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GIS-Based Decision Support System for Safe and Sustainable Building Construction Site in a Mountainous Region

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Abstract: The site selection process for a building entails evaluating a variety of factors with varying degrees of importance or percentage influence. In order to ensure that critical site selection factors are not overlooked, a methodology for calculating a building's safe site selection must be developed. The study identified three broad aspects widely considered in site selection, namely environmental, physical, and socioeconomic criteria. To assess the safest site selection of residential building construction for sustainable urban growth, we used GIS-based multi-criteria decision-making approach that combined Fuzzy-AHP and weighted linear combination (WLC) aggregation method used to calculate the SSPZ. The final safe site suitability map was generated by aggregating all aspects such as geophysical, socio-economic and Geo-environmental thematic layers and their associated Fuzzy-AHP weights using the weighted linear combination method. The sites potential index's mean value of 0.513 with standard deviation of 0.340, minimum and maximum GeoPhySSSI are 0.0 and 0.91, respectively, SSS index is classified into zones by histogram profile using natural breaks (jenks)" Subsequently, safe sites identified and divided into six classes namely no construction, very low suitable site low suitable site, moderate suitable site, high suitable site, and very high suitable site." According to the statistical analysis, 3.64% and 32.12% of the total area were under very high and high SSSZ, while 26.40% and 6.22% accounted to the moderate and low suitable potential, respectively" Our findings suggest that integrating the fuzzy collection with AHP is highly desirable in terms of alternative and decision-making effectiveness. The study reveals that the areas of high and moderate suitability are located near existing habitant area, major roads, and educational and health services; they are not located in restricted/protected areas or are vulnerable to natural hazards. The findings indicate that unsuitable and less-suitable land uses such as vegetation, protected areas, and agriculture lands cover nearly one-third area of Abha-Khamis Mushyet regions, implying that using Fuzzy-AHP and GIS techniques will significantly aid in the conservation of the environment. This would significantly mitigate adverse effects on the ecosystem and climate.

Keywords: safe site selection; MCDA; Fuzzy-AHP; Abha-Khamis Mushayet Twin cities

1. Introduction

Kingdom of Saudi Arabia is a major oil exporter, accounting for 15.7% of world oil production in 2014 [1]. Saudi Arabia's construction industry has grown in response to the country's rapid population growth as a result, demand for new buildings increases, resulting in increased resource utilization [2]. As a result, the Saudi government formed the "Saudi Green Building Council (SGBC)" in 2010 to encourage the use of sustainable building concepts in construction projects [3,4].

Site selection, as one of the fundamental concepts of building planning, is critical and has a direct impact on the design of an ongoing construction [5]. The relationship between a site and its surroundings has a significant impact on the design decisions made by architects and engineers. Building site conditions vary depending on the type of occupancy. For example, a site that is optimal for residential buildings may not be suitable for other types of structures. As a result, different buildings proposed for different purposes have different site selection criteria and considerations. Civil Engineers and Architects play an important role in site selection and involve significant contributions. Their level of expertise is determined by their knowledge and experience, which leads to differences in location-based decisions. In most cases, their site selection decisions are based on basic estimates, prior knowledge, or even personal preference. The conventional method of site selection involves a group of experts from different fields working together to choose the best choice based on available data and spatial variables [6].

The aim of site selection is to find the best location for a building in a given area [7]. A project's success or failure is primarily influenced by the site selection. Project failure is often caused by an unsuitable building site, especially in developing countries [7]. The best site is one where a building can be constructed with the least amount of resources (personnel and equipment, material, machinery, time and money) and is logistical and economical feasible, sufficient, and secure for potential expansions [8].

Urban sustainability has become a growing significance for construction projects in recent years. Sustainable construction initiates with the selection of an appropriate/safe site [8]. The location of a building has a significant impact on a variety of factors, including the environment, security, safety, energy consumption, and accessibility, as well as the impact on the local environmental conditions and the use/reuse of existing infrastructure [9]. "Engineers and architects responsible for site selection should be familiar with sustainability concepts and their implications for the overall safety and performance of a building. As a result, the importance of professionalism in safe site selection increases significantly".

One of the most important aspects of planning is the site selection method for building construction [10]. The site selection process for a building construction is heavily influenced by environmental and economic factors in addition to a set of physical parameters. The cumulative impact of these factors examines the level of appropriateness and also assists to categorize the land into several zones. Analyzing land use/land cover, landscape factors, topographical factors, geology, physiography, and distance from road, existing construction or build-up area, among other items, can be used to determine the physical parameters of the land and which is much amenable to GIS analysis. In contrast, defining and analyzing economic pressures on urban land is extremely difficult. However, the assessment of physical parameters gives an identification of the limitations of the land site selection for a building construction. The concept of limitation stems from the land's quality. If the slope is steep, for example, the limitations it imposes are greater than those imposed by land with gentle slopes or flat terrain. In practice, this means that developing high slope land will require significant resources (finance, manpower, materials, time, etc.) and thus would be less desirable than developing flat land, which requires much fewer resources. The constraints in terms of terrain characteristics (landform) and their suitability for site selection for a building construction use must be evaluated.

The site selection process for a building entails evaluating a variety of factors with varying degrees of importance or percentage influence. It is determined by the significance of locational and topographical factors that are constantly changing as a result of changes in building size, building requirements, technology, safety provisions, and topological factors. To ensure that critical site selection factors are not overlooked, a methodology for calculating a building's safe site selection must be developed.

Various methods for solving site selection problems have been established over the last three decades. Several techniques for safe site selection presented in the literature [11–17]. Selection techniques range from heuristic to exact methods, depending on the complexity of the location problem. SBC 901 [3], have prescribed guidelines, handbooks, and other established practices, which are also adopted in developing countries such as Saudi Arabia. "2D (Two-dimensional) charts, plans, and drawings are commonly used in site selection. Strong 3D (three-dimensional) models and CAD-based 3D models are also used to reflect the concepts of architects and engineers [18]". The visualization is the main subject of CAD-based 3D modeling. However, site selection necessitates additional geospatial analysis capabilities that CAD-based systems lack.

In Mountainous region such as Aseer region, safe site selection must take into account land use/land cover, slope stability, landslides, topography, and drainage network, as well as mitigating negative environmental effects. These factors have a major effect on the building process as well [19]. Additionally, architects and civil engineers require geoinformation about a building's neighbourhood in order to determine the building's reliance on existing facilities/utilities. Without GIS, such dependence is difficult to model. In use of GIS enables the visualization and analysis of the effects of situating a proposed facility adjacent to existing facilities [20]. Expanding GIS accessibility opens new opportunities and prospects for researchers and structural engineers [21]"Additionally, GIS is beneficial for promoting spatial navigation, infrastructure planning, and regional sustainability [22].

The geographical and topographic characteristics of a region are critical in site selection. Keeping these factors in mind, architects and engineers use GIS for the purpose of creating, storing, and sharing three-dimensional models of a structure and its surroundings [23,24]. The literature suggests that GIS should be used to select sites for shopping-malls [5], real estate projects [25], and disposal site for municipal waste [26], as well as to assess the effect of buildings on the landscape when selecting a location [27]. "Additionally, the applicability of building information modeling in a geospatial environment was examined to aid in the site selection process [28]". According to Karan and Ardeshir [29], "GIS is an effective tool for assessing safety and quantifying various hazards associated with construction sites". According to the review of GIS-based MCDA approaches, spatial decisions based on GIS seek to concisely identify the most suitable sites for infrastructural development [30]. Long et al. [31] proposed a GIS-based planning support system for identifying and analyzing development control factors. Carsjens and Ligtenberg [9] developed a GIS-based support tool that incorporated environmental concerns into local spatial planning. Through the assessment of environmental sustainability, rational solutions result in the production of environmental natural resources and the conservation of areas [32].

There are tools that we can use to make complex decisions. They are called multi-criteria decision-making (MCDM) methods. In multi-criteria decision making, one of the issues is that the input data isn't always accurate, and it's hard to figure out how to estimate a numerical value that's written as a word [33,34]. Weights are assigned to different thematic layers and associated feature classes based on expert opinion and location-specific conditions. For the computation of the thematic parameter's relative relevance, several researchers employed the analytical hierarchy process (AHP) [35–37]. The AHP approach for MCDM has been widely utilized and successfully implemented in the disciplines of environmental management, ecological impact analysis, and regional planning [38,39]. The importance of AHP's graphical user interfaces (IGUs), automatic priority and variable computation, and sensitivity analyses in this area has grown even more [40]. Despite the popularity, decision-makers do not effectively deal with the imprecision and inherent uncertainties associated with the geoscientific representation of a crisp number [39]. Many studies that have looked at the theoretical validity and empirical effectiveness of AHP [41], with the focus on four main areas: axiomatic foundation, correct understanding of priorities, 1–9 measurement scale, and rank reversal problem [42]. Most of the critics' concerns have been partially addressed in these areas, primarily three-level hierarchical structures [43]. In the AHP method, decision-making problems are organized hierarchically at different levels, with a finite number of elements at each level. In many cases, however, the decision-preferred maker's model is imprecise and fuzzy, making crisp numerical values of comparable proportions based on subjective perception extremely difficult [40] Due to insufficient information or knowledge, as well as uncertainty about decision-making, decision-makers' level of preference may be subjective and ambiguous. In the assessment of uncertainty, AHP can be coupled with fuzzy logic methods [44] and the use of fuzzy membership functions (FMFs) to set up a framework for the evaluation and consistency of the criteria [45]. The theme criteria in the MCDM framework is standardized using fuzzy sets by assigning each item a membership or non-membership function of each criterion [45,46]. Coupling an AHP with a fuzzy set theory allows for additional freedom in the analysis of the findings and relating to decision.

In recent decades, the AHP approach for MCDM has been widely employed and successfully applied in geospatial zonation mapping, including groundwater, landslide, and so on [38,39]. Despite its widespread use, however, AHP has been critiqued for failing to appropriately address the inherent uncertainties and imprecision that come with mapping a decision-perspective maker's to crisp numbers [40]. Further, Furthermore, the AHP method for MCDM has been used for safe site selection of residential building construction for sustainable urban growth [11]. However, due to the flexibility of fuzzy membership functions, none of the studies using the integration of fuzzy set theory with MCDA, and in specific with FAHP, will lead to an improvement in the accuracy of safe site selection of residential building construction potential maps. Based on this setting, the current paper uses an integrated strategy of RS and GIS with Fuzzy-AHP to produce thematic data layers for safe residential building site selection for sustainable urban growth in the Abha-Khamis Mushyet regions of Saudi Arabia. Secondly, while the use of GIS in site selection has been researched, the use of GIS in safe site selection that incorporate environment, safety, security, accessibility, and energy consumption, for commuting the impact on the local ecosystem has not been thoroughly investigated Site selection for a building in mountainous areas where topography is significant cannot be accomplished without the geospatial modeling and analysis capabilities provided by GIS [47,48]" Site selection entails an extensive integrated geospatial data, as well as spatial safety requirements, which can all be efficiently managed in a GIS platform. Hence, this research is mainly focused on how to determine a safe site selection based on GIS-MCDM methods. The main objective of this study to develop integrated techniques of RS, GIS with Fuzzy-AHP for the safe and sustainable site selection of a building construction site in a mountainous region and analyze the project site location and its long-term integration with the community b) Conduct a sensitivity analysis to identify the most important factors that influence the identification of safe and sustainable building construction zones. Our findings imply that combining the fuzzy incoupled with AHP is very desirable in terms of alternative and decision-making efficacy, which can assist decision-makers, policymakers, and the construction sector in making successful and sustainable land use decisions.

2. Materials and Methods

In the Abha-Khamis-Mushayet twin city, current research demonstrates the use of various sources of knowledge for safe site selection for building construction. Neither current standards' techniques nor approaches highlight any form of aspect needed for safe site selection in mountainous regions. This shortcoming necessitates the identification of numerous factors that may assist construction professionals in properly locating facilities/utilities in mountainous regions [11]. This study established three broad aspects commonly considered in site selection, namely environmental, physical, and socio-economic criteria, through a review of the literature. To assess these three key components and recognize additional factors affecting safe site selection in mountainous regions, a systematic investigation was carried out by sending survey questions to construction professionals working in government/private agencies in the Asir regions of Saudi Arabia. Five of the questionnaires sent to international experts received responses. These five foreign construction management experts also discussed the relative importance of many variables (location evaluators) that could affect secure site selection. Municipalities, stakeholders, structural engineering, and architecture professors were also consulted for their opinions on the relative importance of theme and feature categories. Following the extensive literature review and expert opinion, numbers of themes were selected for this research. Figure 1 depicts the approach used in the study region to model appropriate safe site selection.

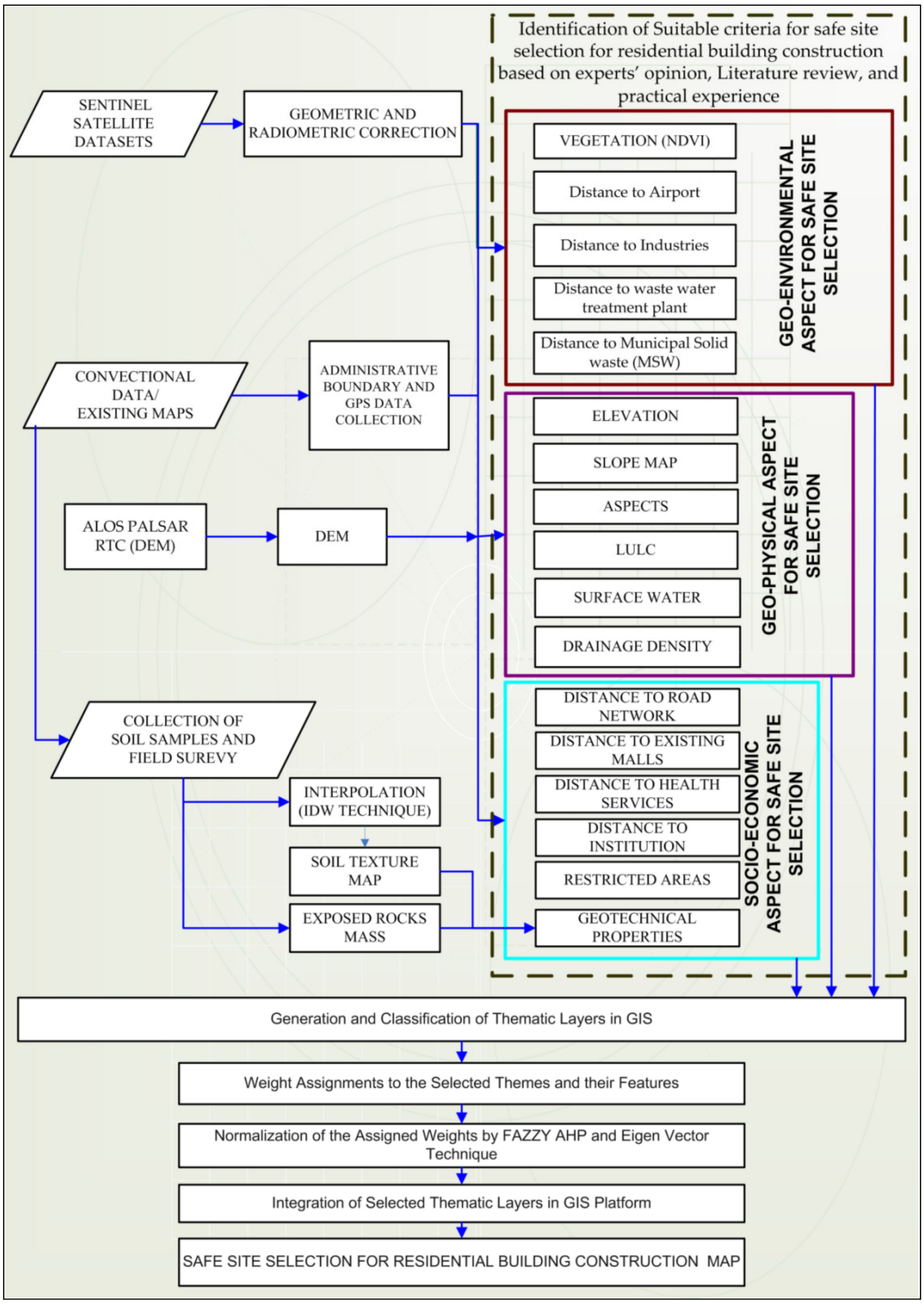

Figure 1. General methodology adopted in the study region to model appropriate safe site selection.

2.1. Description of Study Area

The twin cities of Abha-Khamis Mushayet (Figure 2) in Saudi Arabia's south-western province were chosen for this research. The urban high hills are a popular tourist destination with the most diverse flora and fauna in the Asir region and Saudi Arabia [49]. The study site covers a total area of 1291 km^2 and is dominated by "*J. procera trees*, *Acacia origena* and *A. gerrardii*". The boundary of the Abha-Khamis Mushayet twin cities extends between the latitude of 18°9′33.126″ N to 18°30′56.566″ N latitude and 42°23′52.477″ E to 42°51′42.832″ E longitude and the elevation ranges from 1557 m to 2743 m above sea level, with an average of 2102 m. During February to June months, the region is prone to heavy rain, and some of its neighbouring villages and rural areas have experienced flash floods.

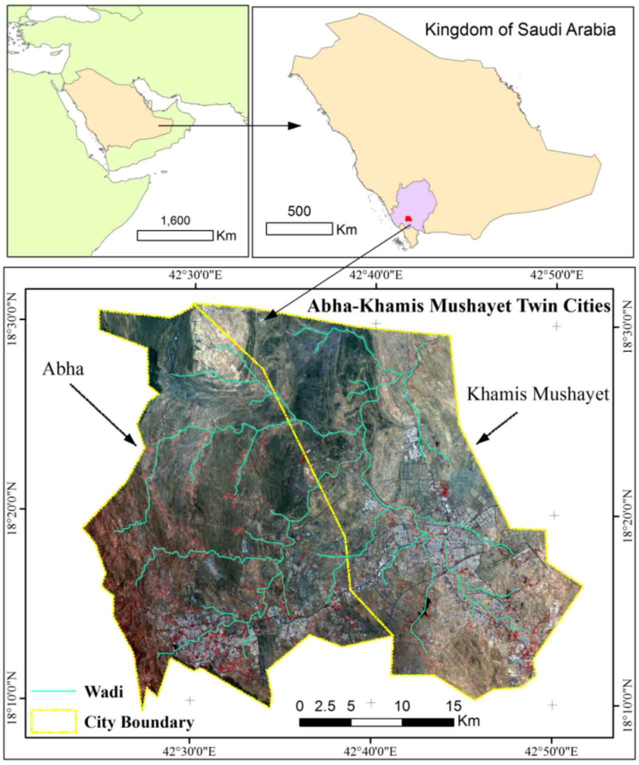

Figure 2. Study Area.

The average annual rainfall for the last 55 years (1965–2019) is 245 mm, from which most of the rainfall occurs during February to June months while the average minimum and maximum air temperature is 9.4 °C and 30.8 °C, respectively. "According to the Saudi Geological Survey, the area is underlain predominately by upper Proterozoic metamorphosed volcanic and sedimentary rocks of the Bahah, and Jiddha group and by upper Proterozoic plutonic rocks ranging in composition from Gabbro to granite". Natural geological erosion and sedimentation phenomena of high severity, as well as man-made accelerated land degradation processes, characterize this eco-region. In terms of terrain variety, the watershed has a varied geography. It is situated in a significant area of Afromontane, with a cold and semi-arid climate [50].

2.2. Data and Material Used

Sentinel datasets are used in this project. The Satellite data is used for preparation of land use/land cover maps, NDVI, Road, etc. Satellite images: Sentinel cloud-free data with 10 m spatial resolution was collected from the Earth explorer website's archives on 8 February 2019. "NASA's Earth Science Data Systems provided the digital elevation model (DEM) [51] ALOS PALSAR RTC (radiometrically terrain corrected) with a resolution of 12.5 m". Field survey and reconnaissance survey were conducted from 1 January to

12 February 2020, from various locations to verify the various LULC categories and to identify the location of the existing building construction site.

2.3. Generation of Thematic Maps

In order to assess the safe site selection for building construction in the study area, number of thematic maps developed based on experts opinions and literature review, viz., drainage density, land use/land cover (LULC), slope, vegetation (NDVI), distance from the airport, distance from road, distance from industries, distance from school, distance from existing mall, distance from MSW, distance from waste water treatment plants, distance from hospital, aspect, and geotechnical properties were created by combining remote sensing and traditional data with the help of GIS software. From the ALOS PALSAR RTC (radiometrically corrected) DEM data, topographic elevation, slope, and drainage density were created. A details geotechnical analysis has been carried out (Field survey + laboratory analysis). The factors considerations for safe site selection residential building construction are categorized into three broad groups such as Geo-Environment aspects, Geo-Physical aspects and socio-economic aspects. The details are describe as below mentioned.

2.3.1. Geo-Environment Aspect for Safe Site Selection

Since our main objective is to achieve safe and sustainable development, the preservation of habitats and natural resources is critical. The future urban area should not have an adverse impact on the environment, especially in ecologically sensitive areas; flora and fauna must be taken into account when developing new urban areas. Forests, green areas, agriculture, and restricted areas should be maintained and protected in order to expand the city with less damage and detrimental effects on nature and the environment [52]. It is now relatively simple to build a resilient, livable, ecological, and sustainable city using science and technology and forward-thinking approaches.

Vegetation: A vegetation index is a numerical value calculated from remotely sensed data that is used to quantify the amount of vegetation on the earth's surface. To estimate vegetation cover, a variety of vegetation indices have been developed; the most widely used index is the "Normalized Difference Vegetation Index (*NDVI*)". A spectral index's fundamental algebraic structure is that of a ratio between two spectral bands: red and near infrared (*NIR*). This index is calculated as follows (Equation (1)):

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \tag{1}$$

The *NDVI* calculation for a given pixel always produces a value between minus one (-1) and one (+1). (1). without green leaves, the value is close to zero. A value of zero indicates no vegetation, while a value close to one indicates the maximum density of green leaves possible. The current study determined the vegetation status using Sentinel datasets and the "*NDVI*". To grow the city sustainably and without causing harm to nature or the environment, forests and green spaces should be maintained and protected [52]. Today, through the application of science and technology, as well as forward-thinking approaches, it is very simple to build a resilient, livable, ecological, and sustainable community. To accomplish this, a vegetation map of the study area was created using *NDVI*, with values greater than 0.2 implying low suitability as per the environmentalists' and architects' opinion.

Distance to Industries: The safe site selection of residential building construction area should be at least 1 km from industrial areas due to noise, pollutions and traffic problem (https://www.esri.com/news/arcuser/0708/growthmanager.html, accessed on 28 December 2021). To avoid Industries site, buffer zones were established and the map was reclassified and graded according to the buffer distances. Areas more than 1000 m from industries were deemed vulnerable and unsuitable, and the ranking score increased as the distance increased.

Distance to Waste water treatment Plant: The safe site selection of residential building construction area must be at least 1 km away from the waste water treatment plant due to health prospective. To avoid waste water treatment plant area, buffer zones were established and the map was reclassified and graded according to the buffer distances. Areas more than 1000 m from waste water treatment plant (as per expert's opinion) were deemed vulnerable and unsuitable, and the ranking score increased as the distance increased.

Distance to Municipal Solid waste (MSW) site: The safe site selection of residential building construction area should be kept safely away from MSW due to health prospective [53]. To avoid MSW, buffer zones were established and the map was reclassified and graded according to the buffer distances. Areas more than 3000 m from MSW were deemed vulnerable and unsuitable (as per experts' opinion), and the ranking score increased as the distance increased.

Distance to Airport: The safe site selection of residential building construction area should be located at least 3 km from the airport. Noise from airport operations, areas impacted by aircraft landing patterns, and areas that would conflict with airport radar could all be reasons for exclusion zones [54].

2.3.2. Geo-Physical Aspect for Safe Site Selection

Land use/land cover map: The maximum likelihood classifier was used to classify the image using Sentinel data. The accuracy evaluation is an important part of analyzing the classification image's outcome. Overall accuracy, producer accuracy, consumer accuracy, and the kappa coefficient are all indicators of classification results. For quantitative analysis of LU/LC classification accuracy, the uncertainty matrix was used. A random sampling approach was used to verify the accuracies of the classified photographs, with a total of 108 sample plots. The reference data was gathered during a field visit

Distance from Drainage network: We may infer that the area protected by wadi and drainage should be conserved to the greatest extent possible based on the proximity of drainage network. The main source of water is wadi and drainage. Agriculture, forestry, and many other ecosystems depend on it. As a result, nothing should be built inside a 100-m buffer zone, and special attention should be paid to preserving it. A combination of remote sensing and a topographic map can be used to extract drainage distribution [53]. When integrating into a GIS platform, buffering analysis is needed. The Euclidean distance was used to calculate the distances away from or outward from the drainage network. The first control point (near drainage network) demonstrates the least suitable distance for siting a residential building, while the second control point (farther from drainage network) demonstrates the most suitable distance for safe site selection for building construction.

Slope: The ratio of rise to fall is defined as the run between two points divided by the rise/fall ratio. It denotes the grade, incline, or steepness. Cutting a hill slope causes ecological damage and slope instability in adjacent areas [55]. As a result, cuttings shall be avoided unless appropriate precautions are taken to avoid such damage and to ensure site safety. According to the IBC [55], no construction should be undertaken in areas with slopes greater than 30% or in areas classified as landslide hazard zones. Slope is a critical criterion for selecting suitable urban development sites in mountainous terrain. Slopes that are too steep are troublesome for construction. Slopes that are steeper increase construction costs, limit the available floor area, and contribute to erosion during construction and subsequent use. A slope of 10 degrees is considered a gentle slope with the greatest degree of significance [56]. Slopes greater than 10 degrees have been deemed unsuitable for construction due to the increased cost. "ALOS PALSAR RTC DEM data was used to compute pixel-based terrain slope ranging from 0° to 60°, Based on the above considerations, weight values with a slope value of 30–68° were classified the lowest and low slope (0–10°) areas considered to be very suitable and assigned the highest weight values".

Aspect: In general, the term "aspect" refers to the horizontal direction that a mountain slope faces. In the northern hemisphere's midwinter, north facing slopes receive very little solar heat. In comparison, south-facing slopes receive significantly more heat. As a result, slopes facing south are generally warmer than those facing north. In hilly areas, residents prefer to build their homes on sunny slopes. Thus, southern-facing slopes have a greater degree of significance. East facing slopes receive sunlight only in the morning, when temperatures are cooler, whereas west facing slopes receive sunlight in the afternoon, when temperatures are warmer. As a result, slopes facing east are colder than slopes facing west [57]. "ALOS PALSAR RTC DEM data was used to compute pixel-based terrain aspects".

Surface water (dams and lakes): A single buffer ring is created approximately 100 m around the study area's water bodies. Water bodies are critical for both rural and urban populations. Water bodies are used to store rainfall water that can be used on other days of the year and its important parameters for hydrological balance, which is why the area within 250 m of water bodies should be left undeveloped in order to prevent pollution and to keep the water bodies safe and conserved.

2.3.3. Socio-Economic Aspect for Safe Site Selection

Distance to Road Network: The safe building construction sites must be accessible under any conditions. Due to the need to transport raw materials and finished materials, the presence of a road is a significant criterion in site suitability. In hilly areas, constructing a new road is costly. As a result, every attempt is made to locate the site as close as possible to every existing road. Furthermore, buffer zones have been established at a 100-m distance from the road in order to improve connectivity to the existing road [57]. The further away a property is from the road and the more difficult it is to access, the higher the transportation expenses and discomfort. Remote sensing data can be used to identify the distribution of roadways. Buffering analysis is essential when interacting with a GIS platform. The continuous distances away from or toward the road network were calculated using the Euclidean distance. The first control point (near to the road) suggests the best location for a building site, whilst the second control point (far from the road network) indicates the worst location for a construction site.

Distance to health services: Health care is also a significant factor in determining the best place for residential buildings [53]. A buffer zone was developed for health care facilities. The Euclidean distance was used to calculate the continuous distances away from or away from the health services. The first control point (closer to the health services) shows the most suitable location for a site, while the second control point (further from the health services) indicates the least suitable location for a construction site.

Distance to Shopping Malls: The proximity of shopping malls was also considered when determining the best locations for residential building. Residents tend to shop in places that are near to their homes rather than in locations that are farther away. Buffer zones were created. The Euclidean distance was used to calculate the continuous distances away from or away from the shopping malls. The first control point (closer to the Shopping Malls) shows the most suitable location for a site, while the second control point (further from the Malls) indicates the least suitable location for a construction site (as per experts opinion).

Distance to Institutions: The proximity of institutions (such as schools, college, university etc.) was also considered when determining the best locations for residential houses. Residents tend to acquire easy access to the institution places that are near to their homes rather than in locations that are farther away. Buffer zones were created. The Euclidean distance was used to calculate the continuous distances away from or away from the shopping malls. The first control point (closer to the Shopping Malls) shows the most suitable location for a site, while the second control point (further from the Malls) indicates the least suitable location for a construction site (as per experts opinion).

Restricted Areas: As a sub-criterion of the safety factor, the map of protected/restricted areas was used. Civil defense, archaeological sites, and a containment area were included in the restricted area. Protected and restricted areas were surrounded by buffer zones, and areas separated by more than 500 m were considered suitable locations (as per experts' opinion).

Geotechnical properties: The soil type within the study area is critical in determining the type of structure that can be constructed there. The type of soil used to build a structure has an effect on the rate of expansion of the foundation and the type of structure that can be supported. According to Nordin (2010), sandy till is the most common type of soil found in Sweden, and it is regarded as a very good soil type for building houses due to its physical properties. Excavation, which includes cutting and filling the soil, is a critical step in infrastructure construction projects. However, excavation-related accidents have increased significantly, affecting project costs, people, and social life. The investigation of geotechnical properties is a necessary step and is regarded a requirement for determining the feasibility of the site for the proposed development, allowing for a safe and cost and time effective design. Due to its high bearing capacity, rock is an excellent choice for the construction of larger structures. Due to their high bearing capacity, rocks pose a low danger of cracks or fissures forming in a structure. However, solid rock, such as bedrock, is one of the best soil types for house construction. It is capable of supporting large structures [58]. For the purposes of this study, sandy till is deemed to be the optimal soil type for residential construction. Additionally, bedrock has favourable physical properties.

In this study, an extensive field survey has been carried out for collecting the soil sample based of soil moisture, i.e., NDMI data Soil samples were collected from a variety of locations within the study region. A total of 88 soil samples were obtained from the study area (0–30 cm depth) using a GPS navigator. Soil sampling is carried out using a stratified composite technique, and the field is subdivided into areas of varying elevations, LULC values, and soil moisture values. The site is then surveyed separately, with two replicates taken two to three meters apart at each survey site. Each specimen is carefully weighed and sieved through a 2 mm mesh, and then analyzed in the laboratory for soil texture and organic matter using the Carter [59] standard procedure. The hydrometer approach is used to calculate the grain sizes of the soil (texture analysis) (Stokes law). The watershed recognized five soil classes: sandy loam, loam, loamy sand, silt loam, and sandy clay loam. Sandy loam infiltrates rapidly when wet and is thus classified as a highly drained soil. Owing to their low infiltration rates, silty loam and sandy clay loam are considered low drained soils, making them ideal for building construction sites.

2.4. MCDM: Fuzzy Set Theory

In MCDM [60], Zadeh's "fuzzy set theory" is a modeling technique for simulating a complex system that is difficult to describe in crisp numbers. Fuzzy set theory [60] was frequently used to model decision-making processes that included ambiguous and imprecise data, such as decision-maker preferences. Fuzzy logic provides an incredibly simple method for deriving specific conclusions from confusion, ambiguity, and inaccuracy [61]. When selecting a spatial entity to act as a member on a map, fuzzy logic is used to aid in spatial planning. In classical set theory, also known as crisp set theory, an object is either a member of or not a member of a set. "Because fuzzy set theory allows for the use of feature objects as membership values between 0 and 1, this reflects the degree of the membership function [60]" M is a triangular fuzzy number (TFN), as shown in Figure 3.

TFNs are expressed by $(l/m, m/u)$ or (l, m, u), the lowest possible value, the highest possible value, respectively, the TFN has a linear representation on its right and left sides during its membership term (Equation (2)).

$$\mu\left(x\backslash\widetilde{\mathrm{M}}\right) = \left\{\begin{array}{cc} 0, & x < l, \\ (x-l)/m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & x > u \end{array}\right\} \tag{2}$$

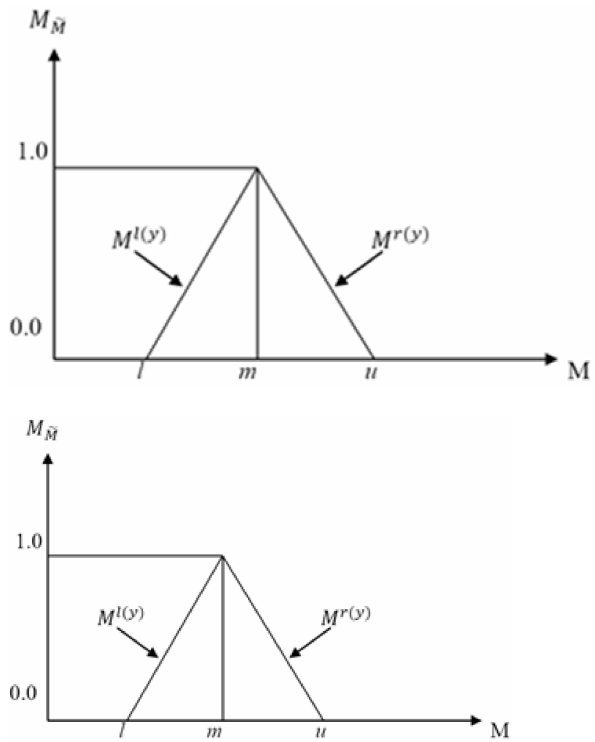

Figure 3. A triangular fuzzy number (TFN) $\widetilde{\mathrm{M}}$.

The following equation shows the fuzzy number of each membership level based on its left and right representation [62].

$$\widetilde{\mathrm{M}} = \left(M^{l(y)},\ M^{r(y)}\right) = (l + m - l)\ y,\ u + (m - u)y) \quad (3)$$

where $l(y)$ and $r(y)$ represent a fuzzy number's left and right sides, respectively.

2.5. Fuzzy Membership Function (FMF)

The "fuzzy set theory" and the primary function of FMF can be used to indicate ambiguous data. In a fuzzy environment, mathematics and coding functions can also be used. "The fuzzy set is an object class defined by a membership function, assigning a membership value from 0 to 1 for each object, and vice versa [60], For safe site selection mapping, the fuzzy set theory makes the definition of a partial location membership considered for multi-class mapping, in this conceptual context, the FMFs have been allocated to the study of spatial variance, and their pattern has led to the creation of fuzzy boundaries for each potential zone". The variance has been attributed to FMFs, and its pattern has resulted in the establishment of fuzzy boundaries for each potential region. The transitions between 1 and 0 are defined using the type of each FMF.

2.6. Feature Data Standardization Using FMFs

Mapping of potential safe sites, generation of feature classes in a variety of units and measurement levels. ordinal, There are four types of estimation scales, nominal, ratio, and interval [63], each of which requires data standardization. To accomplish this, the assessment process incorporates all relevant impact factors for potential safe site selection thematic layer sites into a single production. As a result, a fuzzy membership approach has taken standardization methods into account. The use of fuzzy set theory to map possible safe sites was deemed to produce a more desirable result [64]. As a result, all appropriate site considerations for secure building site selection ranged from zero to one (1). Two membership functions were used in this research to determine the most appropriate safe location, namely, according to the study's objectives and hypotheses. "The linear

FMF (linear decrease or increase in membership between two inputs: linearized sigmoid shape) and categorical FMFs (the expert assigned membership value for each designated class) (Table 1), the first two sigmoidal membership characteristics are commonly used in many fuzzy logic applications and allow for a progressive transition from 0 (non-member) to 1 (full membership) [63], although it is often unavoidable to choose user-defined or categorical membership functions". Table 1 shows membership functions relied on Fuzzy-AHP, such as "(Type I) Linear FMFs" for drainage density, slope, vegetation, distance from waste water treatment plant, distance from Municipal Solid waste site (MSW), distance to Airport, distance from Industries, distance from surface water, distance to road, distance to existing Malls and distance to health services, distance to Institutions and "(Type II) Categorical FMFs" for LULC, aspects, geotechnical properties and restricted areas. All the criteria used for the FMF and subsequent Table 1 shown below.

Table 1. The following is a summary of the criteria's fuzzy standardization.

Cluster	Criteria	"Fuzzy and Shape Membership Functions"	Control Point
Geo-Environmental Aspects	Vegetation (NDVI)	"monotonically decreasing-linear"	C = 0 D = 0.2
	Distance from Waste water treatment plant	"monotonically increasing-linear"	C = 1000 D = 26,000
	Distance from Municipal Solid waste site (MSW)	monotonically increasing -linear"	C = 1000 D = 29,000
	Distance to Airport	Symmetric	A = 3000; B = 3001; C = 6000; D = 40,000
	Distance from Industries	"monotonically increasing-linear"	A = 1000 B = 30,500
Geo-Physical Aspects	Slope	"monotonically decreasing-linear"	C = 10° D = 30°
	LULC	Categorical	User defined Builtup = 0.0; Waterbodies = 0.0 Dense vege = 0.1 Sparse veg, −0.2 Agri = 0.1 Scrub = 0.6 Baresoil = 0.8 Exposed = 0.9
	ASPECT	Categorical	Flat = 1.0; North = 0.2; Northeast = 0.3; East = 0.4; Southeast = 0.6; South = 0.8; Southwest = 0.8; West = 0.6; Northwest = 0.4
	Drainage density	"monotonically increasing-linear"	C = 50 D = 5000
	Surface water	"monotonically decreasing-linear"	C = 500 D = 31,000
Socio-economical aspect	Distance to Road	monotonically decreasing-linear	C = 100 D = 6500
	Distance to Existing Malls	monotonically decreasing-linear	C = 500 D = 31,500
	Distance to Health services	monotonically decreasing-linear	C = 500 D = 31,000
	Distance to Institutions	monotonically decreasing-linear	C = 500 D = 30,000
	Restricted Area	Categorical	
	Geotechnical properties	Categorical	User defined Exposed rock = 1.00 Sand = 0.8 Sandy loam = 0.6 Loamy sand = 0.4 Loam = 0.2 Silty loam = 0.2 Sandy clay loam = 0.1

2.7. Weights Assignments and Normalization

Five experts (construction management and architects) are interviewed through a series of questionnaires in the research areas of construction management and architecture. The questionnaires are explicitly designed to elicit their perspectives on the relative importance of safe site selection criteria variables affecting the establishment of safe sites selection for residential building construction. Additionally, local environmentalists/structural engineers and architects were consulted for their perspectives on the subject and its feature classes through questionnaires. Saaty [38] "suggested weight assignment, but in earlier studies, it was not considered significant". The MCDA often uses the AHP to determine acceptable weights for various standards [38]. AHP determines the weights required to help the chosen matrix with the necessary thematic layers in order to compare and evaluate all defined parameters (thematic layers) [65]. With each choice variable (for example, each location), weights and criterion values have been combined to form a single scalar value representing the variable's relative power. Since conventional AHP does not adequately represent the human choice, the AHP aims to consider expert knowledge. To address fuzzy hierarchical issues, the Fuzzy upgrading of AHP (termed Fuzzy-AHP) was created. The Fuzzy-AHP method was used to perform fuzzy hierarchical analysis in this research, allowing fuzzy numbers to be combined to calculate fuzzy weights. The following measures were taken into account when determining the weights assigned to the evaluation criteria using an FAHP [66]. ***Step I:*** All parameters in the dimensions of the hierarchy structure used to create pairwise comparison matrixes, In each case, which of the two parameters was more important, the linguistic concepts applied to the pair-wise evaluations as follows (Equation (4)).

$$''\widetilde{A} = \begin{bmatrix} \widetilde{1} & \widetilde{a}_{12} \cdots & \widetilde{a}_{1n} \\ \widetilde{a}_{21} & \widetilde{1} & \widetilde{a}_{2n} \\ \vdots & \vdots \ddots & \vdots \\ \widetilde{a}_{n1} & a_{n2} \cdots & \widetilde{1} \end{bmatrix} = \begin{bmatrix} \widetilde{1} & \widetilde{a}_{12} \cdots & \widetilde{a}_{1n} \\ 1/\widetilde{a}_{21} & \widetilde{1} & \widetilde{a}_{2n} \\ \vdots & \vdots \ddots & \vdots \\ 1/\widetilde{a}_{n1} & 1/a_{n2} \cdots & \widetilde{1} \end{bmatrix} \quad (4)$$

where $\widetilde{a}_{ij}$ measure denotes, let $\widetilde{1}$ be (1,1,1), when i equal j (i.e., $i = j$); if $\widetilde{1}$, $\widetilde{2}$, $\widetilde{3}$, $\widetilde{4}$, $\widetilde{5}$, $\widetilde{6}$, $\widetilde{7}$, $\widetilde{8}$, $\widetilde{9}$ measure that criterion i is relatively important to criterion j and then $\widetilde{1}^{-1}$, $\widetilde{2}^{-1}$, $\widetilde{3}^{-1}$, $\widetilde{4}^{-1}$, $\widetilde{5}^{-1}$, $\widetilde{6}^{-1}$, $\widetilde{7}^{-1}$, $\widetilde{8}^{-1}$, $\widetilde{9}^{-1}$ measure that criterion j is relatively important to criterion i Fuzzy conversion scale is described in Mallick et al. [67].

"Stage I Buckley's geometric mean method was used to determine the criterion's fuzzy geometric mean and fuzzy weighting [68] Equation (5)",

$$\widetilde{r}_i = \left(\widetilde{a}_{i1} \bigotimes \widetilde{a}_{i2} \bigotimes \ldots. \bigotimes \widetilde{a}_{in}\right)^{1/n} \text{ And then } \widetilde{w}_i = \widetilde{r}_i \bigotimes \left(\widetilde{r}_i \bigotimes \ldots. \bigotimes \widetilde{r}_n\right)^{-1} \quad (5)$$

where $\widetilde{a}_{in}$ is fuzzy comparison value of criterion i to criterion n, therefore, $\widetilde{r}_i$ is geometric mean of fuzzy comparison value of criterion i to each criterion, $\widetilde{w}_i$ i is the fuzzy weight of the ith criterion, can be shown by a TFN, $\widetilde{w}_i = (lw_i, mw_i, uw_i)$. Here lw_i, mw_i, uw_i stand for the lower, middle and upper values of the fuzzy weight of the ith criterion, respectively.

2.8. Group Fuzzy AHP

The Group Fuzzy AHP is a Fuzzy AHP-based multi-criteria decision-making algorithm. The proposed approach to decision making aggregates decision makers' preferences using the geometric mean operator. This algorithm combines AHP and FAHP capabilities. To begin, as is carried out in AHP, acquire evaluation comparison judgments for different alternatives in crisp values. Then, similar to what is carried out in FAHP, crisp values are fuzzified using triangular fuzzy numbers. The arithmetic mean of the fuzzy evaluators' opinions is determined, and a fuzzy pairwise comparison matrix is constructed [69]. The Group Fuzzy AHP steps are as follows [70]: Establish a team of construction management and architectural experts, and define the project's objectives > Create decision matrices for each expert assessment (construction management and architects) > Determine crisp values from linguistic characteristics > Crisp values are fuzzified using triangular fuzzy numbers > Average Comprehensive Fuzzy values using arithmetic mean > Calculate the Comprehensive Fuzzy Pairwise Comparison Matrix > Split the fuzzy pairwise comparison matrix into lower, middle, and upper crisp pairwise comparison matrices > Determine the local weights of each crisp comparison matrix > Using the geometric mean technique, calculate the overall weight.

2.9. Safe Site Potential Zone (SSPZ) Map Development

The study area's safe site potential mapping (SSPM) is built through the integration of feature thematic maps into a GIS environment. The "weighted linear combination (WLC) aggregation method used to calculate the SSSZ [71] using equation 6 as below mentioned".

$$SSPI = \sum_{w=1}^{m}\sum_{i=1}^{n}(wt_j * x_i) \quad (6)$$

where, $SSPI$ = Safe site potential index, x_i = thematic maps (FMF) and wt_j = normalized weight of the jth theme, m = total number of themes, and n = total number of classes in a theme.

2.10. Sensitivity Analysis

The sensitivity test is used to assess the impact of input parameters on model performance results as well as the impact on the parameter or factor state improvement phase [72]. Sensitivity analysis [73] analyzed data on weighted values control and weights applied to each variable. As a result, the effective weights of each criterion are compared to the assigned weight. The weight [73] was calculated using Equation (7).

$$Effective\_weight = \frac{Theme_{weight} * Theme_{scaled}}{LSPI} * 100 \quad (7)$$

where, the weight and scaled value of the theme (theme) assigned to each pixel, respectively, and SSPI is the safe site potential index as calculated from Equation (6).

3. Results

3.1. Geophysical Aspect for Safe Site Selection of Residential Building Constrcution

The investigation of a safe site suitable for construction is a critical component of urban planning. Below are the geophysical factors that influence land suitability. The cumulation of these factors decides the degree of suitability and also aids in identifying the land's urban development limitations. The following are the different map layers created for this purpose.

Elevation: According to the elevation map (Figure 4), Abha-Khamish Mushyet twin cities is situated at an elevation range of 1557 m to 2743 m above sea level, with an average of 2102 m. The higher elevation was found to the western part of the study, which is correspond to Abha city, while the lower elevation found to the north east and eastern part of the map. In the western part of the study area, very high topographic elevation (2482–2743 m AMSL) dominates whereas the moderate topographic elevation (2143–2344 m AMSL) in the western-central and central part. The majority of the area (1557–2142 m AMSL) in 75% part of the total study area is at the lower topographic elevation, making it ideal for safe site selection for residential building construction occurrence. A position at a high elevation, for example, is considered suitable for overhead tanks, whereas a location at a lower altitude is suitable for rain-harvesting water tanks". However, due to the discussion with the expert, in the current study and study specific area location, the elevation component used to calculate the slope and aspect to evaluate the safe site selection for residential building construction.

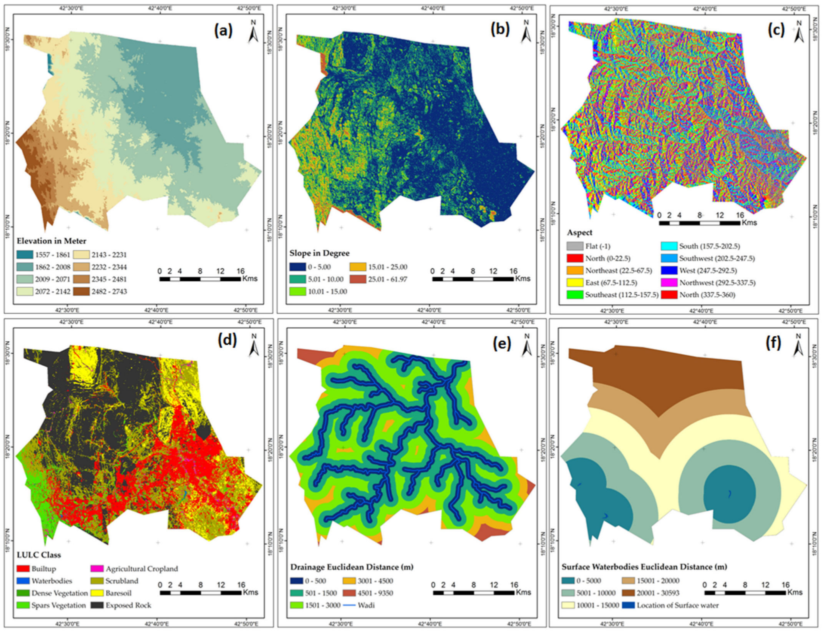

Figure 4. Geophysical Aspect (**a**) Elevation; (**b**) Slope; (**c**) Aspect; (**d**) LULC; (**e**) distance to draiange network; (**f**) distance to surface water) for safe site selection of residential building constrcution of Abha-Khamis Mushyet Cites.

Slope: The slope angle in the study area varies from 0 to 61.97° with an average of 6.06° (std. 5.66). According to the slope map, the majority (i.e., half of the area) of the cities' have a gentle slope of less than 10 degrees (Figure 4b). The study region has a high slope in the western, central north, and central areas, while the east and north-eastern and south eastern parts have a low slope. Cutting a hill slope cause's ecological damage and slope instability in adjacent areas [55]. As a result, cuttings shall be avoided unless appropriate precautions are taken to avoid such damage and to ensure site safety. According to the IBC [55], no construction should be undertaken in areas with slopes greater than 30% or in areas classified as landslide hazard zones. Scores were assigned based on the slope degree after the slope map was reclassified. Areas with a slope of less than 10 degree were considered potentially suitable, and the suitability decreased as the slope increased, with sites with a slope greater than 30 degrees being deemed unsuitable.

Aspect: In hilly areas, residents prefer to build their homes on sunny slopes. South-facing slopes receive significantly more heat than the north facing. As a result, slopes facing south are generally warmer than those facing north. Thus, southern-facing slopes have a greater degree of significance. In similar way, east facing slopes receive sunlight only in the morning, when temperatures are cooler, whereas west facing slopes receive sunlight in the afternoon, when temperatures are warmer. As a result, slopes facing east are colder than slopes facing west. Scores were assigned based on the slope face after the aspect map was reclassified. Areas with a south and east facing were considered potentially suitable, whereas less weightage have been assigned to north and eastern face (Figure 4c).

Land use/land cover: LULC map of 2019 was prepared using supervised classification scheme with MLC algorithm on all bands (reflectance image) because the uncertainties between the classes will be the lowest by using reflectance image than the DNs. The classification result is validated using a confusion or error matrix [74], which found strong agreement (overall accuracy and Kappa coefficient of 93.38 and 0.9112, respectively). Figure 4d depicts the study area's LULC diagram. The results show (Table 2) that exposed rocky land was the dominant land cover/land use in 2019 which had 35.66% of the total area, followed by scrubland (25.85%). Whereas built-up occupies 21.60% and water bodies occupies just 0.04% of the total area. The built-up area occupies significantly high which shows the intensity of sprawling. This change may be due to the scale and nature of economic, social change. Agricultural cropland which includes cultivated land and horticulture accounts 1.38% which is distributed mostly in wadies areas. Apart from this, dense vegetation was occupied only 0.73% and sparse vegetation 5.87% of the total area. Dense vegetation, sparse vegetation, agricultural cropland, buildup land and water bodies are all given a low weight. The exposed rock, baresoil, and scrubland are all assigned to the high weight.

Table 2. Land use/land cover distribution (2019).

LULC	Area in km	% of the Total Area
Built-up	277.45	21.60
Waterbodies	0.52	0.04
Dense Vegetation	9.44	0.73
Sparse Vegetation	75.47	5.87
Agricultural Cropland	17.75	1.38
Scrubland	332.04	25.85
Baresoil	113.94	8.87
Exposed Rocks	458.08	35.66
Total	1284.68	100.00

Drainage density: The average annual rainfall for the last 55 years (1965–2019) is 245 mm, from which most of the rainfall occurs during February to June months. During these months, the region is prone to heavy rain, and some of its neighbouring rural areas (villages) have experienced flash floods [75]. The potential construction area should be far enough away from drainage network to be protected. In addition, water contamination is one of the most important factors in safe site selection; as a result, construction site may not be located near wadies (ponds, lakes, and streams). As a result, in the development of construction site, drainage network areas must be observed. The drainage density is calculated by dividing the total area of a study by the number of all streams (wadis) in the study area [76]. The first control point (near drainage network) demonstrates the least suitable distance for siting a residential building, while the 2nd control point (farther from drainage network) demonstrates the most suitable distance for safe site selection for building construction (Figure 4e).

Distance from the Surface waterbodies: Both rural and urban communities depend on water bodies. Water bodies are critical parameters for hydrological equilibrium. The area within 500 m of water bodies should be left undeveloped in order to prevent pollution and to keep the water bodies safe and conserved. The first control point (near surface water) demonstrates the least suitable distance for siting a residential building, while the 2nd control point (farther from surface water) demonstrates the most suitable distance for safe site selection for building construction (Figure 4f).

3.2. Geoenvironmental Aspect for Safe Site Selection of Building Construction

Geo-Environmental concerns are one of the most critical factors to consider when deciding where to build a residential safe site. As a result, geo-environmental factors including vegetation, distance from Airport, distance from Industries, distance from waste water treatment plant and distance from disposal site of municipal solid waste (MSW) were investigated.

Vegetation (NDVI): When our primary aim is to achieve sustainable development, the protection of ecosystems and natural resources is important. The future urban residential area should not have an adverse impact on the environment, especially in ecologically sensitive areas; flora and fauna must be taken into account when developing new safe site selection of residential building construction. Forests, green areas, agriculture, and restricted areas should be maintained and protected in order to expand the city with less damage and detrimental effects on nature and the environment. In the study area, the vegetation were distributed along the wadies and western part of the study which is correspond to mountainous flora and very rich biodiversity. Hence, these areas need to be protected from the urban development. Scores were assigned based on the NDVI value after the NDVI map was reclassified. Areas with a low NDVI value (less than 0.2) were considered potentially suitable, and the suitability decreased as the NDVI value increased (>0.2), with sites (Figure 5a).

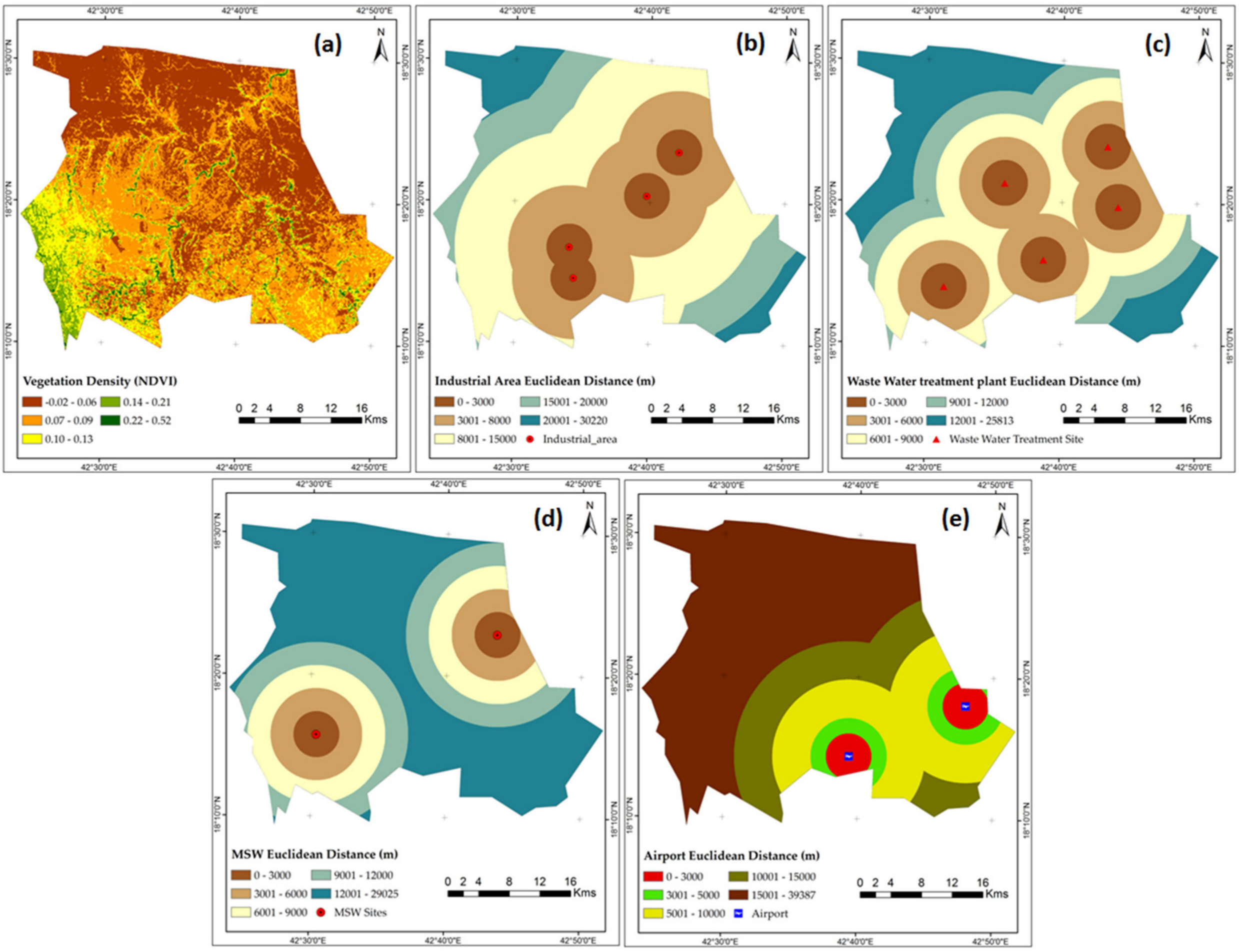

Figure 5. Geoenvironmental Aspect (**a**) Vegetation density; (**b**) distance to industrial area; (**c**) distance to waste waster treatment plant; (**d**) distance to municipal solid waste disposal; (**e**) distance to airport) for safe site selection of building construction of Abha-Khamis Mushyet Cites.

Distance from Industrial area: Owing to noise, pollution, and traffic issues, residential building construction sites should be at least one kilometer away from industrial areas. Figures 4–8 shows the distribution of industrial areas with Euclidean distance. The first control point (1000 m) demonstrates the least suitable distance for siting a residential building, while the 2nd control point (farther from industrial area) demonstrates the most suitable distance for safe site selection for building construction (Figure 5b).

Distance from Waste Water treatment Plant (WWTP): Due to health concerns, the safe site selection for residential building construction must be at least 1 kilometer away from the waste water treatment facility. Figure shows the distribution of waste water treatment plan and Euclidean distance from the waste water treatment plant areas. Buffer zones were defined to avoid the Waste Water Treatment Plant area, and the map was reclassified and graded based on the buffer distances (Euclidean distance). The first control point (1000 m) demonstrates the least suitable distance for siting a residential building, while the 2nd control point (farther from WWTP area) demonstrates the most suitable distance for safe site selection for building construction (Figure 5c).

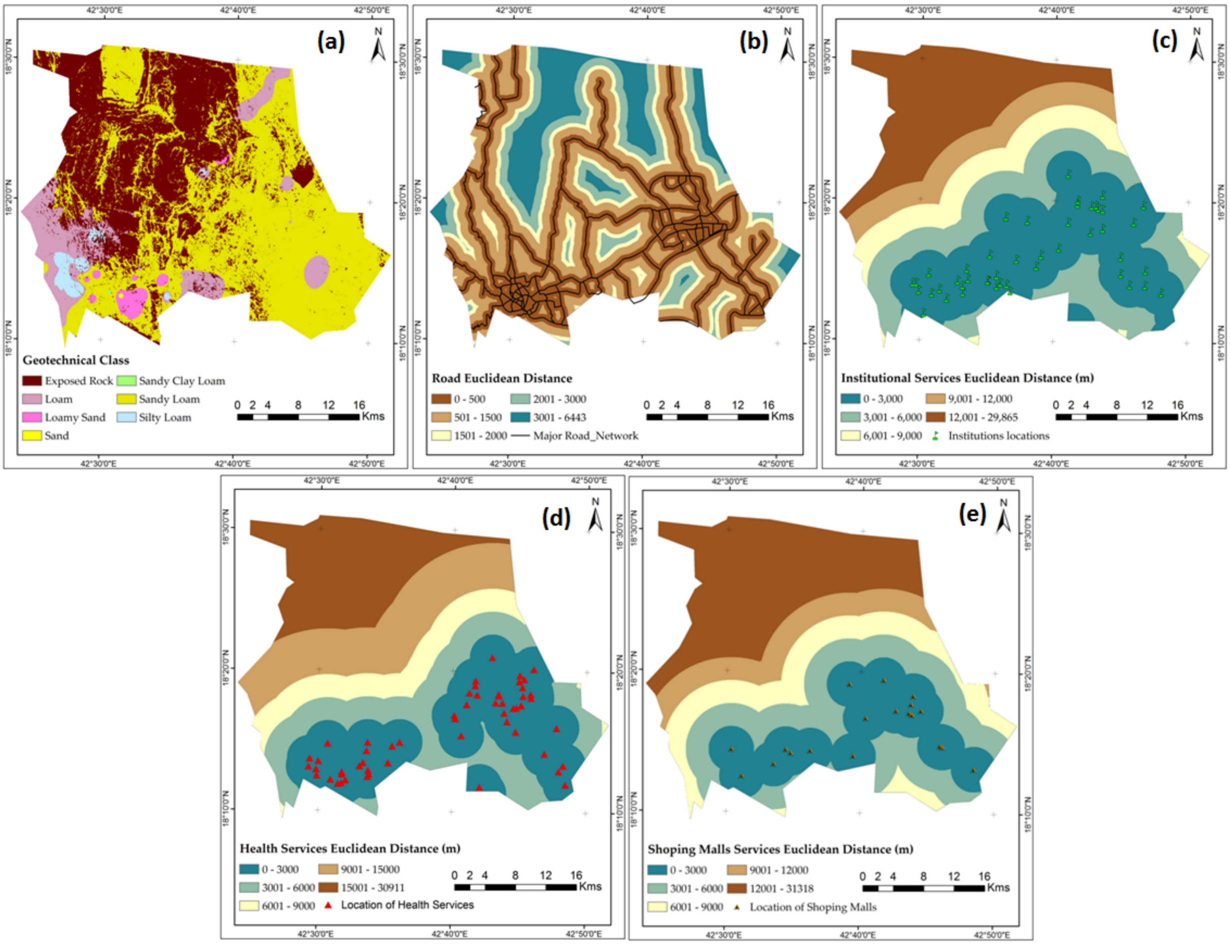

Figure 6. Socio Economic aspects (**a**) geotechnical properties; (**b**) distance to road network; (**c**) distance to institutional services; (**d**) distance to health services; (**e**) distance to shopping malls) for safe site selection of building construction of Abha-Khamis Mushyet Cites.

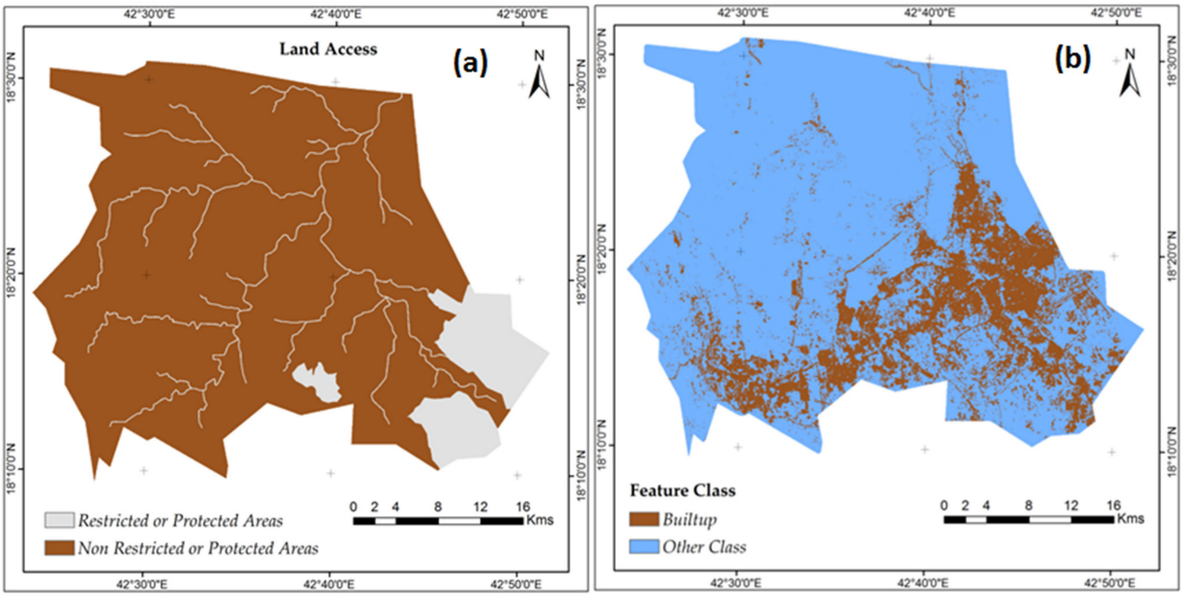

Figure 7. Restricted/Protected area (**a**) and builtup (**b**) in Abha-Khamis Mushyet cities.

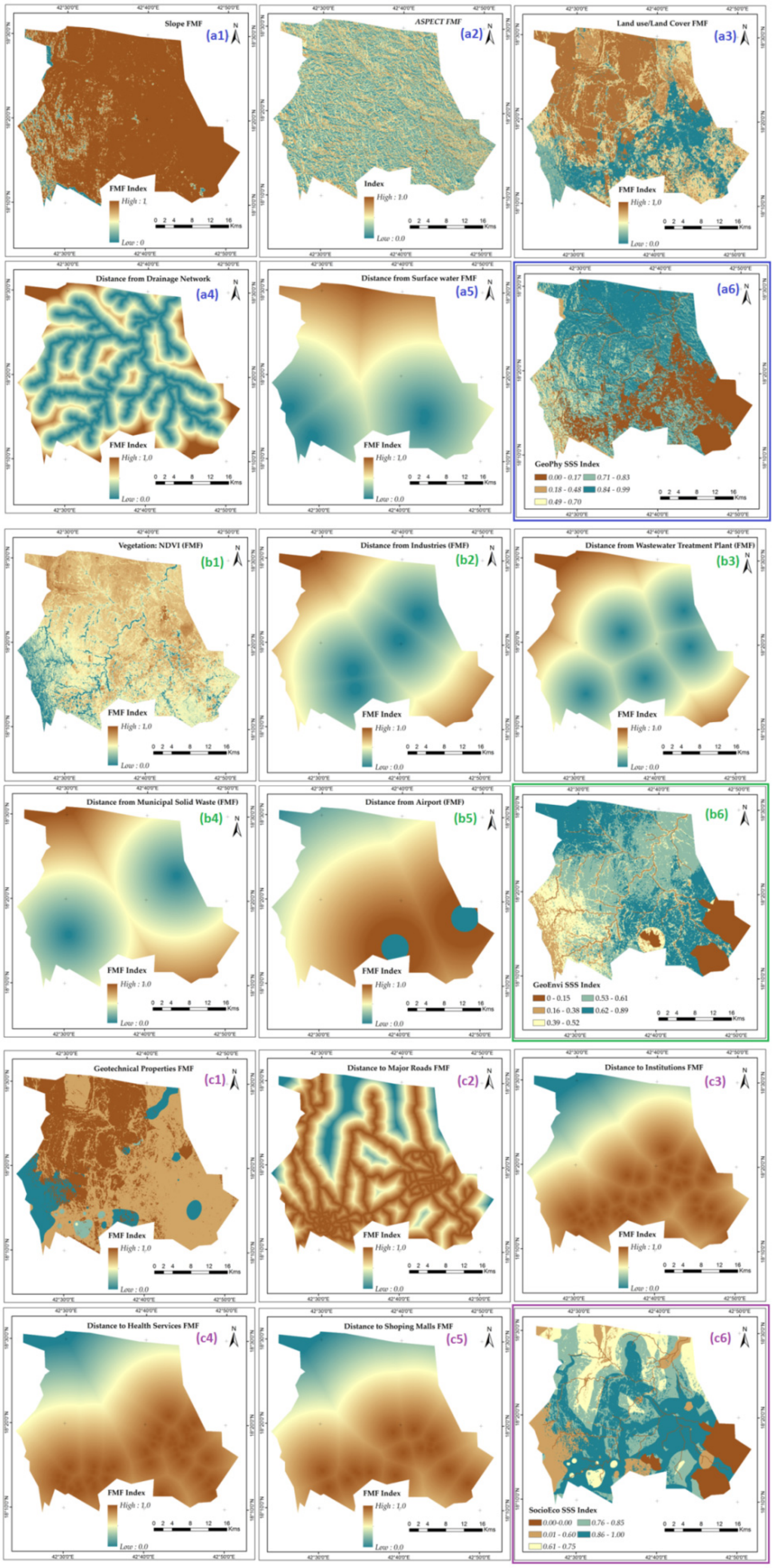

Figure 8. Thematic layers aspects such as Geophysical (**a1**–**a6**), geoenvironment (**b1**–**b6**) and socio-economic (**c1**–**c6**) classifying the study area into various safe site selection residential building construction areas based on fuzzy membership functions (FMF).

Distance from disposal site of Muncipal Solid Waste (MSW): Due to health concerns, the safe site selection for residential building construction should be kept away from disposal site of MSW. Buffer zones were defined on the basis of Euclidean distance to avoid the municipal solid waste disposal sites, and the map was reclassified and graded based on the buffer distances (Euclidean distance). The first control point (1000 m) demonstrates the least suitable distance for siting a residential building, while the 2nd control point (farther from MSW area) demonstrates the most suitable distance for safe site selection for building construction (Figure 5d).

Distance from Airport/Airbase: Residential housing construction sites should be at least 3 kilometers from the airport for safety reasons. These buffer zone should be considered as exclusion zones due to noise from airport operations, areas impacted by aircraft landing patterns, and conflict with airport radar. The first control point (3000 m) demonstrates the unsuitable distance for siting a residential building, the second control point (6000 m) will suitable and demonstrates the most suitable distance for safe site selection for building construction (Figure 5e), while the third control point (farther from airport) demonstrates the most unsuitable distance for safe site selection for building construction due to travel distance for availing the facilities.

3.3. Socio Economic Aspect for Safe Sile Selection of Building Construction

Socio-economic concerns are also one of the most critical factors to consider when deciding where to build a residential safe site. Indeed, road networks, education, health, shopping facilities are fundamental human needs; therefore, potential development areas should be located near established social and economic services [77]. For urban development and planning, this objective is important. In this respect, socio-economic factors including geotechnical properties (cost and time effective), distance to road network, distance to institutions, distance to health services, distance to shopping malls were investigated (Figure 6).

Geotechnical Properties of the Study area: The type of soil used to build a structure has an effect on the rate of expansion of the foundation and the type of structure that can be supported. Solid rock, such as bedrock, is one of the best soil types for house construction. In addition, sandy and sandy loam is the most common type of soil found in Abha-Khamis Mushyet city, and it is regarded as a very good soil type for building houses due to its physical properties (Figure 6a). The distribution exposed rocks are spread towards the north, north western and central northern area, however, within the soil class the distribution of sandy loam extensive distributed across the study mainly located east, south eastern as well as central southern part of the study area. These two classes, i.e., exposed rocks and sandy loam are considered high score, whereas loamy sand considered as low score. Sandy loam infiltrates rapidly when wet and is thus classified as a highly drained soil. Owing to their low infiltration rates, silty loam and sandy clay loam are considered low drained soils, making them ideal for building construction sites.

Distance to road network: Building a new road in a mountainous area is expensive. As a result, every effort is made to locate the site as close to every existing road as possible. Increase the access to the existing road, buffer zones have been built at a 100 m distance from the major road. The farther a site is set back from the road and the more difficult it is to reach it, the higher the costs and discomfort of transportation would be. The areas nearest to major roads (100 m) were deemed highly suitable, and the ratings were steadily decreased as the distance to the buffers (buffer zone classified based on euclidean distance) increased, with areas with distances greater than 5 km receiving lower suitability ratings (Figure 6b).

Distance to Institutions (schools, colleges, and universities): When deciding the best locations for residential houses, the proximity of institutions (such as schools, colleges, and universities) was also considered. Residents prefer to visit institutions that are close to their homes rather than those that are further away. The continuous distances to and from shopping malls were calculated using the Euclidean distance. The first control point (500 m) indicates the most suitable location for a site, whereas the 2nd control point (6000 m away from the malls) infers the least suitable location for a site. Figure 6c shows the distribution of institutions in Abha and Khamis Mushyet cites and their Euclidean distance. The nearer to the institutions considered more suitable site for residential building construction site whereas farther distances considered as low score for site selection.

Distance to Health services: Health care is another important consideration when deciding the best location for residential buildings. A buffer zone around health care facilities has been created. The Euclidean distance was used to measure continuous distances to and from health care facilities. The first control point (closer to health services, i.e., 500 m) indicates the best location for a construction site, whereas the 2nd control point (further from health services) infers the not suitable location for a construction site. Figure 6d shows the distribution of health services available in Abha Khamis Mushyet cites. The nearer to the health services considered more suitable site for residential building construction site whereas farther distances considered as low score for site selection.

Distance to Shopping Malls: Shopping mall proximity was also taken into account when deciding the best locations for residential building construction. Residents prefer to shop in locations close to their homes rather than further out. Buffer zones have been created based on Euclidean distances. The continuous distances to and from shopping malls were calculated using the Euclidean distance. The first control point (closer to the Shopping Malls, about 500 m) indicates the most suitable location for a construction site, whereas the 2nd control point (further from the Malls) infers the least suitable location for a construction site. Figure 6e shows the distribution of malls existing within the study area. The existing malls mostly located southern, south eastern part of the study area. The nearer to the shopping facilities considered more suitable site for residential building construction site whereas farther distances considered as low score for site selection

Restricted Areas: As a sub-criterion of the safety factor, the maps of protected/restricted areas as well as existing buildup area were used. Civil defense, archaeological sites, and a containment area were included in the restricted area. Protected and restricted areas were surrounded by buffer zones, and areas separated by more than 500 m were considered suitable locations. Figure 7a,b shows the restricted/protected areas and buildup areas distribution, respectively.

3.4. Weights Normalization for Thematic Maps of Geo-Physical, Geo-Environmental and Socio-Economic Aspect for Safe Site Selection

Each theme and class were assigned a weight using the fuzzy-AHP process. The relevance of each theme in the matrix was determined using a literature review, expert opinion, and field knowledge (Tables 3–6). In geo-physical aspect, slope has been given the highest weight, as cutting a hill slope causes ecological damage and slope instability in adjacent areas [55]. As a result, cuttings shall be avoided unless appropriate precautions are taken to avoid such damage and to ensure site safety. It is followed by aspect, LULC, surface water, and drainage density. "Statistical analysis i.e., consistency ratios <4.3%, delta = 2.5E-8, principal Eigen value of 5.195, Eigenvector solution 5 iterations for assigned weights for the five thematic layers and their features show that the assigned weights are well suited with the expected outcomes.

In geo-environmental aspect, vegetation has been given the highest weight, as forests, green areas, agriculture, and restricted areas should be maintained and protected in order to expand the city with less damage and detrimental effects on nature and the environment. It is followed by distance to airport, distance to MWS, distance to Industry and distance to WWTP. "Statistical analysis i.e., consistency ratios <9.8%, delta = 8.7E-8, principal Eigen value of 5.442, Eigenvector solution 6 iterations for assigned weights for the five thematic layers and their features show that the assigned weights are well suited with the expected outcomes.

Table 3. Matrix of pairwise comparisons for the five themes.

AHP Priority					
Geo-physical Aspects	Slope	Aspect	LULC	Surface water	Drainage net.
Slope	1.00	5.00	6.00	7.00	9.00
Aspect	0.20	1.00	3.00	4.00	5.00
LULC	0.17	0.33	1.00	2.00	3.00
Surface water	0.14	0.25	0.50	1.00	2.00
Drainage network	0.11	0.20	0.33	0.50	1.00
Geo-environmental Aspects	Vegetation	Distance to Industries	Distance to Airport	Distance to WWTP	Distance to MWS
Vegetation	1.00	8.00	3.00	9.00	4.00
Distance to Industries	0.13	1.00	0.50	8.00	3.00
Distance to Airport	0.33	2.00	1.00	7.00	3.00
Distance to WWTP	0.11	0.13	0.14	1.00	0.25
Distance to MWS	0.25	0.33	0.33	4.00	1.00
Socio-economic Aspects	Geotechnical properties	Distance to road	Distance to institution	Distance to Health services	Distance to Mall
Geotechnical properties	1.00	2.00	7.00	6.00	9.00
Distance to road	0.50	1.00	3.00	7.00	6.00
Distance to institution	0.14	0.33	1.00	2.00	4.00
Distance to Health services	0.17	0.14	0.50	1.00	2.00
Distance to Mall	0.11	0.17	0.25	0.50	1.00
Fuzzy-AHP Priority					
Geo-physical Aspects	Slope	Aspect	LULC	Surface water	Drainage net.
Slope	1,1,1	3,5,7	4,6,8	5,7,9	7,9,9
Aspect	1/7,1/5,1/3	1,1,1	1,3,5	2,4,6	3,5,7
LULC	1/8,1/6,1/4	1/5,1/3,1	1,1,1,	1,2,3	1,3,5
Surface water	1/9,1/7,1/5	1/6,1/4,1/2	1/3,1/2,1	1,1,1	1,2,3
Drainage network	1/9,1/9,1/7	1/7,1/5,1/3	1/5,1/3,1	1/3,1/2,1	1,1,1
Geo-environmental Aspects	Vegetation	Distance to Industries	Distance to Airport	Distance to WWTP	Distance to MWS
Vegetation	1,1,1	6,8,9	1,3,5	7,9,9	2,4,6
Distance to Industries	1/9,1/8,1/6	1,1,1	1/3,1/2,1	6,8,9	1,3,5
Distance to Airport	1/5,1/3,1	1,2,3	1,1,1	5,7,9	1,3,5
Distance to WWTP	1/9,1/9,1/7	1/9,1/8,1/6	1/9,1/7,1/5	1,1,1	1/6,1/4,1/2
Socio-economic Aspects	Geotechnical properties	Distance to road	Distance to institution	Distance to Health services	Distance to Mall
Geotechnical properties	1,1,1	1,2,3	5,7,9	4,6,8	7,9,9
Distance to road	1/3,1/2,1	1,1,1	1,3,5	5,7,9	4,6,8
Distance to institution	1/9,1/7,1/5	1/5,1/3,1	1,1,1	1,2,3	2,4,6
Distance to Health services	1/8,1/6,1/4	1/9,1/7,1/5	1/3,1/2,1	1,1,1	1,2,3

Table 4. Weights for thematic layers for geophysical aspect using Fuzzy-AHP techniques.

	Slope			**Aspect**			**LULC**			**Surface Water**		
Slope	0.648	0.613	0.534	0.648	0.613	0.535	0.649	0.613	0.535	0.649	0.612	0.535
Aspect	0.135	0.161	0.192	0.135	0.161	0.192	0.135	0.161	0.192	0.135	0.161	0.192
LULC	0.086	0.099	0.121	0.086	0.099	0.121	0.086	0.099	0.121	0.086	0.099	0.121
Surface water	0.070	0.075	0.084	0.070	0.075	0.084	0.070	0.075	0.084	0.070	0.075	0.084
Drainage network	0.063	0.055	0.060	0.063	0.055	0.060	0.063	0.055	0.060	0.063	0.055	0.060

	Drainage Network			*l*	*m*	*n*	defuzzify	Weight
Slope	0.648	0.612	0.535	0.64849	0.61253	0.53471	0.5986	59.917
Aspect	0.135	0.161	0.192	0.1346	0.16119	0.19217	0.1627	16.282
LULC	0.086	0.099	0.121	0.08583	0.09866	0.12123	0.1019	10.201
Surface water	0.070	0.075	0.084	0.07002	0.07519	0.0843	0.0765	7.6581
Drainage network	0.063	0.055	0.060	0.06256	0.05513	0.06036	0.0594	5.9411

In socio-economic aspect, Geotechnical properties have been given the highest weight, as solid rock, such as bedrock, is one of the best soil types for house construction. In addition, sandy and sandy loam is regarded as a very good soil type for building houses due to its physical properties. As a result, cuttings shall be avoided unless appropriate precautions are taken to avoid such damage and to ensure site safety. It is followed by distance to major road, distance to institution, distance to health services and distance to shopping malls. "Statistical analysis i.e., consistency ratios <3.7%, delta = 5.4E-8, principal Eigen value of 5.167, Eigenvector solution 4 iterations for assigned weights for the five thematic layers and their features show that the assigned weights are well suited with the expected outcomes"

Table 5. Weights for thematic layers for geo-environmental aspect using Fuzzy-AHP techniques.

	Vegetation			**Distance to Industry**			**Distance to Airport**			**Distance to WWTP**		
Vegetation	0.570	0.543	0.450	0.571	0.543	0.450	0.572	0.543	0.450	0.570	0.544	0.450
Distance to Industry	0.094	0.107	0.115	0.094	0.107	0.115	0.094	0.107	0.115	0.094	0.107	0.115
Distance to Airport	0.169	0.197	0.264	0.169	0.197	0.264	0.169	0.197	0.265	0.169	0.197	0.265
Distance to WWTP	0.057	0.044	0.036	0.057	0.044	0.036	0.057	0.044	0.036	0.057	0.044	0.036
Distance to MWS	0.106	0.106	0.134	0.107	0.106	0.134	0.107	0.106	0.134	0.106	0.107	0.134

	Distance to MWS			*l*	*m*	*n*	defuzzify	Weight
Vegetation	0.570	0.544	0.450	0.571	0.543	0.450	0.521	52.183
Distance to Industry	0.094	0.107	0.115	0.094	0.107	0.115	0.105	10.539
Distance to Airport	0.169	0.197	0.265	0.169	0.197	0.265	0.210	21.021
Distance to WWTP	0.057	0.044	0.036	0.057	0.044	0.036	0.046	4.559
Distance to MWS	0.106	0.106	0.134	0.107	0.106	0.134	0.116	11.591

Table 6. Weights for thematic layers socio-economic aspect using Fuzzy-AHP techniques.

	Geotechnical Properties			**Distance to Road**			**Distance to Institution**			**Distance to Health Services**		
Geotech. properties	0.527	0.521	0.454	0.525	0.521	0.453	0.527	0.520	0.453	0.526	0.520	0.453
Distance to road	0.269	0.276	0.312	0.268	0.277	0.312	0.269	0.276	0.312	0.269	0.276	0.312
Distance to institution	0.081	0.089	0.120	0.081	0.089	0.120	0.081	0.089	0.120	0.081	0.089	0.120
Distance to Health ser.	0.064	0.068	0.071	0.064	0.068	0.071	0.064	0.068	0.071	0.064	0.068	0.071
Distance to Mall	0.056	0.049	0.048	0.056	0.049	0.048	0.056	0.049	0.048	0.056	0.049	0.048

	Distance to Mall			*l*	*m*	*n*	defuzzify	Weight
Geotech. properties	0.526	0.520	0.453	0.526	0.521	0.453	0.500	50.058
Distance to road	0.269	0.276	0.312	0.269	0.276	0.312	0.286	28.587
Distance to institution	0.081	0.089	0.120	0.081	0.089	0.120	0.096	9.651
Distance to Health ser.	0.064	0.068	0.071	0.064	0.068	0.071	0.068	6.799
Distance to Mall	0.056	0.049	0.048	0.056	0.049	0.048	0.051	5.101

Analysis of Safe Site Selection Classification Map Based on Geophysical, Geo-Environmental and Socio-Economic Aspects

Site selection for a building in mountainous areas where geophysical factor plays an important role to identify the safe site selection for residential building constructions. Site selection entails a large amount of integrated geophysical data such as slope, aspect, LULC, surface water, and drainage density, as well as spatial safety provisions, which can all be effectively managed in a GIS platform (Figure 8(a1–a5)). The study's results summarize the weighted overlay analysis methodology as the most powerful tool for mapping potential safe site construction using GIS-based Fuzzy-AHP. Five (5) thematic layers such as slope (Figure 8(a1)), aspect (Figure 8(a2)), LULC (Figure 8(a3)), distance to drainage network (Figure 8(a4)), and distance to surface water (Figure 8(a5)) classifying the study area into various safe site selection residential building construction areas based on fuzzy membership functions (FMF). Figure 8(a6) shows the Geophysical safe site selection classifying map, quantitatively developed for analysis using the Geophysical safe site selection index (GeoPhySSSI). "The sites potential index's mean value of 0.571 with standard deviation of 0.384, minimum and maximum GeoPhySSSI were 0.0 and 0.989, respectively, GeoPhy SSS index is classified into zones by histogram profile using natural breaks (jenks)" Subsequently, safe sites were identified and divided into five classes. The distribution shows high over the central and northern part of the study area.

Geoenvironmental factor also plays an important role to identify the safe site selection for residential building constructions. Site selection entails a large amount of integrated geo-environmental data such as vegetation, distance to airport, distance to MWS, distance to Industry and distance to WWTP (Figure 8(b1–b5)), which effectively managed in a GIS platform. The study's results summarize the weighted overlay analysis methodology as the most powerful tool for mapping potential safe site construction using GIS-based Fuzzy-AHP.

Five (5) thematic layers such as vegetation (Figure 8(b1)), distance to Industry (Figure 8(b2)), distance to WWTP (Figure 8(b3)), distance to MWS (Figure 8(b4)) and distance to airport (Figure 8(b5)) classifying the study area into various safe site selection residential building construction areas based on fuzzy membership functions (FMF). "Figure 8(b6) shows the Geoenvironmental safe site selection classifying map, quantitatively developed for analysis using the GeoEnvi safe site selection index (GeoEnviSSSI) The sites potential index's mean value of 0.496 with standard deviation of 0.201, minimum and maximum GeoPhySSSI were 0.0 and 0.894, respectively, GeoEnvi SSS index is classified into zones by histogram profile using natural breaks (jenks). The distribution shows high over the north western and south western and central southern part of the study area.

The socio-economic factor used to identify the safe site selection for residential building constructions. Site selection entails a large amount of integrated socio-economic data such as geotechnical properties, distance to major road, distance to institution, distance to health services and distance to shopping malls (Figure 8(c1–c5)), as well as spatial safety provisions, which effectively managed in a GIS platform. The study's results summarize the weighted overlay analysis methodology as the most powerful tool for mapping potential safe site construction using GIS-based Fuzzy-AHP. Five (5) thematic layers such as geotechnical properties (Figure 8c1), distance to major road (Figure 8(c2)), distance to institution (Figure 8(c3)), distance to health services (Figure 8(c4)) and distance to shopping malls (Figure 8(c5)) classifying the study area into various safe site selection residential building construction areas based on fuzzy membership functions (FMF). "Figure 8(c6) shows the socio-economic aspect for safe site selection classifying map, quantitatively developed for analysis using the socio-economic safe site selection index (SESSSI)" The sites potential index's mean value of 0.694 with standard deviation of 0.276, minimum and maximum SESSSI were 0.0 and 0.999, respectively. The distribution shows the concentration is high over the central and northern part of the study area.

3.5. Weights Normalization for Thematic Maps of All Aspect for Final Safe Site Selection

All aspect such as geophysical, Geoenvironmental and socio-economic were assigned a weight using the fuzzy-AHP process. The relevance of each aspect in the matrix was determined using a literature review, expert opinion, and field knowledge (Tables 7 and 8). Geo-Physical has been given the highest weight, due to study area specific and safety concern. It is followed by socio-economic and Geo-environmental aspect.

Statistical analysis, i.e., consistency ratios <5.6%, delta = 9.2E-9, principal Eigen value of 3.054, Eigenvector solution 4 iterations for assigned weights for the three aspect such as geophysical aspect, socio-economic aspect, and → Geoenvironmental aspect thematic layers show that the assigned weights are well suited with the expected outcomes"

Table 7. The Aspects' pairwise comparison matrix.

	AHP Priority		
	Geophysical Aspect	**Socio-Economic Aspect**	**Geoenvironmental Aspect**
Geophysical Aspect	1.00	1.00	2.00
Socio-Economic Aspect	1.00	1.00	1.00
Geoenvironmental Aspect	0.50	1.00	1.00
	Fuzzy-AHP Priority		
	Geophysical Aspect	**Socio-Economic Aspect**	**Geoenvironmental Aspect**
Geophysical Aspect	1,1,1	1,1,1	1,2,3
Socio-Economic Aspect	1,1,1	1,1,1	1,1,1
Geoenvironmental Aspect	1/3,1/2,1	1,1,1	1,1,1

Table 8. Weights using Fuzzy-AHP techniques for three different aspect theme.

	Geophysical Aspect			**Socio-Economic Aspect**			**Geoenvironmental Aspect**		
Geophysical Aspect	0.370	0.403	0.412	0.369	0.403	0.412	0.369	0.403	0.412
Socio-Economic Aspect	0.370	0.339	0.294	0.369	0.339	0.294	0.369	0.339	0.294
Geoenvironmental Aspect	0.264	0.258	0.294	0.264	0.258	0.294	0.264	0.258	0.294

	l	***m***	***n***	**defuzzify**	**Weight**
Geophysical Aspect	0.369	0.403	0.412	0.395	39.513
Socio-Economic Aspect	0.369	0.339	0.294	0.334	33.435
Geoenvironmental Aspect	0.264	0.258	0.294	0.272	27.221

3.6. Analysis of Safe Site Selection Classification Map Based on All Three Aspects Such Geophysical, Socio-Economic and Geoenvironmental

Site selection for a building in mountainous areas where all three aspects factor plays an important role to identify the safe site selection for residential building constructions. Site selection entails a large amount of integrated aspects data such as geophysical, socio-economic and Geo-environmental, as well as spatial restricted/protected and existing built-up area provisions, which can all be effectively managed in a GIS platform. Figure 9 shows the spatial distribution of all the result from different aspects for safe site selection for residential building construction.

The study's results summarize the weighted overlay analysis methodology as the most powerful tool for mapping potential safe site construction using GIS-based Fuzzy-AHP. Three aspects such as geophysical, socio-economic and Geo-environmental thematic layers classifying the study area into various safe site selection residential building construction areas (Figure 9) based on fuzzy membership functions (FMF) (9) of each thematic aspect. Figure 9 shows the cumulative safe site selection classifying map using all three aspects as an input, quantitatively developed for analysis using the safe site selection index (SSSI).

The sites potential index's mean value of 0.513 with standard deviation of 0.340, minimum and maximum GeoPhySSSI were 0.0 and 0.91, respectively, SSS index is classified into zones by histogram profile using natural breaks (jenks)" Subsequently, safe sites were identified and divided into six classes namely no construction, very low suitable site low suitable site, moderate suitable site, high suitable site, and very high suitable site (Figure 10). Statistics on integrated safe site categories for residential building construction sites are shown in Table 9. "According to the statistical analysis, 3.64% and 32.12% of the total area were under very high and high SSSZ, while 26.40% and 6.22% accounted to the moderate and low suitable potential, respectively" The spatial variance of high and very high safe site suitable residential building construction zones found in the central-west, central north and eastern parts of the cites.

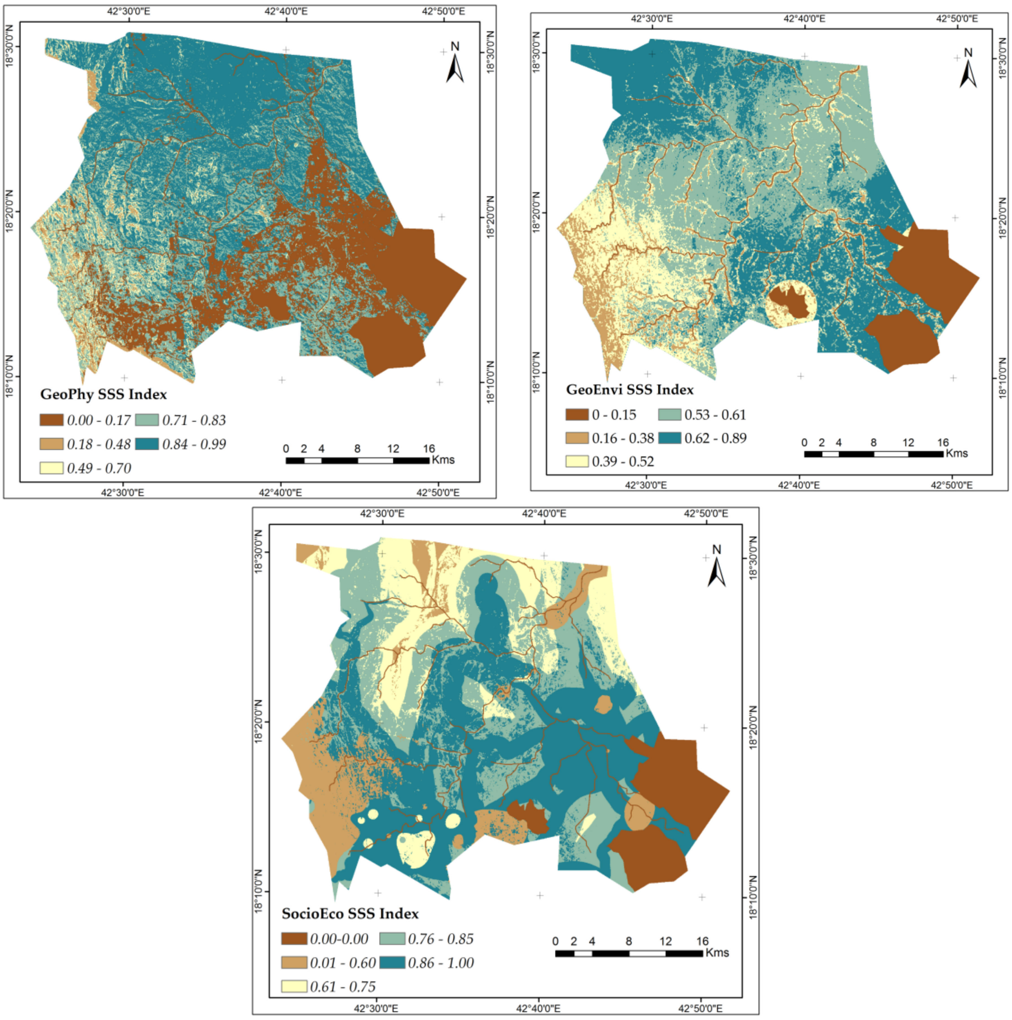

Figure 9. All three derived aspects layers (Geophysical, Geoenvironmental, and Socio-economic) for safe site selection.

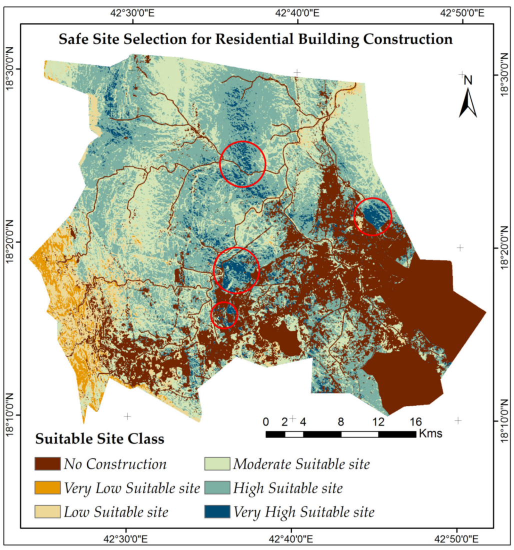

Figure 10. Safe site suitable zone map based on Geophysical, socio-economic and Geo-Environmental Aspect.

Table 9. Statistics of Integrated Categories of safe site selection of residential building construction in Abha-Khamis Mushyet.

Suitable Class	Area in Km	% of Total Area
No construction	377.53	29.39
Very Low Suitable site	28.75	2.24
Low Suitable site	79.90	6.22
Moderate Suitable site	339.14	26.40
High Suitable site	412.61	32.12
Very High Suitable site	46.76	3.64
Total	1284.68	100.00

3.7. Sensitivity Analysis

The statistical analysis in Table 10 (from Equation (7)) confirms major variations in SSSPI and also infers the effective weights for each safe site parameter in comparison to the theoretical weight. The significant SSSPI variance verified by statistical analysis is depicted in Table 10 (calculated from Equation (7)). However, the effective weights assigned to each theme vary slightly from the theoretical weight assigned to the field of safe site suitability.

Table 10. Theoretical and effective weights are compared.

Sl. No	Theme	"Theoretical Weight (%)"	"Effective Weight (%)"			
			Min.	Max.	Mean	Std. Dev.
Geo-Physical Aspect	Slope	59.917	2.18	99.80	57.38	14.25
	ASPECT	16.282	0.00	38.65	17.56	8.460
	LULC	10.201	0.00	35.85	11.86	4.568
	Surface water	7.6581	0.00	25.85	7.21	5.673
	Drainage density	5.9411	0.02	21.27	5.99	2.497
Geo-Environmental Aspect	Vegetation (NDVI)	52.183	0.00	88.69	51.45	13.57
	Distance from Industries plant	10.539	0.00	34.71	10.54	4.472
	Distance to Airport	21.021	0.00	52.66	20.91	9.323
	Distance from Waste water treatment	4.559	0.00	14.35	4.32	1.834
	Distance from site (MSW)	11.591	0.00	37.54	12.78	4.635
Socio-Economic Aspect	Geotechnical properties	50.058	0.00	92.14	49.12	21.042
	Distance to Road	28.587	0.00	66.25	27.27	10.251
	Distance to Institutions	9.651	0.00	30.45	10.15	4.035
	Distance to Health services	6.799	0.00	28.12	7.14	4.589
	Distance to Shopping Malls	5.101	0.00	12.12	6.32	2.120
SSS index	Geo-Physical Aspect	39.513	0.00	88.52	40.01	18.254
	Geo-Environmental Aspect	27.221	0.00	66.12	25.97	15.471
	Socio-Economic Aspect	33.435	0.00	87.42	34.02	16.142

4. Discussion

Current research in the Abha-Khamis-Mushayet twin city demonstrates the value of integrating multiple sources of information to ensure safe site selection for building construction. Neither the strategies nor the methods used in current standards emphasize any factor necessary for safe site selection in mountainous regions. This deficiency necessitates the identification of various factors that could aid construction professionals in properly locating facilities/utilities in mountainous regions [11]. Through a review of the literature, this study identified three broad aspects widely considered in site selection, namely environmental, physical, and socioeconomic criteria. To evaluate these three critical components and to identify additional factors affecting safe site selection in mountainous regions, a systematic investigation was conducted by sending survey questions to construction professionals employed by government/private agencies in Saudi Arabia's Asir region. Five questionnaires distributed to foreign experts elicited responses. Following an extensive review of the literature and expert consultation, a number of themes were chosen for this research, including drainage density, land use/land cover (LULC), slope, vegetation (NDVI), distance from the airport, distance from the road, distance from industries, distance from school, distance from an existing mall, distance from MSW, distance from waste water treatment plants, and distance from health services. These themes were developed through the use of RS (remote sensing) and conventional data.

To assess the most safe site selection of residential building construction for sustainable urban growth, we used GIS-based multi-criteria decision-making approach that combined Fuzzy-AHP (Multicriteria decision making analysis) and weighted linear combination (WLC) aggregation method used to calculate the SSPZ. Using GIS software, each requirements map was pre-processed and prepared for geospatial analysis. The maps were converted to pixel format using the normalized score values. Suitability maps were created using Fuzzy-AHP's weight values and weighted overlay tool. Figure 10 illustrates the effects of the weighted overlay based on related categories. Suitability maps were divided into six classes namely no construction, very low suitable site low suitable site, moderate suitable site, high suitable site, and very high suitable site. The final safe site suitability map was generated by aggregating all aspects such as geophysical, socio-economic and Geo-environmental thematic layers and their associated Fuzzy-AHP weights using the weighted linear combination method.

However, though MCDA sometimes introduces subjectivity into the process of selecting criteria and determining the weight of each thematic layer, the initial step of selecting criteria weights based on expert opinion and literature review increases the accuracy of the results. During the verification process, the following points must be considered in future studies such as to verify sample areas, a field survey (ground truth verification) should be performed and reasonability and realism in the resulting map.

After creating the final suitability map, visual observations were used to test and verify the results, in addition to assessments using alteration criterion numbers and corresponding weights. The findings corroborated our field observations. Areas of high and moderate suitability are located near existing habitant area, major roads, and educational and health services; they are not located in restricted/protected areas or are vulnerable to natural hazards. The findings indicate that unsuitable and less-suitable land uses such as vegetation (forest), protected areas, and agriculture lands cover nearly one-third area of Abha-Khamis Mushyet regions, implying that using Fuzzy-AHP and GIS techniques will significantly aid in the conservation of the environment while developing future sustainable development plans. This would significantly mitigate adverse effects on the ecosystem and climate. Additionally, the findings indicated that the city's growth is constrained by protected areas and geo-hazards such as flash flood hazards, geomaterials, and steep slopes.

The safe site selection for residential building construction was determined in this study using a geospatial-based fuzzy-AHP-MCDA. The aim of this study is to investigate the system's use of artificial values derived from pairwise comparisons. Duru et al. [78], on the other hand, "addressed several Fuzzy-AHP studies that did not have a matrix consistency problem, despite the fact that the choices were inconsistent". The results indicate that fuzzy set theory in conjunction with AHP satisfies all requirements. "Our findings suggest that integrating the fuzzy collection with AHP is highly desirable in terms of alternative and decision-making effectiveness The weighting and standardization/normalization criteria also account for the inconsistencies in the safe site selection mapping by comparing the relative importance of suitable site criteria using both FMFs and Triangular Fuzzy Number (TFN) methods rather than crisp numbers" Additionally, fuzzy logic is attractive because it is simple to comprehend and execute. Fuzzy logic can be applied to data from any measurement scale, with the weighting determined by an expert [40]. Nonetheless, the study, by incorporating linguistic variables, offers a more accurate assessment of safe site suitability mapping. The data's fuzziness introduces errors in estimation that can be effectively corrected by using fuzzy-AHP weights [79].

This study's findings are consistent with those of Aburas et al. [80]. They investigated four primary aspects (environment, socio-economic, facilities, and physical factors). They concluded that using Multicriteria decision making analysis and GIS techniques is critical for sustainable urban growth. In Turkey, Akbulut et al. [81] used the same approach of multi-criteria decision making approach and GIS techniques. They suggested that the approach be implemented in additional regions in part of world. It can serve as a basis for evaluating the suitability of potential urbanization policies in terms of their wider consequences for ecosystem services and sustainability functions. They concluded that by considering sustainability, the effects of degraded ecological resources, such as increased risk of landslides, flash flood, and biodiversity degradation, became visible and quantifiable to decision-makers.

5. Conclusions

The site selection process for a building construction is heavily influenced by environmental and economic factors in addition to a set of physical parameters. The cumulative impact of these factors examines the level of appropriateness and also assists to categorize the land into several zones. Analyzing land use/land cover, landscape factors, topographical factors, geology, physiography, and distance from road, existing construction or buildup area, among other items, can be used to determine the physical parameters of the land and which is much amenable to GIS analysis. The site selection process for a building entail evaluating a variety of factors with varying degrees of importance or percentage influence. To ensure that critical site selection factors are not overlooked, a methodology for calculating a building's safe site selection must be developed. In Mountainous region such as Aseer region, safe site selection must take into account land use/land cover, slope stability, landslides, topography, and drainage network, as well as mitigating negative environmental effects. These factors have a major effect on the building process as well. Additionally, architects and civil engineers require geoinformation about a building's neighbourhood in order to determine the building's reliance on existing facilities/utilities. Without GIS, such dependence is difficult to model. In use of GIS enables the visualization and analysis of the effects of situating a proposed facility adjacent to existing facilities.

To assess the safest site selection of residential building construction for sustainable urban growth, we used GIS-based multi-criteria decision-making approach that combined Fuzzy-AHP (Multicriteria decision making analysis) and weighted linear combination (WLC) aggregation method used to calculate the SSPZ. Using GIS software, each requirements map was pre-processed and prepared for geospatial analysis. The maps were converted to pixel format using the normalized score values. Suitability maps were created using Fuzzy-AHP's weight values and weighted overlay tool. Suitability maps were divided into six classes namely no construction, very low suitable site low suitable site, moderate suitable site, high suitable site, and very high suitable site. The final safe site suitability map was generated by aggregating all aspects such as geophysical, socio-economic and Geo-environmental thematic layers and their associated Fuzzy-AHP weights using the weighted linear combination method.

Site selection for a building in mountainous areas where all three aspects factor plays an important role to identify the safe site selection for residential building constructions. Site selection entails a large amount of integrated aspects data such as geophysical, socio-economic and Geo-environmental, as well as spatial restricted/protected and existing built-up area provisions, which effectively managed in a GIS platform. The study's results summarize the weighted overlay analysis methodology as the most powerful tool for mapping potential safe site construction using GIS-based Fuzzy-AHP. Three aspects such as geophysical, socio-economic and Geo-environmental thematic layers classifying the study area into various safe site selections residential building construction areas based on fuzzy membership functions (FMF) of each thematic aspect.

The sites potential index's mean value of 0.513 with standard deviation of 0.340, minimum and maximum GeoPhySSSI are 0.0 and 0.91, respectively, SSS index is classified into zones by histogram profile using natural breaks (jenks)" Subsequently, safe sites identified and divided into six classes namely no construction, very low suitable site low suitable site, moderate suitable site, high suitable site, and very high suitable site. "According to the statistical analysis, 3.64% and 32.12% of the total area were under very high and high SSSZ, while 26.40% and 6.22% accounted to the moderate and low suitable potential, respectively" The spatial variance of high and very high safe site suitable residential building construction zones found in the central-west, central north and eastern parts of the cites.

The sensitivity analysis was carried out in order to properly understand the function of each parameter. The statistical analysis confirms variations in SSSPI and also infers the effective weights for each safe site parameter in comparison to the theoretical weight. The effective weights assigned to each theme vary slightly from the theoretical weight assigned to the field of safe site suitability. After creating the final suitability map, visual observations were used to test and verify the results. Areas of high and moderate suitability are located near existing habitant area, major roads, and educational and health services; they are not located in restricted/protected areas or are vulnerable to natural hazards. The findings indicate that unsuitable and less-suitable land uses such as vegetation (forest), protected areas, and agriculture lands cover nearly one-third area of Abha-Khamis Mushyet regions, implying that using Fuzzy-AHP and GIS techniques will significantly aid in the conservation of the environment. This would significantly mitigate adverse effects on the ecosystem and climate. Additionally, the findings indicated that the city's growth is constrained by protected areas and geo-hazards such as flash flood hazards, geomaterials, and steep slopes.

The results indicate that fuzzy set theory in conjunction with AHP satisfies all requirements. "Our findings suggest that integrating the fuzzy collection with AHP is highly desirable in terms of alternative and decision-making effectiveness The weighting and standardization/normalization criteria also account for the inconsistencies in the safe site selection mapping by comparing the relative importance of suitable site criteria using both FMFs and Triangular Fuzzy Number (TFN) methods rather than crisp numbers. Additionally, fuzzy logic is attractive because it is simple to comprehend and execute. Nonetheless, the study, by incorporating linguistic variables, offers a more accurate assessment of safe site suitability mapping. The data's fuzziness introduces errors in estimation that can be effectively corrected by using fuzzy-AHP weights. Future research will look at other advanced artificial intelligence approaches for safe site selection, such as fuzzy-topsis, artificial neural networks, and so on. Other infrastructures, such as power and water, can be added as considerations in determining the best locations to construct residential houses and should be integrated as decision-making criteria to better understand site suitability.

In addition, we recommend that the governing bodies, such as municipality, consider the following recommendations:

- MCDA may be used to find potential building sites for residential homes.
- Fuzzy-AHP incoupled with GIS technology methods appears to be the robust method for identifying areas of high suitability.
- Other considerations and restrictions, such as social, economic, and environmental factors, must be taken into account when deciding where to construct residential houses. Schools, parks, and other social services and amenities should be considered.
- Other infrastructures, such as power and water, may be considered when determining the best locations for residential housing.

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