facilities are as follows:

Site 1: El Tabbaneh. This site is near the El Tabbaneh area. The land is situated away from densely populated areas and has a well-developed road network. Its proximity to the sea provides an additional advantage; if the municipality decides to export waste, the Port of Tripoli can be accessed easily, reducing transportation costs and minimizing environmental pollution from fuel combustion. Additionally, this site can serve as a major collection hub for waste from various points established by the El Fayhaa Tafrouz Association in the areas of Tabbaneh, Zahiriyeh, and the old city. These areas are characterized by high population density and significant waste generation, particularly organic waste.

Site 2 and Site 3: Mina and Bhsas. These sites are strategically located near three important areas in Tripoli: El Mina, Moharram, and El Dam & Farez. Similar to the El Tabbaneh site, they have a dense road network, making them easily accessible from various parts of the city at a lower transportation cost. Their proximity to the sea facilitates access to the port. These sites can be utilized for processing two types of waste: (1) organic waste, particularly from the El Dam & Farez area, which hosts numerous restaurants and cafes generating substantial organic waste; and (2) industrial waste, especially from the Moharram area, an industrial hub with many mechanical workshops and crafts.

Site 4: Abou Samra. This site serves the Abou Samra area. It is well-connected to the road network and is located away from urbanized zones. This site can be utilized to collect recyclable waste from schools in the area, which number approximately 20. These schools are expected to generate a significant amount of recyclable waste.

After defining these four potential recycling sites, the El Fayhaa Tafrouz Association has placed waste collection containers in Tripoli. These four sites will be used to conduct a road matrix analysis to determine the distance required to reach each collection point. This analysis will assist decision-makers in developing a feasibility study for the project. For this purpose, the "ORS Tools" plugin in QGIS software will be employed. This plugin provides access to most functions of OpenRouteService.org, which is based on OpenStreetMap. The toolset includes routing, isochrones, and matrix calculations, which can be performed interactively in the map canvas or from point files within the processing framework. The output files include extensive attributes such as duration, length, and start/end locations.

The analysis of the road distance matrix between each proposed site and the waste collection points designated by the El Fayhaa Tafrouz Association revealed that the El Tabbaneh site was the closest to all collection points, with distances ranging from 1.18 km to 6.68 km. On the other hand, the Abou Samra site was characterized by the longest distances to all collection points, ranging from 1.92 km to 9.34 km. For the other two sites, Mina and Bahsas, the distances varied between 1.11 km and 8.16 km (Table 20).

Table 20. Road's Tabular Matrix analysis between the proposed sites and the collecting points

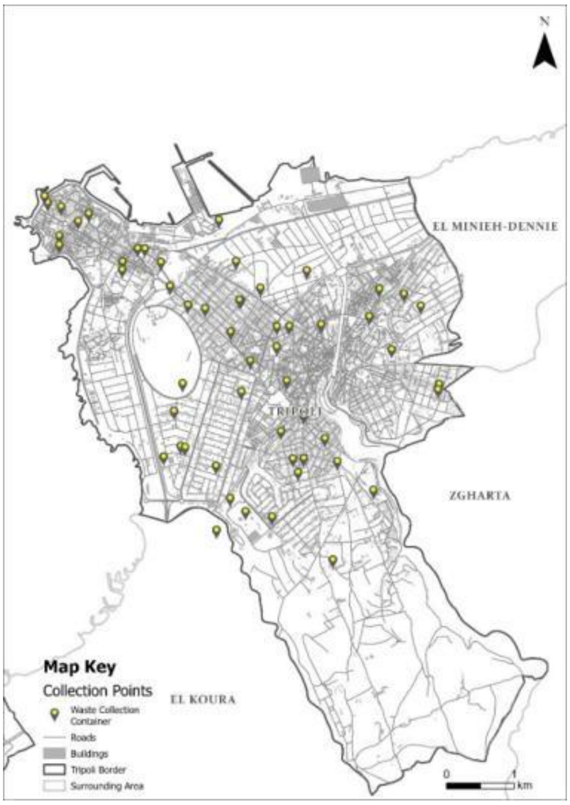
Orgin/Destination	Mina behind Mar Elias School	Mina Road: Al Salam Mosque parking	Al-Matin: Municipal Stadium Roundabout	Mina: Popular Swimming Pool Corniche	Al-Ma'arra: Next to Al-Ghandour Mosque	Al-Dam and Sorf: Behind Al-Mazloum Hospital	Al-Dam and Sorf: Behind the Engineers Syndica	Abi Samra: Near Haddadin Girls' High School	Abi Samra: Talat Al-Manar	Mina: Disabled Forum	Al-Dam and Sorf: Faculty of Health Garden	Al-Qobba: Faculty of Business Administration	Bab Al-Tabbaneh: Rawad Al-Tanmia Building	Jabal Mohsen: Abi Firas Al-Hamdani School	Tripoli Port	Bab Al-Raml-Al-Azm Center	Lebanese University-Faculty of Engineering	Rashid Karami Exhibition Parking
Tabbaneh	5.44	4.22	1.99	6.36	3.80	2.88	4.07	4.63	5.31	4.49	3.87	3.47	1.95	2.64	2.72	3.22	5.35	3.65
Mina Site	3.14	3.11	4.15	2.61	3.38	5.07	4.14	5.08	5.06	2.33	3.77	8.16	6.65	7.34	3.79	5.56	4.38	4.50
Bhsas Site	5.62	4.11	3.60	5.50	3.89	2.66	1.73	2.67	2.65	4.46	1.36	6.71	5.19	5.88	6.39	3.15	1.96	2.09
Abou Samra	9.29	7.06	6.56	9.16	6.84	5.61	6.48	2.75	3.07	8.13	4.89	5.78	8.15	8.84	9.34	6.11	5.19	6.70

Orgin/Destination	Mina: Port Said Street	Abi Samra: Saadoun Square	Tripoli: Al-Nour Square	Tripoli: Al-Ma'arra-Spinneys Supermarket	Tripoli: Al-Rifa-Al-Rabieh	Tripoli: Al-Tall Square	Tripoli: Al-Zahrieh-Evangelical School	Tripoli-University City	Tripoli: Mina Road opposite Abu Sobhi	Tripoli: Mina Road - opposite pain d'or	Mina: Mina Roundabout - opposite TEC	Tripoli: Azmi Nadim Al-Jisr intersection	Rawdat Al-Faihaa School French: Exhibition	Rawdat Al-Faihaa School English: Exhibition	Rawdat Al-Faihaa School: Al-Ma'tani	Al-Azm School	Lebanese University, Faculty of Arts	Lebanese University, Faculty of BA
Tabbaneh	4.65	3.54	2.53	5.18	3.10	2.34	1.93	4.86	2.92	3.35	3.67	2.43	4.23	4.17	2.59	1.18	2.82	3.43
Mina Site	2.77	5.32	5.03	3.53	7.80	5.29	6.25	4.61	3.95	3.68	2.83	4.48	3.72	3.66	4.37	5.88	7.52	8.13
Bhsas Site	4.62	2.91	2.62	1.11	6.34	2.87	3.83	2.19	3.01	3.44	3.57	3.44	1.30	1.25	4.20	4.02	6.07	6.68
Abou Samra	8.29	3.34	5.57	5.86	9.30	5.83	6.79	3.67	5.97	6.39	7.24	6.39	6.05	6.00	7.16	6.97	9.02	8.40

Orgin/Destination	Social Services Center	Al-Iman School: Abi Samra	Al-Rahma Medical Complex	Adnan Al-Jisr Secondary School	Modern Education School	Andre Nahhas Secondary School	Mar Elias School	Antonine School	Al-Nahda Official School for Girls	Al-Namouthaj School for Boys	Al-Tahdhibiyya School for Girls	Al-Qubba Secondary School	Al-Salah Official School	Princess Nasab School	Al-Islah Islamic Secondary School	School Victory - Adnan Darwish	Saba Zureiq School	Farah Anton School
Tabbaneh	4.47	4.71	6.68	4.73	5.16	5.34	5.11	4.95	3.76	2.06	5.23	1.75	3.90	4.62	5.71	4.12	4.33	2.00
Mina Site	4.92	5.16	6.43	4.48	5.61	2.43	3.18	3.02	2.68	5.70	2.86	6.45	5.41	5.07	6.16	2.52	2.17	5.97
Bhsas Site	2.51	2.75	4.02	2.07	3.19	5.31	5.08	4.92	3.80	3.29	4.72	4.99	3.00	2.66	3.75	4.03	4.30	3.56
Abou Samra	3.38	2.84	1.92	3.89	2.77	8.98	8.75	8.59	7.47	6.24	8.39	7.95	3.08	2.94	2.98	7.69	7.97	6.51

Source: own study, 2024

Based on this analysis, decision-makers can use the matrix to determine the number of waste collection points assigned to each site based on their respective distance values. However, other factors should also be considered, such as the distribution of waste collection points. As shown on the map (Fig. 19), certain areas in the south and west of the city are not adequately covered by existing waste collection points, indicating a need to add more points to ensure comprehensive coverage.



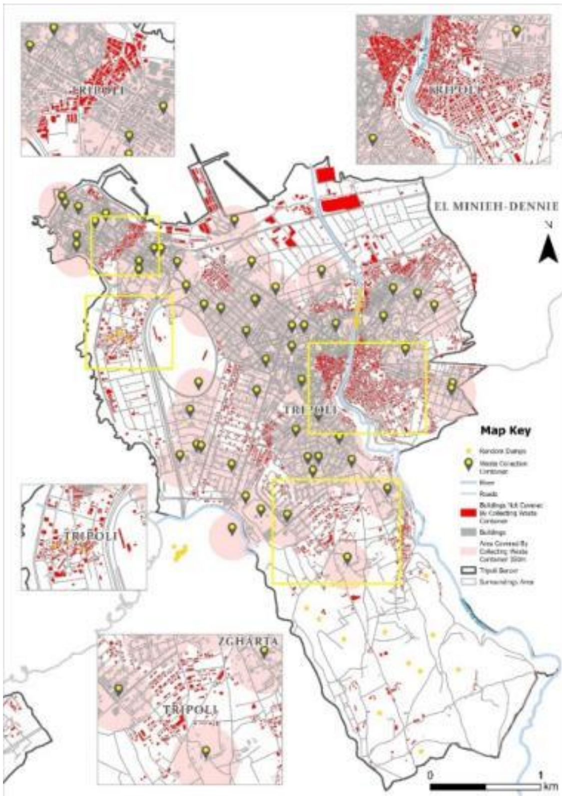


Fig. 19. The distribution of collection waste container and area not covered by 350m (the number of buildings not have a waste container near to 350 m is 5634 buildings)
Source: own study, 2024; Al Fayhaa Tafrouz Association, 2022

Conclusion

The SWEPT model proves to be an effective spatial decision-support tool for identifying suitable sites for waste management infrastructure in urban environments. By integrating a multi-criteria approach social and economic factors, waste characteristics, environmental pollution, and topographic feature the model delivers a comprehensive analysis that supports sustainable urban planning. The final suitability map highlighted four optimal locations for waste collection points, strategically positioned near residential zones for improved accessibility and service efficiency.

The model's outputs were further validated through a road network matrix analysis, ensuring that the proposed sites are not only environmentally and socially viable but also logistically accessible. The detailed sub-criteria weighting and area distribution provide clear insight into land suitability, demonstrating that most of the selected zones fall within "Highly Suitable" to "Very Highly Suitable" categories, especially in relation to elevation, slope, proximity to water resources, and low wind speed.

These findings affirm the model's reliability in guiding local authorities toward informed and sustainable waste management decisions in Tripoli, serving as a replicable framework for other urban regions facing similar environmental and infrastructural challenges.

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