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Insights for Landfill Site Selection Using GIS: A Case Study in the Tanjero River Basin, Kurdistan Region, Iraq

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Citation: Othman, A.A.; Obaid, A.K.; Al-Manmi, D.A.M.; Pirouei, M.; Salar, S.G.; Liesenberg, V.; Al-Maamar, A.F.; Shihab, A.T.; Al-Saady, Y.I.; Al-Attar, Z.T. Insights for Landfill Site Selection Using GIS: A Case Study in the Tanjero River Basin, Kurdistan Region, Iraq. *Sustainability* **2021**, *13*, 12602. https://doi.org/10.3390/su132212602

Academic Editor: Luca Salvati

Received: 20 October 2021
Accepted: 12 November 2021
Published: 15 November 2021

Abstract: The increasing world population and the growing quantity of solid waste have become a challenging problem facing governments and policy makers because of the scarcity of suitable sites for new landfills and the negative perception of these sites by the people. This study aims to evaluate the performance of different Multi-Criteria Decision-Analysis (MCDA) approaches using remote sensing and Geographic Information System (GIS) data for identifying suitable landfill sites (LFSs). We evaluated the methodologies used by various investigators and selected appropriate ones as suitable sites for Municipal Solid Waste (MSW) landfill in the Tanjero River Basin (TRB) in the Iraqi Kurdistan region. We applied Boolean Overlay (BO), Weighted Sum Method (WSM), Weighted Product Method (WPM), Analytic Hierarchy Process (AHP), and Technique for Order Performance by Similarity to an Ideal Solution (TOPSIS) to allow combined use of 15 thematic layers as predictive factors (PFs). In this study, we applied the Topographic Position Index (TPI) for the first time to select MSW LFSs. Almost all methods showed reliable results and we identified eight suitable sites situated in the western part of the TRB having total area of ~18.35 km^2. The best accuracy was achieved using the AHP approach. This paper emphasizes that the approach of the used method is useful for selecting LFSs in other areas, which are located in similar environments.

Keywords: GIS; landfill; MSW; WSM; WPM; AHP; TOPSIS; MCDA

1. Introduction

Waste refers to any substance requiring disposal, which includes unusable materials, worthless, defective and unwanted items. The site of the disposal of waste materials is called landfill. This site involves either collecting, sorting, processing, or recycling of wastes [1–3]. Population has a direct relationship with waste production possesses, which contribute to environmental deterioration [4]. Therefore, for each city, solid waste management is a crucial environmental challenge [5].

Growing world population along with ever-increasing global urbanization has emerged as a major environmental concern in the 21st century. A direct correlation exists between population and waste quantity. Urbanites are generating more waste than ever before, as 56.2% of world population was residing in cities in 2020. It is estimated that by the middle of this century about 70% of people in the world will live in cities [6]. In addition, proximity to manufacturing facilities and industrial plants in urban areas contribute to a large amount of waste representing a mix of ordinary garbage, termed Municipal Solid Waste (MSW). Electronic or e-waste, medical/health care waste (that became a serious issue during the COVID-19 pandemic) further adds to the problem of managing the increasing volume of waste [6]. Despite the technological advances in converting waste to energy (WtE) and increasing recycling rates, landfills, as yet, are the predominant way of MSW disposal: For example, in 2019, China accounted for 45% landfill sites, where China produced more than 242 million tons of MSW [7]. Yet, suitable sites for locating new landfills are getting scarce due to various geological, engineering, legal, and societal constraints. This paper is an attempt to provide a sound basis for landfill site (LFS) selection by using the most widely used criteria and subjecting them to rigorous Geographic Information System (GIS) methodologies. The article is intended to serve as a screening tool to select candidate sites that meet the known criteria to be followed by detailed site investigations. This approach would entail significant cost savings because field studies would be focused on only these promising (candidate) sites that have met the criteria, thereby substantially reducing time and expenses involved in site investigations.

Dozens of studies have been done to solve the waste disposal problem. Part of these studies applied various Multi-Criteria Decision-Analysis (MCDA) models to select suitable location for municipal solid waste (MSW) disposal sites [8]. The most common MCDA models are: fuzzy Analytic Hierarchy Process (AHP) [9], Technique for Order Performance by Similarity to an Ideal Solution (TOPSIS) [10], Weighted Sum Method (WSM) [11], and Weighted Product Method (WPM) [12]. All these methods have been widely used in the field of MSW management [13–18].

A simple review of 27 high quality articles (Table 1) selected from Scopus database and published recently, dealing with landfilling of MSW shows that more than 80% of these papers used slope gradient, distance to the villages, the towns and the cities, and distance to the road as important predictive factors (PFs) for LFS selection. More than 73% of these articles applied distance to surface water bodies as a predictive factor (PF), while >50% used lithology, soil, land use and land cover (LULC), groundwater depth, and distance to the airport as PFs. Elevation, distance to the active fault, distance to the powerline and distance to the agricultural lands were used less frequently (between 25% and 50%).

In this study, we identified suitable sites for LFS using GIS methods and prepared maps showing suitable LFSs for the Tanjero River Basin (TRB) in the Iraqi Kurdistan region. The aims of this paper were twofold: (1) to compare and evaluate the efficacy of five MCDA methods (Boolean Overlay (BO), WSM, WPM, AHP and TOPSIS); and (2) to find the most suitable site(s) for LFS in the TRB. For this purpose, we used 15 layers to assess methods' performance. These thematic layers involve (1) lithology, (2) soil, (3) land cover, (4) distance to road, (5) slope gradient, (6) Topographic Position Index (TPI), (7) groundwater depth, (8) distance to the towns and the cities, (9) distance to the village, (10) distance to the active fault, (11) distance to the powerline, (12) distance to the surface water bodies, (13) distance to the agricultural lands, (14) elevation, and (15) distance to the springs.

Part of the TRB has been studied by [19]. They used MCDA methods to identify seven suitable LFSs. However, we considered the entire TRB to give full evaluation of the whole basin. In addition, we expanded the factors used by [19] via adding some important factors, such as distance to springs, distance to active faults, distance to agricultural lands, and Topographic Position Index (TPI). To the best of our knowledge, the TPI as a PF for LFS selection is being used first time in this study.

Table 1. Significant factors used for LFS selection in recent articles.

Reference	Slope (%)	Residential Areas (m)	Roads (m)	Surface Waters (m)	Lithology	LULC	Groundwater Depth (m)	Village	Airport and Religious (Protected Area)	Soil	Topography	Fault (m)	Powerlines (m)	Spring	Historical sites	Orchards and Agricultural Lands (m)	Aspect	Railways	Oil and Gas Pipelines	Industries (m)	Floodway (m)	Rainfall	Mine	Erosion	Sensitive Ecosystems	Population/km−2	Wind	Temperature	Drainage Density	Geomorphology
[2]	*	*	*	*	*	*	*	*		*				*		*	*					*					*	*		
[3]	*	*	*	*	*	*	*	*	*		*	*		*				*												
[19]	*	*	*	*	*	*	*	*	*	*	*		*						*											
[20]	*	*	*	*	*		*	*	*			*		*								*								
[21]	*	*	*	*	*	*	*	*			*	*	*	*									*							
[22]	*	*	*	*	*	*		*		*	*	*	*	*	*	*				*										
[23]	*	*	*	*	*			*				*																		
[24]	*	*	*	*		*	*	*		*	*		*		*			*	*											
[25]	*	*	*		*		*	*	*	*				*		*	*		*		*									
[26]	*			*	*	*					*																			
[27]	*	*	*	*	*	*		*			*																*			
[28]	*	*	*		*					*							*													
[29]	*	*		*	*	*		*	*																	*				
[30]	*	*	*	*		*	*	*		*															*					
[31]	*	*	*	*	*	*	*	*	*	*		*												*						
[32]	*	*	*		*		*		*				*			*	*													
[33]	*	*	*	*		*		*	*	*	*		*																	
[34]				*	*	*			*	*	*	*			*			*		*			*							
[35]	*	*	*		*		*	*	*		*																			
[36]	*	*	*	*			*		*				*		*			*												
[37]	*	*	*	*	*	*			*	*	*	*		*	*		*	*					*	*						
[38]		*	*	*	*	*	*	*			*	*					*													
[39]	*				*	*	*			*		*														*			*	*

Table 1. *Cont.*

Reference	Slope (%)	Residential Areas (m)	Roads (m)	Surface Waters (m)	Lithology	LULC	Groundwater Depth (m)	Village	Airport and Religious (Protected Area)	Soil	Topography	Fault (m)	Powerlines (m)	Spring	Historical sites	Orchards and Agricultural Lands (m)	Aspect	Railways	Oil and Gas Pipelines	Industries (m)	Floodway (m)	Rainfall	Mine	Erosion	Sensitive Ecosystems	Population/km−2	Wind	Temperature	Drainage Density	Geomorphology
[40]	*	*	*	*		*	*	*	*			*	*		*															
[41]						*	*			*	*			*		*														
[42]	*	*	*	*			*					*	*			*				*	*									
[43]	*	*	*	*		*	*	*		*	*		*		*	*		*	*											
Average rate	85.2	85.2	81.5	74.1	66.7	66.7	63	63	51.9	51.9	48.2	40.7	33.3	29.6	25.9	25.9	22.2	22.2	14.8	11.1	7.4	7.4	7.4	7.4	7.4	7.4	7.4	3.7	3.7	3.7

* Predictive factor is existed.

2. Methodology

2.1. Study Area

The Tanjero River flows northwest, west, and southeast of Sulaymaniyah governorates in the Kurdistan Region between latitude 34°53′34′′ N and 35°47′12′′ N, and between longitude 45°11′16′′ E and 46°12′7′′ E. The TRB covers ~3317 km^2 and encompasses the Sulaymaniyah and Halabja cities and Syed Sadiq town, in addition to Darbandikhan Lake, which is one of the important and main water storages in Iraq (Figure 1). In the last 20 years, the maximum water-level of the Darbandikhan Reservoir was recorded on 27 April 2016 (485.06 m above sea level (m a.s.l.), while the minimum water-level was recorded on 18 October 2015 (459.49 m a.s.l.) [44]. Tanjero River and its tributaries feed the Darbandikhan Reservoir, which is located in the southwest part of the basin.

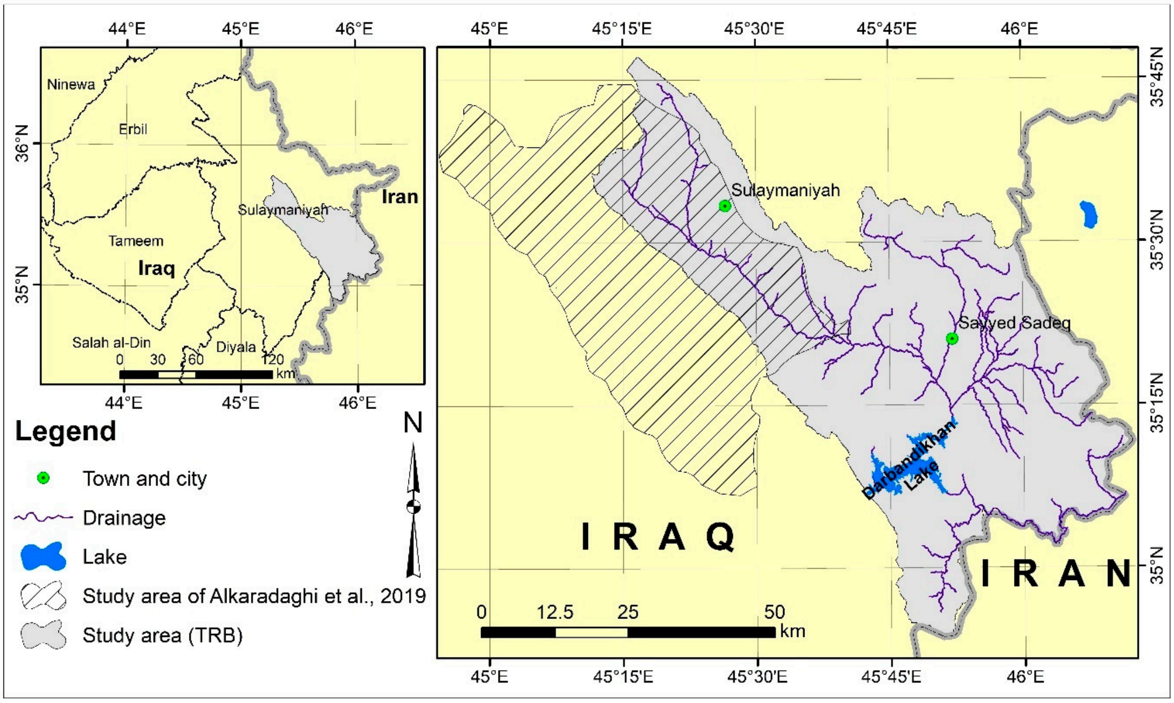

Figure 1. Location map of the Tanjero River Basin [19].

The quantity of MSW generation in Sulaymaniyah City has been increasing rapidly concomitantly with the population's increase, underscoring the need of reliable studies to select suitable LFSs for MSW. According to Iraqi government documents, the population of three major cities, Sulaymaniyah, Halabja and Syed Sadiq on 1 July 2018, was 676,500, 109,000 and 61,600, respectively [45]. However, taking into account residents in over 650 villages within the TRB, the total population will be more than a million. [46] estimated the total volume required to accommodate all municipal waste streams to be generated over the 20 years at 39 million m^3 with per capita waste producing >1.4 kg per day. This volume needs at least two landfills [46]. Currently, all MSW is being deposited at the Tanjero site, which is located 4.5 km south of Sulaymaniyah City [47]. Despite co-mingled waste being deposited in an open dump that lacks engineered barriers, leakage and landfill gas management system, Sulaymaniyah government has done its best to make the randomly selected site environmentally safe, despite the lack of financial resources. Nonetheless, the Tanjero dump is unsafe, causing pollution of air, water, and land, and threatening people's health. The problems get worse due to lack of adequate oversight, weakness in the management, monitoring at the site, and weak enforcement of the regulations by responsible parties [48]. It is not only the common urban waste, but wastes from oil refineries, cement plants, along with medical waste from local hospitals are all disposed at the same place [49]. The deficiencies of the existing Tanjero dump and the need of environmentally safe LFS are the major drivers of this article to determine suitable sites for new LFS. In addition, the GIS and MCDM methods have not been applied in the larger part of the basin, with the exception of [19] which dealt with the northeast part of the basin.

2.2. Material

GIS is a powerful approach due to its capability for processing and analyzing vast data from different sources [1]. The Synthetic Aperture Radar (SAR) was used to identify water bodies, since large areas in the vicinity of the Darbandikhan Reservoir are covered by cloud. We processed one C-band scene of Sentinel 1A/Ground Range Detected High (GRDH) data with instrument mode type of this data, which is the Interferometric Wide Swath (IW). It has 10 m resolution and Descending orbit pass. This scene was acquired on 27 April 2016 (maximum water-level). Due to frequent cloud coverage on the region before and after 27 April 2016, microwave data were used to penetrate cloud cover. As a first step, we extracted the calibrated backscatter coefficient (σ0), then, converted the linear data to log scale (dB) data. The dB data were corrected by applying the Range-Dobbler terrain correction. The maximum water body of the reservoir was determined by thresholding the corrected dB, where the water body has dB ≤ -20.

We mosaiced three scenes of Digital Elevation Model (DEM)-Shuttle Radar Topography Mission (SRTM)-with resolution of 1 arc-second (~30 m). The elevation factor is represented by the DEM, which is also used to extract the slope gradient and the TPI.

SAR data were processed using Sentinel Application Platform (SNAP) software [50]. GIS operations (slope, TPI, distance maps, inverse distance weighted interpolation, and base map), as well as the preparation of final maps, were done using ArcGIS10 [51]. Statistical operations were performed using R-based scripts.

3. Predictive Factors

A several of appropriate factors must be taken into account to select the most suitable LFSs. Table 1 shows the 27 reviewed high-quality articles published recently [2,3,20–43]. We depend on these articles to select the PFs dealing with landfilling. Fourteen PFs were selected (Table 2; factors #1–5 and #7–15), which were applied >30% in the literature, and the rest factors were excluded (Table 1). We used the TPI as a PF (Table 2; factor no. 6) to select MSW landfill sites (LFSs) for the first time.

Table 2. Factors relations towards the LFS selection.

No	Factor	Relationship Type	Type of Data	Relation Intensity
1	Lithology	No relation	Discrete	Strong
2	Soil	No relation	Discrete	Weak
3	LULC	No relation	Discrete	Weak
4	Distance to road	No relation	Discrete	Weak
5	Slope (°)	No relation	Continuous	Weak
6	TPI	No relation	Discrete	Very weak
7	Groundwater depth (m)	Direct	Continuous	Strong
8	Distance to towns and cities (m)	Direct	Continuous	Strong
9	Distance to village (m)	Direct	Continuous	Strong
10	Distance to active fault (m)	Direct	Continuous	Moderate
11	Distance to Powerline (m)	Direct	Continuous	Weak
12	Distance to surface water bodies (m)	Direct	Continuous	Very strong
13	Distance to agricultural lands (m)	Direct	Continuous	Weak
14	Elevation	No relation	Continuous	Weak
15	Distance to springs	Direct	Continuous	Very weak

The PFs used to select the LFSs can be categorized as: hydrologic geologic, topographic, socio-economic and land use factors [20]. We selected fifteen PFs as thematic layers (Table 2).

The pixel of the layers were resized to 30 m spatial resolution. Two raster formats were used for the PFs (continuous and discrete; Table 2). We converted the continuous factors to discrete factors by selecting multi threshold values based on our knowledge and background of the study area. The numbers and boundaries of categories can affect the results of the MCDA methods [52]. We classified each continuous PF into five main groups, which are: most suitable, suitable, moderately suitable, less suitable, and not suitable. The classes in the discrete PFs are assigned to have the same five groups (i.e., most suitable, suitable, moderately suitable, less suitable, and not suitable). The weights of the five main groups are 1, 3, 5, 7, and 9, where the not suitable is 1 and the most suitable is 9.

3.1. Geological Factors

Geological factors significantly influence the seepage rate and flow direction of the leakage. Therefore, low permeability geological units were selected to mitigate the contamination risk resulting from the leakage [20]. According to [53], the study area is located within the Unstable Shelf (i.e., Imbricated Zone (IZ), and the High Folded Zone (HFZ)) and the Zagros Suture Zone (ZSZ) of the Zagros orogenic belt. This belt extends approximately 2000 km long, and trends in NW-SE direction from southern Iran through Iraq to SE Turkey [54–59].

We used the following three geological factors, which are lithological units, distance to active faults, and soil types. (1) Lithological units were obtained by scanning, georeferencing, and digitizing 1:250,000 scale geological quadrangle map of Sulaymaniyah [60] and Khanaqin [61]. The compiled map of the study area includes 21 lithological units (Figure 2A). The ZSZ consists of five units, which consist of limestone, shale, radiolarian cherts, conglomerates, and basalt, ranging in age from Triassic to Late Cretaceous. The Unstable Shelf (USh) includes 11 units. These units mainly include limestone, besides minor amount of dolomite, marl, claystone, shale, conglomerate, siltstones, sandstones, gypsum, and bitumen, were deposited during the Triassic and the Middle Miocene periods. The ZSZ and USh are overlain by five types of Quaternary sediments. The Quaternary sediments include alluvial fans, depression fill, slope debris, and flood plains deposits.

(2) Distance to active faults, where faults are potential pathways for fluid migration and could also be seismically active. Highly faulted areas are not suitable for landfill siting and vice versa [1]; the LFS should be located far from the active faults [62]. We obtained the active faults by digitizing the two series of 1:250,000 scale above mentioned geological maps [60,61]. The TRB includes 148 fault segments. Eight of them are normal faults, while the rest are thrust faults (Figure 2B). The total length of faults is ~161.5 km but most of them are <2 km in length. The major directions of the faults are NNW-SSE and WNW-ESE (Figure 3A). The distance to the faults reaches 34.35 km. Several studies recommended that the landfill could not be located within 500 m of active faults [3,38,63,64].

(3) Soil types were extracted from the Harmonized World Soil Database (HWSD) [65], which consist of a 1 km raster image. The LFSs should be located in areas of low permeability soil [66] to prevent water entering the landfill from carrying dissolved polluted materials, causing serious contamination of groundwater system. Three types of soil are occurred in the TRB: leptosols, vertisols, and calcisols (Figure 2C). The leptosols (thin soil with predominantly high infiltration rate) and calcisols (thick soil with predominantly moderately infiltration rate) are loamy soil, while the vertisols is thick light clay soil with predominantly low infiltration rate [67,68] (Figure 3B).

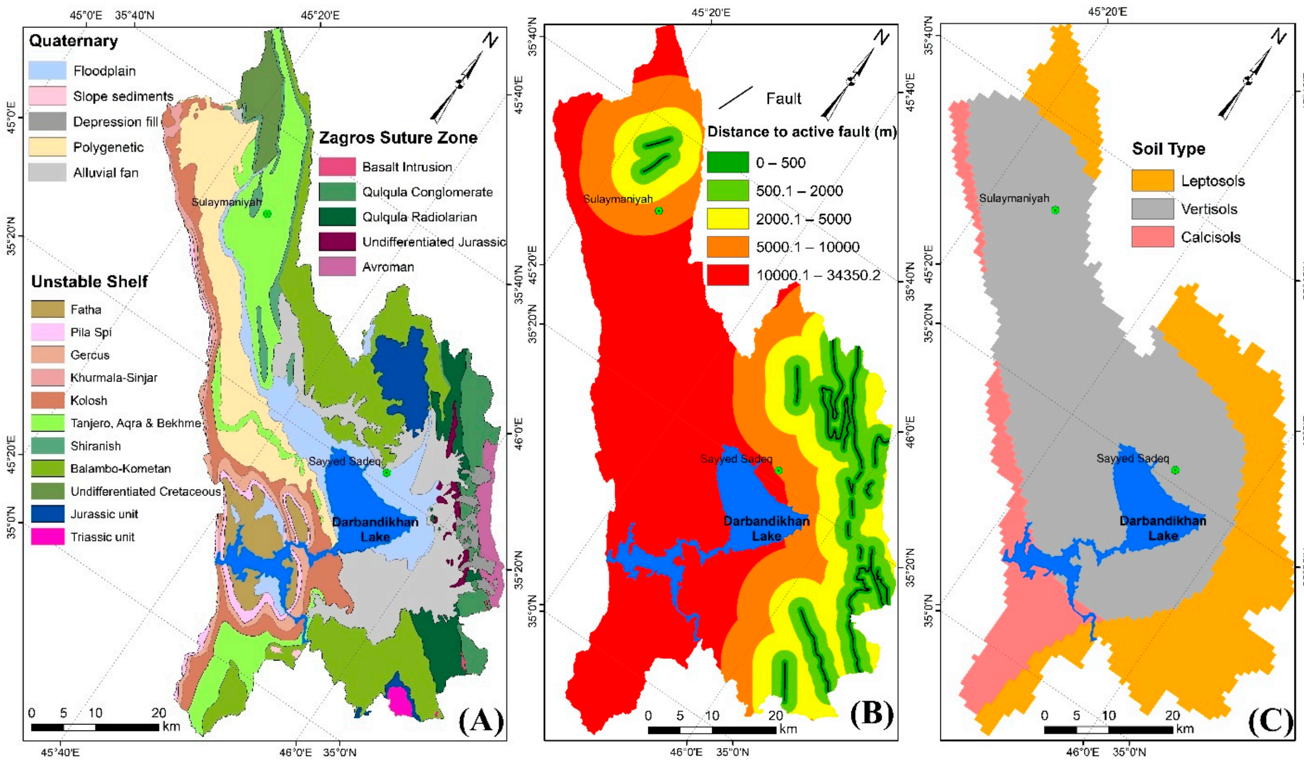

Figure 2. Maps of MSW landfill factors: (**A**) lithological units [60,61]; (**B**) distance to faults; (**C**) soil types [65].

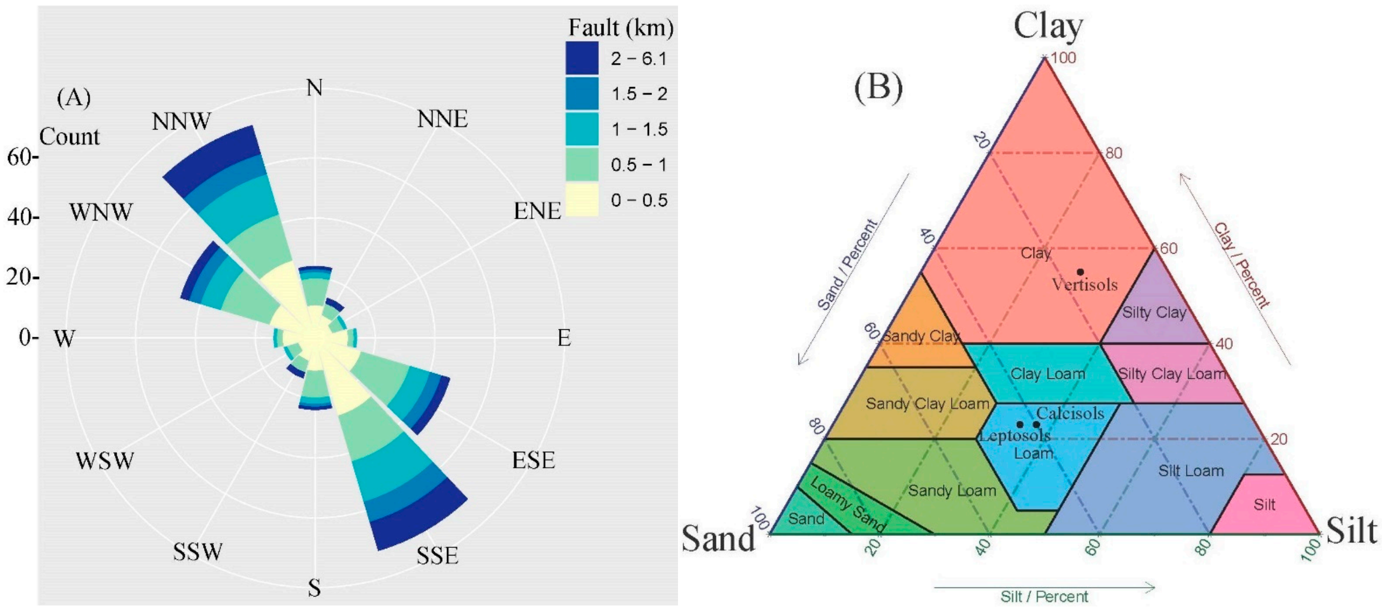

Figure 3. (**A**) Rose diagram of active faults, and (**B**) soil textural classification [69] of soil types occurring in the Tanjero River Basin.

3.2. Topographic (Morphological) Factors

We used three topographic factors, which are elevation, slope gradient, and Topographic Position Index (TPI).

(1) Elevation factor: high elevation lands are most suitable for LFSs than the low elevation lands in terms of flooding potential [70]. But the drawback is high cost of MSW transportation in the high lands due to high runoff erosion, unstable slopes cuts for roads, all requiring frequent maintenance [71]. In addition, the high lands maybe represent

groundwater recharge zones [72]. The range of elevation in TRB is between 423 and 2615 m (Figure 4A). The highest suitability rank is assigned to moderate elevation lands (Table 3).

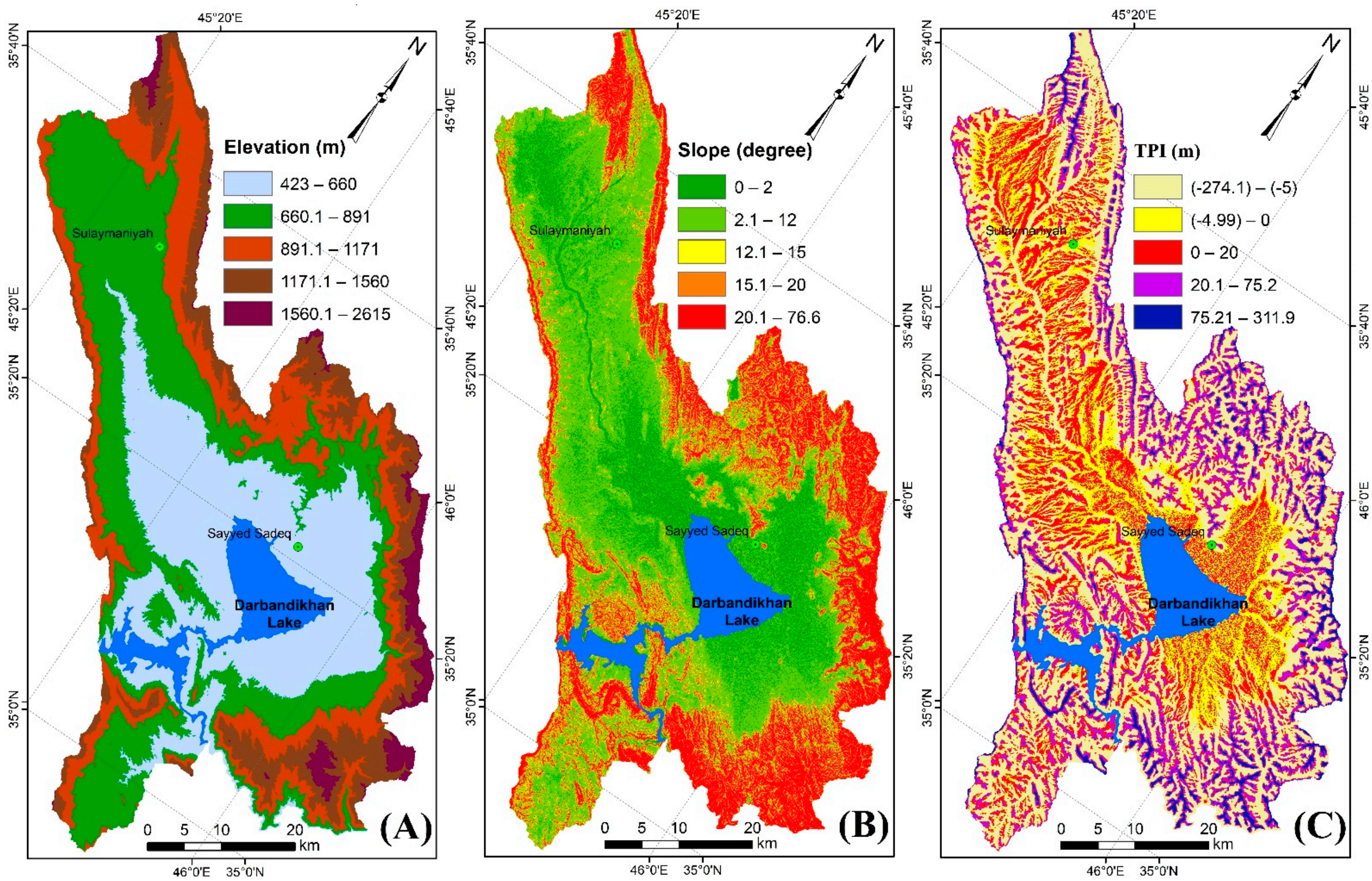

Figure 4. Maps of the landfill factors: (**A**) Elevation, (**B**) Slope gradient, and (**C**) Topographic Position Index (TPI).

(2) Slope gradient data were extracted from DEM. The significance of the slope gradient is in evaluating the stability of slopes and landslide potential and road failures for construction and operation of landfill. Lands having gentle slopes are more suitable than lands with a steep slope for landfill siting [71]. The pixels with slope > 20° are unsuitable for MSW landfill [8]. Slope gradients in TRB range between flat and 76.6° (Figure 4B). We determined the slope gradient pixels in the 2°–12° [3,73] and 12.1°–15° range to be most suitable for landfill location. The horizontal, steep, and very steep slopes areas are moderate, less suitable, and not suitable sites, respectively (Table 3).

(3) TPI, as a PF for landfill, is calculated using Equation (1) [74], which calculates the fluctuation between the pixel elevation and the surrounded pixels average elevation using a pre-specific kernel-matrix (M).

$$TPI = E_c - \left(\frac{1}{nM} \sum_{i \in m} E_i\right) \quad (1)$$

There is a relationship between the slope curvature and water infiltration to the groundwater where water infiltration increases with the concave up and decreases with the concave down. However, the slope curvature function considers a few pixels around the central point of the used Kernel (three by three pixels) [75], which exhibits higher errors in terms of the occurrence of local depressions. Thus, some areas seem to be locally suitable for landfilling while, in fact, it is unsuitable for large-scale LFS selection. To overcome this challenge and propose more accurate sites to be used as landfilling, we proposed the use of TPI, which considers larger area and avoid local curvature.

Table 3. Decision rules for used PFs and finalized weights of factors acquired from WSM, SPM, AHP models.

Lithology	**Suitability**	**Rank**	**Normalized Weight**	**Groundwater Depth (m)**	**Suitability**	**Rank**	**Normalized Weight**
Lake	Not suitable	1	0.00317	0–13	Not suitable	1	0.003623
Floodplain	Not suitable	1	0.00317	13.1–30	Less suitable	3	0.01087
Slope sediments	Not suitable	1	0.00317	30.1–48	Moderately suitable	5	0.018116
Depression fill	Not suitable	1	0.00317	48.1–80	Suitable	7	0.025362
Polygenetic sediments	Not suitable	1	0.00317	80.1–159.38	Most suitable	9	0.032609
Alluvial fan	Not suitable	1	0.00317	**Distance to Towns and Cities (m)**	**Suitability**	**Rank**	**Normalized Weight**
Avroman limestone	Less suitable	3	0.009511	0–1000	Not suitable	1	0.00317
Undifferentiated Jurassic	Moderately suitable	5	0.015851	1000.1–5000	Less suitable	3	0.009511
Qulqula radiolarian	Not suitable	1	0.00317	5000.1–10,000	Moderately suitable	5	0.015851
Qulqula conglomerate	Less suitable	3	0.009511	10,000.1–20,000	Suitable	7	0.022192
Basalt intrusion	Most suitable	9	0.028533	20,000.1–14,725.7	Most suitable	9	0.028533
Fatha	Most suitable	9	0.028533	**Distance to Village (m)**	**Suitability**	**Rank**	**Normalized Weight**
Pila Spi	Less suitable	3	0.009511	0–1000	Not suitable	1	0.00317
Gercus	Most suitable	9	0.028533	1000.1–2000	Less suitable	3	0.009511
Khurmala-Sinjar	Less suitable	3	0.009511	2000.1–3000	Moderately suitable	5	0.015851
Kolosh	Suitable	7	0.022192	3000.1–4000	Suitable	7	0.022192
Tanjero, Aqra and Bekhme	Less suitable	3	0.009511	4000.1–5768.3	Most suitable	9	0.028533
Shiranish	Suitable	7	0.022192	**Distance to Active Fault (m)**	**Suitability**	**Rank**	**Normalized Weight**
Balambo-Kometan	Less suitable	3	0.009511	0–500	Not suitable	1	0.002264
Undifferentiated Cretaceous	Less suitable	3	0.009511	50.1–2000	Less suitable	3	0.006793
Jurassic	Less Suitable	3	0.009511	2000.1–5000	Moderately suitable	5	0.011322
Triassic	Less suitable	3	0.009511	5000.1–10,000	Suitable	7	0.015851
Soil	**Suitability**	**Rank**	**Normalized Weight**	10,000.1–34,350.2	Most suitable	9	0.02038
Leptosols	Less suitable	3	0.004076	**Distance to Powerline (m)**	**Suitability**	**Rank**	**Normalized Weight**
Vertisols	Suitable	7	0.009511	0–300	Not suitable	1	0.001359
Calcisols	Moderately suitable	5	0.006793	300.1–5000	Less suitable	3	0.004076

Table 3. *Cont.*

Lithology	Suitability	Rank	Normalized Weight	Groundwater Depth (m)	Suitability	Rank	Normalized Weight
LULC	**Suitability**	**Rank**	**Normalized Weight**	5000.1–10,000	Moderately suitable	5	0.006793
Water bodies	Not suitable	1	0.001812	10,000.1–20,000	Suitable	7	0.009511
Urban and built-up land	Not suitable	1	0.001812	20000.1–40,864.9	Most suitable	9	0.012228
Vegetated land	Less suitable	3	0.005435	**Distance to Surface Water Bodies (m)**	**Suitability**	**Rank**	**Normalized Weight**
Harvested land	Less suitable	3	0.005435	0–500	Not suitable	1	0.004076
Cultivated land	Less suitable	3	0.005435	500.1–5000	Less suitable	3	0.012228
Carbonate rocks	Suitable	7	0.012681	5000.1–10,000	Moderately suitable	5	0.02038
Clastics rocks	Most suitable	9	0.016304	10,000.1–30,000	Suitable	7	0.028533
Burn land	Moderately suitable	5	0.009058	30,000.1–59,722.4	Most suitable	9	0.036685
Distance to Road (m)	**Suitability**	**Rank**	**Normalized Weight**	**Distance to Agricultural Lands (m)**	**Suitability**	**Rank**	**Normalized Weight**
0–1000	Not suitable	1	0.001359	0–300	Not suitable	1	0.000906
1000.1 –5000	Most suitable	9	0.012228	300.1–600	Less suitable	3	0.002717
5000.1–10000	Suitable	7	0.009511	600.1–1200	Moderately suitable	5	0.004529
10000.1–20000	Moderately suitable	5	0.006793	1200.1–2500	Suitable	7	0.006341
>10000	Less suitable	3	0.004076	2500.1–4183.4	Most suitable	9	0.008152
Slope (°)	**Suitability**	**Rank**	**Normalized Weight**	**Elevation (m)**	**Suitability**	**Rank**	**Normalized Weight**
>20	Not suitable	1	0.001359	1560.1–2615	Not suitable	1	0.000906
15.1–20	Less suitable	3	0.004076	1171.1–1560	Moderately suitable	5	0.004529
12.1–15	Suitable	7	0.009511	891.1–1171	Suitable	7	0.006341
2–12	Most suitable	9	0.012228	660.1–891	Most Suitable	9	0.008152
0–2	Moderately suitable	5	0.006793	423–660	Less suitable	3	0.002717
TPI (m)	**Suitability**	**Rank**	**Normalized Weight**	**Distance to Springs**	**Suitability**	**Rank**	**Normalized Weight**
(−274.1)–(−5)	Not suitable	1	0.000453	0–500	Not suitable	1	0.004076
(−4.99)–0	Less suitable	3	0.001359	500.1–1000	Less suitable	3	0.012228
0–20	Moderately suitable	5	0.002264	1000.1–5000	Moderately suitable	5	0.02038
20.1–75.2	Most suitable	9	0.004076	5000.1–15,000	Suitable	7	0.028533
75.21–311.9	Suitable	7	0.00317	15,000.1–28,909.1	Most suitable	9	0.036685

Negative TPI means that the central pixel has elevation lower than the average surroundings pixels, while positive TPI means that the central pixel has an elevation higher than the average surroundings pixels [52]. We computed TPI for the study area in ArcGIS software using a moving window of 50 pixels [52]. The range of TPI in TRB is between −274.1 and 311.9 m (Figure 4C). The highest rank of suitability is assigned to the areas within moderate topographic positions (i.e., 20.1–75.2 m; Table 3).

3.3. Hydrogeological and Hydrological Factors

MSW landfills are a significant cause of groundwater pollution, so the depth to groundwater surface at a LFS is a very critical. The depth to groundwater in the study area is more than 10 m, which is suitable for landfilling [76]. The available data of 243 boreholes obtained from Sulaymaniyah Groundwater Directorate is used [77] to generate depth to groundwater map, the depth ranges between 0 to 159.4 m (Figure 5A). In addition, data of surface water and springs (which will be mentioned below) as a zero-groundwater level are used. The groundwater in TRB classified as a fresh water [78], the TDS content varies between <500 to 900 mg/L. Previous studies, such as [19,79–84], have revealed that the ground and surface waters in the area are polluted with many organic and inorganic contaminants, and the problem is getting worse due to the prevailing draught condition in the area.

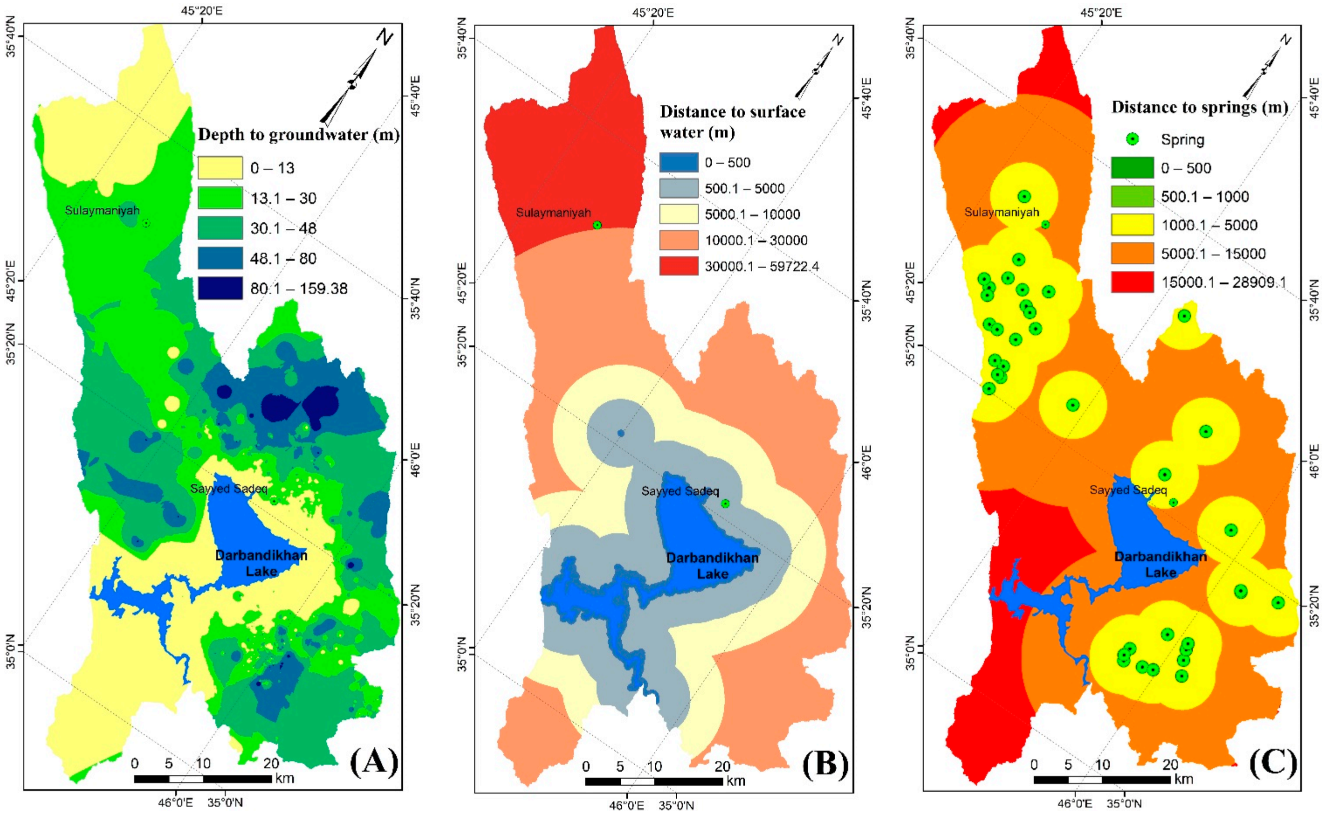

Figure 5. Maps of MSW landfill factors: (**A**) depth to groundwater, (**B**) distance to surface water, and (**C**) distance to springs.

Water bodies and surrounding areas cannot be used as sites for MSW LFS due to high potential of direct contamination. [3,38,85] stated that 500 m distance around the surface water is a fair buffer, while [76] thought that the buffer zone should be >5000 m. Both the Darbandikhan Lake (with an area of 66.86 km^2) and the Tanjero River, located in the TRB, contain potable water with the TDS varying from 271 to 412 ppm, respectively [86]. The distance to water bodies is up to 59.7 km (Figure 5B), with water level of 485.06 m a.s.l.; [87]).

Distance to springs is produced using 37 springs acquired from Sulaymaniyah Surface Water Directorate [87]. According to [3,88], a minimum buffer of 300 m must be used around springs to determine MSW LFSs, while [70,89] stated that a MSW landfill should not be sited <500 m. The distance to springs areas in TRB reaches 28.9 km (Figure 5C).

3.4. Socio-Economic Factors

This factor is included to evaluate potential impacts from landfill siting and to minimize economic and aesthetic deterioration. We used four socio-economic factors, which are: distance to towns and cities (m), distance to villages (m), distance to roads (m), and distance to powerlines (m). The MSW landfill must be located at a reasonable distance far from villages, towns, and cities due to health and public concerns [66]. [3,88] reported appropriate distance of the landfill from villages, towns, and cities to be >1000 m. In the TRB, the farthest pixel from cities and towns is ~14.7 km away (Figure 6A), while the farthest pixel from villages is ~5.7 km (Figure 6B).

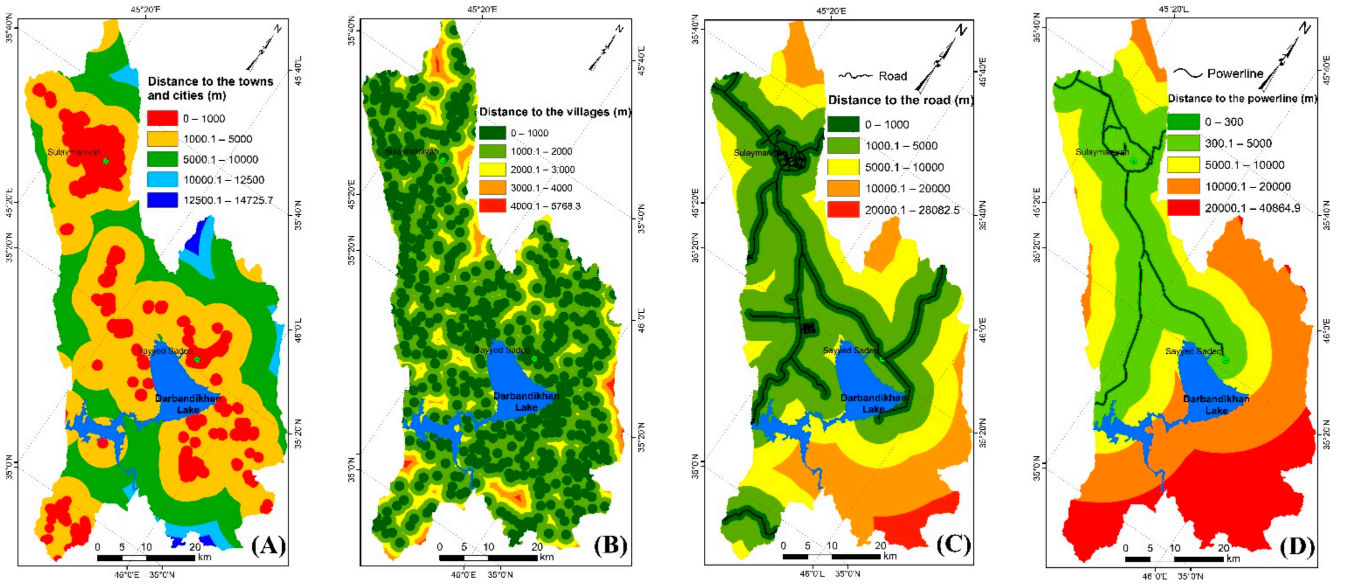

Figure 6. Maps of MSW landfill factors: (**A**) distance to the towns and cities, (**B**) distance to the village, (**C**) distance to the road, and (**D**) distance to the powerline.

LFSs should be selected to be at a justifiable distance away from the roads to avoid negative aesthetic impacts [24]. The researcher used different values as minimum distance to the road (m) for selecting the MSW landfill. They proposed 300 m [30,38], 500 m [36,37], and 1000 m [66,90] as buffer distance from MSW landfill. Accordingly, we eliminated sites within 1000 m of major roads. We believe that it will provide adequate buffer zone for noise, dust, etc. created from movement of garbage trucks, without requiring construction of new access roads for transportation and collection of solid wastes [22,27]. The farthest point from roads in the TRB is ~28.1 km (Figure 6C).

As [36] suggested, we used a buffer 300 m (4) distance to the powerline (m) as non-suitable areas for MSW LFSs. The farthest area from powerlines in the TRB is ~41 km (Figure 6D). The shapefiles of the settlements, the roads and powerlines were obtained from [91]. We calculated the Euclidean distances from existing villages, towns, cities, roads, and powerlines minimum distances from these features to each pixel in the TRB.

3.5. Land Use Factors

We used two land use PFs: (1) land use and land cover (LULC), and (2) distance to agricultural lands.

(1) The LULC map was supplied by Iraq Geological Survey and contains nine classes (Figure 7A). It was produced using Landsat satellite data having 30 m spatial resolution. It has been validated by fieldtrip with an overall accuracy of ~93.60% [92]. Several land covers are present in the study area and include: water bodies, urban and built-up land, vegetated land, harvested land, cultivated land, burnt land, carbonate rocks, conglomerates and gravels, and other clastic rocks [92].

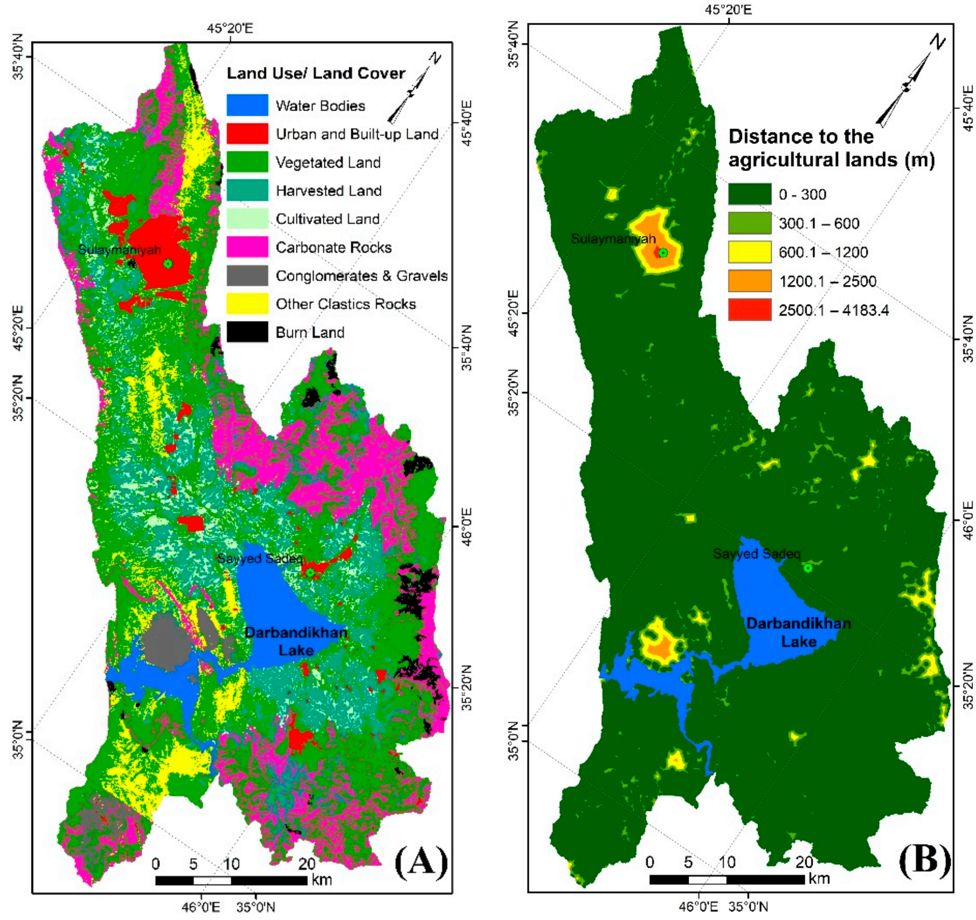

Figure 7. Maps of MSW landfill factors: (**A**) land use and land cover (LULC), and (**B**) distance to agricultural lands.

(2) The area under forest cover must be avoided for landfill siting because it negatively affects natural forest resources [93]. We used distance to agricultural lands (m) to avoid selecting landfill in and near the vegetation cover. We calculated the Euclidean distances from vegetation cover distances within TRB (Figure 7B). The Normalized Difference Vegetation Index (NDVI) was used to characterize the vegetation cover. We used the equation proposed by [94] to calculate the NDVI. It was calculated after extraction of the reflectance (ρ) from the digital number (DN) of Landsat data [38]. proposed that 300 m distance away from agricultural and forest lands could be acceptable for locating MSW landfill.

4. Suitable Landfill Site Selection Model

There is no agreement about a specific method that can be considered to be the most suitable for all types of decision-making technique [95–97]. A big criticism of MCDM is the fact that various methods might obtain various results if used to the same issue [98]. The definition of a suitable MCDM approach is thus not a simple task, and the focus should be on the precise determination of the approach [95]. Available papers show huge practical applications of comparative analyses of various MCDM approaches [9,11–18,99]. We employed five methods to distinguish suitable locations for MSW LFSs. These methods are BO, WSM, WPM, TOPSIS, and AHP.

4.1. Boolean Overlay (BO)

BO is a simple method, widely used to determine suitable sites for solid waste landfills [2,16,17,31,37,38,100–103]. It is based on reclassifying multi-factors used to select LFSs into binary values (0, 1), where 1 and 0 are suitable (yes) and unsuitable (no) pixels, respectively [31]. We prepared a final suitability map for landfilling by combining whole-created binary maps for the constraints using the Boolean overlay (AND operation), which is defined by Equation (2) [17]:

$$1 = \{\text{if A} > \text{X} \ \geq \text{B}\},\ \text{OR } 0 \tag{2}$$

where A and B are constant, and X is the factor

To be on the safe side for LFS selection, we used the maximum distance for various factors (Table 4).

Table 4. Safe distance of Boolean conditions.

Factor	Threshold	Reference
Lithology	*	/
Soil	**	/
LULC	***	/
Distance to main roads (m)	1000	[66,90]
Slope (°)	>20	[8]
TPI (m)	<−5	/
Groundwater depth (m)	13	[76] #
Distance to villages, city and towns (m)	1000	[3,88]
Distance to active faults (m)	500	[3,38,63,64]
Distance to Powerline (m)	300	[36]
Distance to surface water bodies (m)	500	[3,38,85]
Distance to agricultural lands (m)	300	[38]
Elevation	>1560	/
Distance to spring	500	[70,89]

* Qulqula radiolarian, Lake, and all Quaternary sediments (i.e., floodplain, slope sediments, depression fill, polygenetic sediments, and alluvial fan) is nominated as not suitable for LFS selection. ** No soil classes have been nominated as not suitable for LFS selection. *** Water bodies, and urban and built-up land have been nominated as not suitable for LFS selection # Abd-El Monsef and Smith (2019) used minimum groundwater depth of 10 m.

4.2. Weighted Sum Method (WSM)

WSM is a straightforward MCDM method, used for solid waste LFS selection [37,104–106]. This method considers that all factors have equal weight, which is one of its deficiencies [107,108]. Where the weight of the factors equals to each other. Firstly, we categorized each factor into five categories. These are 1, 3, 5, 7, and 9 for the not suitable, less suitable, moderately suitable, suitable, and most suitable for landfill location, respectively. The weight of these five categories was identified according to the possibility of air, water, and soil contamination for the surrounding areas of the proposed landfill. The relationship between LFSs and landfill PFs is shown in Table 3. Column "Rank" shows the final WSM ranks for the factors used to select the LFSs. Following is a summation of whole PFs using the equation proposed by [109,110].

$$WSM = \sum_{i=1}^{n} w_j a_{ij} \tag{3}$$

where n is the number of factors, a_{ij} is the actual value of the ith of the jth criterion and w_j is the weight of the jth criterion.

4.3. Weighted Product Model (WPM)

WPM is very similar to the WSM, the essential variation is that instead of summation in the mathematical expression there is multiplication [109,110]. Similar to WSM, the weight of factors equals to each other. We used the same weight of the classes used in WSM (Table 3 column "Rank") to select the suitable LFSs. Equation (4) suggested by Bridgman (1922) was implemented [109].

$$WPM = \prod_{i=1}^{n} (x_{kj}/x_{ij})^{w_i} \tag{4}$$

where n is the number of factors, x_{ij} is the actual value of the ith of the jth criterion (Table 3), x_{kj} is relative value, and w_i is the weight of the jth criterion.

4.4. Technique for Order Performance by Similarity to an Ideal Solution (TOPSIS)

The alternative of choosing the shortest distance from the ideal best solution and the longest distance from the ideal worst solution in the TOPSIS method, makes this method suitable for LFS selection [111–113]. This method is reliable because the decision makers may desire a decision not only on the most suitable LFSs but also to avoid unsuitable sites [113]. Following steps that have been used to implement TOPSIS method [71,109–112,114–119]. As a first step, we utilized the same weight of the classes in Table 3 (column "Rank") to build the TOPSIS method. Then, we normalized each PF X'_{ij} using Equation (5).

$$X'_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=0}^{n} X^2}} \tag{5}$$

where X_{ij} is pixel value.

Furthermore, we compute the suitability value of the PF W_j by calculating the mean of the weights given by previous eleven papers (Table 5), and, hence, structured the normal weighting matrix V_{ij} by multiplying the normalized PF by its weight Equation (6).

$$V_{ij} = X'_{ij} \times W_j \tag{6}$$

Table 5. Calculating the weight of the PF.

References	Factors														
	Lithology	Soil	LULC	Distance to Road (m)	Slope (°)	TPI (m)	Groundwater Depth (m)	Distance to towns and Cities (m)	Distance to Village (m)	Distance to Active Fault (m)	Distance to Powerline (m)	Distance to Surface Water Bodies (m)	Distance to Agricultural Lands (m)	Elevation (m)	Distance to Springs
[66]		3		3	1		9	7	7			9	1		
[85]	7		3	1	1		7			5		9		1	9
[120]	5		3	3	3			9	9	5		9		1	9
[38]	1		9	7	1		7	9	9	3		7		3	
[8]	7		5	3	4		7	9	7			7		4	
[40]		3	1	2	2		9	7	5			7	2	3	
[39]	1	3	5		4		7	9	9	2				1	
[43]		3	1	2	2		9	7	5			7	2	3	
[121]				3	3			2	9			9			9
[122]	9			1	4			1	1	7				2	
[5]	9		7	6	6		9	8	7			9			9
W_{Mean}	5.6	3	4.3	3.1	2.8		8	6.8	6.8	4.4		8.1	1.7	2.3	9
Weight	7	3	4	3	3	1	8	7	7	5	3	9	2	2	9

The Euclidean distance from the ideal best (S_{i+}) and Euclidean distance from the ideal worst (S_{i-}) value for each layer were calculated by using Equations (7) and (8), respectively. The final step was accomplished by calculating the performance score (P_i) using Equation (9).

$$S_{i+} = [\sum_{j=1}^{m} (V_{ij} - V_{j+})^2]^{0.5} \quad (7)$$

$$S_{i-} = [\sum_{j=1}^{m} (V_{ij} - V_{j-})^2]^{0.5} \quad (8)$$

$$P_i = \frac{S_{i-}}{S_{i+} + S_{i-}} \quad (9)$$

4.5. Analytic Hierarchy Process (AHP)

The AHP method proposed by [123]. It measures the index weight by comparing the PFs with each other [124]. It is one of the most common approaches applied for LFS selection. The GIS environment was used to LFSs, ratings of each PF are provided on a five-point continuous scale (Table 3 column "Rank"). While the suitability weight of the PF was computed by calculating the mean of the weights (Table 5). This was based on a simple review of 11 papers that have applied these PFs for LFS selection. Map of suitable sites for LFS is computed by the raster overlay algorithm, using Equation (10) [125]:

$$AHP = \sum_{i=1}^{n} x_i w_i \quad (10)$$

where x_i is the value of PF i [where i = (list of PFs in Table 5)], w_i is the weight for PF i, and n is the number of PFs (Table 3 column "Rank"). We correlated all PFs used by normalizing their scales and units following the common equation, Equation (11). The final normalized weights were computed in Table 3 column "Normalized weight".

$$Z_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (11)$$

where Z_i is normalized value of pixel, X_i is the value of pixel, X_{min} is the minimum value of pixel and X_{max} is the maximum value of pixel.

The resulting maps using the WSM, WPM, TOPSIS and AHP methods were grouped into five classes, which are most suitable, suitable, moderately suitable, less suitable, and not suitable for landfill. We determined the final suitable LFSs based on the average weights of the landfill probability maps. The pixels that have average ranking $\geq$ moderate suitable were selected as suitable sites for landfill.

5. Results

Besides the BO map, which shows the suitable landfill locations within the TRB (Figure 8), we generated four suitability maps for LFSs using WSM, WPM, TOPSIS, and AHP methods in the ArcGIS environment. In BO maps, the suitable landfill locations are presented in red color while the unsuitable locations appear in beige. Figure 8A shows suitable landfill locations after combining all normalized binary maps using BO conditions, which are stated in Table 4, while Figure 8B exhibits the results without the distance to agricultural lands condition. Nearly all suitable sites are placed in the center and to the east of the TRB (Figure 8A). The suitable locations represent 0.13% and 4.33% for the BO with and without agricultural lands condition, respectively.

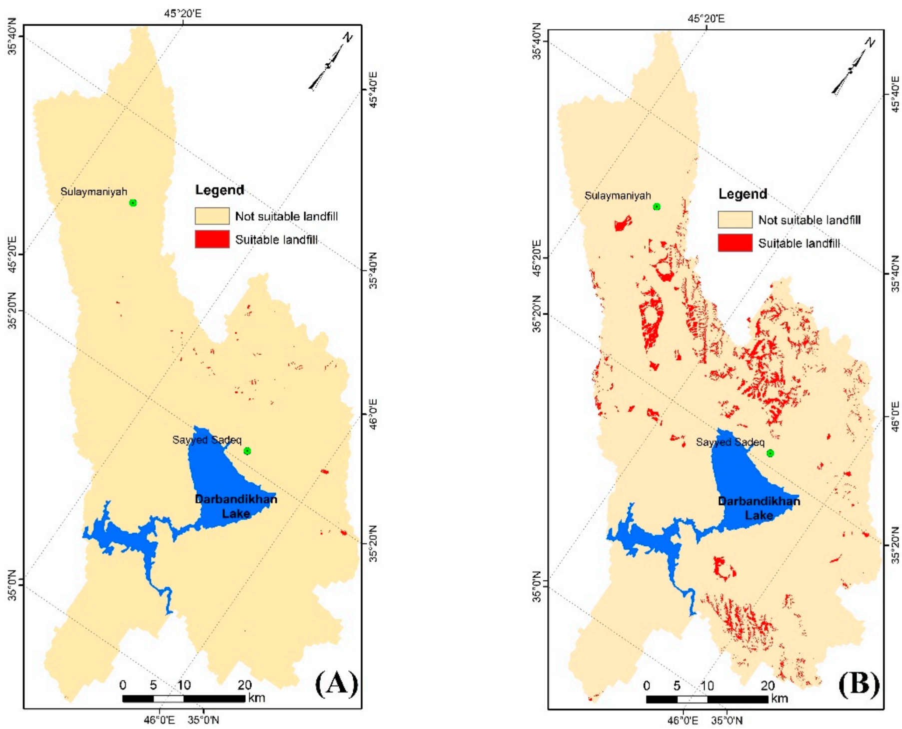

Figure 8. Boolean Overlay (BO) results (**A**) with all PFs (**B**) all PFs avoided except the distance to agricultural lands factor.

The final spatial distribution for LFSs probability maps based on the WSM, WPM, TOPSIS, and AHP models were developed using 15 PFs. The weights of the PFs have been estimated by using the prediction model Equations (3), (4) and (7)–(10). For each method, each PF has a specific predictive weight, which differs from one model to another. Wide range of the predictive weights means high effectiveness of these factors for LFS selection. We classified the LFS selection map into five groups using equal intervals. We used the frequency threshold levels (i.e., 20, 40, 60, and 80%), representing "Not suitable", "Less suitable", "Moderate suitable", "Suitable", and "Most suitable".

The distributions for LFS suitability of WSM and AHP are very close to each other (Figure 9A,D). The WSM, TOPSIS and AHP landfill maps exhibit that their spatial distributions are somewhat similar, where more than 96.6% of "very high" and "high" probability classes are shared between these three methods. For the "very high" and "high" probability classes, the similarity between WPM and other methods is less than 11%. For these three models the suitable and most suitable areas for LFSs are located close to the watershed boundary of the TRB and those for "not suitable" and "less suitable" areas are placed in the center of the TRB (Figures 9 and 10A).

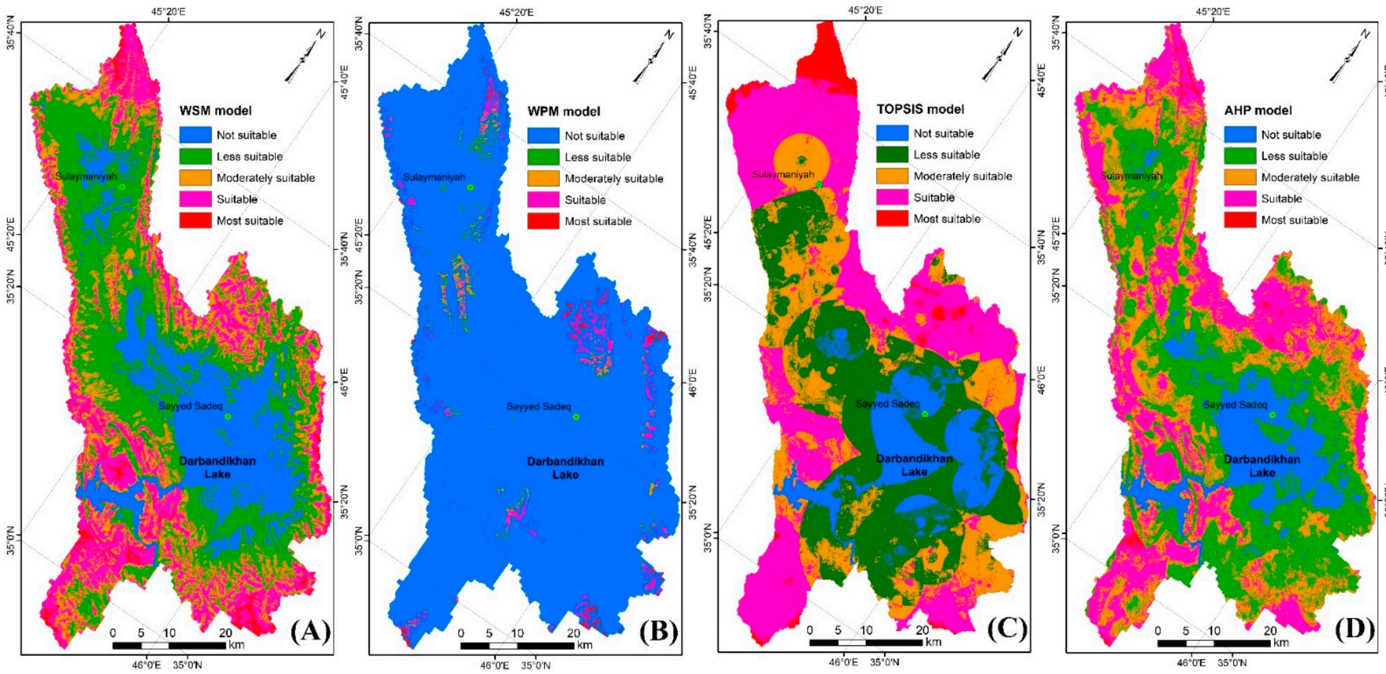

Figure 9. Spatial distribution of LFS probability of the TRB: (**A**) WSM; (**B**) WPM; (**C**) TOPSIS; and (**D**) AHP.

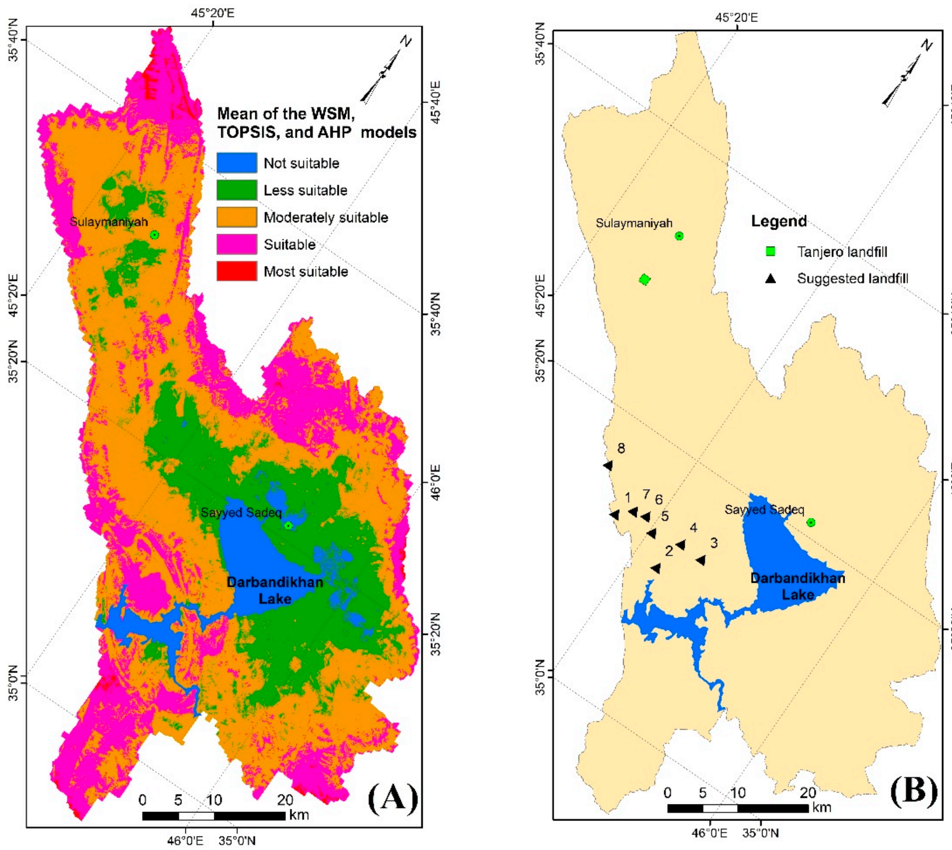

Figure 10. (**A**) Spatial distribution of LFS probability of the study area using average of the WSM, TOSIS, and AHP; (**B**) the location of the suggested LFSs, which have areas more than, 1 km^2.

We calculated average map of the WSM, TOPSIS, and AHP models (Figure 10A). The WSM has been neglected from our consideration (See Section 6.2). Based on Figure 10A, eight best sites for landfill have been selected. Several areas appeared as suitable sites for

LF, but most of them have small areas. Figure 10B and Table 6 show the locations of the eight suggested LFSs, with average landfill suitability weight ≥70% for the WSM, TOPSIS, and AHP models. These suitable sites are placed in the western part of the TRB, which have total area of 18.35 km^2.

Table 6. Number and location coordinates of the biggest eight suggested landfill within Projected Coordinate System UTM/WGS 84 zone 38N.

No.	Easting	Northing	Area (km^2)
1	555381	3897517	1.63
2	564557	3894646	2.23
3	569143	3899259	1.69
4	565540	3899390	2.68
5	561218	3898361	4.65
6	559192	3899796	1.03
7	557291	3899372	3.04
8	550614	3902710	1.4

Figure 11 shows the relationship between the suitability of the suggested sites and the PFs. All the eight suggested sites are lying out of [19] studied area. They are located in suitable lithological units and far from springs, with lower suitability "but acceptable" distance to the villages. The most suitable landfill location is Site-6 while the least suitable location is Site-5.

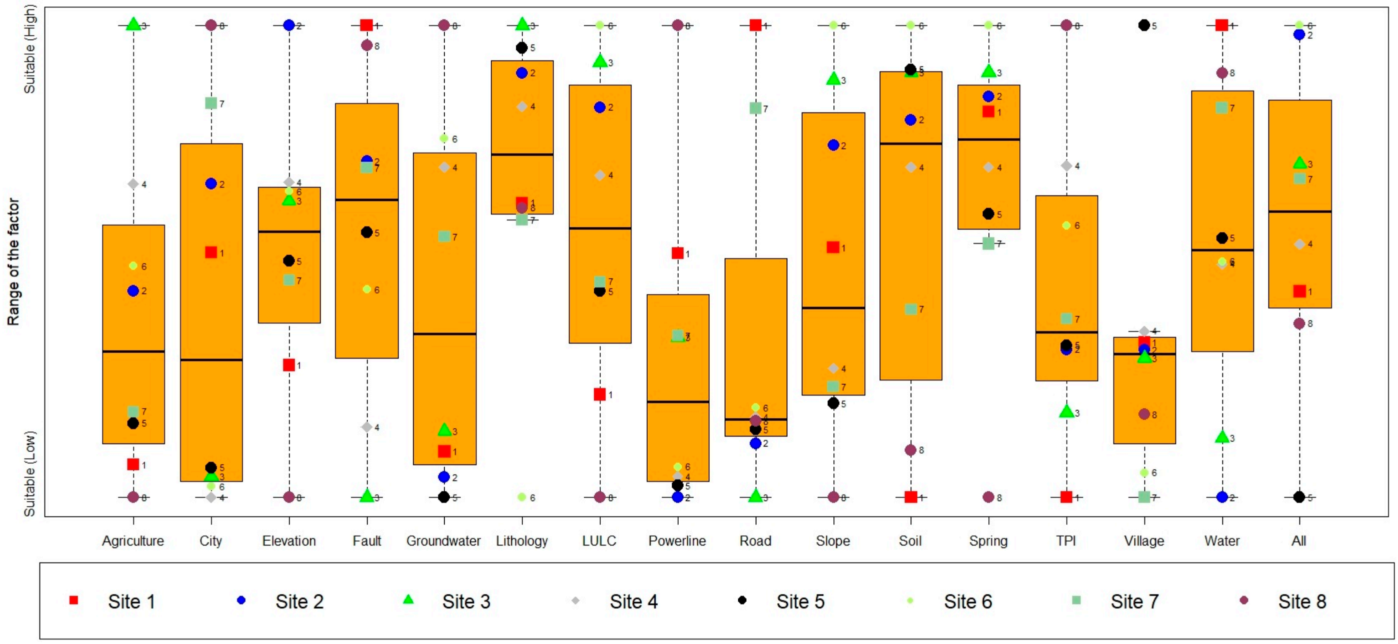

Figure 11. Relationship between suitability of the 8 LFSs suggested and suitability weight of PFs.

6. Discussion

6.1. Evaluation Tanjero Landfill

This study was prompted by our concern for the uncontrolled solid waste dump site, the Tanjero dump, which is the only MSW site in the Sulaymaniyah governorate [48]. Field investigations and previous studies (e.g., [49]), reveal that the Tanjero dump was used to dispose of huge amount of oil refineries, cement plants, and hospitals waste. No study has been done to evaluate the Tanjero dump and propose alternative locations that meet accepted MSW citing criteria. This research aimed at filling this need by proposing suitable locations based on scientific studies.

There was a lack of adequate and reliable data that could be used as LFS selection criteria available for the study area, which limited our evaluation of the MCDA models statistically. This prompted us to follow the recent literature [2,3,20–42] (Table 1) for selecting the most important PFs (criteria) to select LFSs. In addition, we included TPI as one of the PFs, because [52,55] had found that using TPI instead of the slope aspect increased the accuracy of lithological classification for landslide susceptibility prediction. Several studies have been done to simulate and evaluate the disaster of landfills sliding, such as [126–128]. As the study area is a mountainous, it should be noted that TPI has been applied for the first time for LFS selection.

Figure 12 shows the mean weight of the 15 factors that have been evaluated for Tanjero landfill. The minimum, first quarter, third quarter, maximum, and average, of the mean weight of these PFs are 0.0001, 0.0523, 0.2981, 1, and 0.2045, respectively. In other words, almost all the PFs (except the distance to surface water bodies and soil factors), used to evaluate Tanjero LFSs range between not suitable and less suitable classes.

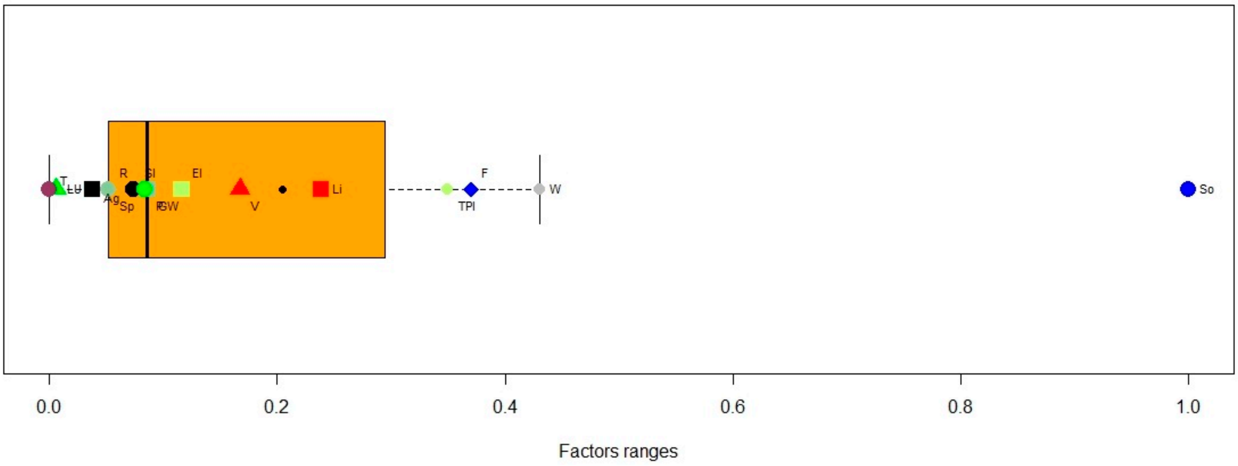

Figure 12. Boxplot shows the mean weight ranges of the 15 factors for landfills within the Tanjero basin, where Li is lithology, So is Soil, LU is land use and land cover, R is distance to the road, Sl is slope, TPI is topographic position index, GW is groundwater depth, T is distance to the towns and cities, V is distance to village, F is distance to the active fault, P is distance to the powerline, W is distance to surface water bodies, Ag is distance to the agricultural lands, El is elevation, and Sp is distance to the springs.

As the lithology is one of the most important factors [5,122], which is controlling directly and indirectly the suitability of LFS selection (Table 5). The lithology of the Tanjero landfill is represented by the Tanjero Formation, which consists of an alternation of shale, sandstone, claystone, mud, and conglomerate [60], which allow higher rate of water infiltration forming large quantity of leakage that will contaminate the groundwater system. This formation can be classified as less suitable for waste dump.

Although the distance from Tanjero dump to the surface water bodies is within the moderate suitability class, its ranking is lower than the accepted range (43%). Only the soil PF is acceptable for selecting the Tanjero dump (Figure 12).

We considered that the range of suitability is from 0 to 1. The average suitability of the existing Tanjero LFS using WPM, WSM, AHP, and TOPSIS method are 0.01, 0.28, 0.41, and 0.48, respectively, giving it the subtility ranking of 0.39. Therefore, it is not adequate for the existing Tanjero dump to be considered a suitable dump site for MSW in the Sulaymaniyah governorate.

6.2. Statistical Evaluation of the MCDA Used in TRB

Although the BO determines suitable regions for landfill, it has a significant disadvantage by not providing suitable alternatives if the conditions mismatch [98]. Therefore, we used the MCDA for selecting the suitable LFSs. For the purpose of evaluating our statistical models, we tested the relationship between all proposed models in this study. Figures 13 and 14 show the uncertainty tests of the four MCDA models. Figure 13 shows six tested graphs of the relationships between the WSM, WPM, AHP, and TOPSIS. In this figure, all (3,615,924) pixels within the TRB have been tested. It shows that the best correlations are between AHP and TOPSIS and AHP and WSM models, with R^2 of 0.62 and 0.6, respectively. However, the correlation (R^2) between the TOPSIS and WSM is 0.36. Other correlations (i.e., WPM with WSM, AHP, and TOPSIS) are very weak. The worst correlation is between WPM and TOPSIS methods. Therefore, as shown in Figure 10A, we ignored WPM model from our consideration in this study.

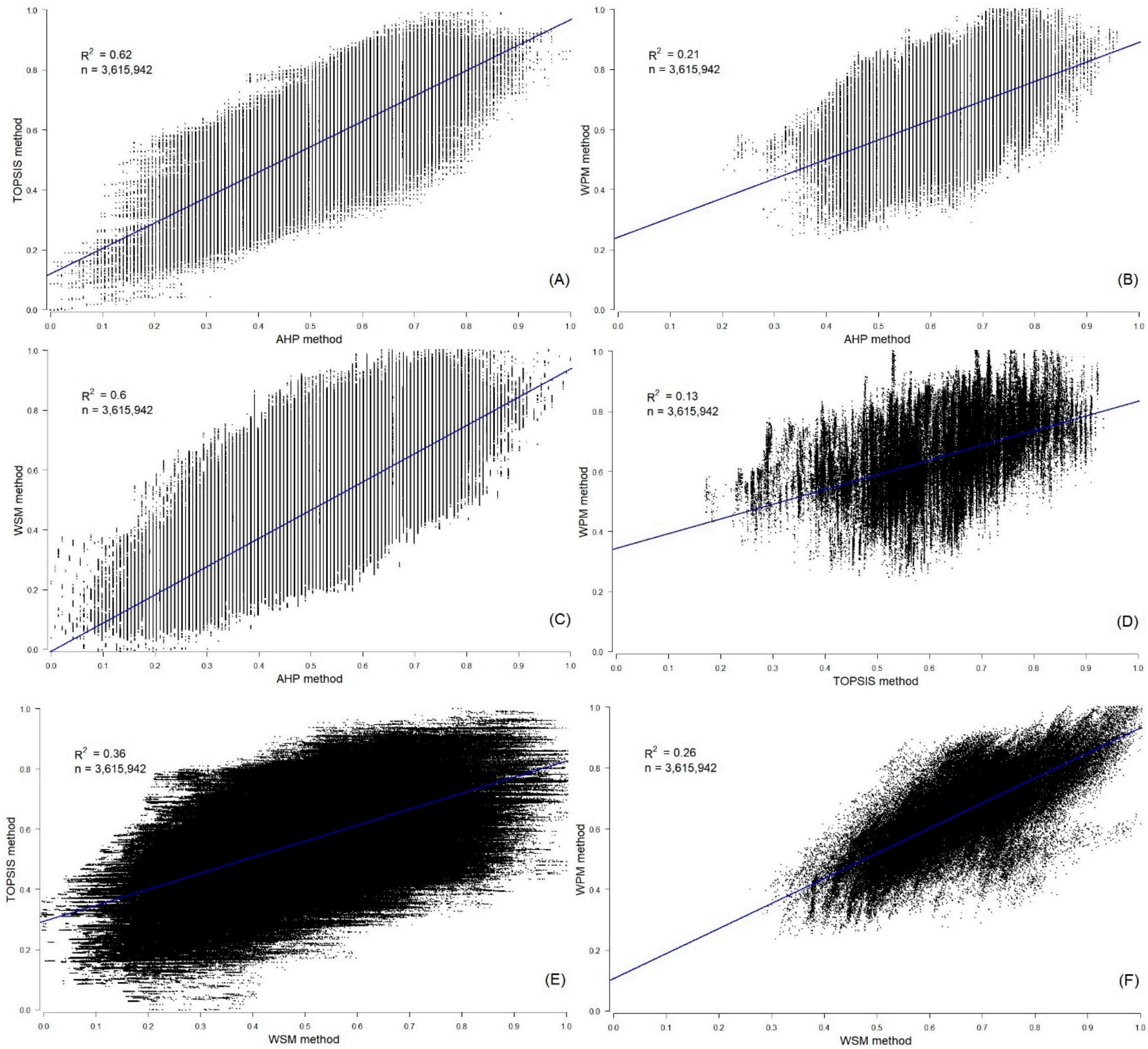

Figure 13. Similarity analysis using the correlation between the statistical models, where the correlations are between (**A**) AHP and TOPSIS, (**B**) AHP and WPM, (**C**) AHP and WSM, (**D**) TOPSIS and WPM, (**E**) WSM and TOPSIS, and (**F**) WSM and WPM models.

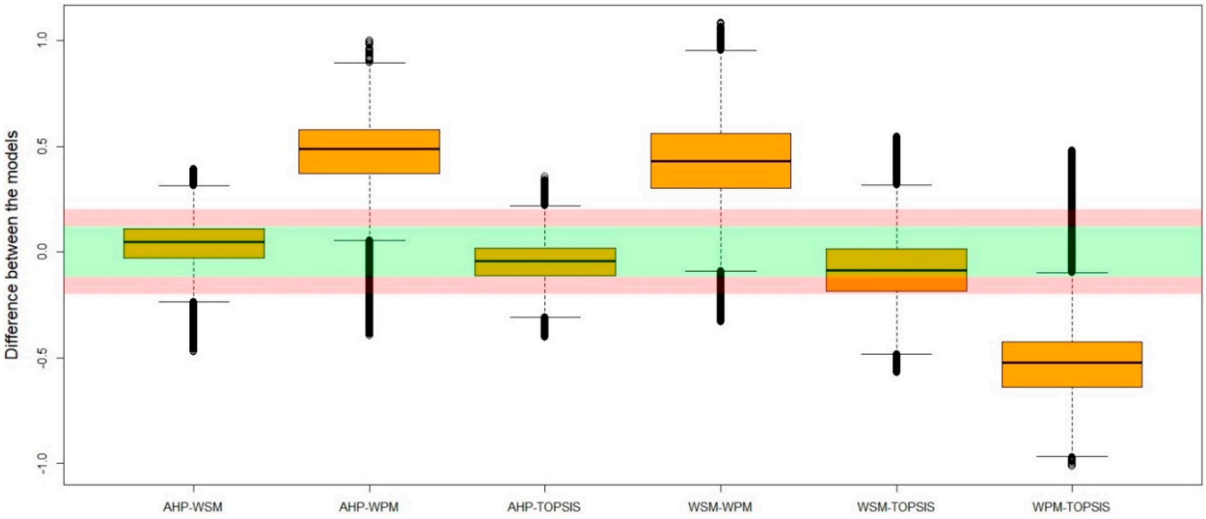

Figure 14. Sensitivity analysis of statistical models.

Figure 14 shows the subtraction between AHP and TOPSIS, AHP and WPM, AHP and WSM, TOPSIS and WPM, WSM and TOPSIS, and WSM and WPM. The best matching between each two subtracted models will be close to the zero value. The higher value of any subtracted model means higher difference between these models, which in turns means less matching. Subtraction between AHP-TOPSIS and AHP-WSM show the best matching (located within green zone between ±0.12) among other subtracted models, similar to TOPSIS and WSM (located within red zone between ±0.2). The highest difference can be noted between AHP-WPM, TOPSIS-WPM, WSM-WPM. This pattern supports our decision to ignore the WPM from our interpretation.

6.3. Landfill Sites Suitability

It should be noted that the above rankings are generalized for quick and broad evaluation of candidate sites for LFS. The final selection of LFS should be made after detailed on-site surface and subsurface investigations.

Improving the sites to be suitable for landfilling can be achieved by modifying the suitability factors that render an otherwise suitable sites score low in the analyses. As can be noticed in Figure 11, some factors lie within the lower part of the suitability boxplot. For example, distance from villages is the least suitable factor among the eight selected LFSs within the TRB, with Site-7 being the least suitable (Figure 11). As there are a number of very small villages distributed within the TRB, consisting of a few houses only (less than ten), so the lower suitability ranking of these villages can be neglected relative to the main towns and cities.

The second and the third lower suitable factors are the distances to powerline and distance to the road. Small villages in the TRB have their own powerlines and paved roads, which will affect the suitability ranking of the later factors. The fourth lower suitable factor is the distance to the agricultural land. It causes misinterpretation in the ranking as well because it takes into account wild shrubs and forest trees, which do not belong to cropped plants. To overcome this constraint, we proposed the overall ranking to include all PFs (Figure 11), which show higher suitability except for Site-6, while the most suitable LFS is Site-5.

6.4. Models Validation

In addition to the fieldtrip to check the suitability of the eight selected LFSs, we obtained the data of twelve groundwater samples stated by [81] (Figure 15A). These data were collected from boreholes dug in Tanjero and Quaternary aquifers outcropped within TRB [60,61,81]. Several studies have used the total dissolved solids (TDS) in water to validate the groundwater contamination [129,130]. The TDS has a direct relationship with groundwater contamination as a result of leakage from the recharge area. The higher TDS, the higher groundwater contamination [129,130], and thus the lower suitability of landfilling. In other words, the decreasing of the TDS concentration is consistent with the increase of the LFS selection suitability.

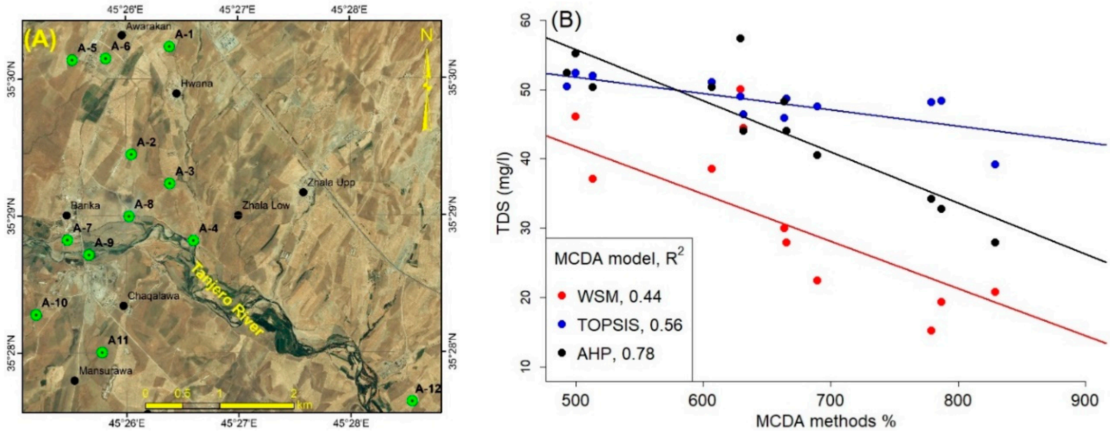

Figure 15. (**A**) QuickBird satellite images overlapped by 12 groundwater samples collected from boreholes dug in Tanjero and Quaternary aquifers [81]; (**B**) the relation between the values of the MCDA methods (i.e., WSM, TOSIS, and AHP) and the TDS of the 12 groundwater samples.

TDS concentrations of the twelve groundwater samples were used to validate our results. Figure 15B shows the relation between the TDS and the WSM, TOPSIS, and AHP models. The TDS shows an inverse relationship with the WSM, TOPSIS, and AHP models where the R^2 values are 0.44, 0.56, and 0.78, respectively. The WPM model has been excluded as the R^2 value is <0.1. While the AHP model shows the best results based on the strong relationship with the TDS concentration.

7. Conclusions

The main aim of this paper was to recognize suitable landfill sites (LFSs) in the Tanjero River Basin (TRB) in the Kurdistan region, Iraq. In the current study, Boolean Overlay (BO) in addition to four Multi-Criteria Decision-Analysis (MCDA) models included Weighted Sum Method (WSM), Weighted Product Method (WPM), Analytic Hierarchy Process (AHP), and Technique for Order Performance by Similarity to an Ideal Solution (TOPSIS) were applied to enable combined the use of the 15 thematic layers. The distribution maps for LFSs probability from WSM and AHP are very close to each other; while the WSM, TOPSIS and AHP landfill results exhibit that their spatial distributions are somewhat similar; while the similarity between WPM and other methods is less than 11%. The accuracy of all methods was calculated, and the best accuracy was achieved by AHP method.

According to the results, the final suitable LFSs were identified by calculating average weights of the WSM, TOPSIS and AHP maps. Accordingly, the pixels weights that have suitable and very suitable ranks have been nominated for landfill.

To sum up, based on the final analyses, most of the suitable sites are located close to the TRB boundary. Eight suitable sites have been identified, that have the best condition for citing MSW landfills. These sites are situated in the western part of the TRB, and the most suitable site is Site-6 and the less suitable is Site-5. According to this research, the current location of the Sulaymaniyah dump is not suitable and its location might lead to pollution in the area. It is worth noting that ours is the first study to have used the Topographic Position Index (TPI) to select MSW LFSs. From 12 borehole dug in the TRB, a validation shows that the best model is AHP, where it has an inverse strong relationship (R^2 = 0.78) with the TDS model. Finally, we recommend that the most suitable site among the eight determined sites for choosing landfill should be based on detailed on-site surface and subsurface investigations.

Author Contributions: Conceptualization, A.A.O.; methodology, A.A.O.; software, A.A.O.; validation, A.A.O., A.K.O., and D.A.M.A.-M.; formal analysis, A.A.O.; investigation, A.A.O., A.F.A.-M., A.T.S., and Y.I.A.-S.; resources, A.A.O., D.A.M.A.-M., S.G.S.; V.L., and Z.T.A.-A; writing—original draft preparation A.A.O., A.K.O., and M.P.; writing—review and editing, A.A.O., and A.K.O.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: We do not report any data.

Acknowledgments: We would like to thank the USGS, OCHA-IRAQ, Sulaymaniyah groundwater Directorate, and ESA for their free data used in this study. Also, we would like to thank ESA and SEOM (Scientific Exploitation of Operational Missions) for providing SNAP software. The First author would like to thank GREEN CHARTER GC. Foundation and elbarlament organization from Germany for the fruitful discussion during the water dialogue—Clean Tigris project and provided the roadmap for water challenges and solutions in context of Iraq. The second author would like to thank CARA for their support to his research. Our appreciation fo Syed E. Hasan from Department of Earth & Environmental Sciences, University of Missouri, Kansas City, US for editing the language of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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