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CASE STUDY

Evaluation of urban ecological sustainability in arid lands (case study: Yazd-Iran)

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Abstract

Nowadays, the world is facing rapid urbanization and increasing desertification. Therefore, urban planning in these regions should be based on comprehensive understanding of the constraints and vulnerabilities of arid lands. In this study, the sustainability condition of a rapidly growing city in a dry landscape, Yazd, Iran, was assessed using a previously developed framework. The framework is based on the conceptual principle of close relations between structure and function and is comprised of three main components and 16 metrics. By evaluating the status and trends of these metrics, and using the analytical hierarchy process method, the score of Yazd sustainability was determined as 0.28 out of 1.0, indicating the city is far from a state of sustainability. Current urban development policies in this region exacerbate unstable conditions. Given the constraints on achieving urban sustainability in arid regions, physical urban development should be aligned with local ecological potential. In the process of urban growth, local knowledge and ecological values in these areas must be protected. Applying this sustainability assessment process in other dryland cities will improve this evaluative framework and help achieve rational principles for sustainable urban development strategies in arid lands.

Keywords Arid lands · Urban biophysical structure · Urban ecosystem dynamic · Citizens' security and satisfaction

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1 Introduction

Drylands occupy 41.3% of the Earth's surface, 90% of which are located in developing countries. Approximately 25–30% of the world's population (2.1 billion people), with 18.5% Population growth rate which is higher than other ecological zones, live in arid and semiarid regions (United Nations, 2019). There are many cities in arid lands that are growing rapidly due to the expansion of urbanization in the world. Many of these cities are severely vulnerable to physical, ecological, and climate change constraints (Baker et al. 2004), and hence these cities are moving away from sustainability as a result of the overwhelming expansion. Accordingly, it is extremely important to study the sustainability of cities in arid lands. Determining the status of urban sustainability helps urban managers to plan for a more sustainable future.

Urban sustainability is a multidimensional concept that incorporates a combination of economic, technological, ecological, and social systems (Kremer et al. 2019). Indicator-based approaches have been used in many studies to measure urban sustainability. Such approaches provide essential information for decision-makers and urban planners to improve urban environmental quality (Hiremath et al. 2013). Hitherto different frameworks have been developed for urban sustainability assessment. In each of these frameworks, it has been attempted to address the issue of urban sustainability from a number of dimensions or all aspects of sustainable development, for example, City Prosperity Index (CPI) (UN-Habitat 2015), Sustainability Assessment by Fuzzy Evaluation model (SAFE) (Phillis et al. 2017), and Iraqi Urban Sustainability Assessment Framework (IUSAF) (Raed Fawzi and Monjur 2018).

Although many frameworks have attempted to address urban sustainability issues comprehensively, there is a need for a framework that focuses on evaluating urban sustainability in arid lands, especially on the basis of ecological approaches.

The new approach of urban ecology is influenced by landscape ecology (Wu 2014; Wu et al. 2011; Wu and Wu 2013). The intellectual basis of landscape ecology focuses on the close relationships between structure and function (Forman 1995). Based on this approach, cities are defined as socioecological systems, and their performance is interpreted based on relationships between urban patterns and ecological processes (Alberti and Marzluff 2004). Accordingly, any changes in the physical structure of the cities and suburbs will result in functional changes in ecosystem services (Tratalos et al. 2007; Wu 2013; Young 2010) and other environmental functions such as hydrological system failure (Arnold and Gibbons 1996), and changes of energy flow and food cycles (Grimm et al. 2000).

Based on this approach, a number of different frameworks have been developed to assess urban sustainability (Pickett et al. 2001; Grimm et al. 2000; Alberti et al. 2003; Alberti 2005). These frameworks are designed based on relationships between causes and effects and also the relations between structure and function in cities.

Based on these theoretical foundations of structure–function relations, a framework to assess urban sustainability is developed here that is comprised of three main components: Urban Pattern of Biophysical Structure, Urban Ecosystem Dynamic and Function, and Citizens' Security and Satisfaction. A total of 16 quantitative criteria (metrics) are defined within these three components to measure sustainability of cities in arid lands. The relevance of each metric, based on environmental importance, is provided in Table 1.

The purpose of this study is to apply the proposed indicator framework to evaluate the sustainability of the city of Yazd, Iran. Yazd is one of the important cities of Iran and is located in an arid landscape. Despite environmental constraints, Yazd has experienced

Table 1 Importance of metrics for urban sustainability assessment in dry lands

Main components of framework	Component	Criteria	Importance of criteria in arid regions
Urban pattern of biophysical structure	Source of urban ecosystem services	Urban green cover	Water treatment, source of primary environmental services in cities, local climate adjustment, carbon sequestration, reduction in soil erosion, habitat, rising the residential property prices, improving the quality of urban landscape, increasing human psychological well-being (Lundy and Wade 2011; Pataki et al. 2011; Young 2010; Flores et al. 1998; Wu 2014), improving urban resilience and increasing the capacity of the urban against disturbances (Alberti and Marzluff 2004)
Urban ecosystem dynamic and function	Urban air quality	Air quality index	Higher risk of mortality (Liu et al. 2014; Achilleosa et al. 2019), increasing allergic airway diseases such as asthma and rhinitis (Archsmith et al. 2018), increasing crime especially aggressive behavior (Burkhardt et al. 2019), restriction on recreational activities, negative impact on social justice (Yan et al. 2019)
		Dust	Negative impact on human health, especially in developing lung diseases ("desert lung" syndrome) (Querola et al. 2019) increasing the emergency visits and hospitalizations (Hyewon et al. 2013) increasing soil erosion (O'Loingsigh et al. 2014)
	Urban water resources	Volume of interbasin water transfer	Biological and hydrological degradation in donor and recipient basins, expansion of dry land, ecological destruction in the donor basin, increasing water consumption in the receiving basin (Pozdnyakov et al. 2013; Chen 2004), the spread of diseases and the devastating impact on human health (Sible et al. 2015), salinity, destruction of soil and desertification (Liu et al. 2013; Wen 2016)
		Groundwater	Groundwater vulnerability to indiscriminate harvesting (Lictevout and Faysse 2018; Viguiera et al. 2019), groundwater level change, ground subsidence, groundwater quality decline (Massuel and Riaux 2017), reduce the number of native species (Decuyper et al. 2016)
	Urban soil	Impervious surfaces	Rapid transmission of precipitation to drainage systems thus eliminating the source of moisture for evaporation (Xiao et al. 2007), increasing urban floods (Zhang et al. 2018), absorbing heat and solar radiation during the day and release heat after sunset, thereby keeping the temperature high during the night (Roberts et al. 2006; Taha 1995)

Table 1 (continued)

Main components of framework	Component	Criteria	Importance of criteria in arid regions
	Urban climate	Drought severity	Drought and water scarcity causes more dependency of the societies on precipitation and water resources (IPCC 2014), the adverse effects on the environment, economy and society especially on agricultural sector (Wilhite et al. 2014), reducing grass and feed availability (Parsonsa et al. 2019), Increasing the environmental refugees and mortality (Vicente-Serrano et al. 2012), Environmental degradation (Hassan et al. 2019)
		UV index	Negative effect on human health especially on skin diseases including skin cancer, accelerate skin aging process, sunburn, skin cancer and eye damage (Wai et al. 2017; Krutmann et al. 2012; Mac-Mary et al. 2010)
Citizens' security and satisfaction	Biophilic activities	Access to nature	Promotion of community cohesion, create sense of identity, education, and learning opportunities, promotion of active lifestyle (Gidlow et al. 2016), developing the social networks (Dadvand et al. 2016), promotion of well-being especially among vulnerable groups (McCabe et al. 2010), positive effects on health such as reductions in stress, anxiety and depression, diabetes, and cardiovascular and respiratory diseases (Shanahan et al. 2015; Hartig et al. 2014; Beatley and Peter 2013)

rapid growth in recent years. Evaluating the status of sustainability in Yazd can therefore provide a beneficial example for planners and decision-makers to better understand the vulnerability of dryland cities.

2 Materials and methods

Yazd is located in the middle of the Persian Plateau (Fig. 1) between the Shirkouh and Kharanagh Mountains at an elevation of 1215 m above sea level and in a wide plain called Yazd–Ardakan. According to the Koppen system of climate classification, which is based on annual rainfall and average annual temperature, the city is classified as a desert region (Hammon 1 Consultant Compony 2016). Yazd is currently the 15th largest city in Iran and in 2016 had a population of 529,673 and an estimated growth rate of 2.02% (Statistical Center of Iran 2016).

Data for the 16 studied metrics were obtained from a variety of sources, including interpretation of satellite imagery, statistics, and information provided by different organizations, and questionnaires filled out by local citizens. It is important to note that it was not possible to evaluate trends and index changes using a single uniform time period for all metrics, due to constraints and lack of data access. Therefore, in order to provide the same basis for comparison within the indicator framework, the 16 metrics were weighted according to the method of AHP.

Landsat satellite images from 1991 and 2018 (U.S. Geological Survey 2019) (Table 2) were used to prepare maps categorizing land cover in three classes: green, open, or built-up area.

After the provision of satellite data, in order to prepare the data to be processed and to extract efficient information, geometrical correction of images was carried out using vector-based topographic mapping. Spectral and radiometric enhancement of images was performed to clarify the coverage, improve the quality of images, and eliminate adverse effects of light and atmosphere distortion. Land covers were classified using maximum likelihood algorithm. Map accuracy was assessed using ground truth mapping

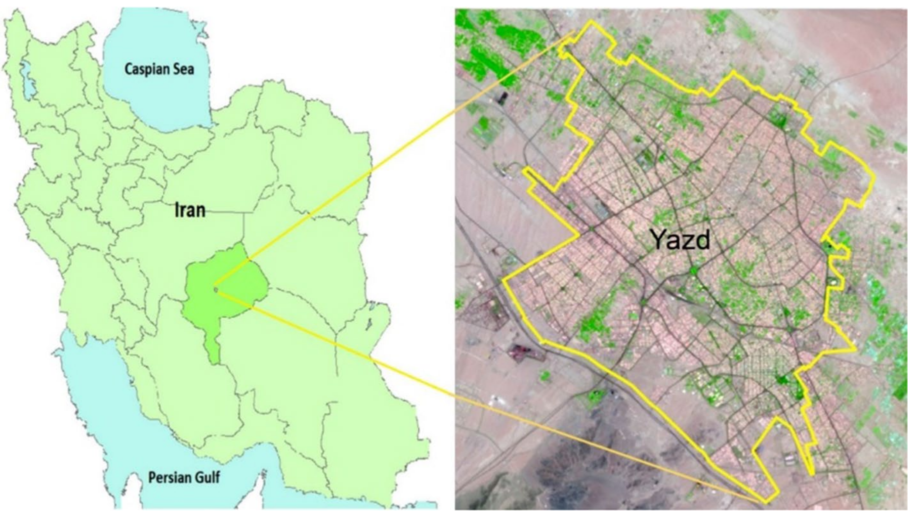


Fig. 1 Location of Yazd-Iran

Table 2 Satellite imagery specifications

Satellite	Sensor	Reference	Date
Landsat8	OLI	USGS	2018 Jun 12
Landsat5	TM	USGS	1991 Jun 18

and the results were considered as satisfactory. In the interpretation of data, the land use maps with 1:2000 scale and personal experiences of field surveys were used. Land coverage classifications for 1991 and 2018 are shown in Fig. 2.

Landscape metrics were calculated using Moving window tools in FRAGSTAT 4.2 software (McGarigal et al. 2012). This technique makes it easier to interpret the metrics because it shows the results of the metrics calculation as zoning map. Utilizing a variety of urban sustainability metrics as described below, the sustainability of Yazd was quantified using the analytical hierarchy process (AHP), a multi-criteria decision-making technique developed by Thomas Saati (Saaty 1980). AHP is a structured method for analyzing both quantitative and qualitative decision criteria and uses an appropriate weighting system based on pairwise comparison. Expert judgment was then applied to weight criteria and subcriteria with scores (1 to 9). A team including seven experts selected for decision on weight of component of AHP structure based on their background and experience on the subject of urban planning and urban environment. The weighting was considered acceptable if the inconsistency ratio in the expert judgments was less than 0.1 (Saati 1990).

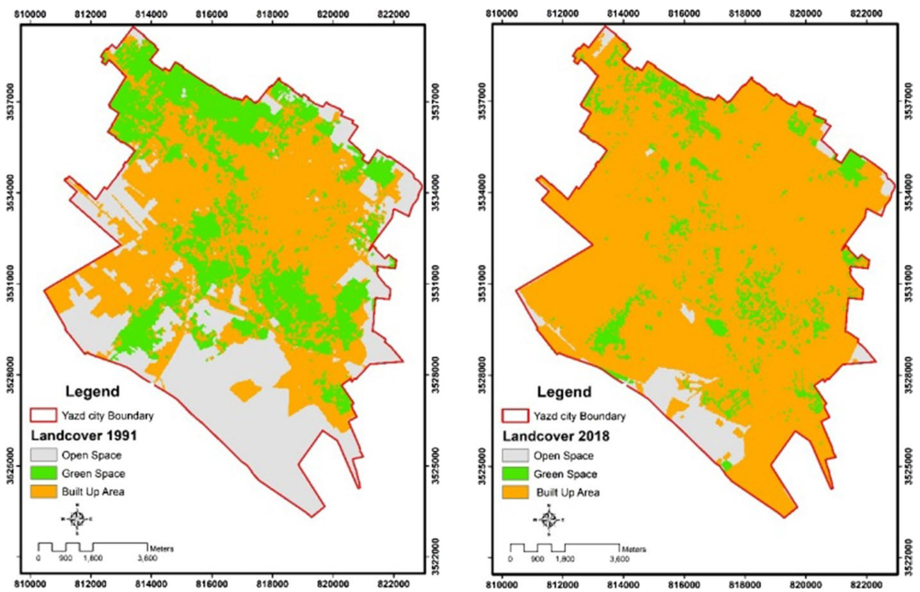


Fig. 2 Land coverage map of Yazd in 1991–2018

3 Results

3.1 Pattern of ecological structure: Yazd

This group of urban sustainability indicators is related to urban ecological structure of Yazd that produces the ecological services. Urban green spaces are the most important ecological structure in a city like Yazd. Therefore, our analysis is based on the analysis of the composition and configuration of green patches. The criteria used in this analysis include spatial heterogeneity, connectivity, and modularity.

3.1.1 Urban pattern of biophysical structure in Yazd

Spatial heterogeneity of green patches in the city of Yazd was assessed using two metrics: patch area (PLAND) and patch density (PD).

Green patch areas in Yazd (PLAND) PLAND is one of the most important metrics to measure landscape composition and quantifies how much of a target patch type (green patches) exists within the landscape (Yazd). Figure 3 shows the area and distribution of green patches, defined as areas containing greater than 50% vegetation, in Yazd in 2018. Green patches occur in very limited areas and only in the old gardens of the city. The majority of Yazd is in a severely degraded condition with substantial areas having vegetation cover of less than 25%.

Aggregation and density of green patches (PD) in Yazd Green patches in urban landscapes affect a variety of ecological processes, such as biodiversity. Patch density is the most useful metric as the basis for computing other more interpretable metrics and is determined as the total number of patches in the city divided by the total area of the landscape and is expressed as Number per 100 hectares. Through this metric, we can compare different landscapes. As shown in Fig. 4, the density of green patches in most areas of Yazd is less than 40, meaning that in most areas, green patches are disaggregated. Patch density is greater than 80 only in the old gardens area of the city.

3.1.2 Connectivity of green patches in Yazd

Connectivity of green patches in Yazd was assessed using two metrics: Euclidean distance to nearest-neighbor patch (ENN) and intensity of the patch (GYRATE).

Euclidean distance to nearest-neighbor of green patches (ENN) The ENN metric is defined as the Euclidean distance between each individual patch and the nearest patch of the same type. This metric quantifies the amount of isolation for patches of the same type (e.g., green patches of Yazd) and is expressed as the arithmetic mean or the average weight of the nearest distance neighborhood. Figure 5 shows the ENN values of green patches in Yazd. In the old gardens area of the city, the average neighborhood distance between green patches is between 50 and 100 m, whereas in the majority of the city, distance between green patches (generally urban green spaces) is more than 100 m, indicating these patches are more isolated and farther apart.

Intensity of green patches (GYRAT) Intensity of patches (GYRAT) is a metric measuring the extended area of patches (or their intensity) and indicates how far across the landscape a patch extends. This metric is calculated as the average distance between each cell

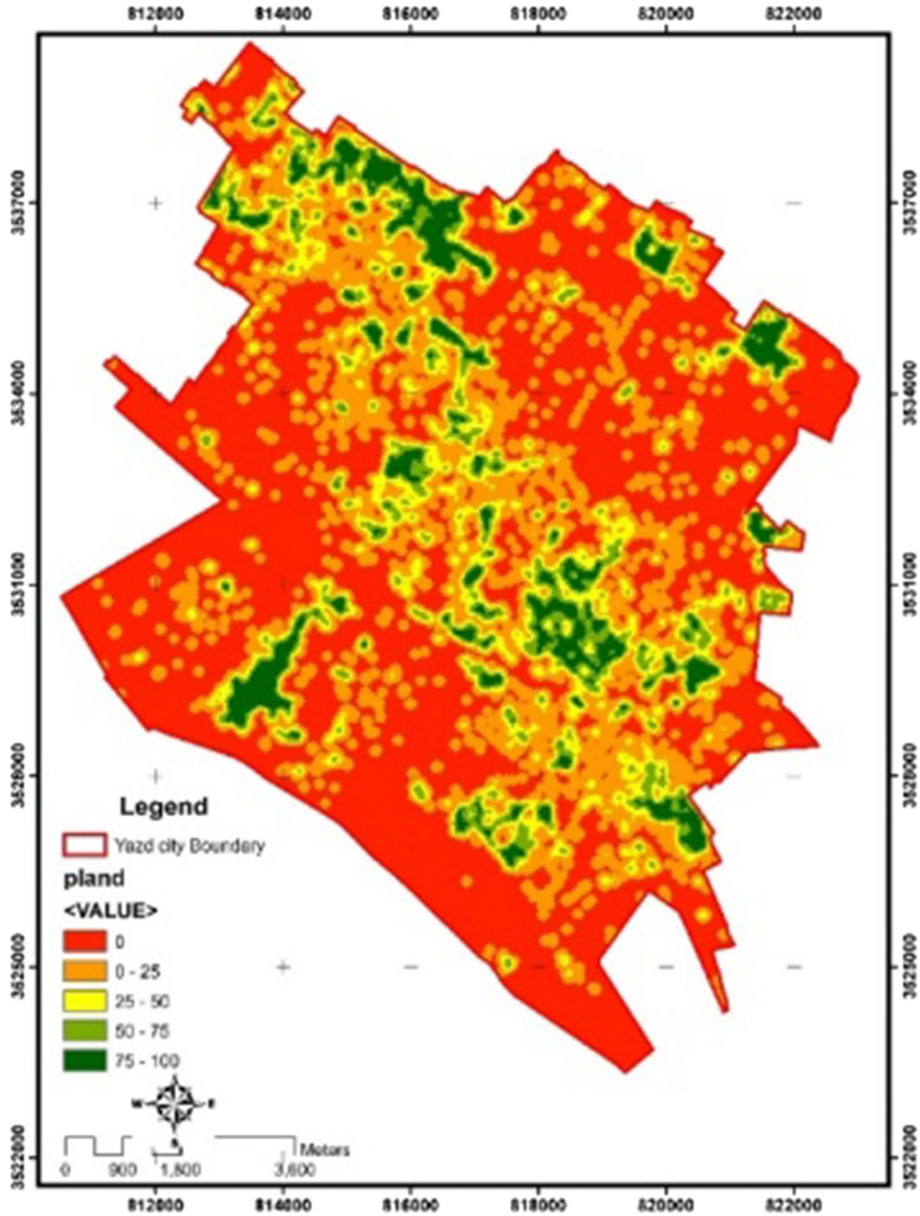


Fig. 3 PLAND of green patches—Yazd 2018

in the patch to the center of the patch [54]. Then it was summarized, for all the patches or patches of the landscape, as the average of the weighted area. When aggregated at the class or landscape level, radius of gyration provides a measure of landscape connectivity. In areas with few widely scattered patches, this metric is considered as zero. Intensity of green patches in Yazd is shown in Fig. 6. The connectivity of green patches within the

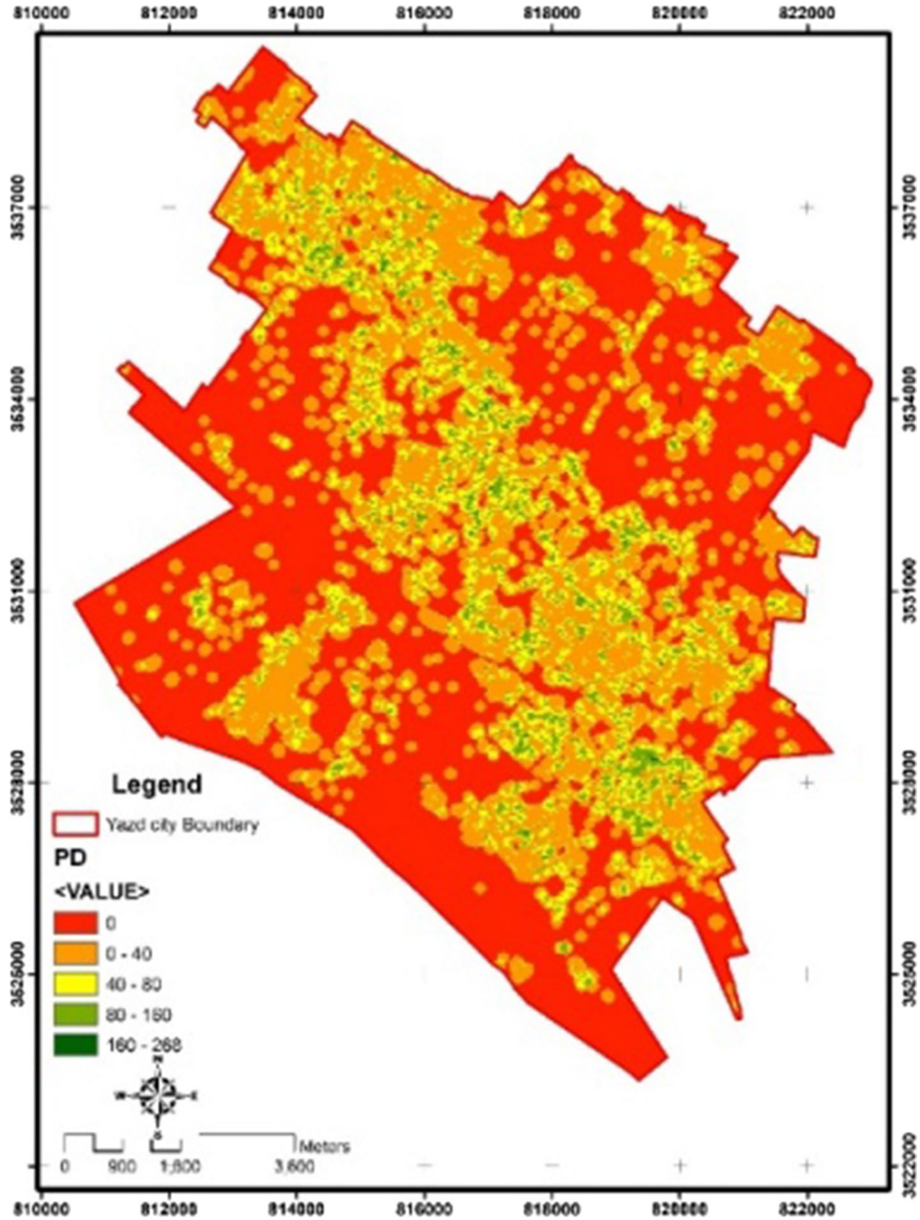


Fig. 4 PD of green patches—Yazd 2018

city's gardens ranges from 34 to 73 meters. In most areas of the city, due to the lack of green cover, the equivalent of zero has been measured.

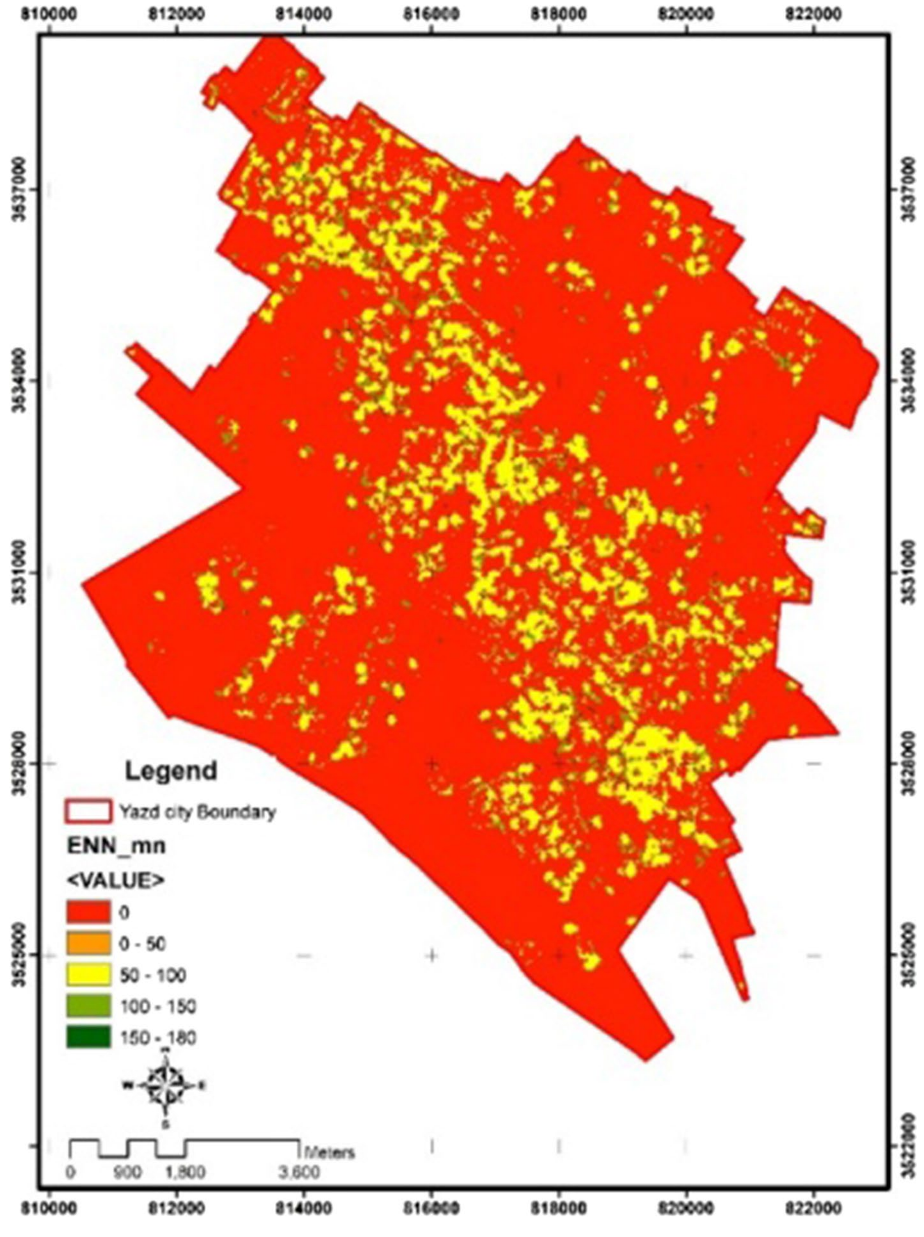


Fig. 5 ENN of green patches—Yazd 2018

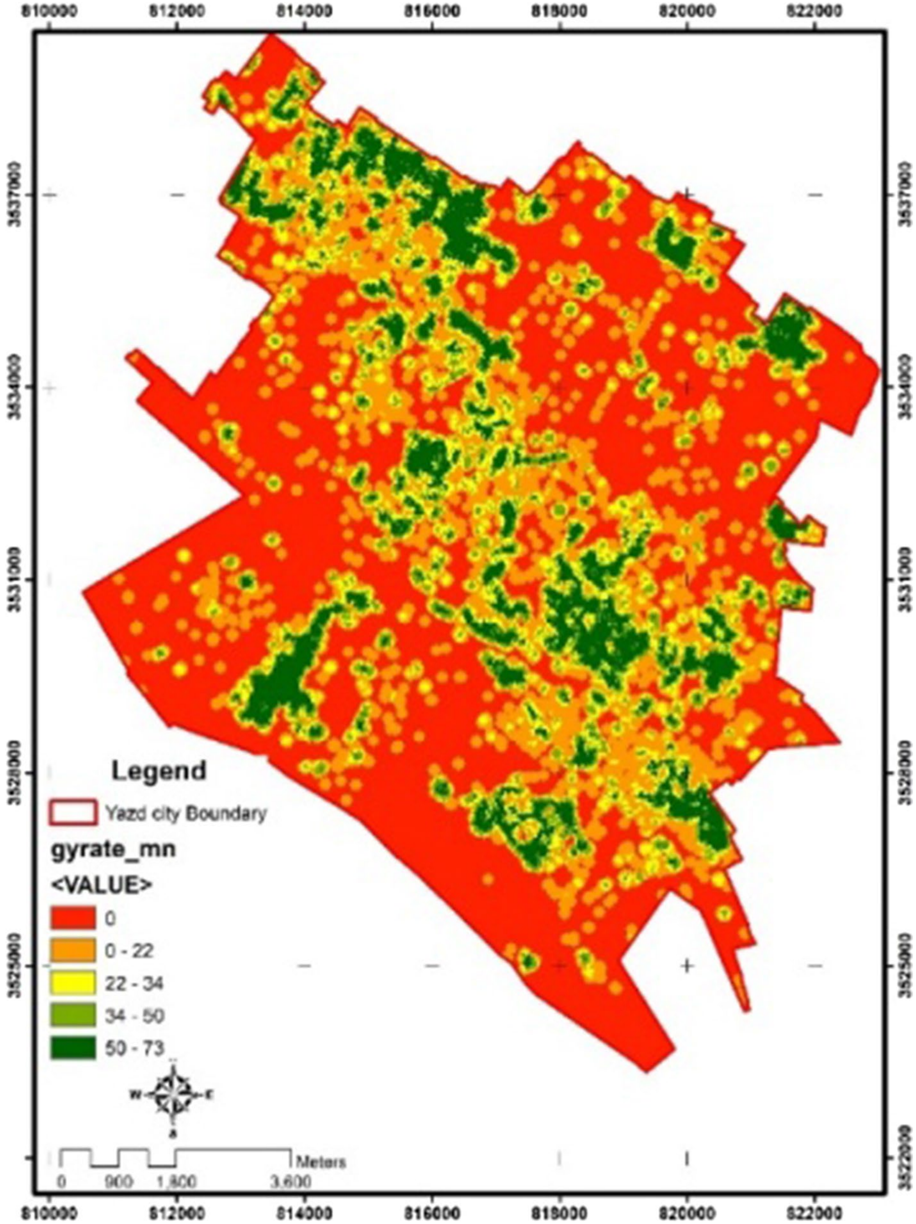


Fig. 6 GYRATE of green patches—Yazd 2018

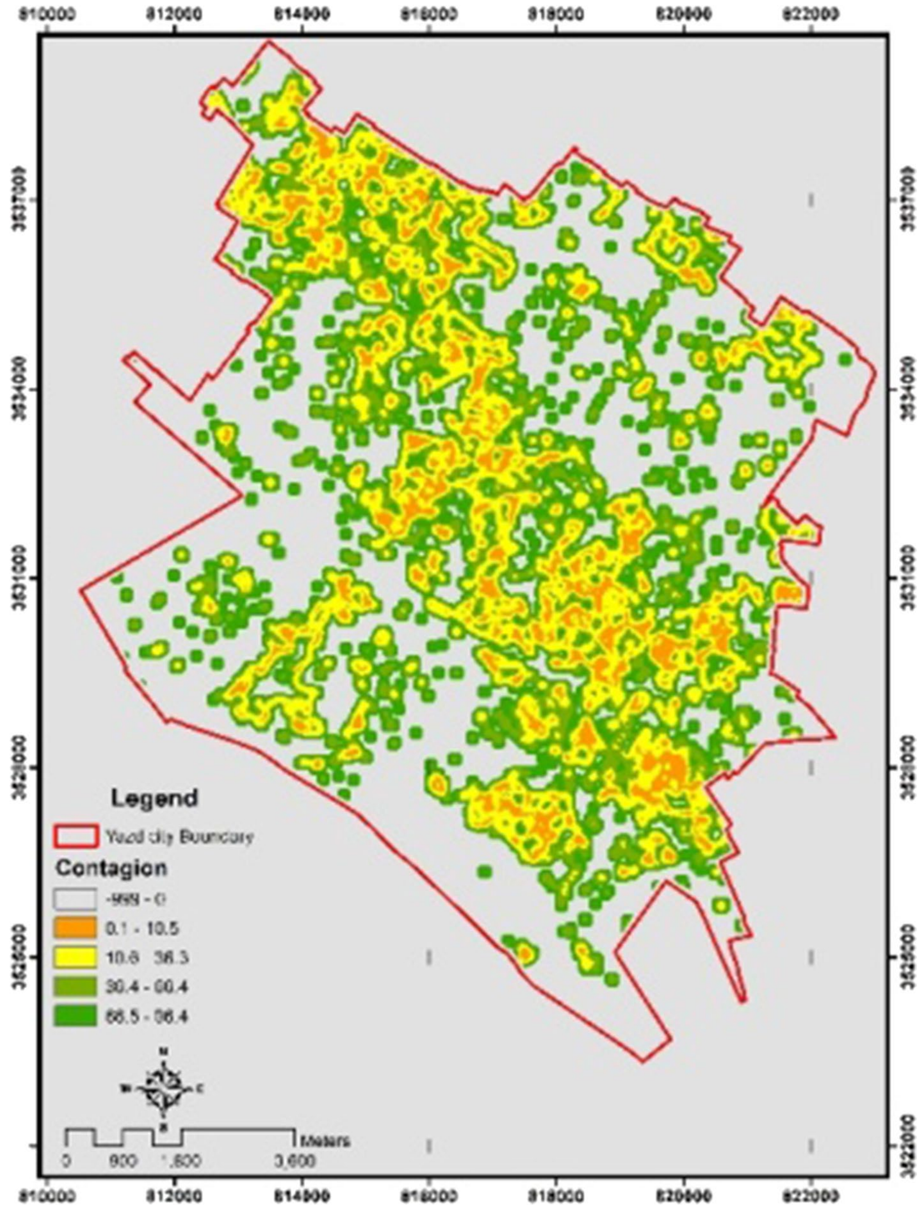


Fig. 7 CONTAG of green patches—Yazd 2018

3.1.3 Modularity of green patches in Yazd

The distribution (modularity) of green patches across Yazd was assessed using the metric of contagion (CONTAG). Higher CONTAG values reflect landscapes with few large contiguous patches, whereas lower values generally characterize landscapes with many small and dispersed patches (McGarigal et al. 2012). CONTAG values can range from 0 to 100%, with values close to zero indicating green patches are small and scattered and values close to 100 indicating green patches are clustered in few areas and do not have a congruent distribution in the urban landscape of the city. The CONTAG values of green patches in Yazd are shown in Fig. 7 and indicate that in most areas of the city, green cover is disaggregated (the contagion is less than 36%).

3.1.4 Landscape metric assessment

In 2018, the green patches in Yazd are small and scattered with a total combined area of 981.36 hectares representing just 9% of the city's total area. Since the composition and configuration of green patches is highly dependent on geographical conditions and many other parameters, universal standards are currently lacking to assess sustainability of urban green patches. The urban landscape metrics described above were used to quantify structural changes of green patches in Yazd over time and then to assess if trends are toward or away from sustainability. This study indicates a drastic negative trend in Yazd for these sustainability metrics over time. During the period of 1991 to 2018, the area of green cover (CA) decreased by 63%, the number of green patches (NP) increased by 73%, and the mean size of these patches (AREA-AM) decreased by 92% (Table 3). The closest neighbor distance (ENN) between these patches increased by 37% over this time period. Such a situation reflects the fragmentation and increased isolation of urban green cover in Yazd, and it can be concluded that the instability of green cover in Yazd has increased.

3.2 Urban ecosystem dynamic and function in Yazd

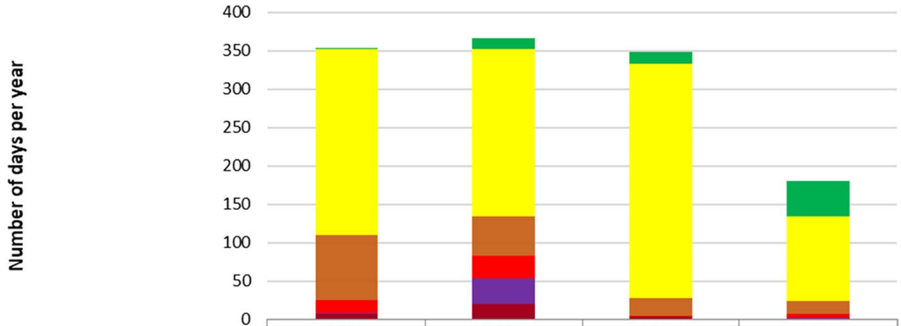
3.2.1 Urban air quality

Air quality index (AQI) Based on the data obtained from air quality monitoring stations in Yazd (Department of Environment Yazd 2018), the AQI was evaluated on an annual basis from 2015 to 2018. Values of the AQI index can range from 0 to 500 and are calculated using four major air pollutants: ozone, particulates, carbon monoxide, and sulfur dioxide. According to the AQI, air quality in Yazd has improved in recent years, based on an increase in the number of healthy days per year from 2015 to 2018 (Fig. 8).

Dust storm index (DSI) Wind erosion of soils is a process that has shaped arid and semiarid lands of the world. To understand how the sustainability of arid and semiarid lands as well as human health can be influenced by dust storms, it is important to evaluate the magnitude and temporal trends of this phenomenon. The Dust Storm Index (DSI) is a

Table 3 Yazd green cover metrics: 1991, 2018

Year	NP	CA(ha)	AREA_AM(m2)	ENN_AM(m)
1991	249	2648.97	427.6379	63.8769
2018	433	981.36	31.4253	87.4949



	2015	2016	2017	2018
Good	2	14	16	46
Moderate	242	218	305	111
Unhealthy for sensitive group	84	51	23	16
Unhealthy	17	29	1	6
Very unhealthy	1	34	0	1
Hazardous	8	20	4	1

Fig. 8 Air quality index

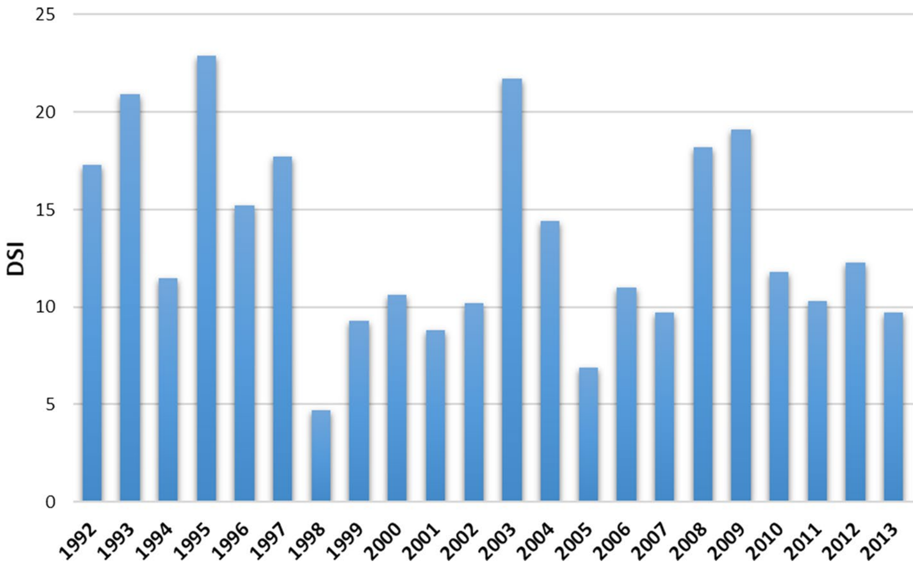


Fig. 9 Mean annual DSI of Yazd station for the period 1992–2013. *Source* Yazd Department of Environment

composite measure of the frequency and intensity of wind erosion events, based on occurrences of severe dust storms, moderate dust storms, and local dust events (O'Loingsigh et al. 2014). Figure 9 shows the mean annual DSI in Yazd for 1992 through 2013 (Arid Land and Desert Research Institute, Y.U. 2016). Although DSI has declined modestly over this time period, dust storms in Yazd still occur at a frequency and intensity that may affect the health of citizens.

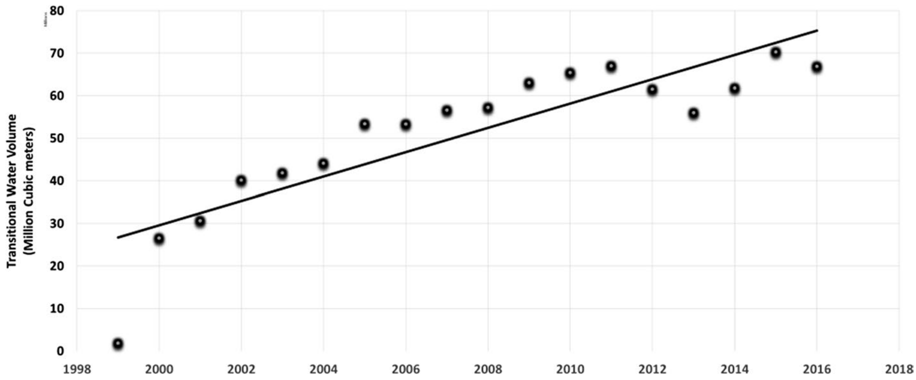


Fig. 10 Annual volume of interbasin water transfers

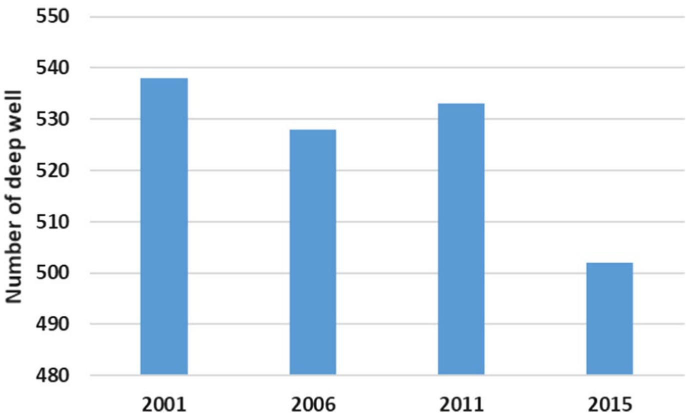


Fig. 11 Number of active producing deep wells in Yazd

3.2.2 Urban water resources

Interbasin water transfers A substantial portion of Yazd's water resources is delivered by pipelines from the Zayandehrood watershed located east of Zagroos Mountain. Due to rising water demand in Yazd, the volume of these interbasin water transfers (Reginal Water Company of Yazd 2018) has increased significantly in recent decades (Fig. 10).

Groundwater In past years, Yazd was known worldwide for its sustainable utilization of groundwater through a system of Qanats (Boustani 2008). In recent decades, however, the increasing demand for water has been supplied through the development of many deep wells in the area and the Qanats have lost their role in providing water in Yazd (Reginal Water Company of Yazd 2018).

Due to overpumping of these deep wells, the depth to the water table in the local aquifer has increased in recent years, resulting in some shallower wells and Qanats going dry and a net reduction in groundwater production. During the time period 2001 to 2015, the number of active wells in the region decreased from 538 to 502 (Fig. 11), and the volume of water discharge from these wells decreased from 185 million cubic meters (MCM) per year to 106.8 MCM per year (Fig. 12) (Reginal Water Company of Yazd 2018).

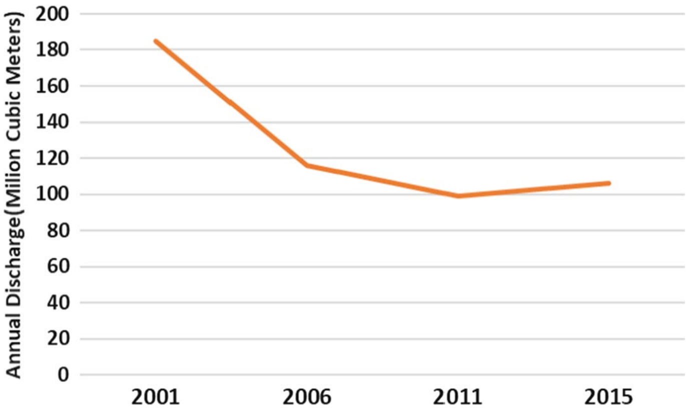
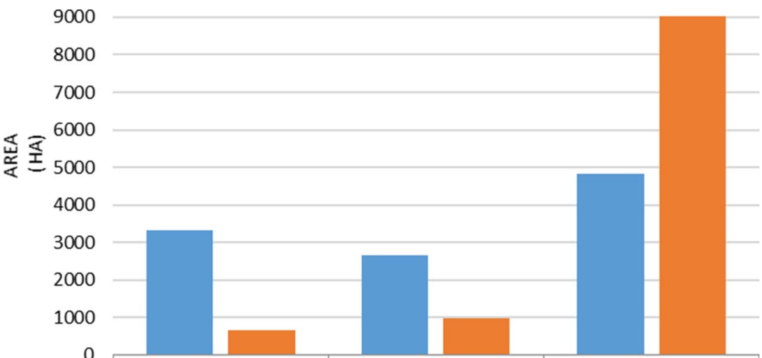


Fig. 12 Annual volume of pumped groundwater in Yazd

3.2.3 Urban soil

Change in ratio of impervious surfaces The change of urban impermeable surfaces over time in Yazd was investigated by comparing satellite images from years 1991 and 2018 (Table 1). Using FRAGSTAT software, the total areas (ha) of impermeable surfaces (built-up area) and permeable surfaces (open and green space) were quantified to determine changes in land use over this time period. Figure 13 shows comparisons of open, green, and impervious surface areas (ha) for 1991 and 2018. The continuum, impermeable levels (built area) increased strongly during the period under study. From 1991 to 2018, there was an 80% decrease in open space, 63% decrease in green space, and a 90% increase in built-up area.



	Open Space	Green Space	Built up area
1991	3333.87	2648.97	4840.02
2018	654.57	981.36	9186.84

Fig. 13 Land areas (Ha) in Yazd categorized as open, green, and built-up space (1991–2018)

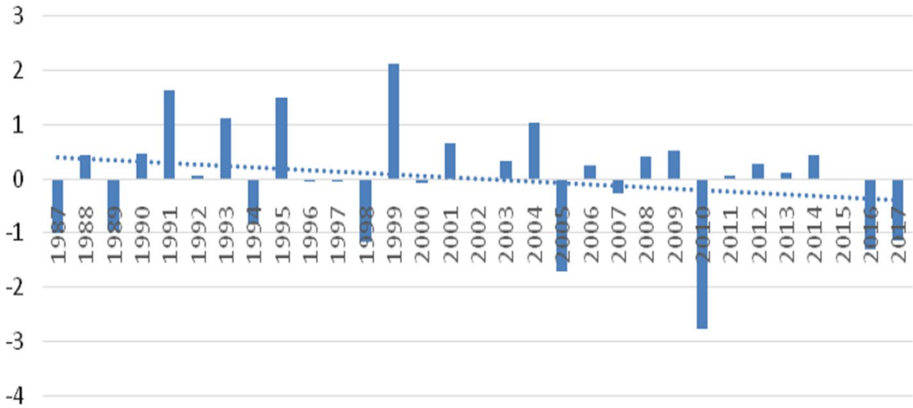


Fig. 14 Standardized precipitation index (SPI) Yazd

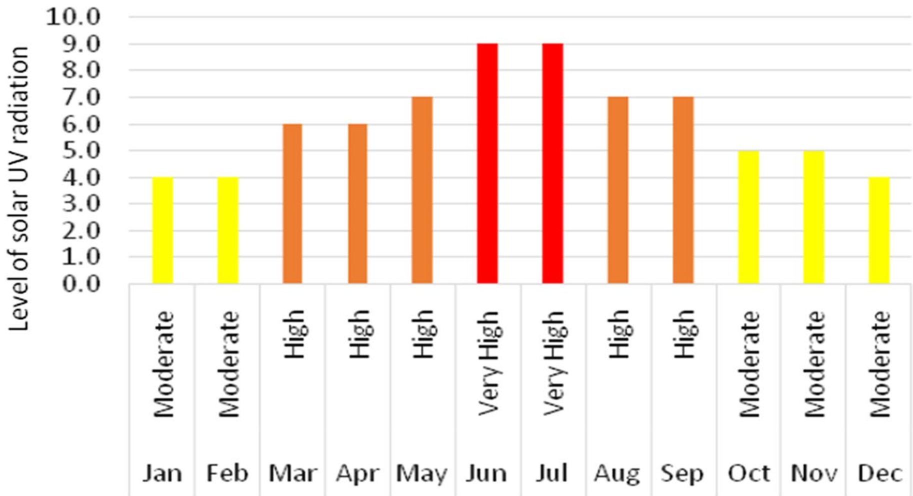


Fig. 15 Average monthly UV index—Yazd (2009–2019)

3.2.4 Urban climate

The standardized precipitation index (SPI) According to this index, drought occurs when the SPI value is consistently negative at -1 or less and drought ends when the SPI again becomes positive (Akbari et al. 2016). During the time period 1987–2017 (Ministry of Roads and Urban Development 2018), the SPI index has had an overall negative trend (Fig. 14), indicating a decrease in rainfall and corresponding increase in drought. In 2017, the drought in Yazd was considered moderate. The worst drought conditions occurred in 2010 (SPI-2.76), and the wettest non-drought conditions were in 1999 (SPI 2.14), an extremely wet year.

UV index The UV index predicts the level of solar UV radiation and indicates human health risk of overexposure on a scale from 0 (low) to 11 or more (extremely high) (World Health Organization 2019). Yazd UV data were obtained from the World Weather website

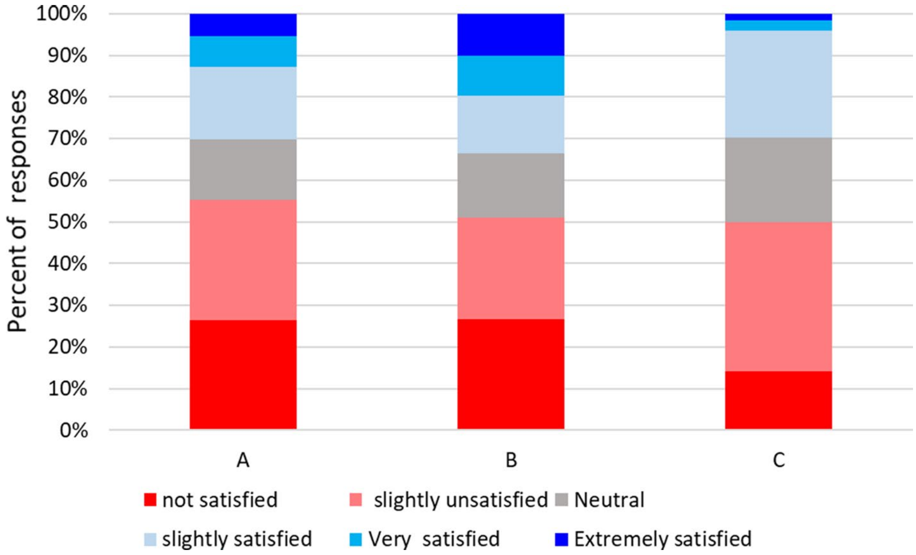


Fig. 16 Results of the questionnaire related to health

and processed in Excel software to determine average monthly UV Index values in Yazd over 11-year period from 2009 to 2019. The UV Index was high or very high from March through September (Fig. 15).

3.3 Citizens' security and satisfaction

This category includes metrics related to citizen health and also their feelings about their urban landscape and how they are able to interact with nature, known as Biophilia. These metrics related to Citizens' security and satisfaction were assessed using questionnaires. The statistical population includes the citizens of Yazd, 529,673 people according to the 2016 census. A sample size of 386 questionnaires was determined based on using Cochran's formula with 95% confidence level. Questionnaires were distributed to Yazd citizens in the five regions of the city based on cluster sampling method. A few questionnaires were excluded from the analysis due to response incompleteness.

3.3.1 Health

Citizen health was measured using responses to three questions pertaining to amount of access (at least 30 min per day) to nature in the city:

A: I use the city's green space for at least 30 min a day
B: I spend at least 30 min outdoors during the day
C: In city schools, children have at least 30 min of access to nature and greenery on a daily basis

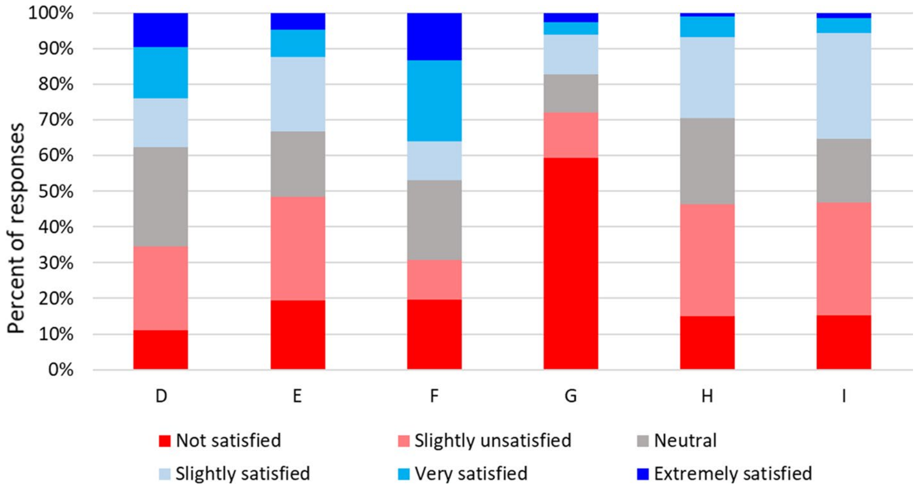


Fig. 17 Results of the questionnaire related to biophilia activity

As the poll results show (Fig. 16), more than 50% of citizens (questions A and B) and nearly 50% of educational centers (question C) reported having insufficient access to green and open spaces, (<30 min' access per day). This lack of access to green and open spaces may endanger the health of citizens (White et al. 2019).

3.3.2 Biophilia activities

Biophilia activities relate to the presence of facilities and infrastructures in the city that enable citizens to interact with nature. This indicator is measured as percentage of population active in clubs or nature or with outdoor organizations. Six questions in the questionnaire were used to calculate this metric.

D: The number and area of green and open spaces in the city have provided citizens with daily access.
E: There are ample recreational–educational facilities in urban parks and green spaces, resulting in high tourist attractions.
F: It is possible to grow flowers and plants in a personal garden, at work or in home.
G: Citizens have the opportunity to meet some of their vegetable needs through home cultivation (balconies, roof gardens)
H: schools in the City have ample facilities for nurturing children's creativity and social play
I: schools in the City devote enough time to children's games in the natural environment

The results of the questionnaire (Fig. 17) show that almost 48% of people do not consider the level of parks and urban green spaces sufficient for daily use (question D). About 68% of citizens are not satisfied with the facilities and equipment of urban green spaces, and believe that urban green spaces do not have a tourist attraction (question E). Only 35% of citizens have the opportunity to grow flowers and plants in their home (question F). Fewer than 5% of citizens were extremely satisfied with ability to grow vegetables through home cultivation (question G). Sixty-seven percent of citizens are not satisfied with the possibilities of schools to foster children's creativity (question F). Seventy-five percent of citizens believe that in schools, students are not given the time needed to get to know about the nature (question I).

3.3.3 Urban governance and biophilic institute

Urban governance and biophilic institute are measured by the amount of investing to facilitate citizens' communication with nature.

Local budgets allocated to nature conservation, recreation, education, and related activities by municipalities The total budget allocated by the municipality of Yazd for conservation and biophilic activities in 2018 was only 0.01% of the total development budget, far less than the minimum budget of 5% considered acceptable for biophilic cities (Beatley 2010).

Number of NGOs (local biophilic supporting organizations) The number of active organizations in the field of environmental protection and tourism is limited and environmental-based NGOs are also very limited. There are only 13 NGOs active in the city and according to approximate statistics, only 0.22% of the city's population is active in these organizations.

3.4 The score of sustainability in Yazd

The goal of this study was to assess the state of sustainability in Yazd. Using the metrics described above, the analytical hierarchy process (AHP) with Super Decision $_{2.1}$ software was then employed to assess sustainability based on the following six steps.

1. The hierarchical structure of the AHP model was developed based on the central issues, comprised of one goal, 3 components, 16 subcriteria (metrics) and 2 alternatives (Fig. 18). Alternative One is the sustainable city at the desirable level and Alternative Two is the existing state of sustainability in Yazd.
2. Weighting of the criteria (metrics) was determined by expert judgments based on pairwise comparison method (inconsistency less than 0.1) (Fig. 19). In this approach, the sum of all the individual weights adds up to 1.0 and the sum of metric weights within each of the three main components is 0.3333.
3. Based on the expert judgments, each of the 16 criteria (metrics) were scored according to the Likert classification scale (Table 4).
4. The team of experts considered the score of each criterion based on their state of sustainability in Yazd and the Likert scores were normalized to their fractional values (scale 0 to 1) for incorporation in the rating model of the Super Decision software. Results for each metric in the three groups (pattern of biophysical structure, urban ecosystem dynamic and function, and citizen's health and security) are provided in Tables 5, 6 and 7, respectively.

Using the Super Decision software, the relative weights of each metric (Fig. 19) were calculated based on pairwise comparison method (Saaty 1980). Each calculated weight was multiplied by its corresponding normalized Likert score and results then summed to obtain the total sustainability score for each of the two alternatives. Results show that the

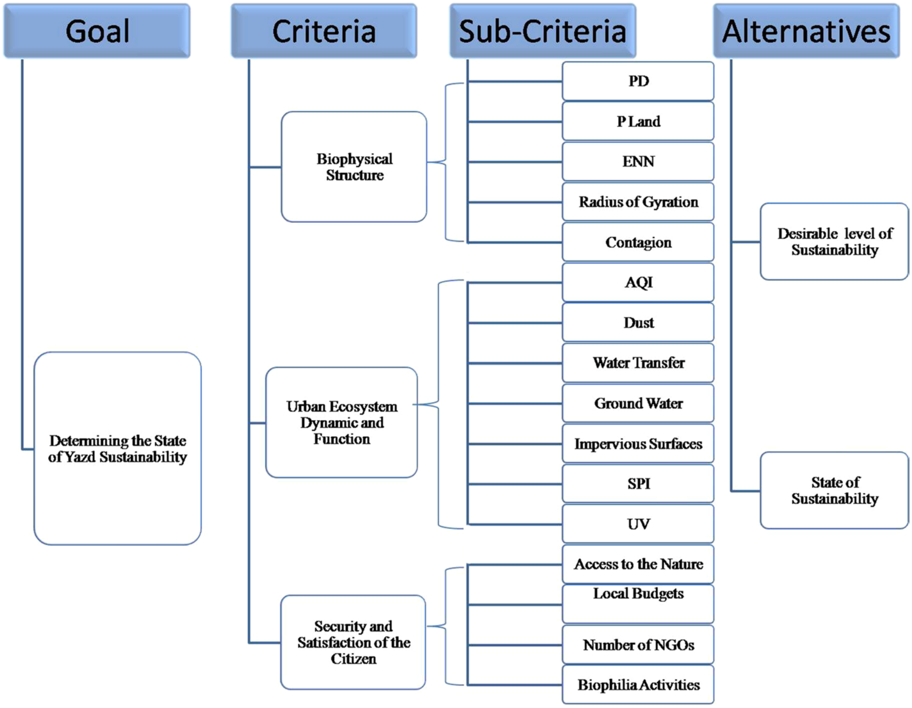


Fig. 18 Hierarchical structure used in super decision software

total score of "the existing state of sustainability of Yazd" is 0.28, compared to a "perfect" score of 1.0 indicating complete sustainability (Alternative One).

4 Discussion

In this study, the sustainability of Yazd was evaluated based on a framework specifically designed to assess urban sustainability in arid lands. In this framework, evaluation of urban sustainability is performed based on three main components: Urban Pattern of Biophysical Structure, Urban Ecosystem Dynamic and Function, and Citizens' Security and Satisfaction. These three main components are defined based on the relations between structure and function. According to this concept, Pattern of Biophysical Structure and Urban Ecosystem Dynamic and Function have a mutual relationship with each other. The Pattern of Biophysical Structure is defined by the composition and configuration of green patches that are the source of environmental services in cities (urban green land cover). If urban green cover has a suitable composition and configuration in the city, it can help improve the urban ecosystem dynamics and functions. These two components determine the status of the citizens' security and satisfaction.

Sixteen metrics are considered in this framework to evaluate urban sustainability. The results of measuring the state of composition and configuration of urban green cover in Yazd show that green patches are small and scattered and do not provide sufficient ecological services through the city. An important part of Yazd's green cover is the old patch

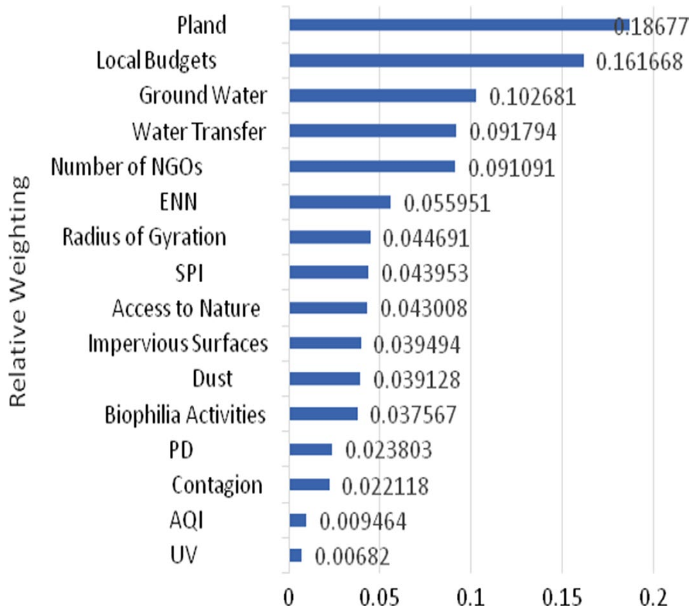


Fig. 19 Weighting of criteria based on pairwise comparison method

Table 4 Spectrum of Likert classification

Score	State of metric	Metric characteristic
1	Very critical	The current state of this metric is critical
2	Critical	The current state of this metric is risky, if this trend continues and the lack of planning will lead to a critical situation
3	Medium	Currently, the metric is relatively stable. But it can be unstable due to the conditions
4	Fairly acceptable	The current state of this metric is low risk. Conditions are relatively stable
5	Acceptable	The metric is quite stable

gardens that have unfortunately become fragmented and are disappearing in recent years due to high amount of new construction and ongoing drought.

The results of measuring the state of related metrics to urban ecosystem dynamics and function in Yazd show the unstable and stressful conditions. Although changes in two dimensions, air quality index and dust storms, show a positive trend, but due to industrial pollution, increased traffic and dust storms, air quality is not favorable. Through declining groundwater reserves and increasing water demand, this region has become more dependent on interbasin water transfers, and the water resources situation in this region is becoming critical. Impermeable surfaces have increased sharply due to the high amount of new construction. The UV index is also high in the majority of months of the year.

The results of measuring the state of related metrics to the Citizens' security and satisfaction in Yazd are also unfavorable due to the loss of green and open spaces, limited recreational facilities, lack of proper municipal budget allocation for nature-based activities,

Table 5 Likert scoring for pattern of biophysical structure's metric in Yazd

Urban pattern of bio-physical structure criteria	Metric	State of metric in Yazd	Score	Modified score
Heterogeneity	Patch richness density (PD)	In most areas of the city, patch density of green cover is less than 40	2	0.4
	Percentage of Landscape (PLAND)	In most areas of the city, this metric is less than 25%	2	0.4
Connectivity	Euclidean nearest-neighbor distance (ENN)	In most areas of the city, the Average distance between green patches, is more than 100 m	2	0.4
	Radius of Gyration (GYRATE)	In most areas of the city, this metric is close to 0	2	0.4
Modularity	Contagion index (CONTAG)	In most areas of the city, contagion is less than 36%	2	0.4

Table 6 Likert scoring for Urban ecosystem dynamic and function's metric in Yazd

Urban ecosystem dynamic and function	Metric	State of metric in Yazd	Score	Modified score
Urban air quality	AQI	Number of healthy days in this period increased.	3	0.6
	Dust	Number of days with the phenomenon of dust storm is increasing.	2	0.4
Urban water resources	Changing in volume of Interbrain Water Transfer	Volume of transitional water has also increased in recent years due to rising demand for water.	1	0.2
	Changing in volume of groundwater	Annual discharge rate of groundwater has decreased over 14 years	1	0.2
Urban soil	Change in Ratio of impervious surfaces	Impermeable surfaces (built area) strongly increased during the period under study	1	0.2
Urban climate	SPI	SPI has had a negative trend. We faced a decrease in rainfall and eventually an increase in drought	1	0.2
	UV indicator	UV index is in the high level in 10 months of the year and very high level in June and July	1	0.2

Table 7 Likert scoring for security and satisfaction of citizen's metric in Yazd

Security and satisfaction of citizen	Metric definition	State of metric in Yazd	Score	Modified score
Health	Percent of citizens that have at least 30 min access to nature	More than 50% of citizens do not have access to green and open spaces	2	0.4
Urban governance and biophilic institute	Local budgets allocated to nature conservation, recreation, education, and related activities by municipalities	Total budget allocated by the municipality for conservation and biophilic activities was only 0.01% of the total development budget	1	0.2
	Number of NGOs (local biophilic supporting organizations)	Only 0.22% of city's population active in Environmental-based NGOs	1	0.2
Biophilia activities	Percentage of population active in clubs or nature or outdoor organizations	Fewer than 5% of citizens have biophilia activities. 67–75% of citizens believe education system is not nature-based	1	0.2

lack of public participation, and limited number of organizations active in sustainable urban development.

The score of Yazd sustainability was determined as 0.28 out of 1.0, based on weighting and scoring of the 16 metrics assessed. This score means that Yazd is not a sustainable city and the present situation is far from the sustainability state.

The metric assigned the highest weighting in this study was percentage of green landscape (PLAND). Accordingly, the importance of reforming urban land structure to enhance vital functions of the city should be examined. Preventing the destruction of urban gardens, expanding native green spaces, and controlling city expansion and construction are all structural reforms that urban planners can consider for improving urban sustainability. Such structural reforms can be effective in controlling impermeable surfaces, reducing the effects of high UV radiation, controlling water demand, acting as a sink of air pollutants, and increasing the satisfaction of citizens.

Water supply planning is a high priority in cities located in drylands. Of the metrics related to Urban Ecosystem Dynamic and Function, groundwater supply and interbasin water transfers are of particular importance and are ranked third and fourth in the weighting process, respectively. In order to improve the critical situation of water resources in Yazd, macro-level land use planning is needed. Comprehensive planning for the sustainable supply of water resources can have both a positive impact on Urban Pattern of Biophysical Structure indicators and improve the state of Citizens' Security and Satisfaction indicators.

5 Conclusions

Based on this study, the quality of ecological processes and environmental services in Yazd has been negatively affected by rapid population growth and urban structural changes. Indicators evaluated in this study that are in a critically unsustainable condition in Yazd include urban land cover, water resources, air quality, and public satisfaction.

On the other hand, local knowledge and social–ecological values have been forgotten in the process of urban growth in this region. For many centuries, the systems of Qanat provided sustainable water resources in Yazd. As a result of unsustainable development practices in recent decades, most Qanats have been destroyed and the gardens irrigated through these systems have subsequently declined.

Targeted planning is needed to reverse the unsustainable conditions of Yazd. By evaluating the criteria proposed in this study, urban planners and managers can better provide coherent urban policies, plans, and programs. Ultimately, urban planning based on this assessment framework may transform cities in drylands into sustainable and desirable places for their citizens.

Based on this study, urban planning policies to improve sustainability should include controlling urban landscape change, controlling consumption of resources, and increasing participation by the public. The experiences gain by past generations to cope with harsh conditions in arid lands should be considered and incorporated in current planning policies. It is also emphasized that physical urban development in arid regions should be constrained within local ecological capabilities.

Applying the sustainability assessment process proposed here to other dryland cities will improve this evaluative framework and help achieve broadly applicable rational principles for sustainable urban development in arid lands. In conclusion, achieving urban sustainability in drylands is dependent on eco-friendly physical development and empowering cities to cope with harsh natural conditions.

References

Achilleosa, S., Al-Ozairic, E., Alahmad, B., Garshick, E., Neophytou, A. M., Bouhamrai, W., et al. (2019). Acute effects of air pollution on mortality: A 17-year analysis in Kuwait. *Environment International, 126,* 476–483.

Akbari, M., Ownegh, M., Asgari, H., Sadoddin, A., & Khosravi, H. (2016). Drought monitoring based on the SPI and RDI indices under climate change scenarios (case study: Semi-arid areas of West Golestan Province). *Ecopersia, 4,* 1585–1602.

Alberti, M. (2005). The effects of urban pattern on ecosystem function. *Integration Regional Science Review, 28,* 168–190.

Alberti, M., & Marzluff, J. (2004). Ecological resilience in urban ecosystems linking urban patterns to human and ecological functions. *Urban Ecosystems, 7*(3), 241–265.

Alberti, M., Marzluff, J. M., Shulenberger, E., Gordon, B., Ryan, C., & Zumbrunnen, C. (2003). Integrating humans into ecology: Opportunities and challenges for studying urban ecosystems. *BioScience, 53*(12), 1169–1179.

Archsmith, J., Heyes, A., & Saberian, S. (2018). Air quality and error quantity: Pollution and performance in a high-skilled, quality-focused occupation. *Journal of the Association of Environmental and Resource Economists, 5,* 827–863.

Arid Land and Desert Research Institute, Y. U. (2016). *Studying and identification of the sources of dust in Yazd Province*. Yazd: Department of Environment.

Arnold, C. L., & Gibbons, J. C. (1996). Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association, 62,* 243.

Baker, L. A., Brazel, A. T., & Westerhoff, P. (2004). Environmental consequences of rapid urbanization in warm, arid lands: Case study of Phoenix, Arizona (USA). In C. Marchettini, A. Brebbia, E. Tiezzi, & L. C. Wadh (Eds.), *The sustainable city III, urban regeneration* (pp. 155–164). Boston: WIT Press.

Beatley, T. (2010). *Biophilic cities: Integrating nature into urban design and planning* (2nd None ed. edition ed.). Washington, D.C: Island Press.

Beatley, T., & Peter, N. (2013). Biophilic cities are sustainable, resilient cities. *Sustainability, 5,* 3328–3345.

Boustani, F. (2008). Sustainable water utilization in arid region of Iran by Qanats. *Proceedings of the World Academy of Science, Engineering and Technology, 33,* 213–216.

Burkhardt, J., Bayham, J., Wilson, A., Carter, E., Berman, J. D., O'Dell, K., et al. (2019). The effect of pollution on crime: Evidence from data on particulate matter and ozone. *Journal of Environmental Economics and Management, 98,* 102267.

Chen, Y. H. (2004). Analysis on advantages and disadvantages of large scale, long distance and transbasin diversion. *Water Resource and Protection, 59*(2), 48–50.

Dadvand, P., Bartoll, X., Basagaña, X., Dalmau-Bueno, A., Martinez, D., Ambros, A., et al. (2016). Green spaces and general health: roles of mental health status, social support, and physical activity. *Environment International, 91,* 161–167.

Decuyper, M., Chávez, R. O., Copini, P., & Sass, K. (2016). A multi-scale approach toassess the effect of groundwater extraction on Prosopis tamarugo in the Atacama Desert. *Arid Environment, 131,* 25–34.

Department of Environment, D. o. E._Yazd. (2018). *Report of the number of days of Yazd air quality in 2015–2018.* Yazd: Department of Environment-Yazd. https://yazd.doe.ir/Portal/Home/Default.aspx.

Flores, A., Pickett, S., Zipperer, W., Pouyat, R., & Piranid, R. (1998). Adopting a modern ecological view of the metropolitan landscape: The case of a greenspace system for the New York City region. *Landscape and Urban Planning, 39,* 295–308.

Forman, R. T. (1995). *Land mosaics: The ecology of landscapes and regions*. Cambridge: Cambridge University Press.

Gidlow, C. J., Jones, M. V., Hurst, G., Masterson, D., Clark-Carter, D., Tarvainen, M. P., et al. (2016). Where to put your best foot forward:psychophysiological responses to walking in natural and urban environments. *Journal of Environmental Psychology, 45,* 22–29.

Grimm, N. B., Grove, J. G., Pickett, S. T., & Redman, C. L. (2000). Integrated approaches to long-term studies of urban ecological systems. *BioScience, 50*(7), 571–584.

Hammon 1 Consultant Company. (2016). *Landuse planning—Yazd province—Natural resources and environment*. Yazd: Yazd Management and Planning Organization.

Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and health. *Annual Review of Public Health, 35,* 207–228.

Hassan, A. G., Fullen, M. A., & Oloke, D. (2019). Problems of drought and its management in Yobe State, Nigeria. *Weather and Climate Extremes, 23,* 100192.

Hiremath, R. B., Balachandra, P., Kumar, B., Bansode, S. S., & Murali, J. (2013). Indicator-based urban sustainability—A review. *Energy for Sustainable Development, 17,* 555–563.

Hyewon, L., Kim, H., Yasushi, H., Youn-Hee, L., & Seungmuk, Y. (2013). Effect of Asian dust storms on daily mortality in seven metropolitan cities of Korea. *Atmospheric Environment, 79,* 510–517.

IPCC, & IPCC. (2014). *Climate change 2014. Impacts, adaptation, and vulnerability. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press.

Kremer, P., Haase, A., & Haasec, D. (2019). The future of urban sustainability: Smart, efficient, green or just? Introduction to the special issue. *Sustainable Cities and Society, 51,* 101761.

Krutmann, J., Morita, A., & Chung, J. H. (2012). Sun exposure: What molecular photodermatology tells us about its good and bad sides. *Journal of Investigative Dermatology, 132,* 976–984.

Lictevout, E., & Faysse, N. (2018). A doubly invisible aquifer: Hydrogeological studies and actors strategies in the pampa del Tamarugal aquifer, northern Chile. *Water Alternatives (WaA), 11,* 592–606.

Liu, J. G., Zang, C. F., Tian, S. Y., Yang, H., Jia, S. F., You, L. Z., et al. (2013). Water conservancy projects in China: Achievements, chalenges and way forward. *Global Environmental Change, 23,* 633–643.

Liu, T., Zhang, Y. H., Xu, Y. J., Lin, H. L., & Xu, X. J. (2014). The effects of dust haze on mortality are modified by seasons and individual characteristics in Guangzhou, China. *Environmental Pollution, 187,* 116–123.

Lundy, L., & Wade, R. (2011). Integrating sciences to sustain urban ecosystem services. *Progress in Physical Geography, 35,* 653–669.

Mac-Mary, S., Sainthillier, J. M., Jeudy, A., Sladen, C., Williams, C., & Bell, M. (2010). Assessment of cumulative exposure to UVA through the study of asymmetrical facial skin aging. *Clinical Interventions in Aging, 5,* 277–284.

Massuel, S., & Riaux, J. (2017). Groundwater overexploitation: Why is the red flag waved? Case study on the Kairouan plain aquifer (central Tunisia). *Hydrogeol, 25,* 1607–1620.

McCabe, S., Joldersma, T., & Li, C. (2010). Understanding the benefits of social tourism: Linking participation to subjective well-being and quality of life. *International Journal of Tourism Research, 12,* 761–773.

McGarigal, K., Cushman, S. A., & Ene, E. (2012). *FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst*. Retrieved from https://www.umass.edu/landeco/research/fragstats/fragstats.html. Accessed 6 Feb 2019.

Ministry of Roads and Urban Development. (2018). *Report of master plan of Yazd*. Yazd: Ministry of Roads and Urban Development.

O'Loingsigh, T., McTainsh, G. H., Tews, E. K., Strong, C. L., Leys, J. F., Shinkfield, P., et al. (2014). The Dust Storm Index (DSI): A method for monitoring broadscale wind erosion using meteorological records. *Aeolian Research, 12,* 29–40.

Parsonsa, D. J., Reyb, D., Tanguyc, M., & Holmanb, I. P. (2019). Regional variations in the link between drought indices and reported agricultural impacts of drought. *Agricultural Systems, 173,* 119–129.

Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., & Pinceti, S. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment, 9,* 27–36.

Phillis, Y. A., Kouikoglou, V. S., & Verdugo, C. (2017). Urban sustainability assessment and ranking of cities. *Computers, Environment and Urban Systems, 64,* 254–265.

Pickett, S., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., et al. (2001). Urban ecological systems linking terrestrial ecological physica and socioeconomic components. *Annual Review of Ecology and Systematics, 32,* 127–157.

Pozdnyakov, D. V., Korosov, A. A., Petrova, N. A., & Grassle, H. (2013). Multi-year satellite observations of Lake Ladoga's biogeochemical dynamics in relation to the lake's trophic status. *Journal of Great Lakes Research, 39,* 34–45.

Querola, X., Tobíasa, A., Péreza, N., Karanasiou, A., Amatoa, F., Stafoggiab, M., et al. (2019). Monitoring the impact of desert dust outbreaks for air quality for health studies. *Environment International, 130,* 104867.

Raed Fawzi, M. A., & Monjur, M. (2018). Urban sustainability assessment framework development: The ranking and weighting of Iraqi indicators using analytic hierarchy process (AHP). *Sustainable Cities and Society, 44,* 356–366.
Regional Water Company of Yazd. (2018). *Regional water company of Yazd-census and information*. Retrieved from http://www.yzrw.ir/SC.php?type=static&id=21. Accessed 8 May 2019.
Roberts, S. M., Oke, T. R., Grimmond, C. S., & Voogt, J. A. (2006). Comparison of four methods to estimate urban heat storage. *Journal of Applied Meteorology and Climatology, 45*(12), 1766–1781.
Saati, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48*(1), 9–26.
Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw-Hill.
Shanahan, D. F., Fuller, R. A., Bush, R., Lin, B. B., & Gaston, K. J. (2015). The health benefits of urban nature: How much do we need. *BioScience, 65*(5), 476–485.
Sible, E., Cooper, A., Malkia, K., Bruder, K., Watkins, S. C., Fofanov, Y., et al. (2015). Survey of viral populations within Lake Michigan nearshore waters at four Chicago area beaches. *Data in Brief, 5,* 9–12.
Statistical center of Iran. (2016). *Census of population and housing-Yazd.* https://www.amar.org.ir/. Accessed 9 Feb 2018.
Taha, H. (1995). Urban climates and heat islands: Albedo, evapotranspiration, and anthropogenic heat. *Energy and Buildings, 25*(2), 99–103.
Tratalos, J., Fuller, R. A., Warren, P. H., Davies, R. G., & Gaston, K. J. (2007). Urban form, biodiversity potential and ecosystem servises. *Landscape and Urban Planning, 83,* 308–317.
UN-Habitat. (2015). *The city prosperity initiative: Global city report.* UN-Habitat. https://cpi.unhabitat.org/sites/default/files/resources/CPI_2015%20Global%20City%20Report._0.pdf. Accessed 8 Feb 2019.
United Nations. (2019). (UN) Retrieved from https://www.un.org/en/events/desertification_decade/whynow.shtml. Accessed 16 May 2019.
U.S. Geological Survey. (2019). *Earth explorer-home*. Retrieved from https://earthexplorer.usgs.gov/. Accessed 2 Aug 2019.
Vicente-Serrano, S. M., Beguería, S., Gimeno, L., Eklundh, L., Giuliani, G., Weston, D., et al. (2012). Challenges for drought mitigation in Africa: The potential use of geospatial data and drought information systems. *Applied Geography, 34,* 471–486.
Viguiera, B., Jourdec, H., Leonardic, V., Danielea, L., Batiot-Guilhec, C., Favreauc, G., et al. (2019). Water table variations in the hyperarid Atacama Desert: Role of the increasing groundwater extraction in the pampa del tamarugal (Northern Chile). *Journal of Arid Environments, 168,* 9–16.
Wai, K.-M., Yu, P. K., & Chan, P.-M. (2017). Urban UV environment in a sub-tropical megacity—A measurement and modelling study. *Results in Physics, 7,* 2705–2710.
Wen, Z. (2016). Eco-environmental impact of inter-basin water transfer projects: A review. *Environmental Science and Pollution Research, 23,* 12867–12879.
White, M. P., Alcock, I., Grelier, J., Wheeler, B. W., Hartig, T., Warber, S. L., et al. (2019). Spending at least 120 minutes a week in nature is associated with good health and wellbeing. *Scientific Reports, 9,* 7730.
Wilhite, D. A., Sivakumar, M. V., & Pulwarty, R. (2014). Managing drought risk in a changing climate: The role of national drought policy. *Weather and Climate Extremes, 3,* 4–13.
World Health Organization (WHO). (2019). *Ultraviolet radiation (UV)*. Retrieved from: https://www.who.int/uv/intersunprogramme/activities/uv_index/en/. Accessed 8 Oct 2019.
Wu, J. G. (2013). Landscape sustainability science: Ecosystem services and human well-being in changing landscapes. *Landscape Ecology, 28,* 999–1023.
Wu, J. (2014). Urban ecology and sustainability: The state-of-the-science and future directions. *Landscape and Urban Planning, 125,* 209–221.
Wu, J. G., Jenerette, G. D., Buyantuyev, A., & Redman, C. (2011). Quantifying spatio temporal patterns of urbanization: The case of the two fastest growing metropolitan regions in the United States. *Ecological Complexity, 8,* 1–8.
Wu, J. G., & Wu, T. (2013). Ecological resilience as a foundation for urban design and sustainability. In S. T. Pickett, M. L. Cadenasso, & B. P. McGrath (Eds.), *Resilience in urban ecology and design: Linking theory and practice for sustainable cities*. New York: Springer.
Xiao, Q., McPherson, E. G., Simpson, J. R., & Ustin, S. L. (2007). Hydrologic processes at the urban residential scale. *Hydrological Processes, 21*(16), 2174–2188.
Yan, L., Duarte, F., Wang, D., Zheng, S., & Ratti, C. (2019). Exploring the effect of air pollution on social activity in China using geotagged social media check-in data. *Cities, 91,* 116–125.
Young, R. F. (2010). Managing municipal green space for ecosystem services. *Urban Forestry and Urban Greening, 9,* 313–321.

Zhang, H., Cheng, J., Wu, Z., Li, C., Qin, J., & Liu, T. (2018). Effects of impervious surface on the spatial distribution of urban waterlogging risk spots at multiple scales in Guangzhou, South China. *Sustainability, 10,* 1589.