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Investigating domestic gardens landscape plant diversity, implications for valuable plant species conservation

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Abstract

Urbanization has resulted in deterioration of natural lands and extinction of indigenous species. Domestic gardens are neglected spots of plants biodiversity. This research aimed to assess domestic garden plants diversity, composition, distribution, and identify the conserved indigenous plant species in a heavily urbanized arid city. Domestic gardens within each district were randomly selected, visited, and surveyed. Cultivated plant species in gardens were identified and counted; their frequencies and abundance levels were calculated. Plant species richness, Shannon, evenness, and Simpson's indices were calculated. More than 12,000 plants belonging to 223 plant species compromising 72 plant families were found. Domestic gardens played a significant role in conserving regionally extinct or endangered native plant species while undesirably sustained exotic and invasive plants. Overall, exotic plants species represented 84% of all identified species. The highest percentage of native plants (29%) was found in Uhod district, while the lowest (11%) was in Jubaiha district. The minimum and maximum proportion of medicinal, poisonous, and fruit bearing plants on a district bases were 9–26%, 9–22%, and 11–43% of domestic garden plants, respectively. The highest species richness (103) was in Zahran, while the lowest (20) was in Al-Madinah district. Shannon diversity index was the highest in Zahran and Sweileh districts. Shannon, evenness, and Simpson diversity indexes revealed Badr Al-Jadidah as the lowest plant diversity district. District history, lots sizes, garden sizes, socioeconomic status, residents' preferences, and housing regulations resulted in variation in plants diversity and species composition. Thus, monitoring species composition in domestic gardens and raising public awareness about plants benefits/risks supports environmental sustainability. Attention should be given to these neglected biodiversity hotspots, especially in arid environments.

Keywords Domestic gardens · Urban greenspace · Biodiversity · Native plants species · Domestication

Extended author information available on the last page of the article

1 Introduction

Deterioration of natural lands at the expense of manmade lands is an ongoing behavior. Agricultural lands are diminishing, natural habitats are fragmented, natural cycles are being interrupted, and natural resources are extensively used because of the population inflation, urban sprawl, and human activities (Al-Kofahi et al., 2018a). The natural lands and urban green spaces reduce the anthropogenic impacts on the ecosystem and offer humans principal services (Al-Kofahi et al., 2019; Cameron et al., 2012; Demuzere et al., 2014). These services include controlling the steadily increasing atmospheric CO_2 levels, adjusting land thermal comfort (Yunos & Saring, 2012), mitigate the urban heat (Zhang et al., 2017), improve the microclimate temperatures, reduce flooding problems, improving air and water quality (Demuzere et al., 2014), and other services such as food production, pollination, water infiltration, and water retention (Green et al., 2016). These ecological services and urban green spaces benefits are interconnected, multi-dimensional (Demuzere et al., 2014) and mitigate climate change challenges.

Many researchers warned from diminishing of natural lands at the expense of urbanization (Al Tarawneh, 2014; Al-Kofahi et al., 2018a, 2018b; Makhamreha & Almanasyeha, 2011; Shalaby, 2012). Al-Kofahi et al. (2018a) reported that the agricultural lands in major cities in Jordan were decreasing in alarming rates and projected elimination of the total agricultural lands in these cities by 2050 unless precautionary measures are effectively applied, or expansion trends and directions are changed. However, the urban green spaces in cities work as nodes in a large ecological network that preserve key ecosystem services. Urban domestic gardens are among the remaining green spaces in the densely populated cities that support the environmental services (Beumer & Martens, 2015; Jaganmohan et al., 2012). However, urban greenspaces and their biodiversity composition might lead to ecosystem disservices such as spreading of pathogens, pests, and unwanted species (Blitzer et al., 2012) and thus, monitoring of urban landscapes components, and their drivers are important to maximize urban landscape benefits (Lin et al., 2015). Urban landscape is driven by stakeholders, urbanists, architects, and government decisions in parallel with the homeowners' attitudes that have a crucial role in shaping and sustaining biodiversity in cities. Cameron et al. (2012) identified some basic components of urban green infrastructure such as parks, urban forests, private domestic gardens, public green space, green corridors, roofs, vertical greening, and roadside trees. All are considered essential elements of the urban landscape. Domestic gardens in some cities constitute a significant portion of urban green space and represent a hidden treasure of information about biodiversity (Beumer & Martens, 2015; Cameron et al., 2012).

Private gardens may sustain the connection between the natural lands and the new development (urban areas). Al-Kofahi et al. (2019) reported that domestic gardens are a fundamental component in densely populated cities that resemble nature. Modernization and urbanization resulted in removal of a significant amount of natural vegetation, where distinctive native species are exposed to extinction while other widespread species takeover; thus, disequilibrium in the natural system took place (Taylor et al., 2017). This disequilibrium can be explained by the unsuitability of the new microclimate to native species and favors introduced (alien) tolerant species to colonize (Bigirimana et al., 2011). The urban environment can be a source of alien and invasive plant species (Gulezian & Nyberg, 2010). For example, 88% of cultivated plants in Lauris (France) domestic gardens were alien species, where all gardens occupied invasive plants with a measured frequency reached 48% in some gardens. Invasive species are considered ecologically problematic due to the risk of invasion within the urban area and the surrounding rural areas (Marco et al., 2008) as well as the possibility of contaminating native plants genes and show undesirable plant characteristics (Whelan et al., 2006). Nevertheless, plant composition and its diversity in domestic gardens could enrich the gene pool and support biodiversity in general. Cameron et al. (2012) defined domestic gardens as the adjacent yards or spaces to domestic dwellings which are privately owned or rented. The domestic garden composition may include ornamental, landscape and vegetable plots, lawns, patios, and ponds.

People tend to reside in high densities areas because of the proximity to services, and this results in limited green areas or natural covers in cities (Cameron et al., 2012). Therefore, in some cities, domestic gardens might be the most important constituent of urban green space; they have remarkable potential for sustaining biodiversity, achieving biodiversity benefits (Al-Kofahi et al., 2019; Goddard et al., 2010), and supporting ecosystem functions (Al-Kofahi et al., 2019; Taylor & Lovell, 2015; Wang et al., 2015). In the UK, domestic gardens contribute to about 35% of the overall urban green spaces in Edinburgh and 47% in Leicester (Loram et al., 2007) and it exceeds 50% in Dunedin, New Zealand (Mathieu et al., 2007). Cameron et al. (2012) highlighted that domestic garden could contribute to about 22–36% of the whole urban area based on age and the cities circumstances. However, besides the importance of maintaining a considerable portion of urban area as domestic gardens, Nighswander et al. (2021) consider that alleviation of the urbanization negative impacts on ecosystems requires investigation and manipulation of domestic gardens composition and diversity to further enhance ecosystem services and sustainability. Akinnifesi et al. (2010) studied plant diversity in domestic gardens in São Luís city, Brazil and similarly found that some plant species are seriously at risk of extinction from their native habitats, while home gardens could give a great chance for these plants to survive, reproduce and flourish.

Several researchers studied domestic landscape and mapped domestic gardens composition and distribution in urban areas (Al-Kofahi et al., 2012; Baker & Smith, 2019; Qian et al., 2020), assessed gardens irrigation requirements (Al-Kofahi et al., 2012; Litvak & Pataki, 2016; Mini et al., 2014), identified residents landscape attitudes and preferences (Gao et al., 2019; Rafi et al., 2020), explored gardens plant composition (Al-Kofahi et al., 2019; Bigirimana et al., 2012; Vila-Ruiz et al., 2014; Zhang & Jim, 2014), etc. Different approaches can be employed to investigate domestic gardens depending on the study targets, while a combination of these tools can be employed and include Geographic Information system (GIS), remote sensing techniques (Al-Kofahi et al., 2012; Baker & Smith, 2019; Qian et al., 2020), field visits (Al-Kofahi et al., 2012, 2019; Qian et al., 2020), and questioneers (Blaine et al., 2012; Larson et al., 2009). However, detailed exploring residential landscape composition and plant species diversity cannot be achieved without intensive onsite visits and careful identification of the existing species by specialized taxonomists to feed in different diversity indices.

Plant species diversity in domestic gardens in Hong Kong, China (Zhang & Jim, 2014) and São Luís city, Brazil (Akinnifesi et al., 2010) were studied using diversity indices, among which are Shannon and Simpson diversity indices, Species Richness, Evenness, abundance, and frequency of species occurrence. Akinnifesi et al. (2010) employed species richness accumulation curves tool to investigated plant species diversity in domestic gardens in São Luís, Brazil. Bigirimana et al. (2012) and Vila-Ruiz et al. (2014) studied plant species richness, abundance, species origins and uses of species in domestic gardens in Bujumbura, Burundi, and Río Piedras, Puerto Rico, respectively. Vila-Ruiz et al. (2014) reported in Río Piedras, Puerto Rico the existence of 383 plants species, where the most abundant were exotic ornamental shrubs, and overall exotic plant species were 69.5%. The species richness per garden was higher in higher income neighborhoods with a higher ratio of ornamental gardens. In Tlokwe City, South Africa, Lubbe et al. (2010) reported the dominancy of non-native species in the rich neighborhoods, while utilitarian plants including various indigenous species were found in lower socioeconomic areas.

Arid countries usually have limited urban green spaces and generally limited natural resources, and this becomes more serious in developing countries where biodiversity and sustainability receive little conservation efforts. Jordan as an arid developing country is not an exception. Therefore, conservation programs and people's contribution in conservation and domestication of native plant species are recommended and very crucial (Al-Ghzawi et al., 2016; Hass, 2013). Plant diversity in Jordan is at risk due to demographic reasons, land use problems, human, and environmental stressors (Al-Kofahi et al., 2018a, 2019). According to Al-Kofahi et al. (2019), regulations and policies to overcome the anthropogenic impacts on nature are urgently needed in Jordan as it impacts the biodiversity and the natural species composition. Al Tarawneh (2014) argued that weaknesses and ineffectiveness of regulations and policies that govern cities development are expected to hamper efforts toward sustainability. However, issuing effective and successful regulations and policies required exploration of the existed circumstances and situation. Unfortunately, in developing countries, there are limited studies investigating the existing urban green spaces, especially domestic gardens and their plant composition (Al-Kofahi et al., 2019). The expected lack of information about domestic landscape plants, types, distribution, impacts, and unmonitored choices of plants in Amman triggered the idea of investigating the city's domestic garden plants diversity. Therefore, the objectives of this study were to assess domestic garden plants diversity, cultivated plant species composition, distribution and identify the remaining conserved indigenous plant species within the city domestic gardens.

2 Methodology

2.1 Study location

The study was conducted in Amman, the capital city of Jordan (Fig. 1). The city of Amman (32° N, 36° E) area is 799.93Km^2 (GAM, 2023a) which represents around 8.5% of the total area of Jordan. It is a very populated city. More than 40% of Jordan population lives in Amman, and the population of the city is 4,642,000 (DOS, 2021). Amman residents are a unique blend of old and new multicultural people. Amman has twenty-two districts that are relatively varied in terms of topography and prevailing climatic conditions.

2.2 Study sample

The city GIS layers including districts building footprints, and building numbers were obtained from Greater Amman Municipality and used for sampling. Twenty-five random points were distributed randomly within the limits of each district. The addresses where these points were located represented the selected sample. The selected homes were viewed using high resolution (spatial resolution 0.3 m) true color aerial photography dated 2019, then visited. If the selected residential units contained no gardens, homeowners were not present, the garden was abandoned, or the surveyors were not permitted to access the

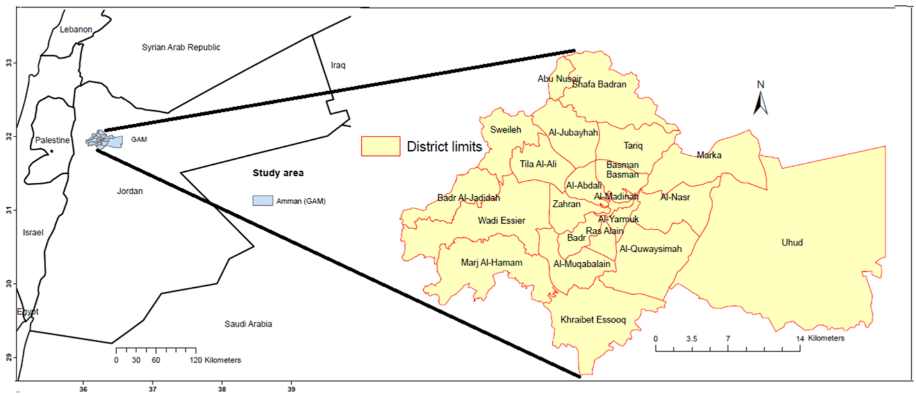

Fig. 1 Study location showing Amman's districts and Jordan map

garden; other residential units were randomly chosen. All identified addresses were visited, and gardens' species compositions were surveyed.

2.3 Data collection

The cultivated plant species in each garden were identified at the species level. The number of plants per species were counted and recorded. The species richness accumulation curves were constructed on a district basis to assess how representative is the selected gardens to the district's gardens composition. When the district species richness accumulation curve showed stabilizing in terms of the total number of identified species (cumulative number of taxa), the number of visited gardens per district was considered satisfactory and representative of the district gardens floral composition. This is because inclusion of more residential gardens to the studied sample is not expected to yield a larger species richness. The sampled gardens per district ranged from 9 to 18 gardens. The total number of visited gardens was 264 gardens. Residential lot area and garden space area were calculated using GIS. The plant species in the investigated gardens were recorded. The identified plant species were sorted into landscape plants, edible fruit trees, and medicinal-condiment plants. These plants were also sorted according to their special characteristics (native, exotic, medicinal value, special conservation status in Jordan, poisonous, or invasive). The plant species information including scientific names, family names, and species origin were identified by the team taxonomist, confirmed, and cross matched with different resources including Plants of the World Online-Kew Science (2022), US-NPGS (2022), PFAF (2022), Taifour et al. (2016), Taifour and El-Oqdah (2014), Al-Esawi (2013), Tristram (2013), Brickell (1997), Scott-Mcnab (1997), and Tenenbaum (2004). Homeowners were visited again and requested to answer some questions related to their income and reasons behind their selection of some plants in their gardens.

2.4 Statistical analysis

Pearson's correlation test using SAS software version 9.4 was used to assess the association between each of lot area, garden surface area, homeowners' annual income and plant diversity indices. The association among all district's vegetation indices were also assessed ($\alpha < 0.05$).

2.5 Plant species abundancy and frequency

Plant species frequency and relative species frequency were determined to assess the plant species distribution in each district and overall the city. The species frequency (S_iF) represents the proportion of visited gardens within the study area (district) that contained at least one individual plant of that species (Eq. 1). The Relative species frequency (RS_iF) represented the species frequency value relative to the summation of all species frequency values within the same area (Al-Ghzawi et al., 2016) (Eq. 2). Species abundance and relative species abundance were calculated for each species in each district. Species abundance ($S_{i\,ab}$) represents the average number of a specific species counted across domestic gardens where that species was identified (Eq. 3). Relative species abundance ($RS_{i\,ab}$) represents the proportion of specific species abundance relative to the summation of all species abundance values within the same area (Eq. 4):

$$S_iF = \frac{NG(S_i)}{NG} \tag{1}$$

$$RS_iF = \frac{S_iF}{\sum_i^n S_iF} \tag{2}$$

$$S_{iab} = \frac{\sum S_i}{NG(S_i)} \tag{3}$$

$$\mathrm{RS}_{iab} = \frac{\mathrm{S}i\ \mathrm{ab}}{\sum_i^n \mathrm{S}_{\mathrm{ab}}} \tag{4}$$

where

$NG(S_i)$: Total number of gardens where the species (*i*) was existed within the district.

NG: Total number of visited gardens within the district.$\sum_i^n S_iF$: Summation of all species (*i*-*n*) frequencies within the district.

$\sum S_i$: Summation of the numbers of a specific species (i) identified within a district.$\sum_i^n S_{\mathrm{ab}}$: Summation of all species (*i*-*n*) abundance values within the district.

2.6 Plant species indices

Species richness (S) was calculated as the number of different species identified in each district, and it represents the total number of existing species in a specific geographical area at specific time (Rajan, 2001). Shannon diversity index (*H*') is another plant species diversity index (Farrag, 2012; Khafagi et al., 2013; Rad et al., 2009) where it considers the count of each species relative to that of all species in the district (Eq. 5). Shannon diversity index was calculated as follows:

$$H' = -\sum_{i}^{x} \text{pi ln pi} \tag{5}$$

Where$\sum_{i}^{x}$pi: summation of the proportion of the total number of a specific species (*i to x*) found in all visited gardens in a district over the total number of all species found in all visited gardens in the same district.lnpi: is the natural logarithm of pi.

Species Evenness Index (EH) represents the pattern of distribution of individuals between all different species (Akinnifesi et al., 2010; Peet, 1974) in the district (Eq. 6). EH describes how even are the number of individuals of all species are distributed, EH values ranged from 0 and 1.0 where 1.0 is complete evenness (all species are equally abundant, i.e., the existed species have equal numbers of individuals in the investigated gardens). EH can be calculated according to the following formula:

$$\text{EH} = \left(\text{H}'/\ln S\right) \tag{6}$$

where

H' = Shannon diversity index; *S* = Species richness.

Simpson's diversity index (*D*) is a measure of species diversity (species homogeneity or heterogeneity) in a specific area (Akinnifesi et al., 2010; Anandan et al., 2014) (Eq. 7). The values of Simpson's index range between 0–1 where "0" represents high diversity of species in the ecosystems, while a value of "1" represents low diversity. To make Simpson's diversity more intuitive where higher values represent higher diversity, the Simpson's index values are subtracted from "1" as bellow:

$$D = 1 - \frac{\sum n(n-1)}{N(N-1)} \tag{7}$$

where:

"n" represents the total number of individual plants from specific species found in the district. "N" represents the total number of individuals from all species found in the district.

3 Results

The visited domestic gardens in all districts of Amman city showed the existence of more than 12,000 plants belonging to 223 plant species, compromising 72 plant families. Fifteen different plant species were found to belong to the Rosaceae family (Table 1) that distributed in 179 gardens. These species included ornamental and edible fruit bearing trees such as *Rosa spp., Prunus spp., Malus domestica,* and *Eriobotrya japonica*. The second most common plant family in these domestic gardens is the Oleaceae family that is distributed in 163 gardens. Eleven species were identified belonging to the Oleaceae family; the most common plant in that family is *Olea europaea*. Eleven species were found to belong to the Asteraceae family. The other identified plant families compromised 10 different plant species or less.

Table 1 Common plant families and the number of species found per family in Amman's domestic gardens

Family Name	Different plant species found
1. Rosaceae	15
2. Oleaceae	11
3. Asteraceae	11
4. Fabaceae	10
5. Asparagaceae	10
6. Cupressaceae	9
7. Moraceae	7
8. Lamiaceae	7
9. Rutaceae	7
10. Malvaceae	6
11. Myrtaceae	6
Others (61 plant family)	≤5

3.1 Conserved native plant species in domestic gardens

Thirty-three native plant species were found in domestic gardens in Amman districts which represented 16% of the total plant species identified in the visited gardens. Around 42% of the identified native plant species in domestic gardens are species with special conservation status. For example, *Salvia fruticosa* was reported as regionally extinct species in the wild, while its average frequency in domestic gardens was 20% with an average of 5 plants existing in 16 districts (Table 2). Home gardens also conserved some species that are critically endangered, endangered, or vulnerable to extinction. The highest percentage of native plants (29%) was found in Uhod district, while the lowest (11%) was found in Jubaiha district (Table 3). Eighty four percent of domestic garden plant species were exotic species; 14% were poisonous plants. Around 5% were reported as invasive species. The highest percentage of poisonous plants (22%) was found in Al-Nasr district, while the lowest (9%) was in Kherbet Al-Souq district (Table 3).

3.2 The common plant species in domestic gardens of Amman's districts

A total of 223 different plant species were found in the visited gardens in Amman's districts. The highest abundant landscape plants are exotic species. For example, the most common landscape plant is Garden geranium (*Pelargonium hortorum*) that grew in all city districts (Table 4) except Al-Madinah district. The highest species frequency (75%) was noticed in Abu Nusair district. Damask rose (*Rosa damascena*), Monterey cypress (*Cupressus macrocarpa*), and Japanese euonymus (*Euonymus japonicas*) are other landscape plants that are common in Amman's domestic gardens where they were existed in 91%, 77%, and 73% of city districts, respectively.

Thirty edible fruit bearing trees were found in the visited domestic gardens in the city. The highest percentage of fruit bearing plants (43%) was found in Ras Al-Ein district, while the lowest (11%) was found in Zahran district (Table 3). The most abundant fruit bearing tree was *O. europaea* where it represents around 60% of the total fruit trees in Amman city domestic gardens. *O. europaea* trees are grown in all city districts with a minimum

Table 2 Selected native plant species with special conservation status in the wild, their families, average frequencies, and abundancy estimates in domestic gardens, Amman, Jordan

Scientific name	Status in wild[a]	Family Name	Species Frequency (%)[b]	Species Abundance (A) in "n" districts[b]	
				A	N
Salvia fruticosa	RE	Lamiaceae	0.2	5	16
Aloe vera	CR	Xanthorrhoeaceae	0.14	3.3	11
Cupressus sempervirens	CR	Cupressaceae	0.12	6.7	8
Laurus nobilis	CR	Lauraceae	0.11	2.1	11
Matthiola incana	CR	Brassicaceae	0.07	9	2
Sambucus nigra	EN	Adoxaceae	0.11	1	1
Lavendula dentate	EN	Lamiaceae	0.08	10.8	6
Ophrys apifera	EN	Orchidaceae	0.06	2	1
Olea europaea	VU	Oleaceae	0.53	12	20
Quercus ithaburensis	VU	Fagaceae	0.23	14	2
Narcissus tazetta	VU	Amaryllidaceae	0.2	13.2	8
Antirrhinum majus	VU	Plantaginaceae	0.08	2	3
Majorana syriaca	VU	Lamiaceae	0.13	11.7	9
Origanum syriacum	VU	Lamiaceae	–	22	1

[a]The conservation status in the wild; RE: Regionally Extinct species; CR: Critically Endangered species; EN: Endangered species; VU: Vulnerable species

[b]The value represents the average of total number of a plant count over all city gardens where the species existed

frequency of 17% in Wadi Essier district and a maximum frequency of 91% in Uhud district (Table 4). Grapes (*Vitis vinifera*) and lemon (*Citrus limon*) trees were also among the most abundant fruit trees in the city gardens. The percentage of medicinal plants in the city districts gardens ranged from 9% (Al-Abdali district) to 26% (Tariq district) (Table 3). Among the common medicinal plants in the city was Rosemary (*Rosmarinus officinalis*), *R. officinalis* was the most abundant (75%) medicinal plant species in the city domestic gardens followed by Greek sage (*Salvia fruticosa*) and Bay (*Laurus nobilis*) trees (Table 4).

3.3 Plant species richness in domestic gardens of Amman's districts

Different districts in Amman city showed different plant species richness levels (Fig. 2) where they range from 20 to 103. The highest species richness was found in Zahran followed by Sweileh District with species richness of 103, and 87, respectively. The minimum species richness was found in Al-Madinah district. There was a strong positive correlation ($r = 0.73$, p-value < 0.0001) between district species richness values and homeowners' annual income. Residents in Zahran and Sweileh district are high-income residents, and these districts gardens showed high species richness levels. Al-Madinah district is a low-income district, and it is very populated where it reaches 38,465 capita with an area of 3 Km^2. The district buildings are very adjacent to each other where some gardens may contain only two or three plants, where the percentage of garden surface area relative to the lot

Table 3 Percentages (%) of native, medicinal, poisonous, and fruit bearing plant species found in domestic gardens of Amman city districts

Districts	Native	Medicinal	Poisonous	Fruit bearing
Uhud	29	19	17	29
Al-Madinah	25	30	20	15
Ras Alain	23	20	13	43
Badr Al-Jadidah	23	18	18	14
Sweileh	22	20	9	20
Al-Quwaysimah	21	23	10	23
Badr	20	25	15	33
Basman	19	19	12	30
Al-Nasr	19	11	22	19
Zahran	18	20	11	11
Al-Yarmuk	18	18	9	29
Tariq	17	26	19	17
Abu Nusair	17	18	12	17
Marj Al-Hamam	16	19	14	23
Shafa Badran	16	21	11	27
Khraibet Essooq	16	17	9	27
Al-Muqabalain	15	24	9	21
Marka	13	18	15	27
Al-Abdali	13	9	13	16
Tila Al-Ali	12	11	12	18
Wadi Essier	12	20	16	17
Al-Jubayhah	11	20	9	23

area in this district was the lowest (10%) compared to that in Zahran (20%) and Sweileh (22%). A moderate correlation was observed between district's species richness level and garden surface area ($r = 0.45$, p-value $= 0.03$) and lot area ($r = 0.46$, p-value $= 0.03$).

3.4 Shannon diversity index in domestic gardens of Amman's districts

Amman's districts gardens showed variations in Shannon diversity index values (Fig. 3). Categorizing the city districts into low (2), moderate (> 2–3), and high (> 3–4) diversity showed Badr Al-Jadidah as the lowest district. Seven districts were categorized in moderate, and 14 districts showed a high diversity index. The highest diversity districts were again Zahran (4) and Sweileh (3.85). District's Shannon diversity index is positively correlated with homeowners' annual income ($r = 0.55$, p-value $= 0.008$).

3.5 Plant species evenness and Simpson's diversity indices in domestic gardens of Amman's districts

Unlike species richness and Shannon diversity indices, species Evenness and Simpson's diversity indices did not discriminate between the city districts in terms of plant diversity. Furthermore, there was no association observed between each of lot area, garden surface area and homeowners' annual income with district's Evenness and Simpson's diversity indices. The species Evenness index in twenty districts was between 0.75 and

Table 4 Highest abundant domestic garden plants in Amman domestic gardens

The highest abundant ornamental or landscape plants

Plant category / Scientific Name	Relative Species Abundance in city Gardens[a]	Species frequency in district gardens[b] Minimum	Median	Max	Proportion of city districts where species existed (%)
Landscape plants					
Pelargonium hortorum	0.12	0	0.32	0.75	95
Rosa damascena	0.05	0	0.45	0.91	91
Cupressus macrocarpa	0.04	0	0.15	0.45	77
Euonymus japonicus	0.08	0	0.08	0.36	73
Edible fruit trees					
Olea europaea	0.59	0.17	0.46	0.91	100
Vitis spp	0.11	0	0.39	0.82	91
Citrus limon	0.06	0	0.43	0.73	86
Medicinal/condiment plants					
Rosmarinus officinalis	0.75	0	0.16	0.60	82
Salvia fruticosa	0.13	0	0.09	0.55	59
Laurus nobilis	0.05	0	0.03	0.22	55

[a]The proportion of a plant species count relative to the total number of plants within the same category in the city sampled gardens

[b]Proportion of district gardens where a species was existed

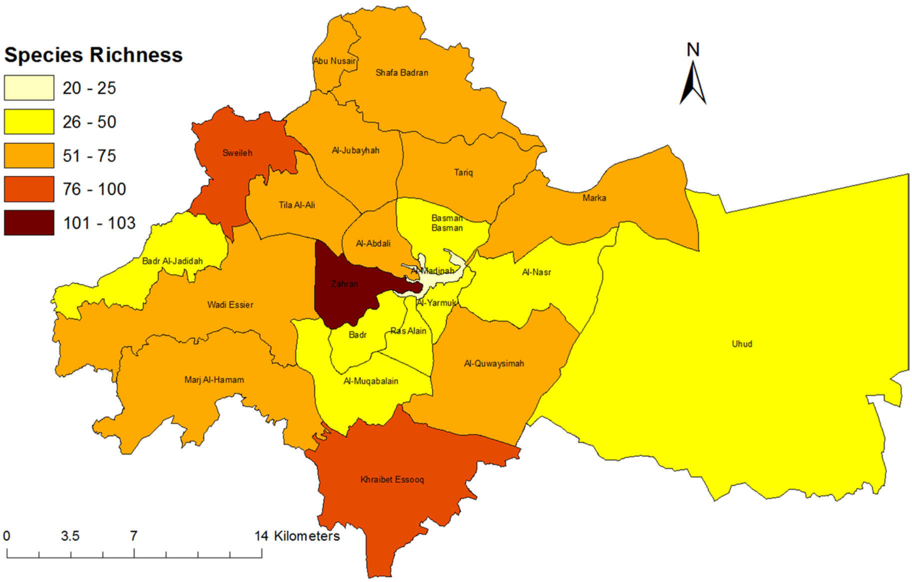

Fig. 2 Plant species richness in domestic gardens of Amman districts

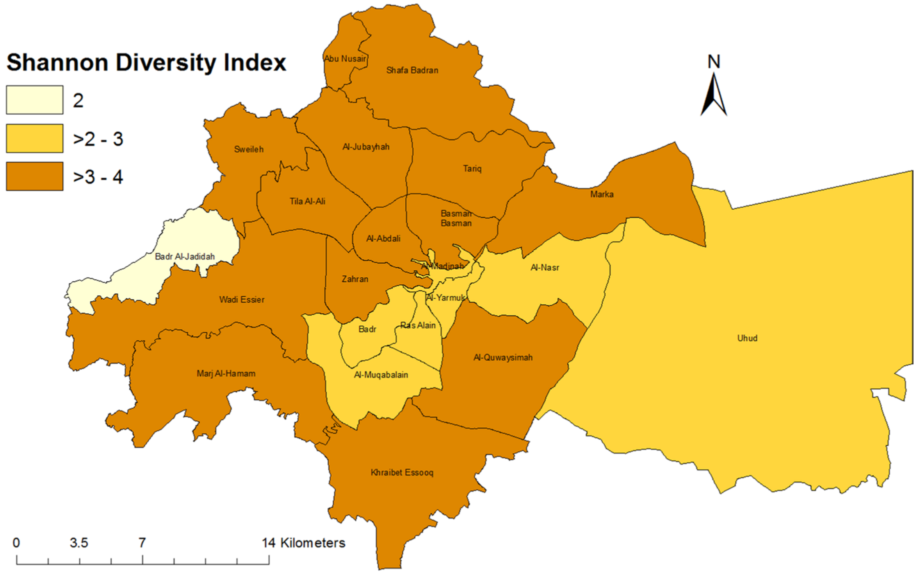

Fig. 3 Shannon Diversity Index in Amman's districts domestic gardens

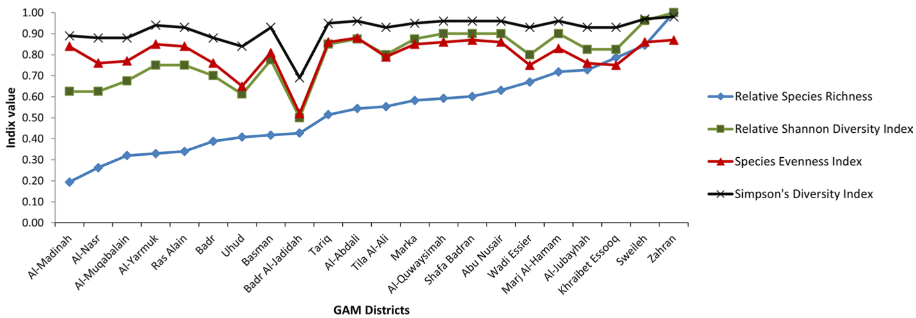

Fig. 4 Relative Species Richness, Relative Shannon Diversity, Simpson's Diversity, and Species Evenness indices of Amman's districts

0.88 (Fig. 4). The lowest species Evenness value was found in Bader Al-Jadidah district. The total number of *O. europaea* trees (1075) in that district sample represented around 50% of all other species population sizes. Simpson's diversity index values did not segregate between the districts garden diversity. The Simpson's diversity index values of 21 districts were high and ranged from 88 to 98%. Badr Al-Jadidah district showed the lowest values in terms Simpson's (69%), Shannon, and Evenness Indices; additionally, it was among the districts that shared the lowest species richness values in Amman districts. Zahran district showed the highest diversity among all tested plant indices (Fig. 4). Shannon, evenness, and Simpson's indices were highly correlated (r = 0.76–0.92; p-value = 0.0001), while no association was found between species richness and each of Evenness and Simpson's indices (r = 0.2, 0.4; p-values = 0.3, 0.02, respectively).

4 Discussion

Modernization and urbanization have led to a considerable removal of natural vegetation, where distinctive native species are exposed to extinction, while other widespread species takeover, this is known as the biological homogenization where disequilibrium in the natural system starts to take place (Taylor et al., 2017). This process can be clarified by the fact that the existing sites for plant colonies in urban environment are split up, and their vegetation becomes relatively sparse. Native species does not have the ability to adapt as the introduced plants that possibly can colonize and tolerate the varied and fragmented environments; this is because many of the introduced species are capable at using finite resource in short times (Bigirimana et al., 2011). Nevertheless, plant composition and its diversity in gardens could enrich the gene pool and support biodiversity in general.

4.1 Conservation of native and exotic plants in domestic gardens

Surveying domestic gardens plants in Amman city indicated a potential to conserve endangered native plant species. The native plants of Jordan were classified based on their existence status in the wild into regionally extinct, critically endangered, vulnerable, and least concern species (Taifour, 2017). The local domestic gardens in Amman served as a habitat for local native plant species that are extinct from the wild habitat such as *S. Fruticosa.* The main reasons behind conserving and the high frequency of growing *S. Fruticosa* by homeowners in their gardens are the medicinal value and the special flavor this plant adds to the traditional tea drink. Similarly, the city domestic gardens conserve other plants that are under risk of extinction from the wild habitat and need to be conserved such as *A. vera*, and *L. nobilis*. These plant species and others are conserved in home gardens because of the services they provide to homeowners including bearing edible fruit, medicinal, condiment, or the associated aesthetic values as homeowners declared. This attitude has a direct impact on the surrounding living creatures where the native plants preserve the native insects, butterflies, birds, and so forth (Vila-Ruiz et al., 2014). Growing native species is cheaper compared to exotic ones that require more water for irrigation and need more maintenance (Hass, 2013; Helfand et al., 2006). Thus, adopting such plants in domestic gardens (domestication of wild plants) are a common practice that conserves the indigenous plants and supports other organisms (fauna and flora) that benefited from or coexisted with these plants (Vila-Ruiz et al., 2014). Diaz-Martin et al. (2023) emphasized the effectiveness of ex situ conservation to avoid extinction of valuable plant species from wild habitat. Hass (2013) encouraged to involve and sustain native plants in domestic gardens landscapes especially threatened plants and emphasized that using native plants in landscape make garden looks simply and imitating the nature.

While domestic gardens offer multiple environmental advantages (Al-Kofahi et al., 2019; Agbogidi, 2013; Cameron et al., 2012; Bigirimana et al., 2012; Smith et al., 2006) and replace the diminishing natural habitats (Van Heezik et al., 2012), there are some related disservices negatively affecting the environment. The excessive use of irrigation water, fertilizers, insecticides, and herbicides lead to environmental and ground water pollutions (Taylor & Lovell, 2015). Furthermore, the uncontrolled or unmonitored choice of garden plants by homeowners results in hosting un-recommended plant species in domestic gardens such as alien, invasive, or poisonous plants. Vakhlamova et al. (2014) emphasized that urban areas host more alien plant species than rural surroundings. Taylor et al. (2017)

warned from the increase in number of exotic plants in urban gardens, while Smith et al. (2006) reported that alien plant species might support fauna biodiversity in the absence of native hosts. Bigirimana et al. (2012) compared the proportion of exotic, native, and invasive plant species in domestic gardens of different cities around the world with that in Bujumbura city and comparatively reported that the proportion of exotic plants (85%) in Bujumbura city gardens is very high. Likewise, the proportion of exotic plants (84%) in domestic gardens in Amman city is quite high.

4.2 Drivers of domestic gardens plant species composition

Several factors contributed to shaping the mosaic composition of plant species in domestic gardens. These factors include districts, residents, or plants traits. Therefore, the composition of domestic gardens plant among city districts is not alike; however, some similarities exist. The similarities or individuality in plant species composition among districts or within district gardens arise from shared or uniqueness of districts history, climate suitability, residential lot metrics, housing regulations, residents' socioeconomic status and their preferences. However, a combination of these factors surely shapes the existing plant species collection. *O. europaea* tree is an example where it is very abundant in Badr Al-Jadidah district having the highest proportion of *O. europaea* trees there with high frequency (0.85) and relative frequency (0.15) values. Historically, this district was agricultural orchards land before turning it into residential area. Homeowners and gardeners in Amman consider *O. europaea* a traditional and religious tree; they grew it for fruit production and to extract olive oil. The annual consumption of olive oil and pickled olives is 4.6 kg and 0.6 kg per capita, respectively (IOC 2012). Uylaser and Yildiz (2011) reported the economic value of *O. europaea* products as a traditional food in Mediterranean diet. *O. europaea* is a native plant to the region and characterized with tolerance to dry climate (Sofo et al., 2008) which encouraged people to grow it in high frequency in such an arid city. These facts explain why *O. europaea* is the most abundant tree in the city. Other fruit bearing trees are common and preferable to residents such as *V. vinifera* and *C. Limon*. These are considered economic trees because of multiple possible uses of their fruits and leaves to residents. *C. limon* is an evergreen tree suitable for warm climate and can grow in cold season (The Gardener, 2023). This tree is a popular tree that produce fruits year-round, and it is an important companion to feeding habits in Jordan and Mediterranean area.

The socioeconomic status of district's residents potentially contributes to the overall species composition in domestic gardens as indicated by the strong positive association between residents' annual income and gardens species richness. Zahran and Sweileh districts as high-income districts were the richest in species composition, while the poorest was Al-Madinah district (low-income district). Different research in both developed or developing countries reported the positive influence of socioeconomic levels of residents on their garden's flora composition (Al-Kofahi et al., 2019; Bigirimana et al., 2012; Cameron et al., 2012; Kendal et al., 2012; Lubbe et al., 2010). However, other factors act to strengthen this association between districts income level and species richness such as residents' backgrounds, residents' preferences, residential lot metrics, and housing regulations. Zahran district is a diplomatic district where the Royal Palaces, ministries many Arab and foreign embassies, houses of ambassadors, and ministries' staff are existing (GAM, 2023b). Sweileh district residents are from different backgrounds in that district, where in addition to Jordanian's residents, there are immigrants from Circassians, Chechens, and Turks. Resident's ethnicity and culture are among the influential factors of plant species composition and diversity (Mazumdar & Mazumdar, 2012; Taylor et al., 2017), where residents adopted different plant species from these cultures and population traditions. Lot areas in Zahran and Sweileh districts are large, and luxurious buildings are common where homes and gardens as luxury places, containing expensive and fancy plants. On the contrary, the high population density, the small lots sizes, the simplicity of houses and buildings with limited surrounding spaces for gardening in Al-Madinah district explains the moderate influence of lots and garden metrics on species richness in domestic gardens. Bernholt et al. (2009) reported that small parcel sizes contributed to lower species richness in domestic gardens in Niamey, Niger. Mekonnen et al. (2014) emphasized that the difference in species richness values from area to another is attributed to home garden size, income, and preference of homeowners.

Plant traits reveal the existing composition of domestic garden plants (Kendal et al., 2012) where homeowners and gardeners purposively come up with their gardens plant collection. In Amman city, the most abundant ornamental plants are long-lived, flowering, aromatic plants, and those suitable for decoration purposes; Leaf retention, ease of propagation, possible uses, the range of environmental tolerance, visual characteristics are additional characteristics to consider when selecting domestic garden plants. The dominant ornamental plants in the city domestic gardens are *P. hortorum, R. damascene*, *C. macrocarpa*, *R. officinalis*, etc., because of the special characteristics of these plants. For instance, *P. hortorum* tolerates a wide range of environmental conditions, and it is a floriferous, easy growing, and propagating plant. Geranium species are perennial aromatic plants (Rajeswara 2009) with showy multicolor flower clusters. Behe et al. (1999) believed that the variation in flower color and leaf variegation comes in the primary consideration of residents or gardens designers. *R. damascene* plant has colorful flowers, perfuming effect, and a preferable ornamental look. *R. damascena* flower petals can be used in food and other uses (Boskabady et al., 2011). *C. macrocarpa* is an evergreen fast-growing plant with golden yellow leaves (Brickell, 1994) and dense foliage that allows residents to prune and shape. *E. japonicas* is one of the evergreen shrubs characterized with various leaves colors, tolerant to hard pruning and suitable for hedging. *R. officinalis, S. fruticose*, and *L. nobilis* are evergreen long-life plants that can be exploited in food or salad recipes for their aromatic, flavor, medicinal purposes, and other traditional uses.

4.3 Determination of districts plant species diversity

Plant species diversity indices uncover the levels of diversity that exists in districts especially when compared to other districts. However, similar output is expected from different diversity indices, and outputs can be correlated positively or negatively among indices. The insights diversity indices can give about a study area also vary. Plant species richness discriminates between districts plant species diversity and goes in harmony with factors that drive low or high levels of diversity such as that observed in Zahran, Sweileh and Al-Madinah districts. Shannon diversity index corresponds with the results of districts species richness, while it reflects different sense; Akinnifesi et al. (2010) explained the low values of Shannon index as higher fluctuation of plants counts among species within the studied areas. On the contrary, the species Evenness index in twenty districts was very close (0.75–0.88) which indicates a high level of evenness between plant species population sizes within these 20 districts. Akinnifesi et al. (2010) described species evenness values as an index to represent the patterns of similarities between species in terms of their individuals' population sizes in a specific location. The Species Evenness index clearly discriminated

Bader Al-Jadidah as the lowest diversity district because *O. europaea* trees in that district represented 50% of all other plant species population sizes. Simpson's diversity index was less capable of discriminating plant diversity levels among Amman city districts compared to other indices. Statistically, Simpson's index measures the probability of drawing two individual plants from the collection (in this case: district domestic gardens) and appears from different species (Gregorius & Gillet, 2008). Simpson and Evenness indices values were very similar which might suggest that they can be used interchangeably. These findings were confirmed through testing the association between indices.

5 Implications

The findings of this study highlight the fundamental role of urban domestic gardens in supporting the overall city biodiversity. Fulfilling residents' dreamscapes in cities domestic gardens can benefit from native, noninvasive, and safe plants species. Domestic gardens of Amman serve as a suitable habitat for native species and capable of conserving extinct and endangered indigenous plant species. Accordingly, dissemination of forbidden plant species lists and raising public awareness about the pros and cons of existing plant species is of crucial importance, suggesting safe replacements for the unsuitable plant species while maintain residents' satisfaction supports biodiversity conservation in cities. Urban planners and decision makers have a fundamental role in enhancing biodiversity in cities (Van Heezik et al., 2013) and supporting cities sustainability (Al Tarawneh, 2014). Enacting policies that set a minimum residential greenspace area for newly constructed homes based on districts diversity situation is environmentally sound. Thus, municipalities, environmental, and agricultural bodies are encouraged to put more efforts to achieve larger residential greenspaces, govern, and monitor domestic garden plant composition, as well as investigate nurseries plant collection.

This research suggests that detailed spatial and temporal inventory of domestic gardens composition are necessary from conservational, human, and environmental health perspectives. All diversity indices can be used to explore the cities biodiversity, while for frequent monitoring purposes, specific diversity indices can be more effective depending on the specificity of the study area and the lead factors driving plant species composition in locations of interest. The plant species diversity in district gardens is attributed to different socioeconomic factors as well as lot area, garden space area, along with homeowners' preferences. Therefore, understanding these factors and their associations with the level of city's plant diversity, especially in arid areas, are important for supporting and sustaining urban land biodiversity. This can be done through issuing regulations, setting up rules and initiation of conservation programs on a district basis and overall.

6 Conclusions

The home gardens habitat was found to be a suitable place to conserve some valuable wild native plants to Jordan such as *Olea europaea, Aloe vera*, *Salvia fruticosa,* and *Laurus nobilis*. The measured species diversity indices in domestic gardens of Amman districts revealed variation in plant species diversity. Different plant diversity indices provided different levels of details and reflected different meanings. However, some similarities might be observed such as the ability to identify the highest and the lowest diversity districts.

Species richness and to a lesser extent Shannon diversity index successfully segregated districts based on plant diversity levels. Species Evenness and Simpson's diversity indices showed similar results, with limited variation among districts diversity; however, all plant diversity indices identified Badr Al-Jadidah district as low and Zahran district as high diversity district. Resident's background, ethnicities, socioeconomic status, district ages, lot area, and garden space area contributed to the variation in districts garden diversity. All these variables are acting to shape the existing domestic gardens plant species composition where residents' annual income and residential lot metrics potentially contribute to the total districts plant species composition. The species compositions among districts are diverse and include ornamental and utilitarian plants where the exotic plant species represented the majority of exiting plant species including poisonous and invasive plant species. Thus, this study calls for more attention to the hidden biodiversity hotspots in cities and the importance of native plants in domestic gardens. Regular inventory of plants species in domestic gardens can serve as a guide for decision makers and local environmental authorities in arid environments to enact rules governing growing and trading plants in domestic gardens and nurseries, respectively. Decision makers must act on supporting research that aids in gaining more knowledge about biodiversity in the neglected spots in urban areas.

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Declarations

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