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Spatial disparity patterns of green spaces and buildings in arid urban areas

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ABSTRACT

Urban green spaces are a crucial component in regards to the quality of life, ecosystem balance and recreational services of populations, particularly in arid and semi-arid regions. This study aimed to explore spatial patterns of accessibility to public parks on a neighbourhood scale in the Sohar Wilayat, Oman. Utilising GIS techniques and landscape metrics, we investigated the spatial variations of green patches relevant to other land use types predominantly residential buildings in each local area. The entropy index, the landscape shape index (LSI) and the area-weighted mean shape index (AWMSI) were calculated to analyse landscape spatial patterns of urban green spaces across the study area. The results of this study indicated that the large numbers of green space patches in the majority of neighbourhoods were associated with large population size. In measuring spatial accessibility to public parks, the central neighbourhoods were characterised by low scores and long distances from green spaces, while neighbourhoods in the south and north showed short distances and high scores for residents' accessibility to the nearest park. High rates of fragmentation and irregular shapes, particularly within marginal and inner neighbourhoods, can be attributed to rapid urbanisation and sprawl, which has extensively transformed urban green spaces and vacant land into dwellings. Our findings suggest that a spatial quantification and identification of green space distribution patterns and the accessibility of public parks could provide decision-makers and municipality planners with invaluable guidelines for allocating green parks and recreational amenities equitably and efficiently to urban residents.

1. Introduction and background

Urban green space (UGS) is a term used in different studies to refer to an integrated area of natural, semi-natural or artificial green land, including public parks, public or private gardens, edges of roads, urban forest, remnant patches of natural vegetation, sports fields and individual street trees (Boulton et al., 2018 [1,2]; Helms, 1998). The scale is city-wide and its importance and function are in relation to urban residence [3]. UGS can enact manifold direct and indirect benefits and services to urban inhabitants and surrounding parcels, providing recreational opportunities and playing a role in human health [4–7]. They also contribute to the conservation of biodiversity and the cultural identity of a city, offering places for nature experiences, reducing housing density, helping to maintain and improve the environmental quality of the city by improving air quality, providing light and reducing noise levels [3,8–11]. Urban green space is ecologically important and provides social cohesion that is significant for social development.

Different definitions of UGS are found across various literature. These definitions consider different aspects related to an UGS, such as its characteristics, the human dimension and environmental issues. For example, Chong et al. [12] defined UGS as any land that is vegetated and adjoining an urban land area, such as nature reserves, outdoor sports fields, bushland, school playgrounds and national parks. Jim and Chen (2006, p. 338) described UGS as "an open space situated within the city limits with good vegetation cover planted deliberately or inherited from pre-urbanisation vegetation and left by design or by default". Almanza et al. [13] defined UGS as the space that describes the level of vegetation ranging from sparsely landscaped streets to forested parks. Aydin and Cukur [14] defined UGS as a type of land use that serves human needs and uses and contributes to the urban environment in terms of public health, aesthetics and ecology. Alternatively, Bastian et al. [15] defined UGS as a space that provides a whole range of ecosystem services for the residents of the city, which constitutes parks, forests, allotments or cemeteries and trees. Accordingly, the different definitions and aggregations of types of UGS found in the literature make it hard to compare their results.

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Interest in UGS multi-functionality has increased over time due to evidence that they can influence human wellbeing positively in a variety of ways [16]; Frumkin, 2013; Taylora and Hochuli, 2015). Urban green space has different social and environmental benefits relating to ecological functions, recreation, cultural heritage, aesthetics and social interaction [10,16–18]. These functions are important for sustainable urban development [3,19,20]. Therefore, many studies have addressed these issues as being significant to increasing the quality of life for urban citizens and to mitigating the urbanisation-induced environment. Such studies focused on one or more of these benefits, including mental and physical health improvement [21], economic boosts such as the effect of green space on the real Wilayat prices that are located in the vicinity of the green space [22,23], social betterments such as the influence of UGS on social interaction and integration and environmental benefits such as the potential for climate change mitigation in the form of cooling through shade provision and moisture retention [24], noise reduction, air filtration of pollutants through trees and the promotion of biodiversity [25].

On the other hand, several studies focused on the geographical distribution of UGS within the city. Many of these studies found that there is an unequal and uneven distribution of UGS within the same municipality, where green spaces are found to be concentrated mainly at the periphery of the city compared to more central parts [26,27]. This geographical position of the UGS usually overlaps with the residents' socioeconomic status and the time of development [28]. A low availability of green space in urban areas has been related in some studies to residents with a lower socioeconomic status (e.g., Heynen et al., 2006 [27,29]; Dempsey et al., 2012; [30]. More equally accessible and evenly distributed green spaces are seen as a general challenge for urban green space planning (e.g., Dai, 2011; Cohenet al., 2012; Dempsey et al., 2012; [26,29]. Balancing these inequalities by greening disadvantaged areas is challenged by rising housing prices adjacent to these new UGSs, and hence, results in a shift to residents with higher incomes [7].

Accessibility of UGS is a central issue in relation to human well-being because of the considerable benefits of these areas. A high level of recreational services can be provided through a high level of accessibility and maintenance of the UGSs [3,31]. Accessibility is a major factor in defining potential services [32]. Notably, Panduro and Veie [33]; divide accessibility into three different types depending on the level of service provided by the different types. The first is external accessibility, which is related to physical access to the UGS, such as entrances, pathways and roads. The second is internal accessibility, which deals with the physical access within the green space. The third is social accessibility, which deals with social and legal perceptions of the area.

Threshold values for per-capita UGS are provided for a better and more effective management of these areas to ultimately steer cities towards human well-being and sustainability. Proximity to UGS is measured in a Euclidian distance in steps of 100 m from the property. In common areas, size is more significant than proximity as the distance is usually low. Panduro and Veie [33] set a cut-off point at 600 m, which is equivalent to a 5–10-min walking time for green space (parks and natural areas). Kienast et al. [32] set the cut-off point to access an attractive green space to be reachable within a 5–10-min walk or biking distance, which allows residents to use a green space effectively. The cut-off point for a green space, where access is restricted to households near the area, was set at 300 m. Handley et al. [34] and English Nature (1996) substantively described a set of standards for evaluating accessibility and provision of natural green spaces relevant to the quality of the residential environments. The guidelines include that provision of such a space should be made of at least 2 ha of accessible natural green space per 1000 of the population. Furthermore, the guidelines recommend that no person should live more than 300 m away from their nearest area of natural green space of at least 2 ha in size. There should also be at least one accessible 20 ha site within 2 km of home, and one accessible 100 ha site and one accessible 500 ha site within 5 km and 10 km respectively. The cities of Berlin and Leipzig in Germany aim to provide at least between 6 m^2 and 10 m^2 of UGS per person [35,36]. Furthermore, Berlin's Department of Urban Development and the Environment recommends that every resident should have access to a UGS of 0.5 ha within a 500 m distance of their home.

Various studies on UGS have used different techniques to investigate the correlation between such spaces and a human's well-being. Some have used analytical techniques to examine the correlation between the distance to green space and health. The data is usually collected through survey questionnaires or derived from census measures summarised at a centroid, and the hedonic method and Wilayat preference were used to investigate the value of the green space [37,38]. These studies found different results with both positive, negative and insignificant effects for the same categories of UGS [23]. performed a study using a survey on the use of various types of UGS and people's willingness to pay to access them. Their results provided the core of a cost model for UGS development and more precise planning for green space development. These measures are often used to investigate a possible ecological correlation between the availability and accessibility of UGS and health outcomes. Numerous studies have used a geographic information system (GIS) while studying UGS.

GIS methods are used because they are powerful in analysing spatial data, and examining the spatial pattern of accessible natural green space, and identifying those areas currently lacking UGS provision. GIS researchers employed buffering techniques around green spaces and identified population characteristics within buffered areas. Another GIS tool used to study UGS is network analysis, which takes into account actual transport routes with assumed walking speeds. These tools are often integrated with non-spatial factors to examine whether the distribution of green space within the urban context is equitable. Mahon and Miller [39] used GIS to identify green space with high aesthetic, ecological and recreational value to protect these areas from urban development. Randall et al. [40] used GIS techniques to model planning scenarios to create a new green space as part of neighbourhood greening strategies. Herbst and Herbst [41] used GIS tools to ascribe aesthetic and ecological value to green space areas for use in the planning process. Jim and Chen [42] modelled the spatial characteristics of existing green space provision using GIS tools, presenting a three-tiered approach for developing, enhancing and linking existing green space areas in the urban planning process. Furthermore, they used landscape metrics to quantify the accessibility and connectivity of proposed green space development. Zhang and Wang [43] suggested a GIS-based network analysis to investigate the accessibility of proposed green space development. They then used landscape metrics to quantify the spatial configuration of that space.

Utilising advanced GIS methods, a considerable research body recently has focused on analysing the interrelationships between building patches, green spaces, climatic characteristics and other spatial factors within urban areas. For example [44], have developed a theoretical framework for the determination of ventilation potential and human exposure to air pollution in urban area of Antwerp (Belgium) and Gdansk (Poland). Within GIS platforms [45], analyzed the urban heat island (UHI) at local scale implementing spatial interpolation techniques. The findings of this research indicated that decreasing the density of residential buildings could improve air quality and alleviate the impacts of UHI. In another seminal work [46], developed an effective Geo-google based tool which enables users and analysists to extract buildings, trees and sky, views from open sources. Such these databases may provide useful spatial indicator for the measurement of urban geometrical shapes.

The UGSs in the study area are divided into two categories based on ownership. The first category is the private green spaces with restricted public accessibility unless otherwise permitted by the owners. This category consists mainly of farms, home gardens, backyards and domestic gardens. The second category is public green areas which people can access freely and are considered public goods. This category mainly encompasses vegetated natural space (e.g. gardens and parks) and human-modified places (e.g. institutional green spaces, riverside greenbelts).

Globally, and albeit the growing body of literature regarding spatial analysis of green spaces distribution patterns, shapes of buildings and residential patches, social interaction and accessibility to parks in urban areas (e.g. Refs. [4,6,14,19,31], the spatial measurement and metric analysis of green spaces and buildings, built-up areas, and accessibility to public parks in arid and semi-arid urban areas of the GCC countries are still very rare. Accordingly, this research aims to bridge this gap and develop spatial statistical measures for green space distribution, evenness and accessibility in the urban neighbourhoods of arid and semi-arid cities. Such an approach is crucial in identifying the urban areas that have the lowest UGS per capita. Similarly, determining the spatial pattern of accessibility to public green parks across all urban neighbourhoods is essential for providing decision-makers and municipal planners with clear spatial guidelines for ecological service distribution, provision, and deficiency. To achieve this aim, the following research questions will be addressed:

- To what extent does the spatial pattern of accessibility to public green parks vary between urban neighbourhoods?
- What are the distribution patterns of urban green patches compared to residential buildings in each neighbourhood?
- Where are the neighbourhoods that are characterised by low and high compactness of green spaces?
- What are the specific spatial attributes and characteristics of fragmented green spaces in each neighbourhood?

To the best of our knowledge, this is the first study in the GCC countries and Oman which adopts GIS techniques and spatial metrics to analyse spatial distribution patterns of green spaces and residential buildings. Accordingly, the findings of this analysis may provide governmental decision makers and urban planners with a greater understanding of the spatial patterns of green spaces provision and accessibility, delving deeper into examining the associations between built-up areas and density of urban green across urban neighbourhoods. Such this detailed landscape assessment could be a practical and insightful spatial guideline to enhance environmental quality planning through increasing the balance between green spaces and buildings patches within arid and semi-arid urban.

2. Study area and datasets

2.1. Study area

The Sohar Wilayat is located on the low laying coast of the Al-Batinah plain in the Al-Batinah region, which is in the northern part of the Sultanate of Oman. It is the administrative capital of the region, as shown in Fig. 1. The Wilayat is the second largest in terms of population in Oman and is the industrial capital of the country. During the past few decades, the Wilayat has witnessed a rapid increase in population and socioeconomic activities, such as intensive urbanisation, coastal tourism projects, active ports, infrastructure development, agricultural development and industrial activities [47]. The area of Sohar is 1728 km2, with a population of 140,000 as of 2010 (Kazem et al., 2020; [48], where the majority of the population in the Wilayat is concentrated in the coastal strip. Moreover, a large high percentage of the non-Omani population predominantly South Asian are concentrated in the coastal neighbourhoods [49]. Geographically, the Wilayat of Sohar is divided into three major areas. The mountainous area to the west is part of a mountain range named "the western Al-Hajar", and a large number of valleys and villages are scattered in this area. Second is the coastal area,

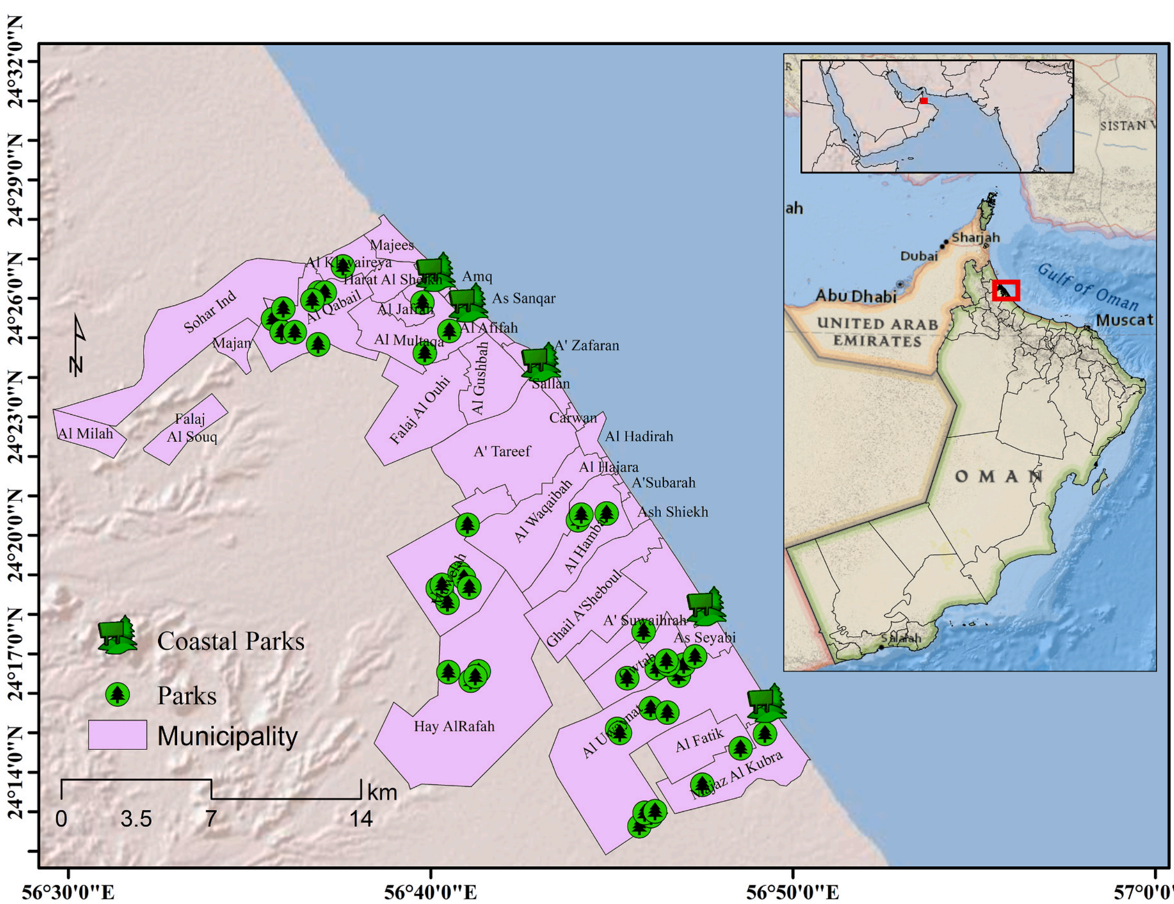

Fig. 1. The location of the study area.

which is located to the east of the mountainous area and up to the coastal strip. This area is part of the Al-Batinah plain, which is the most fertile area in the Sultanate of Oman and the largest agricultural area, covering around 24% of the total cultivated land. Furthermore, the plain is the most concentrated farming area of Oman with about 52% of the land under cultivation, which accounts for 65% of the Omani agricultural production of crops, such as vegetables, dates and forage crops [50]. Finally, there is the coastal strip area with a length of 45 km extending the length of the Gulf of Oman [51]. In terms of climate, the Wilayat is characterised by an arid and semi-arid climate with effectively two main seasons: summer and winter. The summer season is very hot, with a humid air mass, and the average temperature varies between 30 °C and 40 °C. The winter is very mild and the average temperature ranges between 10s and 20s.

Looking at the urban morphology, the predominant types of residential dwellings are semi-detached and single villa which consist of two floors as well as a front or back yard. Indeed, the single villa is an inversion of traditional courtyard dwellings and comprises of a living area, a small garden, and wall boundaries. Therefore, the favor of low-rise houses and the geometries of building design have both led to horizontal urban expansion [52]. The growth of built-up areas and residential dwellings across the study area has been influenced by several factors particularly population size of the Omani youth in the marriage age, migration from rural to urban, residential property investment. These driving forces have accelerated urban sprawl over fertile and agricultural land [53,54].

Sohar includes large areas of agricultural lands particularly agricultural crops, vegetables, and fruit trees. However, the rise in salinity levels of fresh groundwater due to seawater invasion threatens green and vegetation cover including agricultural crops [55]. Accordingly, due to climatic characteristics and the over extracting of underground waters, the availability of irrigation potable water is considered a major challenge and a significant threat to green spaces. Such circumstances may lead to land degradation specifically when the land production declines while its value as a residential land increases.

2.2. Datasets

Spatial and attribute datasets were used in this study to analyse spatial distribution, accessibility and disparity of urban green spaces across the Sohar Wilayat (Table 1). The statistics of the population and neighbourhood boundaries of the area were collected from the National Centre for Statistics and Information (NCSI, 2020). The neighbourhood's zones are subnational administrative boundaries according to the 2010 census, which encompasses the most detailed data aggregation of population size and households. The spatial layers of public parks, landscape structure and built-up areas come from the municipality of Sohar City (Sohar Municipality, 2020).

Table 1
Spatial and attribute datasets.

Variables	Data types	Source
Built-up areas	Vector layers (polygons, point, lines)	Municipality of Sohar City, Oman, 2021
Public parks	Vector layers (polygons& points)	Municipality of Sohar City, Oman, 2021
Private vegetation	Vector layers (polygons)	Supreme Council for Planning (SCP), Oman, 2021
Population density	Attributes (statistical data)	The National Centre for Statistics and Information (NCSI), 2021
Population size	Attributes (statistical data)	The National Centre for Statistics and Information (NCSI), 2021
Land use/land cover	Raster layers (satellite images)	Supreme Council for Planning (SCP), Oman, 2021
Neighbourhood boundaries	Vector layers (polygons)	The National Centre for Statistics and Information (NCSI), 2021

In the pre-processing stage, we examined the completeness of spatial data layers as a validation and verification of spatial data through a comparison of these layers with a reference map. Therefore, the positional accuracy of a sample of the point layers (public parks) was checked and the outcome indicated that each point falls within its correct position on the ground. Similarly, overlying vector layers on an online topographic map, spatial accuracy was evaluated and all layers did not show any misplacement or shifting.

3. Methods

3.1. Spatial disparity of accessibility to public green parks

The spatial disparity of accessibility is a concept that measures geographic differences in accessibility to public services among populations, especially urban residents. In this research, spatial disparity is defined as the distance from each neighbourhood centroid to the nearest public green park and is calculated as follows:

$$d = \sum_{k=1}^{n} (x_i - y_i)^2 \tag{1}$$

Where d refers to the nearest distance measure while x_i displays a neighbourhood centroid (x_1, x_2, x_3, etc.) and y_i is a near green point (public park) (y_1, y_2, y_3 etc.).

3.2. Entropy index

Unlike the Gini index, which measures the inequality distribution of green spaces among populations, the Entropy index calculates the diversity of a neighbourhood in terms of land use patches (residential, green, barren land etc.) and it is computed as follows:

$$E = \sum_{j=1}^{k} p_{ij} \; 1n \left(p_{ij}\right) \tag{2}$$

Where $\boldsymbol{E}$ is the coefficient of the entropy index and $\boldsymbol{k}$ represents the number of land use patches (green, residential, commercial, and others). $\boldsymbol{p_{ij}}$ denotes the proportion of patches $\boldsymbol{j}$ in a neighbourhood $\boldsymbol{i}$ ($\boldsymbol{n_{ij}/n_i}$). $\boldsymbol{n_{ij}}$ reveals the number of patches of land-use class (e.g., green spaces) $\boldsymbol{j}$ **in** neighbourhood $\boldsymbol{i}$ while $\mathbf{n_i}$ refers to the total number of patches in a neighbourhood $\boldsymbol{i}$.

3.3. Landscape shape index (LSI)

The Landscape Shape Index is a standardized measure of buildings and green patches compactness which is adjusts for the size [56]. The index is calculated as follows:

$$LSI = \frac{.25(E)}{\sqrt{TA}} \tag{3}$$

where $\boldsymbol{E}$ denotes the total length of perimeter of building or space patches and $\boldsymbol{A}$ represents the size of the total area. The value of 1 indicates a single green or buildings patches in a circular shape. That is the index value increases without limits as the landscape shape becomes more irregular and disaggregated.

3.4. Area weighted mean shape index (AWMSI)

In order to measure the morphology and irregularity of a particular green patches 'shapes, the AWMSI was calculated as follows:

$$AWMSI = \sum_{j=1}^{n} \left[\left(\frac{0.25_{pij}}{\sqrt{a_{ij}}} \right) \left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \right) \right] \tag{4}$$

Where P_{ij} represents the perimeter of patch $\boldsymbol{i_j}$ while $\boldsymbol{a_{ij}}$ refers to area (m^2)

of patch i_j. The index is substantially calculated as the sum of each land patch perimeter within a specific spatial zone (across all patches types) divided by the square root of patch area (m2), adjusted by a constant for a circular standard, multiplied by the patch area (m2), and divided by the total landscape area (m2) within the same zone. In addition, the index has the advantages of weighting where a larger patch has more weight than a smaller patch. The increasing of the index values above 1 is without limit while larger values indicate more irregularity and complexity of patch shapes.

4. Results

4.1. Spatial distribution of private green spaces

Although private urban green areas in Sohar are not open spaces, they provide the city neighbourhoods with landscape diversity and work as a realm for ecological balance. The spatial distribution of private green patches varies across the Wilayat neighbourhoods. The number of green patches and agricultural farms is lower within coastal neighbourhoods compared to the neighbourhoods in the central part of the Wilayat (Fig. 2). This is due to groundwater salinity in that area, as other studies show that water salinity has been increasing towards areas far from the coast over the past three decades (Abulibdeh et al., 2021). Likewise, a very low number of green patches are found within the new planned neighbourhoods that are located in the western part and far away from the Wilayat centre. Overall, the neighbourhoods' insufficiency of green spaces is largely concentrated in the west and southwest. The distribution of agricultural patches is associated with the longitudinal shape of the Wilayat, where most patches are concentrated in the north and middle parts, while the density of the residential buildings decreases along the Wilayat's edges. Due to the increasing sprawl on the margins of the Wilayat neighbourhoods, spontaneous growth of urban settlements is also associated with sparse agricultural farms on the edges and toward the west.

Fig. 3 illustrates the number of green patches in each neighbourhood as well as the share available to every person in square metres. The large number of patches is concentrated in the central neighbourhoods, predominantly A'Tareef, Al-Waqalibah, and Al-Hambar. However, people living in these neighbourhoods have low shares of private green spaces compared to the neighbourhoods that are located in the north and southeast. This is can be attributed to the high population concentration and residential building densities in the neighbourhoods located in the central area. This spatial pattern also indicates an unequal green space distribution across all neighbourhoods located around the city centre. For example, all coastal neighbourhoods that are characterised by their small size show a low number of patches and subsequently low shares of green spaces with access at less than 500 m per capita.

Overall, and looking at the association between population size, private green spaces and plots in each neighbourhood, Fig. 4 shows a fairly medium Pearson correlation coefficient (0.62) where the majority of neighbourhoods with large population densities contain a large number of green patches. This pattern of urban areas, which is characterised by dense agricultural farms, can be attributed to historical and socioeconomic development, as the city is located in the Al-Batnah coastal plain, which is considered the central region of agricultural activities in Oman.

The number of green plots in each neighbourhood is also associated with the density of buildings, dwellings and population size (Fig. 5). Overall, the fragmentation degree and the density of green plots and patches are higher in the neighbourhoods that are located in the central part of the city, while the density of build-up patches decreases towards the internal places, particularly in the southwest and west. In these directions, in some new planned residential areas such as Al Malih, Al-Rafah and Sohar Ind, the size of green plots is small and the distribution tends to be that of a scatter pattern. On the other hand, the number of buildings patches is higher than the number of green patches where the areas of cultivated land and productive agricultural farms are limited.

4.2. Accessibility to public parks

Accessibility to public urban green spaces is a vital proxy in assessing

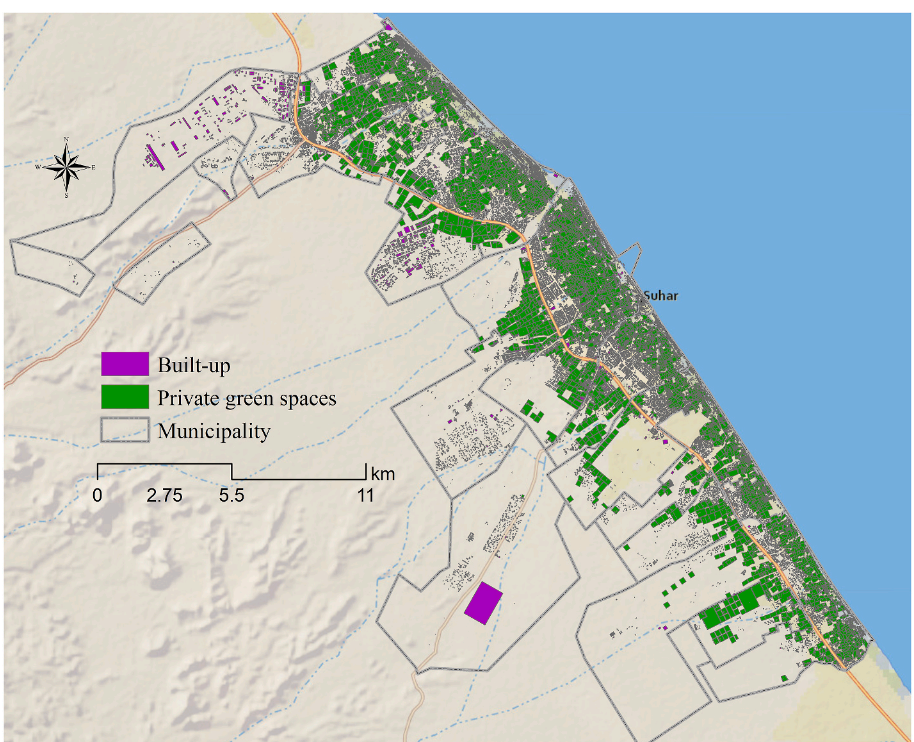

Fig. 2. Spatial distribution of urban green and built-up area patches.

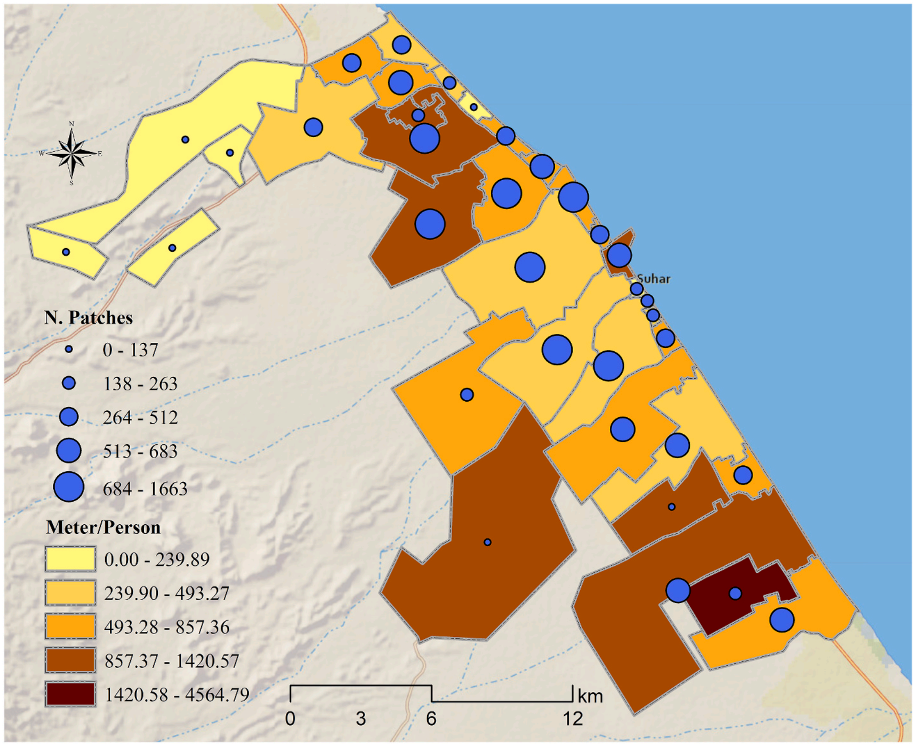

Fig. 3. The number of green patches and the share of green spaces per person in each neighbourhood.

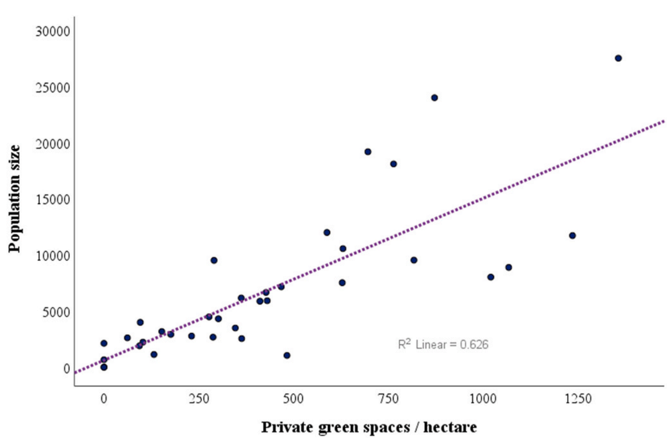

Fig. 4. The correlation between private green spaces and population size in each neighbourhood.

spatial distribution patterns and the provision of ecological services. The findings on measuring accessibility to public parks is presented in Fig. 6. The access to public parks in the Sohar Wilayat varies by neighbourhood zones. The lowest accessibility scores were found across the neighbourhoods that are located in the central part of the Wilayat. The distance to the nearest public park increased by between 5 and 7 km, and thus the accessibility level across these neighbourhoods is as high as the far north of the Wilayat where the Sohar port is located. Conversely, the most accessible neighbourhoods were located to the south, southeast, and northwest of the Wilayat. This distribution pattern indicates that, in going further into the central part of the Wilayat, the distance to public parks increases and the accessibility score of each neighbourhood decreases. It is worth noting that the accessibility of public parks in the marginal parts of the Wilayat has been improved recently due to vacant land availability, which provided open spaces for constructing a high number of parks.

The findings of spatial accessibility of the Sohar Wilayat parks demonstrated that residents in some neighbourhoods can walk less than 500 m to reach the nearest park, and Fig. 7 illustrates the distance from each neighbourhood centroid to the nearest public park. The shortest distances are less than 1 km, which fundamentally indicates high access to public parks in six neighbourhoods (e.g. Amq, Mualeh, al-Hambar and As Sanqar). Another group of neighbourhoods shows a medium level of accessibility to the nearest parks for resident populations within distances of greater than 1 km and less than 2 km (Al-Jafrah, Sallan, and Falaj Al Qabil). The third group of neighbourhoods includes distances of greater than 2 km and less than 3 km from each centroid to the closest park (e.g. Al-Uwayant, AlGushabah, and Majees). Four neighbourhoods show low spatial access to the nearest park with distances greater than 3 km, particularly in the A'Tareef and Sohar Ind neighbourhoods.

4.3. Spatial diversity (entropy index) and landscape metrics (LSI and AWMSI)

Residential and urban green land-use types are the most dominant land categories across the study area. Utilising Shannon's entropy model, the entropy index of land use was calculated as a measure of land types' diversity based on the relative percentages. Fig. 8 illustrates the spatial pattern distribution of urban green and residential area classes, and it can be seen that neighbourhoods that are located in the south of the city show high levels of evenness and subsequently large values of the entropy index. Not surprisingly, built-up areas are more extensive in the central part and near the city centre, while minimal concentration is found in the marginal southern and northern parts. On the other hand, equal concentration of both green spaces and residential areas is observed in the central neighbourhoods showing moderate values of diversity and entropy index levels. The overall areas of green spaces differ substantially according to the distribution of fertile soils and underground water salinity. Scattered patches and lower density of green areas are found along the coastal neighbourhoods where the soil can be characterised as being of a saline type. Thus, the number of farms and private green patches is small while across the internal neighbourhoods,

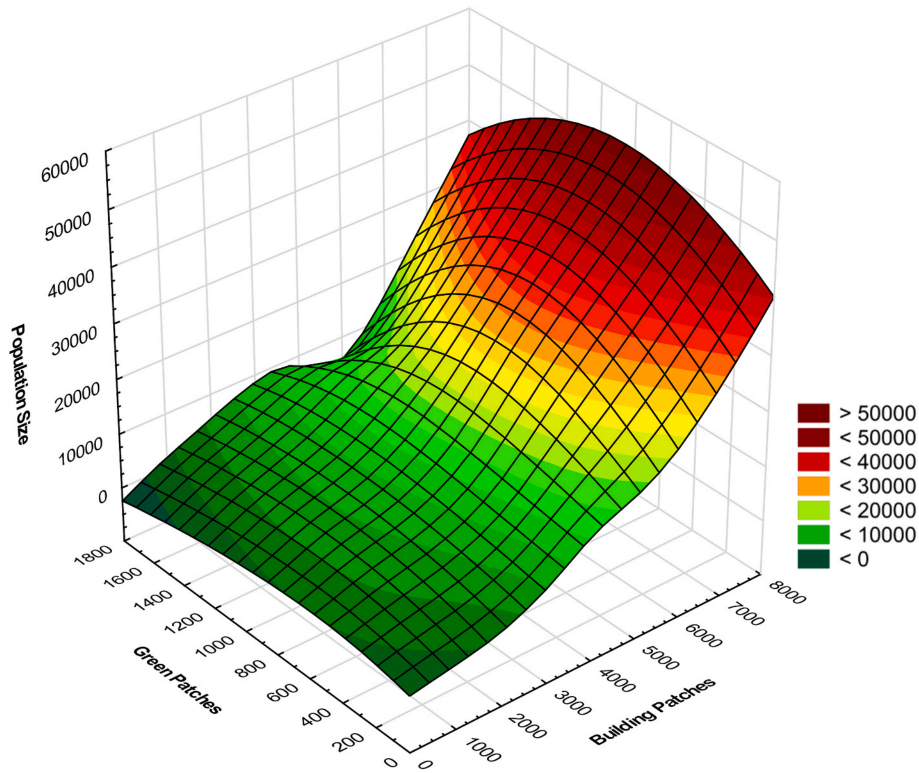

Fig. 5. The association between urban green spaces, built-up patches and population size.

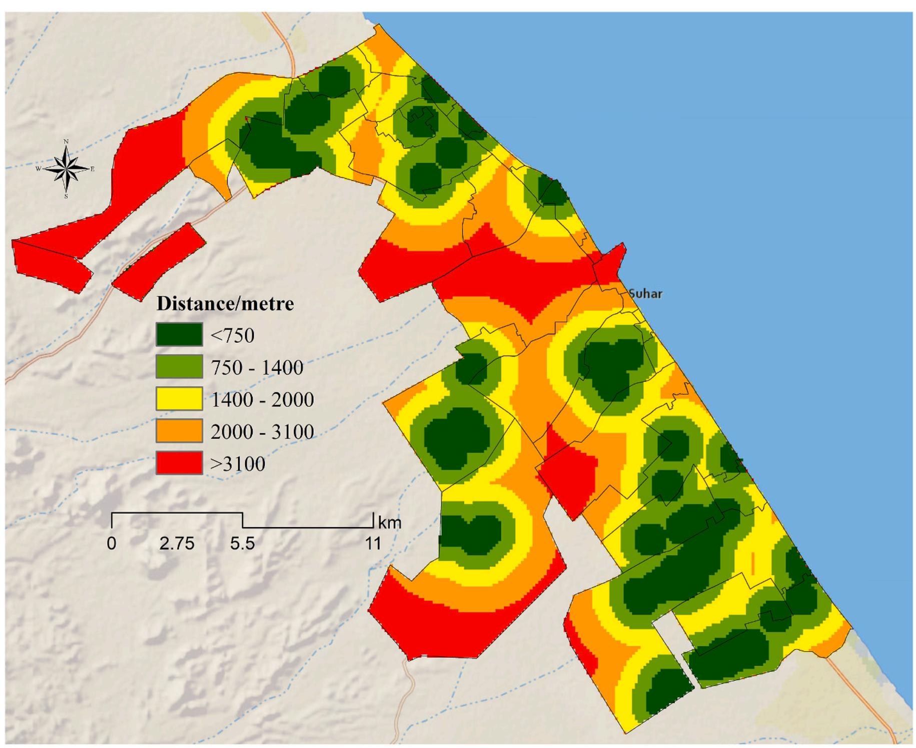

Fig. 6. Distance from each neighbourhood centroid to the nearest public park.

the fertile soils are suitable for crop growth in areas in which urban sprawl occurs.

Spatial landscape metrics were calculated to measure fragmentation and organisation of green patches. The LSI designates the area of a patch or fragment within the neighbourhoods. Fig. 9 demonstrates more fragmented green patches within the northwest and southern neighbourhoods. This pattern of fragmentation is associated with an increased number of patches and high values of LSI (1.4–5.0). In contrast, a low number of green patches was found within the central neighbourhoods and around the city centre. Consequently, a decrease of LSI values

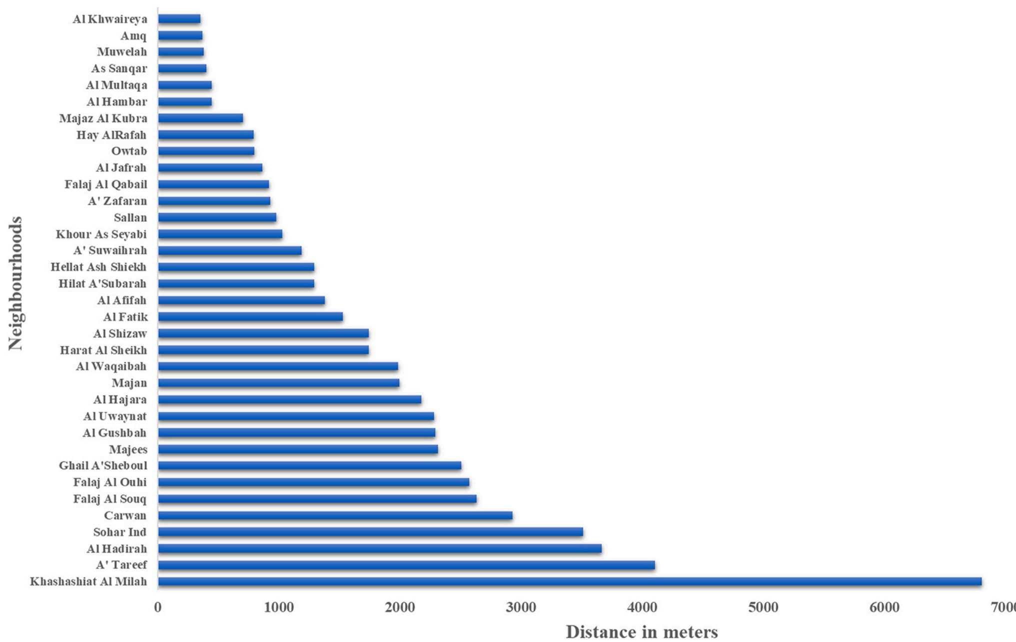

Fig. 7. Classification of neighbourhoods based on distance to the nearest public park.

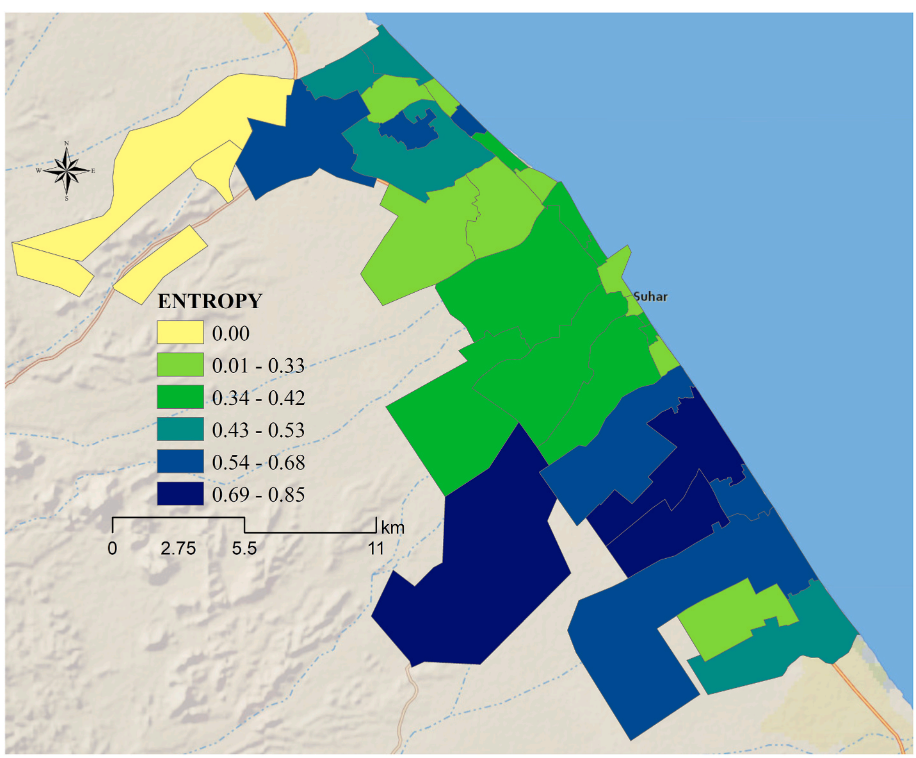

Fig. 8. Spatial pattern distribution of urban green spaces and buildings.

(0.0–0.9) was found, which indicates a clustering of patches in these areas.

The AWMSI measured the irregularity of the green patches' shapes across the study area. Fig. 10 shows that large values of AWMSI were found mainly in the northern and central neighbourhoods, which reflects irregularity in shapes of green spaces since the index values are higher than 1 (1.2–1.4). In essence, this pattern of irregularity can be attributed to the rapid urban sprawl and unplanned housing, particularly on agricultural land. The finding of the index suggests a slight spatial trend towards complexity and irregularity for the private green spaces. Notably, the increased patterns of green space irregularity are associated with increased values of fragmentation, specifically within neighbourhoods that are characterised by low population density and an expansion of informal settlements.

5. Discussion

This research aimed to analyse spatial variations of accessibility to

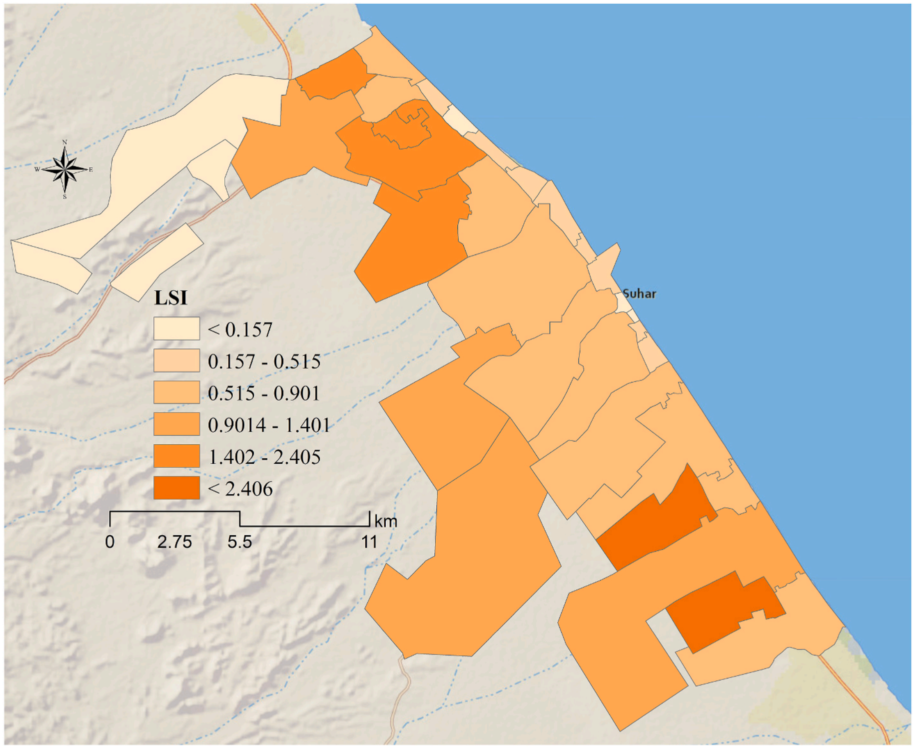

Fig. 9. Spatial distribution patterns of landscape shape index (LSI) for green patches.

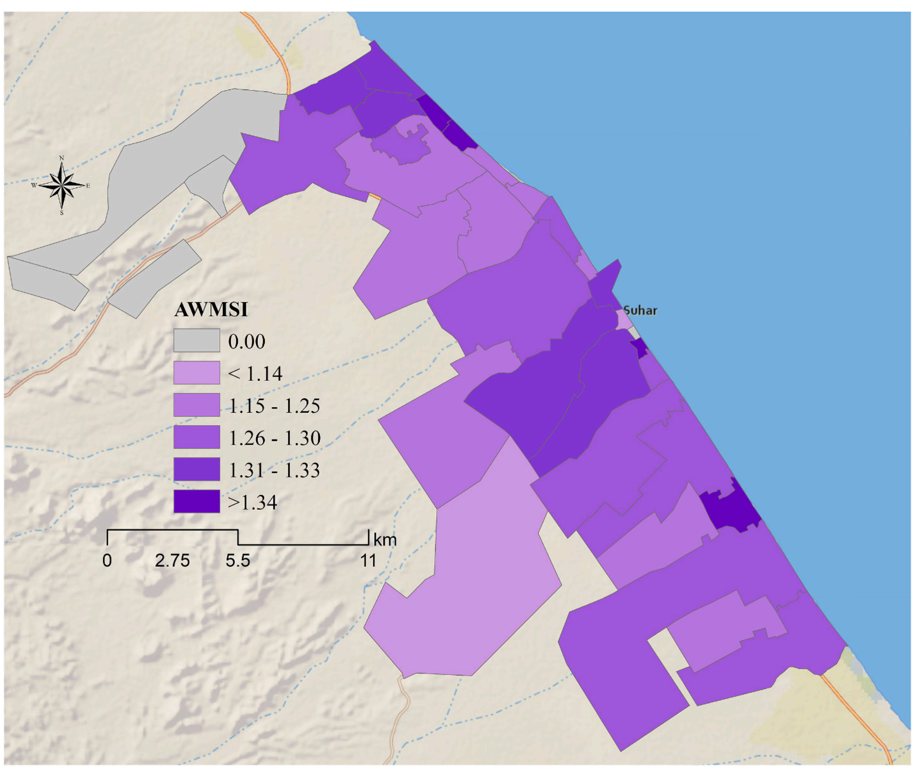

Fig. 10. The spatial distribution patterns of area-weighted mean shape index for green patches.

public parks and assess the importance of green ecosystem services across the Sohar Wilayat in Oman. The analysis outcome has provided a clear picture of the nature of urban green spaces in a semi-arid region, particularly to bridge the gaps in green spaces research not only in Oman or the Gulf Cooperation Council (GCC) countries but also across the wider Middle East. Specifically, this study has therefore reported upon key geographical issues in urban green development within the coastal cities of arid and semi-arid regions. The findings of this research have also provided evidence of accessibility patterns, distribution and landscape metrics on which to base future decisions within municipal planning and design, as well as identifying areas requiring further research.

Although the majority of green spaces are private patches and not open, they provide residents with fresh air, ecological balance and landscape diversity. A low number of green patches were found almost across all coastal neighbourhoods, and this can be attributed to the nature of soil fertility and the high level of salinity. In contrast, the internal neighbourhoods in the middle part of the city are characterised by rich green spaces, whereas a greater extension of private farms are present all around the major road, which passes the city in a north-westerly direction. Building on the direct association between urban green spaces and population density, urban green areas were primarily positively correlated with population and housing densities. Overall, the discrepancy of coastal and internal neighbourhoods regarding urban green concentration might be partially explained by the spatial variations of urban growth rates and the availability of vacant land [47]; Kazem et al., 2020). While the coastal neighbourhoods are characterised by a scarcity of suitable land for crop growth, as well as limited vacant land, the internal neighbourhoods are characterised by fertile soils and no shortage of vacant lots.

Spatial accessibility to open spaces is a crucial measure in assessing service provision and coverage. The results of this study have shown a core-neighbourhood pattern of accessibility to public green areas in the Sohar Wilayat. Employing the fundamental Euclidean distance, the neighbourhoods with higher levels of accessibility to public green areas tended to be concentrated in the core of southern and northeastern parts of the Wilayat, where residents live within short distances from open spaces, sports fields and coastal parks, while, on the other hand, lower levels of accessibility are found in the mid-neighbourhoods in the Wilayat. These spatial inequalities in access to green areas are mainly related to the locational pattern of the amenities in the study area. This result agrees with other studies that were conducted elsewhere and reported inequity in the distribution pattern with a recognised concentration of green spaces in the central parts of urban areas [26,27].

As the arid and semi-arid cities are characterised by water shortage, dry land and sparse vegetation, they face various environmental challenges regarding green infrastructure. Thus, the optimisation of urban green distribution and park construction is quite challenging. Across the study area, the public coastal parks serve as recreational, leisure and functional socioecological destinations for residents living within the coastal neighbourhoods. As urban development continues in most of these places, the open spaces and vacant lots, particularly between buildings' patches, are limited. Consequently, and due to this limitation of the biophysical landscape, residents rely on using public parks along beaches as places for walking, exercise and other social activities. Moreover, the characteristics of landscape fragmentation within the central and marginal neighbourhoods reflect a mixed concentration of residential, agricultural and open spaces' shapes. This pattern of spatial heterogeneity in the fragmentation of land use types can be initially attributed to the rapid urban sprawl as well as the high rates of housing construction within unplanned settlements. Consequently, this growth pattern will further increase the pressure on the remaining open spaces and lead to a further decline in green patches. The finding in this context builds upon the existing evidence which emphasises the fundamental associations between a low provision of green spaces and low access to public parks, with residents living in unplanned and deprived neighbourhoods (e.g. Refs. [27,30]; Dempsey et al., 2012).

Open spaces across the study area vary from one neighbourhood to another according to several spatial conditions, particularly biophysical landscapes and vacant lands. In the arid and semi-arid cities where the incidence of vegetation and natural green are low, open spaces and parks often serve comprehensively as a recreational asset. Within the Sohar Wilayat in Oman, the accelerated urbanisation and socioeconomic development are both putting huge pressure on providing green spaces and parks for all urban neighbourhoods. To increase the provision of public parks and open green spaces, specific plans for how and where such recreational spaces will be allocated should be developed by the municipal planners and decision-makers, specifically noting that the percentage of built-up areas is increasing while the supply of open and green spaces is shrinking within all neighbourhoods. Reclaimed lands and spaces could be allocated for public parks and gardens in each neighbourhood as well as expanding the interconnectivity of the green fingers to link urban to semi-urban areas.

Although the area of private green spaces is large in the central and northern neighbourhoods, access to public parks was low, and thus a low availability of recreational services was reported. Accordingly, the urban municipal policies should assess the areas of green space in each neighbourhood based on population size and concentration. Besides this, accessibility to public parks should be measured spatially considering crowding by visitors, especially within coastal parks. From a policy perspective, constructing local parks within the neighbourhoods with high residential and built-up areas may improve the spatial accessibility to open parks.

6. Conclusion

Green spaces influence well-being in a variety of ways and have different socioeconomic and environmental benefits relating to ecological functions, recreation, cultural heritage, aesthetics, and social interaction. This study aimed to develop geospatial measures of green space distribution and accessibility in the Sohar area. The study utilised different GIS techniques and landscape metrics indices to measure the spatial evenness and distribution of private green spaces, as well as accessibility to public parks. These techniques were quite helpful and important for analysing the landscape structure and heterogeneity and its consequences, particularly in regards to sustainable urban development.

The spatial distribution of urban green areas should be understood based on neighbourhood units and at a finer spatial scale. Accordingly, the findings of the present study indicated that the coastal neighbourhoods lack sufficient green patches compared to other areas due to water salinity and high population density. Similarly, the neighbourhoods located in the western part showed a very low number of green patches since these zones are newly developed. On the other hand, a large number of private green patches were concentrated within neighbourhoods in the north and middle parts where these areas are characterised by low population density and agricultural land fertility. The central neighbourhoods have a large share of green patches; however, residents have a low share of these patches due to the high population and building densities. Furthermore, the central neighbourhoods are characterised by the lowest accessibility scores to public parks compared to the neighbourhoods located in the southern part that are characterised by low residential density and a higher number of small parks.

Linking the urban growth patterns in the Sohar Wilayat to the change in open spaces and green size requires employing various spatial metrics such as LSI and AWMSI. These measures could provide invaluable information on landscape structure and planning, specifically regarding population accessibility to green spaces as well as the diversity of land use types which change through space and time. Accordingly, the outcome of this analysis may provide municipal planners with clear spatial guidelines for how to assess and plan the coverage and provision of green ecological services. Likewise, attention should be paid to the spatial variations and un-evenness of distribution of private green patches and the poor access to public parks, particularly the central neighbourhoods that are located around the city centre.

Our analysis was limited by the absence of a dataset on how people access public parks and the major travel mode they use to reach such areas. Also, as we utilised the polygon centroids of public parks and neighbourhoods for measuring accessibility, the output of processing may have potentially overstated the distance approximation, particularly for parks of a large size. Nonetheless, and to the best of our knowledge, this is the first study to geospatially address urban green issues in the arid and semi-arid areas of Oman and the GCC states. Hence, it opens the door for many research directions through which this study could be developed further. For example, one study could investigate the urban sprawl threats to land-use fragmentation and measure the shrinking of green spaces. Moreover, and as we explored the spatial accessibility to public parks without considering population behaviours and how they travel to these parks, future studies could analyse these aspects by surveying the socio-ecological attributes of population groups.

Authors' contributions

Conceptualization, methodology, data curation, geospatial analysis, investigation, writing—original draft, S.M.; data curation, writing - review & editing, N.A; writing introduction section, data curation, writing - review & editing, A.A; data curation, writing - review & editing, E.R. All authors have read and agreed to the published version of the manuscript.

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Declaration of competing interest

The authors whose names are listed in this manuscript certify that they have NO conflict of interest for subject matter or materials discussed in this manuscript.

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