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Multi-Criteria Decision-Making Approach for Siting Sewer Treatment Plants in Muscat, Oman

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Abstract: Sewer Treatment Plants (STPs) are essential pieces of infrastructure given the growing scarcity of water sources due to the challenges of urbanization. The positioning of STPs is a complex multidimensional process that involves integrative decision-making approaches that consider multiple sustainability criteria to ensure their optimal placement. The Multi-Criteria Decision Method (MCDM) is a suite of approaches available to decision-makers when making systematic and scientifically informed decisions on siting wastewater treatment plants. Although MCDM methods have manifold applications in different geographic contexts, there is a paucity of studies employing MCDM models for the siting of STPs within the context of Oman. In this study, we assessed the locations of existing STPs and identified suitable locations for future STPs within the Muscat Governorate of Oman using a Multi-Criteria Decision-Making Analytic Hierarchy Process (MCDM-AHP) model in a Geographic Information System (GIS) environment. Eight factors were considered in the MCDM-AHP model: slope, elevation, proximity to built-up areas, airports, valleys, road networks, the sea, parks, and golf courses. Each factor was assigned priority weights based on its importance using the AHP method. Thematic maps were generated to categorize the potential sites into different suitability levels. The results showed that the coastal areas of A'Seeb and Bowsher were the most suitable locations for STPs, representing only 1.19% of the total study area. The novelty of this study stems from the perspective of an original application within the context of Oman, which has generated novel results and interpretations. This has significant implications for urban policy and planning with respect to better informing decision-makers with a systematic framework for efficient wastewater treatment.

Keywords: geographic information system (GIS); population growth; sewer treatment plants; suitability analysis; multi-criteria decision-making (MCDM); analytic hierarchy process (AHP); Oman

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1. Introduction

Urban sewer systems are intricate infrastructure networks that have substantial implications for the economic, environmental, and social dimensions of contemporary communities. Ensuring the effective and sustainable management of these critical assets involves grappling with a range of challenges arising from factors such as population growth and its subsequent strain on infrastructure services [1]. Over the past 30 years, there has been increasing interest in treated wastewater worldwide. In several countries, treated wastewater is a key component of sustainable urban water management [2].

According to census data released by the Sultanate of Oman's National Center for Statistics and Information (NCSI), the population of Muscat's governorate increased by more than 50% between 2003 and 2020, rising from 632,073 in 2003 to 1,302,440 in 2020 [3,4]. Data released by the United Nations show that cities house more than 55% of the world population [5]. Projections also suggest that by 2050, this percentage will rise to 68%, a significant increase compared to the 30% of people living in cities in the 1950s [5,6]. This global trend underscores the ongoing urbanization process and the growing importance of addressing the challenges and demands associated with urban populations. As such, cities worldwide are increasingly adopting proactive and optimized strategies to plan and manage their sewer assets. These strategies need to consider the spatial and multi-criteria aspects of urban infrastructure planning [7]. Furthermore, land availability within cities significantly influences the location of STPs. Thus, much-needed data, in conjunction with the application of geospatial techniques, are warranted to determine the optimal locations for sewage treatment plants (STPs) [8,9].

In the literature, MCDM is one of the many available approaches for decision-makers to make systematic and informed decisions on siting areas for the construction of STPs after considering multiple factors derived from available geospatial data [10]. The underlying basis of the MCDM is to examine several alternatives, given the multiple criteria on which the stipulated alternatives are to be evaluated [11,12]. The weights of each criterion within the MCDM model are typically determined using the AHP [11].

MCDM methods have many applications in various disciplines and geographic contexts [8,13–19]. Deepa and Krishnaveni (2012) employed multi-criteria analysis by combining AHP to determine the most suitable sites for Decentralized Treatment Plants (DTPs) in South Chennai City, India [14]. They used several criteria in their study, including population density, land use, slope, and soil type [14]. The results of their study revealed that the most suitable sites for DTPs were in the peri-urban areas of Chennai [14]. These areas are characterized by low population densities, proper land use, and gentle slopes [14]. Similarly, Taghilou et al. (2019) presented a site selection method for STPs using the AHP technique and (GIS) in rural areas of the Zanjanrood catchment located in the Zanjan province of Iran [15]. Their analyses showed that integrating AHP and GIS provides a comprehensive and objective framework for evaluating potential sites based on multiple criteria to assess and identify suitable sites for STPs in rural areas [15].

Other studies have applied a combination of AHP and ANP models with fuzzy multi-criteria to determine suitable sites for water treatment plants [16,17]. This is exemplified in the works undertaken by Shahmoradi and Isalou (2013) and Li et al. (2017), who addressed the shortcomings of other multi-criteria methods by addressing the vagueness or fuzziness of land-use data [16,17]. Li et al. (2017), on the other hand, employed a multi-criteria analysis using Weighted Suitability Analysis (WSA) and Grey Related Analysis (GRA) to identify the most suitable sites for sewage outfalls around the Luoyuan Bay coastal area in Fujian, China [18]. In their analysis, only one site (S5) (which was consistent with local laws, regulations, and zoning) had higher evaluation values using both the WSA and GRA methods. The rankings of other sites varied when calculated using the WSA and GRA methods. Both proposed methods offer decision-makers greater flexibility when evaluating the suitability of optional sites. From a conceptual perspective, Zhou et al. (2022) emphasized the significance of considering dynamic changes in water ecosystems and sociocultural indicators in the site selection process of wastewater treatment plants [19]. The authors proposed a comprehensive methodology that integrates satellite imagery, water quality data, and sociocultural information using GIS [19]. By incorporating these factors, the study highlighted the need for a holistic approach that accounts for evolving water ecosystems and sociocultural factors [19].

The aforementioned studies have demonstrated the potential of integrating multiple multi-criteria methods for the site selection of wastewater treatment plants. Across all studies, it is evident that siting of STPs is crucial for urban planning and management, given that wastewater treatment promotes sustainable development. Studies have shown that the treatment of wastewater (including sewage water) directly contributes to the United Nations Sustainable Development Goals (SDGs) [20]. Specifically, wastewater treatment plants play a crucial role in achieving 11 of the 17 United Nations SDGs [20]. These include increasing the supply and availability of water (SDG 2 and 6), enhancing global human health (SDG 3), providing households with new streams of income (SDG 1 and 8), generating energy from waste (SDG 7 and 9), and minimizing the environmental impacts of wastewater (SDG 11, 12, 13, and 14) [20]. On the other hand, the recovery of wastewater is a practice that can contribute to the management of water resources, especially in arid areas (such as Oman) where water resources are scarce [21–23]. Therefore, the selection of optimal locations for STPs is imperative in the grand scheme of supporting sustainable communities.

From the surveyed literature, it is evident that a combination of GIS tools and MCDM methods have been employed across a suite of geographies to evaluate the optimal placement of wastewater treatment plants. However, within the context of Oman, few studies have employed MCDM-AHP methods for the sole purpose of site selection for STPs. The overarching objective of this study is to analyze and assess the location of existing STPs and identify suitable locations for future STPs within the Muscat Governorate of Oman using the MCDM-AHP method. The novelty of this study stems from its original application in the context of Oman. These findings could have practical implications for decision-makers and planners when assessing the suitability of STP sites.

2. Study Area and Dataset

2.1. Study Area

This study was conducted in the Muscat Governorate, Oman's most populous governorate, according to the 2020 census [4]. Topographically, Muscat encompasses lowland plains, valleys, plateaus and mountains. The total area of the governorate is 3800 km^2, and it is situated in the northeastern region between 22°53′ and 23°47′ N latitude and 58°02′ and 59°13′ E longitude. Administratively, the Muscat Governorate consists of six administrative units considered to be Wilayas (i.e., a state or province). As depicted in Figure 1, STPs were distributed over six Wilayas in the study area. These Wilayas are A'Seeb, Bowsher, Mattrah, Muscat, Al-Amerat, and Qurayyat.

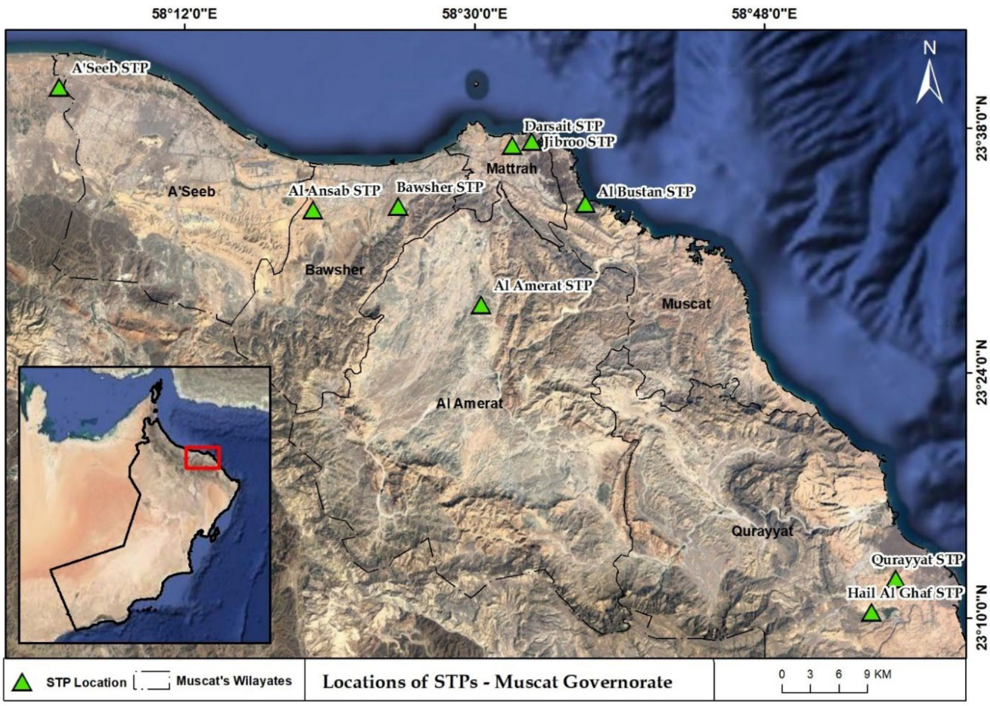

Figure 1. Location of the existing STPs within the study area. The red box indicates the location of Muscat in Oman.

The study area was not as developed when the wastewater system was designed in the early years of the millennium. Nevertheless, this area has undergone tremendous development in several respects. According to the Oman 2020 Census issued by the NCSI, the total population of the Muscat Governorate was 1,302,440 per capita in 2020, with the most populated Wilaya being A'Seeb (479,893 per capita) and the least populated Wilaya being Muscat (31,409 per capita) [4]. However, the total population of the Muscat Governorate did not exceed 632,073 per capita in 2003 [3]. These developments have significantly affected the growth and population of the area. Consequently, the demographic landscape now appears substantially different than it did at the turn of the millennium.

Despite Muscat's complex topography, the current sewer networks cover large built-up areas in the governorate. The study area comprises diverse land uses, including the residential, commercial, and industrial sectors. Wastewater generated from these areas is collected and conveyed through the sewage system to a sewage treatment plant (STP), where it is processed and treated according to specified standards. The sewerage system structure is composed of various sewer lines that terminate at a junction containing a larger sewer line that eventually terminates at a wastewater treatment plant [24]. Given the scarcity of water in the study area, it is imperative to prioritize the selection of optimal STP sites. This is essential for fully leveraging the use of treated effluent (TE) water and optimizing its utilization across vital sectors such as agriculture, industry, and landscaping. Therefore, we can enhance the efficiency and sustainability of water resources and ensure their effective use, thus achieving sustainability of available natural resources.

2.2. Dataset

The data used in this study were pooled from varying sources. They include the National Center for Statistics and Information (NCSI), Oman National Spatial Data Infrastructure (ONSDI) platform, Esri's Living Atlas Portal, and the Nama Water Services Company, Muscat, Oman (formerly known as Oman Water and Wastewater Services Company). Specifically, the locations of current (STPs) were obtained from the Nama Water Services Company. Population and GIS vector data across the study area were acquired from the National Center for Statistics and Information (NCSI) to obtain the 2020 Omani census data along with previous census data (2003 and 2010). Topographic data in raster format were extracted from Digital Elevation Models (DEM) obtained from the National Survey Authority (NSA). The spatial resolution of the DEM was 40 m horizontally and 1 m vertically. The geographical parameters extracted from the DEM were the slope and elevation.

The Oman National Spatial Data Infrastructure (ONSDI) platform (http://nsdig2gapps.ncsi.gov.om/nsdiportal; accessed on 15 March 2023) was finally used to download vector data. The data were downloaded in shapefile format, displaying the road network, valleys, parks, golf courses, and airports. Land cover data, including built-up areas, were downloaded from the Esri Living Atlas Portal (https://livingatlas.arcgis.com/landcover; accessed on 15 March 2023) and extracted from Sentinel-2 Satellite data with a 10 m spatial resolution. Table 1 lists the datasets obtained from the sources mentioned above.

Table 1. Data type and sources.

Data Name	Type	Spatial Resolution	Source
DEM of Muscat	Raster	40 m	Oman National Authority of Survey
Muscat's STPs	Vector	-	Nama Water Services Company
Boundary of Muscat	Vector	-	Oman National Center for Statistics and Information
Muscat International Airport	Vector	-	Oman National Center for Statistics and Information
Land Cover Image 2022	Raster	10 m	Esri's Living Atlas Portal (Extracted from Sentinel-2 Satellite data)
Muscat's Valleys	Vector	-	Oman National Center for Statistics and Information
Muscat's Roads	Vector	-	Oman National Center for Statistics and Information
Parks and Golf Courses	Vector	-	Oman National Center for Statistics and Information
Population	Attribute	-	Oman National Center for Statistics and Information, Oman census 2003, 2010, and 2020

3. Method of Analysis

Land-use suitability mapping has been widely used in numerous studies within the GIS scholarship [8,16,25–29]. This study employed the MCDM-AHP method to analyze and assess the location of existing STPs and identify suitable locations for future STPs in Muscat, Oman. The MCDM-AHP method is a more comprehensive approach to land suitability analysis because it is scalable, not data-intensive, flexible (the hierarchy structure can be easily amended to fit a particular problem) and provides a systematic manner to prioritize criteria and alternatives (through expert judgment). Furthermore, the MCDM-AHP method is designed to handle decisions involving a wide range of factors. These factors include social, economic, environmental, and technical factors. As such, the MCDM-AHP method is a more integrated approach to land suitability analysis because it considers all integral aspects of land use [30–32]. The utilization of this method also enhances the accuracy and reliability of land suitability assessments and provides valuable insights for planning authorities and decision-makers involved in STP infrastructure development.

Mathematically, MCDM involves finding the best alternative among a possible list of alternatives, such that any given MCDM problem consists of m alternatives and n criteria, as expressed in the matrix shown in Equation (1), where $A_1, A_2, \ldots, A_m$ are alternatives; C_1, $C_2, \ldots, C_n$ consists of the evaluation criteria; z_{ij} denotes the performance value of alternative A_i under criterion C_j; and w_j is the weight of criterion C_j [11].

$$\begin{matrix} & & w_1 & w_2 & \ldots & w_n \\ & & C_1 & C_2 & \ldots & C_n \end{matrix}$$

$$M = \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{bmatrix} \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & \cdots & z_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ z_{m1} & z_{m2} & \cdots & z_{mn} \end{bmatrix} \quad (1)$$

Within the MCDM, the weights of each criterion were determined using the AHP method. The AHP theory assumes that there are n distinct alternatives ($A_1, A_2, \ldots, A_n$) with respective weights ($w_1, w_2, \ldots, w_n$) [11]. AHP theory also assumes that the quantified assessments provided by the decision-maker concerning pairs of alternatives (A_i, A_j) are represented in the matrix shown in Equation (2): [11].

$$A_1\ A_2\ \cdots\ A_n\ A = \begin{matrix} A_1 \\ A_2 \\ . \\ . \\ A_n \end{matrix} \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (2)$$

Composite Suitability Analysis (CSA) (within the MCDM) was also used in combination with overlay analysis, as these techniques are extensively employed in GIS analysis to determine suitable locations for many infrastructures, including STPs. Numerous studies have applied this approach to address similar objectives [8,16,26–29]. The Geographic Coordinate System (GCS) with the datum WGS84 was employed as a reference coordinate system for all datasets. ArcGIS Pro 3.1 Software was used for data analysis, performing the Weighted Overlay model, and map production.

3.1. Determination of the Selection Criteria and Weights

To attain the highest possible quality, input factors were evaluated based on their relative importance to the Omani environment and global standards. These factors were assessed by experts from the Nama Water Services Company. Their expertise was utilized to determine the criticality of these factors, ensuring that they aligned with the specific requirements of the Omani context as well as international standards. In this study, we used the model presented by Malczewski (1999), as shown in Equation (3) [33]:

$$Wv = \frac{Vs}{\sum Tr}(100) \quad (3)$$

Variable rank (Vs) is used to assign a numerical value to each variable based on its relative importance or preference. These ranks were then normalized using a process that calculates the normalized weight (Wv). The sum of all rank values ($\sum Tr$) was used in the normalization process to ensure that the weights add up to 100%, indicating the relative significance of each variable within the analysis. Once the selection criteria were determined by the Nama Water Services Company and aligned with global standards, the criteria were set in descending order by the planning experts in the Nama Water Services Company, where the most influential criterion (i.e., proximity to built-up areas) had a rating of 8, and the influence decreased in descending order to the least influential criterion (i.e., distance to the airport), which has a rank of 1, as shown in Table 2. Following this, five categories were identified for the suitability location, including not suitable, less suitable, moderately suitable, suitable, and highly suitable, using ArcGIS Pro 3.1 software to produce thematic maps using the Weighted Overlay model.

Table 2. Criteria selected for STP siting in the study area and their weights.

Criteria	Rank	Weight (%)
Proximity to Built-up Areas	8	22.22
Distance to Valleys	7	19.44
Proximity to Roads Network	6	16.66
Proximity to the sea	5	13.88
Elevation	4	11.11
Slope	3	8.33
Proximity to Parks and Golf Courses	2	5.55
Distance to the airport	1	2.77
Sum	36	100

3.2. Criteria Identification

In the present study, many geographical parameters in the form of thematic layers were chosen as criteria for classifying the study area and identifying favorable sites for STPs. These include geomorphological (slope and elevation) features and location (i.e., proximity to built-up areas, airports, valleys, road networks, sea, parks, and golf courses, proximity to valleys, the sea, airports, and recreational landscapes including parks and golf courses). The selected criteria for STP siting in the study area and their weights are shown in Table 2. Despite these criteria, the current study has limitations owing to the unavailability of critical data, including hydrological and geological analyses of existing formations in the study area.

3.3. Weight Allocation

According to Saaty (1977), as the scale increases, the importance of each higher level also increases compared to the preceding lower level (see Table 3) [34]. Using the weight overlay equation in GIS, the ranked criteria were derived based on the level of importance assigned to each criterion, as shown in Table 4. Following the prioritization of criteria, the suitability scores were assessed by planning experts at the Nama Water Services Company based on their given classification, which contributed to determining the most favorable sites for STPs in the study area. The most influential criterion (i.e., proximity to built-up areas) had a rating of 8, and the least influential criterion (i.e., distance to the airport) had a rank of 1.

Table 3. Fundamental scale of AHP [34].

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential of strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	Activity is strongly favored, and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

Table 4. Criteria used in the study with their rankings and weights.

Rank	Criteria	Classes	Suitability Score	Scale Description	Weight (%)
8	Proximity to Built-up Areas (m)	0–500	5	Very High	22.22
		500–1000	4	High	
		1000–1500	3	Moderate	
		1500–2500	2	Low	
		>2500	1	Very low	
7	Distance to Valleys (m)	0–500	1	Very low	19.44
		500–1000	2	Low	
		1000–1500	3	Moderate	
		1500–2500	4	High	
		>2500	5	Very High	
6	Proximity to Roads (m)	0–300	5	Very High	16.66
		300–600	4	High	
		600–1000	3	Moderate	
		1000–2000	2	Low	
		>2000	1	Very low	
5	Proximity to the Sea (m)	≤1000	5	Very High	13.88
		1000–2000	4	High	
		2000–3000	3	Moderate	
		3000–4000	2	Low	
		>4000	1	Very low	
4	Elevation (m)	0–20	5	Very High	11.11
		20–30	4	High	
		30–40	3	Moderate	
		40–50	2	Low	
		>50	1	Very low	
3	Slope (°)	0 to 2.5	5	Very High	8.33
		2.5 to 5	4	High	
		5 to 7.5	3	Moderate	
		7.5 to 15	2	Low	
		>15	1	Very low	
2	Proximity to Parks and Golf Courses (m)	0–1000	5	Very High	5.55
		1000–2000	4	High	
		2000–3000	3	Moderate	
		3000–4000	2	Low	
		>4000	1	Very low	
1	Distance to Airport (m)	≤5000	1	Very low	2.77
		5001–10,000	2	Low	
		10,000–15,000	3	Moderate	
		15,000–20,000	4	High	
		>20,000	5	Very High	

3.4. Reclassification

When applying the MCDM technique, it is essential to standardize data to ensure compatibility and integration of measurements obtained from various units and scales of measurement, including ordinal, interval, nominal, and ratio scales [35]. Although various approaches exist for standardizing criterion maps, the most commonly employed method is linear scale transformation [36].

To assign weights to the final thematic map, the criteria mentioned above are measured on the same scale. To achieve this, the criteria layers were reclassified on a scale of one to five. This scale represents a descending order of favorable suitability, ranging from very high (5) to extremely low (1). To achieve this, ArcGIS Pro 3.1 software was utilized to prepare and standardize the criteria. The process involved converting all the vector layers into raster format by employing the 'feature to raster' conversion tool found in the Geoprocessing Toolboxes to produce normalized maps, as shown in Figure 2. By reclassifying the criteria layers in this manner, a consistent and standardized scale was established, allowing for the assignment of weights to the final superimposed layers in the thematic map. The approach used was similar to that used by other researchers (see [8,16,17,19]).

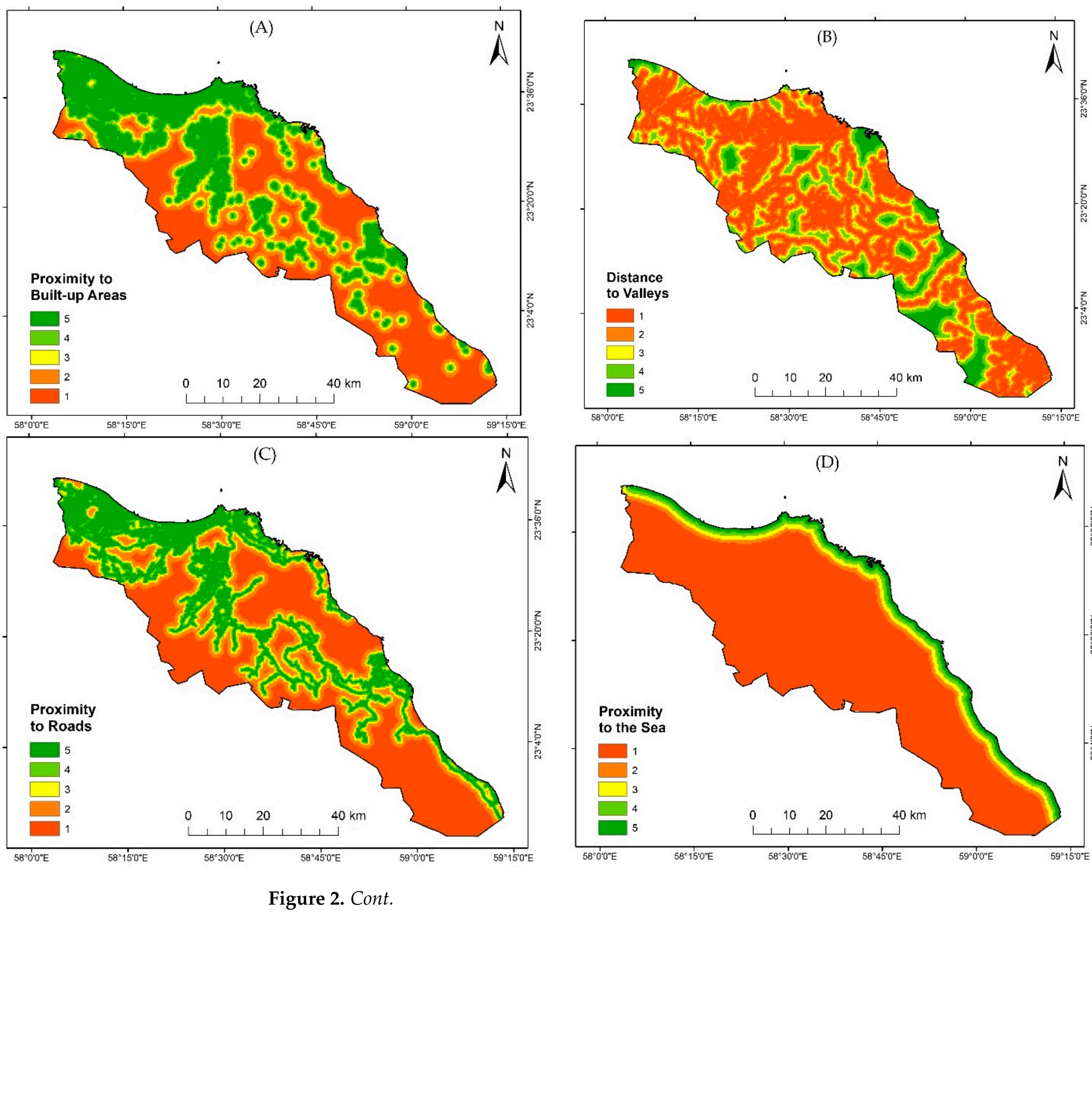

Figure 2. *Cont.*

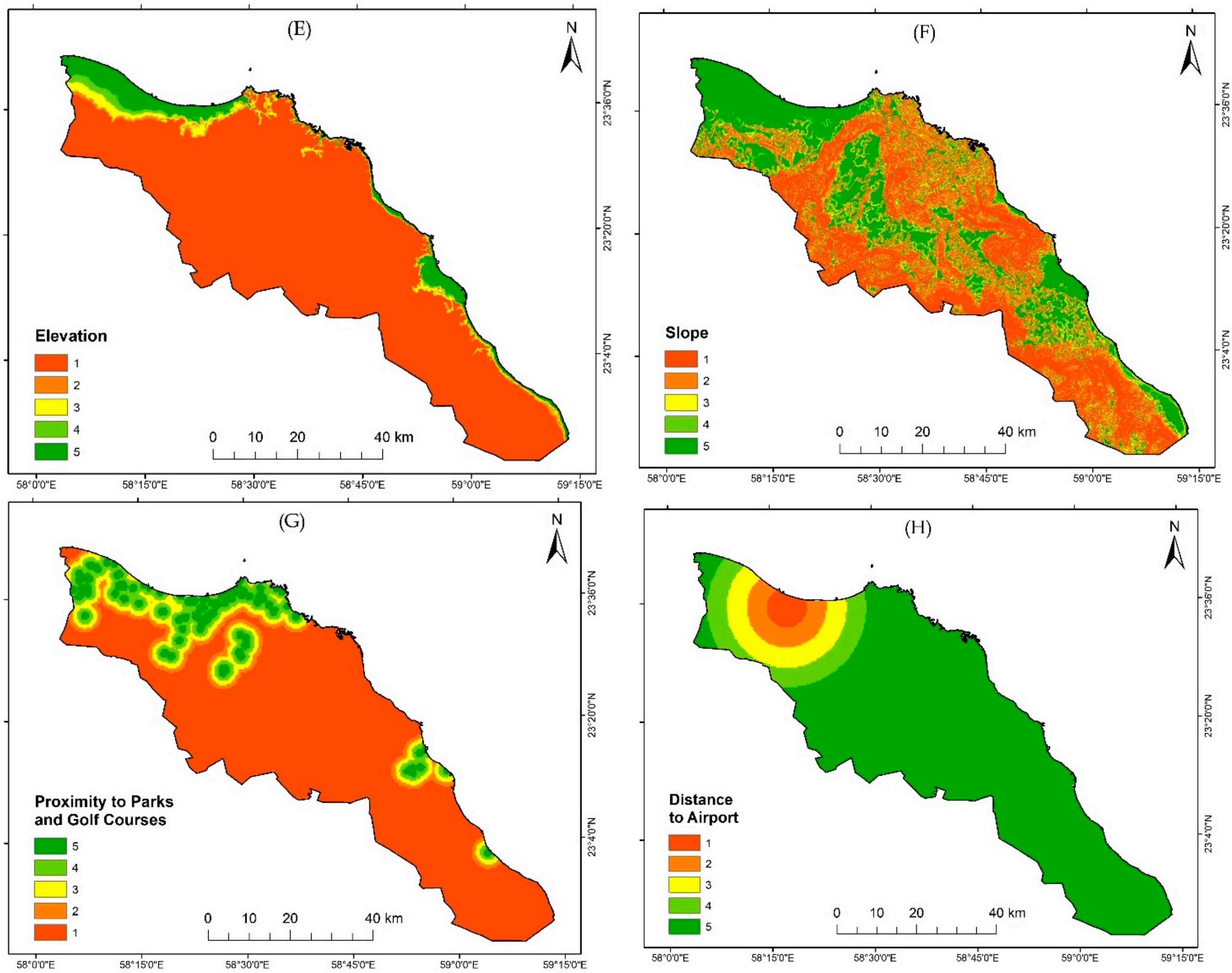

Figure 2. The different weighted criteria used in the study along with their ranking. ((**A**): proximity to built-up areas; (**B**): distance to valleys; (**C**): proximity to roads; (**D**): proximity to the sea; (**E**): elevation; (**F**): slope; (**G**): proximity to parks and golf courses; (**H**): distance to airport).

4. Results

As the current population continues to grow, urban expansion has become an unavoidable reality [37]. In the same context, the population of the Muscat Governorate experienced a significant growth rate of 106% between 2003 and 2020 [3,4]. This significant population increase has resulted in a notable alteration in the spatial suitability of STPs in Muscat. The development plans for the Muscat Governorate include the allocation of several promising sites for urban expansion, tourism, agriculture, or industrial activities [29,38]. Therefore, wastewater treatment should be a key focus in urban action plans to mitigate water scarcity by utilizing alternative water resources [39].

In the current study, eight criteria were employed in the site selection of STPs for the Muscat Governorate. Table 2 presents the selected criteria used for siting STPs in the study area, along with their corresponding ranks and weights. These criteria were evaluated by planning experts at the Nama Water Services Company who assessed their importance in determining suitable locations for STPs. The weights assigned to each criterion represented their relative significance during the decision-making process. According to the planning experts at the Nama Water Services Company, among the employed criteria, over 70% of the allocated weight was assigned to the proximity of built-up areas, distance to valleys, proximity to the road network, and proximity to the sea, respectively. By contrast, the remaining four criteria (elevation, slope, distance to the airport, and proximity to parks and golf courses) were assigned less than 30% of the overall weight, as shown in Table 2.

Based on the composite evaluation using overlay-weighted analysis of all input criteria, five suitability classes were categorized in the study area based on their location suitability level for STPs. Moreover, as shown in Table 4, these five classes were also used to assess the current STP sites among these classes. Figure 3 shows that only 1.19% of the Muscat Governorate is highly suitable as a potential location for STPs, representing 45.44 km^2 out of the total area of Muscat 3800 km^2. This indicates limited options for ideal locations that are deemed highly suitable for STP sites in the Muscat Governorate. The output suitability map also reveals that 8.94% (339.78 km^2) of the study area is suitable, although it does not reach the level of high suitability, which offers viable possibilities for STP siting. A significant portion of the study area, approximately 27.3% (1038.17 km^2), was classified as moderately suitable, representing a substantial land area with potential for STP allocation. This provides a broader range of options for STP siting within the Muscat Governorate. However, a considerable area, accounting for 43.7% (1663.2 km^2), is categorized as less suitable for STPs. These areas pose limitations and may require careful consideration or additional measures to address the suitability concerns. Furthermore, the analysis revealed that 18.05% (686.04 km^2) of the study area was deemed unsuitable for STP locations, as illustrated in Table 5. These areas should be excluded from further consideration because of the inherent limitations that make them unsuitable for establishing STPs. These findings from the suitability analysis highlight the varying distribution of suitability classes for STP locations in the Muscat Governorate. This information is valuable for decision-making processes and for assisting in identifying the most appropriate areas within the governorate for the establishment and assessment of STP sites.

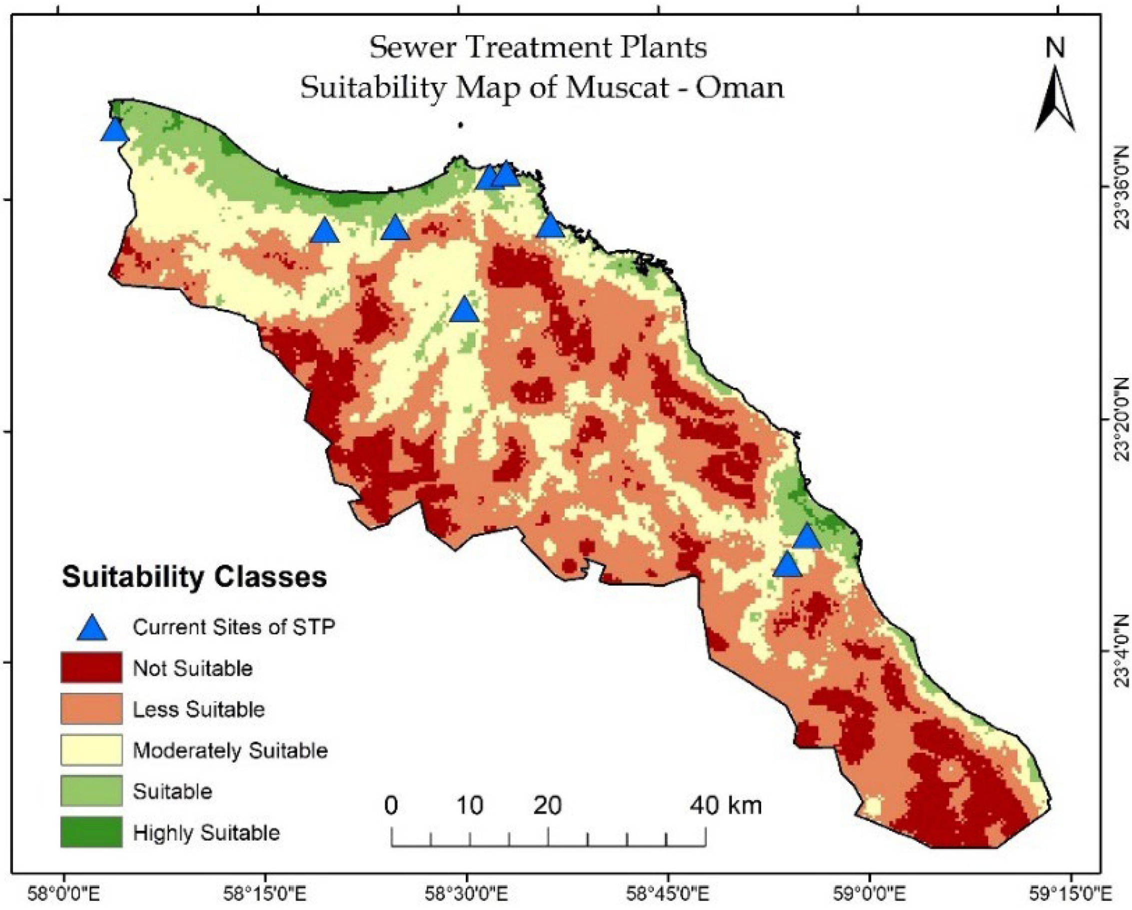

Figure 3. STP suitability map for Muscat, Oman. The dark blue color indicates the existing STP sites.

Table 5. Classified Areas of Muscat Governorate for STP Land Suitability.

Suitability Classes	Area (km^2)	Percentage (%)
Highly Suitable	45.44	1.19
Suitable	339.78	8.94
Moderately Suitable	1038.17	27.3
Less Suitable	1663.2	43.7
Not Suitable	686.04	18.05

5. Discussion and Conclusions

This study utilized a GIS-based approach and an AHP technique to evaluate eight criteria for selecting suitable locations for STPs in the Muscat Governorate of Oman. The analysis categorized the area into five distinct suitability classes. Choosing appropriate locations for STPs is crucial and should be conducted under the relevant standards of any given constituent. The suitability map, as shown in Figure 3, reveals that the coastal area of Muscat, specifically A'Seeb and Bowsher, is the best area for the siting of STPs. These areas appear to have elevations ranging from 0 to 30 m above sea level. This height, combined with the low slope (i.e., 2.5), allows it to take advantage of natural gravitational flow to dispose of treated water into the sea [40]. As it is possible to branch the stations to the sea using an outfall in an emergency, this height is deemed the ideal elevation for an STP site. These stations (A'Seeb STP, Darsait STP, Jibro STP, and Al Bustan STP) fell within a suitable class at altitudes of 17, 14, 12, and 17, respectively. These locations benefit from their proximity to the sea, optimal elevation, and favorable natural topography for efficient STP sites. On the other hand, the remaining STPs with elevations above 50 m (Al Ansab STP, Bawsher STP, Al Amerat STP, Quriyat STP, and Hail Al Ghaf STP) were classified as moderately suitable. While these locations may still be viable for STP placement, their higher elevations present some challenges compared to more suitable sites near the coast. Moreover, the current locations of the Darsait STP, Jibro STP, and Al Bustan STP, which are all situated within less than 2000 m from the seashore, demonstrate that these three STPs are relatively suitable at their current sites. These stations benefit from their proximity to the sea, aligning with the desirable criteria for efficient wastewater treatment and disposal.

Moreover, the output suitability map indicated that only 1.19% of the Muscat Governorate was highly suitable for potential STP locations. The coastal areas of A'Seeb and Bowsher emerged as the most suitable locations within this region. However, most existing STP sites were categorized as moderately suitable, highlighting the need for improved urban sustainability planning in the future.

The lower suitability observed in the study area can be attributed to factors such as challenging topographic characteristics and high population densities [38,41,42]. Moreover, the ongoing trend of population movement towards existing STP sites with continued infrastructure expansion in the study area is expected to have a substantial impact on the suitability of these sites in the near future. This trend may lead to increased pressure on the existing STPs, potentially affecting their performance and capacity. Consequently, it is anticipated that the suitability scale of these sites will experience a notable reduction as population growth and infrastructure development intensify. This analysis highlights the significance of coastal areas in A'Seeb and Bowsher for STP siting, owing to their optimal elevation, low slope, and proximity to the sea.

In conclusion, this study may serve as a useful reference for decision-makers and environmental agencies in the Muscat Governorate to select the most appropriate sites for STPs while considering multiple factors derived from geospatial data. Although the analysis provided some insights into Muscat's suitability for STPs, it should be noted that choosing the optimal location was significantly constrained by data availability. Future studies in Oman should consider incorporating other environmental criteria subject to data availability, such as soil texture and climatic conditions, to further refine the location analysis of STPs. The location of the study area in a water-scarce zone increases the significance of the need to enhance efforts to select optimal STP sites. This is crucial for fully capitalizing on the treated water produced and maximizing its utilization across vital sectors such as agriculture, industry, and landscaping. The use of GIS and AHP in this study demonstrated a potentially effective tool for systematic and scientific decision-making processes for wastewater management. Moving forward, it is essential to consider the long-term vision of Oman's sustainable development through the adoption of other novel multi-criteria GIS-based techniques that leverage a comprehensive suite of data. These techniques will provide valuable insights for informed decision-making for the siting of STP locations in other regional governorates beyond Muscat. Furthermore, future studies should consider a combination of other MCDM methods (e.g., MCDM-ANP) that address deficiencies evident in MCDM-AHP, after careful assessment of their suitability.

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References

1. Halfawy, M.R.; Dridi, L.; Baker, S. Integrated decision support system for optimal renewal planning of sewer networks. *J. Comput. Civ. Eng.* **2008**, *22*, 360–372. [CrossRef]
2. Kim, Y.; Chung, E.S.; Jun, S.M.; Kim, S.U. Prioritizing the best sites for treated wastewater instream use in an urban watershed using fuzzy TOPSIS. *Resour. Conserv. Recycl.* **2013**, *73*, 23–32. [CrossRef]
3. NCSI (National Centre for Statistics and Information). Census Data by Localities, Muscat, Sultanate of Oman. 2003. Available online: https://data.gov.om/OMPOP2016/population (accessed on 15 November 2022).
4. NCSI (National Centre for Statistics and Information). *Final Report of Census Data, Muscat, Sultanate of Oman*; National Centre for Statistics and Information: Muctat, Oman, 2020.
5. UN (United Nations). *The 2018 Revision of World Urbanization Prospects, 2018*; United Nations, Department of Economic and Social Affairs: New York, NY, USA, 2018; Available online: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html (accessed on 15 November 2022).
6. Golden, J.S.; Kaloush, K. A hot night in the big city. *Public Works* **2005**, *136*, 40–43.
7. Coutinho-Rodrigues, J.; Simão, A.; Antunes, C.H. A GIS-based multicriteria spatial decision support system for planning urban infrastructures. *Decis. Support Syst.* **2011**, *51*, 720–726. [CrossRef]
8. Gemitzi, A.; Tsihrintzis, V.A.; Christou, O.; Petalas, C. Use of GIS in siting stabilization pond facilities for domestic wastewater treatment. *J. Environ. Manag.* **2007**, *82*, 155–166. [CrossRef]
9. Swayne, M.D. *Wastewater in Receiving Waters at Water Supply Abstraction Points*; Environmental Protection Agency, Office of Research and Development, Municipal Environmental Research Laboratory: Washington, DC, USA, 1980; Volume 1. Available online: https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30000AXS.TXT (accessed on 15 March 2023).
10. Strager, M.P.; Rosenberger, R.S. Incorporating stakeholder preferences for land conservation: Weights and measures in spatial MCA. *Ecol. Econ.* **2006**, *57*, 627–639. [CrossRef]
11. Sánchez-Lozano, J.M.; Teruel-Solano, J.; Soto-Elvira, P.L.; García-Cascales, M.S. Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. *Renew. Sustain. Energy Rev.* **2013**, *24*, 544–556. [CrossRef]
12. Voogd, J.H. Multicriteria Evaluation for Urban and Regional Planning. Ph.D. Thesis, Delftsche Uitgevers Maatschappij, Delft, The Netherlands, 1982. Available online: https://pure.tue.nl/ws/portalfiles/portal/3744610/102252.pdf (accessed on 15 March 2023).
13. Kallali, H.; Anane, M.; Jellali, S.; Tarhouni, J. GIS-based multi-criteria analysis for potential wastewater aquifer recharge sites. *Desalination* **2007**, *215*, 111–119. [CrossRef]
14. Deepa, K.; Krishnaveni, M. Proper site selection of decentralized treatment plants using the multicriteria approach in GIS. *J. Geogr. Inf. Syst.* **2012**, *4*, 254–260. [CrossRef]

15. Taghilou, S.; Peyda, M.; Khosravi, Y.; Mehrasbi, M.R. Site selection for wastewater treatment plants in rural areas using the analytical hierarchy process and geographical information system. *J. Hum. Environ. Health Promot.* **2019**, *5*, 137. [CrossRef]
16. Anagnostopoulos, K.; Vavatsikos, A. Site suitability analysis for natural systems for wastewater treatment with spatial fuzzy analytic hierarchy process. *J. Water Resour. Plan. Manag.* **2012**, *138*, 125–134. [CrossRef]
17. Shahmoradi, B.; Isalou, A.A. Site selection for wastewater treatment plant using integrated fuzzy logic and multicriteria decision model: A case study in Kahak, Iran. *J. Adv. Environ. Health Res.* **2013**, *1*, 51–61. [CrossRef]
18. Li, Y.; Lin, C.; Wang, Y.; Gao, X.; Xie, T.; Hai, R.; Wang, X.; Zhang, X. Multi-criteria evaluation method for site selection of industrial wastewater discharge in coastal regions. *J. Clean. Prod.* **2017**, *161*, 1143–1152. [CrossRef]
19. Zhou, Y.; Song, Y.; Li, S.; Qin, W.; Sun, J. A Location Selection Method for Wastewater Treatment Plants Integrating Dynamic Change of Water Ecosystem and Socio-Cultural Indicators: A Case Study of Phnom Penh. *Water* **2022**, *14*, 3637. [CrossRef]
20. Obaideen, K.; Shehata, N.; Sayed, E.T.; Abdelkareem, M.A.; Mahmoud, M.S.; Olabi, A.G. The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline. *Energy Nexus* **2022**, *7*, 100112. [CrossRef]
21. Gómez-López, M.D.; Bayo, J.; García-Cascales, M.S.; Angosto, J.M. Decision support in disinfection technologies for treated wastewater reuse. *J. Clean. Prod.* **2009**, *17*, 1504–1511. [CrossRef]
22. Capra, A.; Scicolone, B. Recycling of poor quality urban wastewater by drip irrigation systems. *J. Clean. Prod.* **2007**, *15*, 1529–1534. [CrossRef]
23. De Faria, D.C.; de Souza, A.A.U.; Ulson, S.M.D.A.G. Optimization of water networks in industrial processes. *J. Clean. Prod.* **2009**, *17*, 857–862. [CrossRef]
24. Swamee, P.K.; Sharma, A.K. Optimal design of a sewer line using linear programming. *Appl. Math. Model.* **2013**, *37*, 4430–4439. [CrossRef]
25. Collins, M.G.; Steiner, F.R.; Rushman, M.J. Land-use suitability analysis in the United States: Historical development and promising technological achievements. *Environ. Manag.* **2001**, *28*, 611–621. [CrossRef]
26. Hamlat, A.; Kadri, C.B.; Sekkoum, M.; Guidoum, A.; Remada, A. Multi-criteria decision-making approach for selecting an alternative wastewater treatment plant site in urban areas of Laghouat (North-Central Algeria). *Euro-Mediterr. J. Environ. Integr.* **2022**, *7*, 511–530. [CrossRef]
27. Kafil, M.; Albaji, M. Selecting wastewater sites using analytical hierarchy and geographic information system. In *Proceedings of the Institution of Civil Engineers-Municipal Engineer*; Thomas Telford Ltd.: London, UK, 2018; Volume 171, pp. 86–92. [CrossRef]
28. Neji HB, B.; Turki, S.Y. GIS–based multicriteria decision analysis for the delimitation of an agricultural perimeter irrigated with treated wastewater. *Agric. Water Manag.* **2015**, *162*, 78–86. [CrossRef]
29. Rezaali, M.; Karimi, A. Decentralized wastewater treatment plants site selection of Qom Province by using fuzzy logic and AHP. *Iran-Water Resour. Res.* **2019**, *15*, 76–91.
30. Wang, Y.; Zhang, C.; Liu, Y. Assessing the suitability of land for urban development using multi-criteria decision making with analytical hierarchy process. *Sustain. Cities Soc.* **2017**, *33*, 213–222. [CrossRef]
31. Zhang, J.; Liu, X.; Liu, S.; Wang, X. Application of MCDM-AHP in land suitability analysis for urban development. *J. Clean. Prod.* **2018**, *182*, 532–540. [CrossRef]
32. Chen, X.; Zhang, J.; Liu, X.; Wang, X. A comparison of multi-criteria decision making methods for land suitability analysis. *Sustainability* **2020**, *12*, 661. [CrossRef]
33. Malczewski, J. *GIS and Multicriteria Decision Analysis*; John Wiley & Sons: New York, NY, USA, 1999.
34. Saaty, T.L. A scaling method for priorities in hierarchical structures. *J. Math. Psychol.* **1977**, *15*, 234–281. [CrossRef]
35. Pereira, J.M.; Duckstein, L. A multiple criteria decision-making approach to GIS-based land suitability evaluation. *Int. J. Geogr. Inf. Sci.* **1993**, *7*, 407–424. [CrossRef]
36. Malczewski, J. GIS-based land-use suitability analysis: A critical overview. *Prog. Plan.* **2004**, *62*, 3–65. [CrossRef]
37. Haaland, C.; van Den Bosch, C.K. Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban For. Urban Green.* **2015**, *14*, 760–771. [CrossRef]
38. Hereher, M.E.; Al-Awadhi, T.; Mansour, S.A. Assessment of the optimized sanitary landfill sites in Muscat, Oman. *Egypt. J. Remote Sens. Space Sci.* **2020**, *23*, 355–362. [CrossRef]
39. Akhtar, S.; Ahmad, S.; Huifang, W.; Shahbaz, A.; Ghafoor, A.; Imran, S.; Zafar, A. An analysis of wastewater irrigation practices and its impacts on the livelihood generation and food chain contamination in Faisalabad District, Pakistan. *ISABB J. Health Environ. Sci.* **2018**, *5*, 33–42. [CrossRef]
40. Kanwal, S.; Sajjad, M.; Gabriel, H.F.; Hussain, E. Towards sustainable wastewater management: A spatial multi-criteria framework to site the Land-FILTER system in a complex urban environment. *J. Clean. Prod.* **2020**, *266*, 121987. [CrossRef]
41. Abushammala, M.F.; Qazi, W.A.; Frrag, S.; Alazaiza, M.Y.; Younes, M.K. Site selection of municipal solid waste incineration plant using GIS and multicriteria decision analysis. *J. Air Waste Manag. Assoc.* **2022**, *72*, 1027–1039. [CrossRef]
42. Alalouch, C.; Al-Hajri, S.; Naser, A.; Al Hinai, A. The impact of space syntax spatial attributes on urban land use in Muscat: Implications for urban sustainability. *Sustain. Cities Soc.* **2019**, *46*, 101417. [CrossRef]

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