



Assessing the composition, diversity, and allergenic risk of street trees in Qingyang District of Chengdu City

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ARTICLE INFO

Handling Editor: J Jun Yang

Keywords:

Allergenic risk

Diversity

Pollen

Urban street trees

ABSTRACT

The growing evidences suggest an association between street green space and health in cities. Pollen released by street trees has a considerable adverse impact on human health. This study aims to analyze the characteristics and assess the seasonally allergenic risk of street trees in Qingyang District, Chengdu City. There are 495 streets in Qingyang District, which have been divided into five categories according to their width. Fifty-seven species were identified, belonging to 46 taxa, and 28 botanical families in these streets. However, no significant differences in average diameter at breast height (DBH), tree height, and crown width of street trees were found among the five defined street categories. Both the street trees per capita (0.06) and the number of tree species are significantly higher than that in many Chinese cities. The Shannon's diversity index (SHDI) of street categories are clearly different, ranging from 0.94 to 3.84. Street category 5 (community street) has the highest tree density, area ratio, and SHDI of all street categories. In addition, Chengdu City is exposed to high allergenic risk of street trees. The index of urban green zone allergenicity (I_{UGZA}) ranged from a minimum of 0.1002 for category 1 (urban expressway) to a maximum of 1.0391 for category 5, which indicates that the I_{UGZA} value of different urban green spaces can exceed the upper limit (1.00). A increasing trend of the I_{UGZA} values is observed with decreasing street width. The highest allergic risk of street trees is observed in spring, followed by summer. *Ginkgo biloba* shows a highly contribute to the I_{UGZA} value for all street categories. Pearson's correlation analysis identified area ratio and tree density, as crucial factors that affect the I_{UGZA} . No correlation was observed between I_{UGZA} scores and species richness (i.e., SHDI and the total number of species). A series of greening strategies have been proposed to minimize the volume of allergen production for the well-being of inhabitants in Chengdu City.

1. Introduction

In recent decades, the rate of urbanization is accelerating across the whole world. According to the USC Bureau (2017), from 2009 to 2050, the percentage of population living in urban areas is expected to rise from 50 % to 69 %, although the urban areas cover only about 2–3 % of the world's land area (Deng et al., 2015). The United States, China, and India contribute the highest rates of urban land expansion, and almost 43 % of the total urban land area increases (Liu et al., 2018). This growing urbanization places an increasing demand on the quality of the urban environment.

Street trees constitute key natural components of urban ecosystems and offer diverse ecological and social services, including carbon storage and sequestration (Yoon et al., 2013), biodiversity preservation (Aronson et al., 2017), the improvement of air quality (Pugh et al., 2012), the management of stormwater runoff (Berland and Hopton,

2014), filtering noise, blocking UV-B radiation (Kumakura et al., 2013), and the amelioration of urban heat island (Wang and Akbari, 2016; Coutts et al., 2016). Further and equally important social benefits, which improve human well-being and community vitality, include economic, social, and health benefits, all of which are also provided by street trees (Saha et al., 2015). Evidences suggested street trees can help to reduce domestic violence, increase property values, and decrease the incidence rate of traffic accidents and the risk of negative mental health outcomes (Troy et al., 2012; Sander et al., 2010; Schwarz et al., 2015; Taylor et al., 2015).

However, despite their undeniably beneficial effects on society and the environment, street trees can pose a series of real risks on human society. Falling leaves, twigs, and overgrown roots could damage sidewalks and surrounding properties (Rae et al., 2017; Mullaney et al., 2015). They also emit toxic biogenic volatile organic compounds, which may react with oxides of nitrogen released by vehicles on roads

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<https://doi.org/10.1016/j.ufug.2020.126747>

Received 21 February 2020; Received in revised form 30 May 2020; Accepted 1 June 2020

Available online 04 June 2020

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to further exacerbate problems to threaten human health and safety (Cariñanos et al., 2017). A number of studies further confirmed that urban trees could cause episodes of pollen pollution during their flowering period, thus exerting a harmful impact on human health and wellbeing (D'Amato et al., 2007). Moreover, over the last 30 years, sensitization rates of airborne tree pollen markedly increased in comparison with the 1990s (Hong, 2015). Today, almost all research identified the pollen allergenicity of common or potentially allergenic tree species in urban parks, and developed the allergenic index (Hruska, 2003) and the index of urban green zone allergenicity (I_{UGZA}) (Cariñanos et al., 2014; Samson et al., 2017) to quantify the allergenicity risk posed by trees in European urban ecosystems (Ciferri et al., 2006).

Because of these real conflicts, street trees require scientific design and maintenance in a way that avoids their negative effects. So far, the urban street planning mainly has focused on specific requirements (e.g., environmental tolerance, pruning tolerance, and shading effects) as well as aesthetics. However, to date, the allergenic risk of street trees has not been explored, although this is considered to be a widespread and common phenomenon in the urban green spaces. Since Chengdu City has been planned to renewal as the “garden city” of China in 2018, green space area is constantly growing. A hypothesis, therefore, was put forward that the street trees of Chengdu City could generate a potentially allergenic threat to human health and its impact depends not only on the allergenic potential of tree species, but also on the quantitative and qualitative composition of street trees. As an attempt to solve this problem, this study has four objectives: a) to investigate the basic information on species composition, diversity, and distribution of the street trees in Qingyang District; b) to assess the seasonally allergenic risk of street trees using the I_{UGZA} ; c) to clarify the correlation between the allergenic risk and characteristics of street trees, d) to offer a number of greening proposals that promote the scientific design of street trees with a focus on health demands.

2. Methods

2.1. Study area and sample selection

The studied area is situated in Qingyang District (N 30°68', E 104°05') of Chengdu City (Fig. 1a, b). Chengdu City is the political and commercial center of western China, and one of the birthplaces of the ancient Shu civilization as well as the poetic culture. Almost 3/5 of the area of the ancient Chengdu City belonged to Qingyang District, which had 14 sub-districts with a total area of 67.78 km², and a permanent population of 707,084 in 2018. The surrounding areas of Qingyang District are highly urbanized and industrialized (Fig. 1c). There are 495 streets in Qingyang District, 33 (6.67 %) of which are without trees. The remainder of the streets (462) have been used as research objects for this study. The total length of these 462 streets is 31.03 km. The typology of these streets is the traditional grid-road (Qin, 2015). The street width was used as classification criteria, since streets with different widths have been dominated by different types of urban land use, which resulted in differences of tree species selection, and ecological welfare (Nagendra and Gopal, 2010). Thus, streets in this study have been divided into five categories according to their width (Fig. 2). Urban expressway (category 1, ≥ 46 m) connect the main areas of city, the major suburbs, satellite towns, and external highways to serve long distance traffic. Main (category 2, 36–45 m) and secondary (category 3, 26–35 m) streets tend to be located in areas that are dominated by commercial properties with high road traffic densities. Precinct streets (category 4, 15–25 m) and community streets (category 5, 8–14 m) are located in predominantly residential neighborhoods.

Chengdu City is characterized by monsoon-influenced humid subtropical climate, and divided into the hot summer and cold winter zone of China (Yu et al., 2009). The mean temperature of the hottest month July ranged from 25 °C to 30 °C, about 2 °C higher than other places of

the same latitude in the world; while, the mean temperature of the coldest month January ranged from 2 °C to 7 °C, which is about 8–10 °C lower than other places of the same latitude in the world (Yu et al., 2009). The weather here is perennially foggy and cloudy (Wen and Li, 2019; Li et al., 2019). Moreover, there is a typical calm wind region (0–0.9 km/h) in China (Jia et al., 2017), where the annual average wind speed was 1 m/s from 2010 to 2017 (Chengdu City Statistics Yearbook, 2010–2017).

2.2. Data collection and analysis

Field studies of the characteristics of street trees were implemented from April 2018 to April 2019. Within each street, all trees (located on either side or in the center) were counted and the species were identified. Their diameter at breast height (DBH), height, crown width, spacing, and the duration of pollination period, were measured and recorded. For each street category, the total number of trees and tree species, the average DBH, average height, average crown width, area ratio and Shannon's diversity index (SHDI) were assessed. Five classes of DBH of street trees were classified as follows: small trees (class 1: 0–15.1 cm), medium trees (class 2: 15.2–30.4 cm, class 3: 30.5–45.6 cm, and class 4: 45.7–60.9 cm), and big trees (class 5: ≥ 61 cm) (McPherson et al., 2016). Area ratio was determined based on the proportion of the total crown area of all trees (S_i) occupied by the total street area (S_t). S_i is obtained by the average horizontal crown projection area (m²) multiplied by the species number (n_i). The average horizontal crown projection area are based on the formula developed by Cariñanos et al. (2014). S_t is collected using remote sensing and geographic informationsystem (GIS) techniques. The SHDI theoretically ranges from 0 to infinity, and is a popular index used to estimate community richness and evenness (Stohlgren, 2007). It is defined as:

$$SHDI = - \sum_{i=1}^N p_i \times \log_2 p_i \quad (1)$$

where N represents the total number of tree species in each street category, and p_i represents the proportional abundance of the i th species.

To assess the allergenic risk of the streets of each category, the I_{UGZA} of varying between 0 and 1, as proposed by Cariñanos et al. (2014, 2019), was applied in each street and each street category of Qingyang District (Table 1), and is defined as:

$$I_{UGZA} = \frac{1}{\max VPA \times S_t} \sum_{i=1}^k VPA \times S_i \times H_i \quad (2)$$

Where the value of potential allergenicity (VPA) represents the value of the potential allergenicity of each tree species. The following variables directly affecting VPA are linked to the three parameters for pollen-release features of the tree species: type of pollination (tp), duration of pollination period (dpp), and allergenic potential of the pollen grains (ap) (Cariñanos et al., 2014). tp refers to the pollination strategy of the tree species, which is based on the database of the National Plant Specimen Resource Center. dpp is defined as the phase from the onset of flowering (5% of flowers open) to the end of full flowering (95 % of flowers shed) in a year, with a given taxa in a 1–3 scale. During the flowering season, ten phenological observation plots ranged in size from 10 m² to 20 m² were established for each species, and conducted at 3-day intervals. The dates from the beginning of full flowering to the end of full flowering were recorded, and their mean values were calculated as the value of dpp. ap of tree species is based on the database of the previous reports (Qiao, 2014; Jiang et al., 2018; Cariñanos et al., 2019). The VPA ranges from 0 to a maximum of 27 and provides a potential allergenicity value for each tree species.

For each street and each category, the values of I_{UGZA} , tree density, area ratio, and SHDI were calculated and detected the significant differences using one-way ANOVA test. Then detailed pairwise comparisons were done using Duncan's post hoc test. The statistical hypotheses

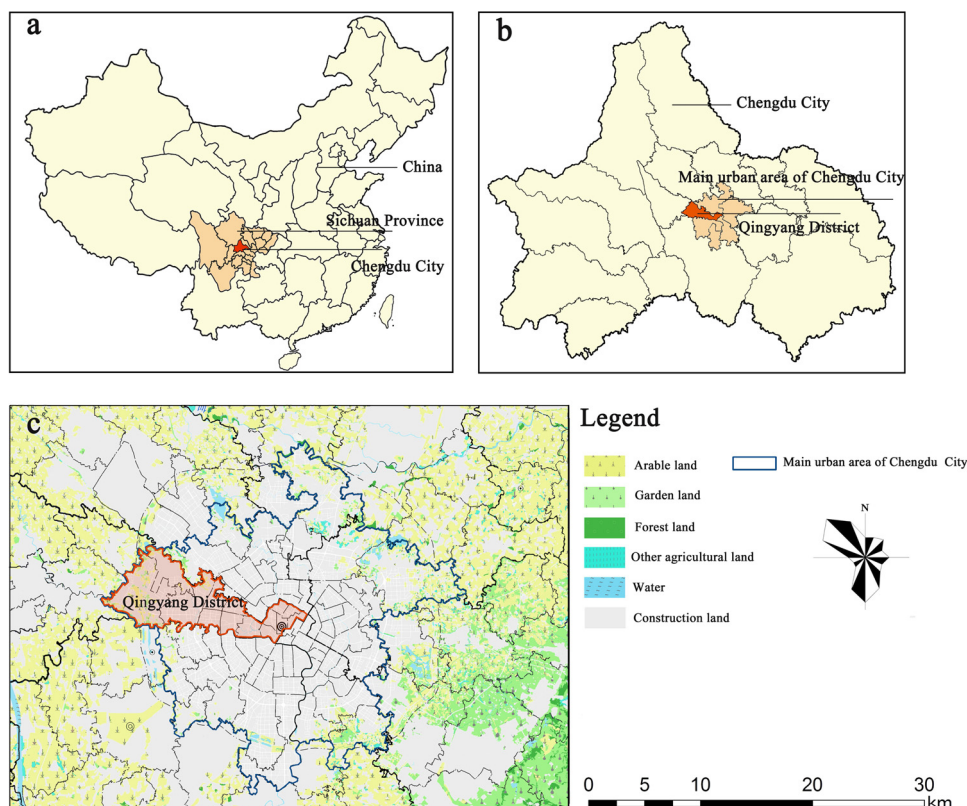


Fig. 1. Location and land use status of Qingyang District, Chengdu City.
(Base map of the land use status in Chengdu City (2014) from Chengdu municipal bureau of planing and natural resources, modified by author).

were tested at $\alpha \leq 0.05$, and all calculations were carried out with SPSS (Statistical Product and Service Solutions) 11.0 software package (SPSS Inc, Chicago, USA). Pearson's correlation analysis was used to identify the allergic risk factors from street trees characteristics using SPSS 11.0. Origin 8.0 was used to draw charts and for function fitting.

3. Results

3.1. Distribution characteristics of street trees

Table 2 shows the distribution characteristics of street trees species in Qingyang District. A total of 40,701 trees are distributed throughout this region. The value of street trees per capita in Qingyang District is 0.06. Fifty-seven species were identified, belonging to 46 taxa, and 28 botanical families in these streets. *Lauraceae*, *Moraceae*, and *Palmae*



Fig. 2. The five street categories of Qingyang District.
(Base map from google Earth, modified by author).

Table 1
Parameters and values to be assigned for obtaining VPA and I_{UGZA} (Cariñanos et al., 2014).

Parameter	value	Description	Parameter	Description
tp	0	No pollen emit	Si	Sum of crown area of all tree species in each street category
	1	Exclusively entomophilous	k	Number of tree species
	2	Amphibious		
	3	Anemophilous	St	The total area of each street category
dpp	1	1–3 weeks	Hi	Average crown height of the each of tree species
	2	4–6 weeks		
	3	More than 7 weeks		
ap	0	Non-allergenicity	ni	The number of the ith species
	1	Low allergenicity		
	2	Moderate allergenicity		
	3	High allergenicity	VPA	$= tp \times dpp \times ap$

have the highest species abundance (five each). Two species represent more than 10 % of the total number. The most dominant species is *Ficus concinna*, which constitutes about 27.27 % (11,100) of the total population and appears in 35.93 % (166) of the streets. The next dominant species is *Ginkgo biloba*, with 20.63 % (8397) of the total population and 25.75 % (119) of the streets. About 38.60 % (22) of the tree species appear in a single street, such as *Sapium sebiferum*, *Erythrina corallodendron*, and *Pittosporum tobira*. More than 50 % of the 462 streets have only one tree species. In contrast, only 15.37 % of streets have more than three trees species. The average DBH of trees across all streets is 27.09 cm, the average height is 9.93 m, the average crown width is 5.62 m, and the average tree spacing is 5.71 m (data not shown).

The distribution of street trees by DBH class indicates that trees in class 2 (15.2–30.4 cm) represent 63.64 % of the total population, followed by trees of class 3 (30.5–45.6 cm), which represent 29.00 % (Fig. 3). Only 0.22 % of the surveyed trees are classified in the biggest sized group (≥ 61 cm, class 5). *E. corallodendron* has the largest average DBH of 42 cm. With regard to tree height, the majority (42.10 %) of trees species are within 10–15 m height. The tallest tree is *Populus alba* with an average height of 14.15 m. The maximum crown width of 10.00 m was observed in *Ficus altissima*. In addition, 46.11 % of the tree species are deciduous, while 53.89 % are evergreen. In relation to the origin of the species, 56.14 % of street trees are native. Fig. 4 shows that 68.42 % of street trees bloomed in spring (from March to May), followed by 21.05 % in summer (from June to August), 8.77 % in autumn (from September to November), and 1.75 % in winter (from December to February).

3.2. Differences across street categories

Table 3 summarizes the differences in tree distribution across street categories. Category 1 (urban expressway) has the least tree species (7) and the lowest tree density (0.07) of all categories. In contrast, category 4 (precinct streets) has the highest street number (336), tree number (29,128), total length of streets (205,298 m), number of tree species (51), and tree density (0.14), but the smallest average tree spacing (5.60). The largest average DBH (27.56 cm) is also observed in precinct street trees, followed by secondary streets (category 2) (data not shown). Community streets have the smallest average DBH (24.84 cm) of trees. Additionally, category 1 has the tallest average tree height (10.65 m), while trees in precinct streets have the largest average crown width (5.53 m) (Fig. 5). An obvious increasing trend of area ratio is showed with decreasing street width (Table 3). Category 5 has the biggest average value of area ratio (0.29) and tree density (0.14), which are significantly higher than that of other categories. The values of SHDI are clearly different, ranging from 0.94 to 3.84 (Table 3). Category 5 have the highest SHDI compared with other street categories.

The different evenness levels of tree species could be the main reason why category 4 do not show the optimal diversity, although the highest numbers of trees and species are observed in this street category. However, according to one-way ANOVA test followed by Duncan's post-hoc test, SHDI does not show any significant differences among the five street categories.

3.3. Analysis of the index of urban green zone allergenicity

The I_{UGZA} , combines aspects of VPA, species richness, street area, and the height and width of the tree crown. VPA indicates the potential intrinsic allergenicity of each tree species. This value enabled the classification of species as being of low allergenicity (from 0–6), moderate allergenic (from 8 to 12) or highly allergenic (from 16 to 27) (Cariñanos et al., 2014, 2017, 2019). The latter group includes the major tree species that trigger allergic reactions in a high percentage of local residents who suffer from pollen allergies. For the three parameters of VPA, according to their strategy of pollination, 49.12 % are anemophilous (Fig. 6). In contrast, 29.82 % of street trees are insect-pollinated. With regard to the duration of pollination period attributes, 61.40 % of the tree species' flowering times are 4–6 weeks. A high allergenic potential of pollen is present in 26.32 % of street trees, while 42.11 % have moderate allergenic potential. A total of 47.36 % of tree species display VPAs in the range of 0–6 (low allergenicity), while 22.81 % of trees are classed as having high allergenicity (16–18) (data not shown). Fig. 7 summarizes the VPA differences in tree species across five street categories. Highly allergenic species account for 42.86 % of category 1, which is much higher than that of other street categories. The percentage of high allergenic species in narrow streets (category 3, 4, and 5) is clearly lower than that in wide streets. Three species of high allergy, *Platanus orientalis*, *G. biloba*, and *Cinnamomum septentrionale*, can be found in all street categories. Their allergenic potential is associated with a wind-pollination strategy, which prompts abundant pollen release during a long period.

The VPAs obtained for tree species in streets are used to calculate I_{UGZA} . For street category, the I_{UGZA} values for this index range from a minimum of 0.1002 for category 1 to a maximum of 1.0391 for category 5 (Table 4). A increasing trend of the I_{UGZA} values is observed with decreasing street width. For each street, there is no street with an I_{UGZA} value more than 1.00 in category 1, 2, and 3. Ninety-nine streets (21.43 %) out of the total 462 streets have the I_{UGZA} values more than the upper limit (1.00). Among them, 70 streets belong to category 4, accounting for 20.83 % of category 4, and 29 streets belong to category 5, accounting for 39.18 % of this category. This founding indicated that the value of I_{UGZA} can exceeded 1 for other urban green spaces. This is because numerous narrow alleys (with a width of 8–10 m) belong to category 5 in Qingyang District. The small surface of these streets and the large and high crowns of trees, together with the high tree density, generate a large volume of emitted allergens, which prompt the value of I_{UGZA} beyond its maximum. *G. biloba* is the dominant tree species here for contribution to I_{UGZA} to almost all street categories (Table 4). The highest allergenicity risk of street trees exists in spring, followed by summer (Fig. 8). The pollination period of most tree species in Qingyang District ranges from March to June, leading to a large pollen load over this very specific period. Category 5 also has the maximum possible value (0.8944) in spring. Adversely, winter is the season with the lowest allergenicity risk for all street categories.

With regard to the variables with the greatest impact on the value of the I_{UGZA} , Pearson's correlation analysis clarified the relationship between I_{UGZA} and certain characteristics of street trees. A similar effect from street characteristics on I_{UGZA} has been observed in category 1, 3, 4 and 5, which were significantly influenced by area ratio and tree density ($p \leq 0.05$) (Table 5). Area ratio (0.52, $p \leq 0.05$) and tree density (0.42, $p \leq 0.05$) were also the two key parameters that significantly affect the average value of I_{UGZA} . These relationships are indicated in Fig. 9, using a one-dimensional linear regression equation. However, no

Table 2
Characteristics list of street trees.

Number	Tree species	Number of trees	Number of Streets	Average DBH (cm)	Average tree height (m)	Average crown width (m)	Origin	Life form of leaf	Flowering season	VPA
1	<i>Sapium sebiferum</i>	69	1	26.00 ± 1.41	12.00 ± 0.00	3.50 ± 0.00	Native	Deciduous	Spring	8
2	<i>Bischofia javanica</i>	546	10	32.05 ± 4.78	11.16 ± 2.01	6.79 ± 1.44	Introduced	Deciduous	Spring	12
3	<i>Erythrina corallodendron</i>	18	1	42.00 ± 0.00	12.00 ± 0.00	8.00 ± 0.00	Native	Deciduous	Summer	2
4	<i>Albizia julibrissin</i>	40	2	29.00 ± 8.49	9.00 ± 0.00	5.25 ± 1.77	Native	Deciduous	Summer	2
5	<i>Sophora japonica</i> var. <i>pendula</i>	66	1	15.00 ± 0.00	4.00 ± 0.00	3.00 ± 0.00	Introduced	Deciduous	Summer	4
6	<i>Gleditsia sinensis</i>	75	3	40.40 ± 9.91	11.40 ± 1.34	8.00 ± 2.00	Native	Deciduous	Spring	4
7	<i>Bauhinia purpurea</i>	172	4	19.33 ± 4.97	5.83 ± 2.38	4.50 ± 0.84	Introduced	Deciduous	Autumn	4
8	<i>Sophora japonica</i>	309	3	30.25 ± 1.04	13.06 ± 3.59	8.31 ± 3.13	Native	Deciduous	Summer	18
9	<i>Samanea saman</i> (Jacq.) Merr.	81	2	25.50 ± 4.00	11.75 ± 1.16	6.81 ± 1.19	Introduced	Deciduous	Spring	2
10	<i>Elaeocarpus decipiens</i>	630	15	18.00 ± 5.31	6.93 ± 1.80	4.07 ± 1.28	Introduced	Evergreen	Summer	6
11	<i>Eucommia ulmoides</i>	27	1	23.00 ± 0.00	13.00 ± 0.00	1.50 ± 0.00	Native	Deciduous	Spring	9
12	<i>Pittosporum tobira</i>	4	1	10.00 ± 0.00	3.00 ± 0.00	3.00 ± 0.00	Native	Evergreen	Spring	3
13	<i>Phyllostachys</i>	80	1	5.00 ± 0.00	8.00 ± 0.00	2.00 ± 0.00	Native	Deciduous	Spring	6
14	<i>Pterocarya stenoptera</i>	24	1	25.00 ± 0.00	9.00 ± 0.00	3.00 ± 0.00	Native	Deciduous	Spring	18
15	<i>Hibiscus syriacus</i>	11	1	5.00 ± 0.00	2.50 ± 0.00	1.00 ± 0.00	Native	Deciduous	Autumn	4
16	<i>Ailanthus altissima</i>	25	1	24.00 ± 0.00	12.00 ± 0.00	8.00 ± 0.00	Native	Deciduous	Spring	18
17	<i>Michelia alba</i> DC.	103	2	23.50 ± 5.31	12.25 ± 1.80	5.00 ± 1.15	Native	Evergreen	Summer	2
18	<i>Liriodendron tulipifera</i>	243	3	31.50 ± 2.35	9.33 ± 1.03	5.42 ± 1.36	Introduced	Deciduous	Spring	2
19	<i>Michelia figo</i> (Lour.) Spren.	503	4	19.36 ± 4.54	6.69 ± 5.00	3.46 ± 0.85	Introduced	Evergreen	Spring	2
20	<i>Magnolia grandiflora</i>	380	15	19.67 ± 6.56	6.96 ± 1.57	2.83 ± 1.06	Native	Deciduous	Spring	3
21	<i>Osmanthus fragrans</i> var. <i>semperflorens</i>	689	23	22.29 ± 7.43	6.21 ± 2.23	2.79 ± 1.04	Native	Evergreen	Summer	4
22	<i>Ligustrum compactum</i>	1042	32	25.77 ± 4.92	10.03 ± 2.73	5.90 ± 2.26	Native	Evergreen	Autumn	12
23	<i>Araucaria cunninghamii</i>	9	1	32.00 ± 0.00	14.00 ± 0.00	6.00 ± 0.00	Introduced	Evergreen	Autumn	18
24	<i>Pistacia chinensis</i>	31	2	25.33 ± 4.62	9.20 ± 6.35	2.33 ± 2.31	Native	Deciduous	Spring	9
25	<i>Acer palmatum</i>	89	2	11.00 ± 0.00	3.00 ± 0.00	2.00 ± 0.00	Introduced	Deciduous	Spring	12
26	<i>Lagerstroemia indica</i>	52	1	13.00 ± 0.00	4.00 ± 0.00	3.00 ± 0.00	Native	Deciduous	summer	6
27	<i>Photinia serrulata</i>	52	1	15.00 ± 0.00	7.00 ± 0.00	3.00 ± 0.00	Native	Evergreen	Spring	2
28	<i>Eriobotrya japonica</i>	119	4	14.75 ± 4.50	6.25 ± 0.96	3.00 ± 1.15	Native	Evergreen	Winter	2
29	<i>Prunus serrulata</i>	68	1	14.00 ± 0.00	7.50 ± 0.00	4.00 ± 0.00	Introduced	Deciduous	Spring	2
30	<i>Cerasus yedoensis</i>	130	3	16.75 ± 13.25	4.75 ± 0.96	3.50 ± 0.58	Introduced	Deciduous	Spring	2
31	<i>Ficus benjamina</i>	5	1	10.00 ± 0.00	5.00 ± 0.00	2.00 ± 0.00	Introduced	Evergreen	Spring	2
32	<i>Ficus religiosa</i>	8	1	36.00 ± 0.00	4.00 ± 0.00	2.50 ± 0.00	Introduced	Evergreen	Spring	2
33	<i>Ficus altissima</i>	12	1	38.00 ± 0.00	13.00 ± 0.00	10.00 ± 0.00	Introduced	Evergreen	Spring	2
34	<i>Ficus virens</i>	2644	46	32.30 ± 8.25	10.88 ± 2.41	6.77 ± 2.42	Native	Deciduous	Spring	2
35	<i>Ficus concinna</i>	11,100	166	29.39 ± 6.06	9.85 ± 2.68	5.50 ± 2.25	Introduced	Evergreen	Spring	2
36	<i>Metasequoia glyptostroboides</i>	246	4	29.43 ± 2.70	10.43 ± 3.59	3.42 ± 1.10	Native	Deciduous	Spring	18
37	<i>Cedrus deodara</i> (Roxb.) G. Don	163	3	34.17 ± 2.04	9.67 ± 1.21	3.58 ± 1.24	Native	Evergreen	Spring	18
38	<i>Koeleruteria paniculata</i>	1249	29	28.14 ± 7.15	11.96 ± 7.15	7.08 ± 3.69	Native	Deciduous	Summer	6
39	<i>Firmiana platanifolia</i>	117	3	29.00 ± 0.00	10.00 ± 0.00	6.00 ± 0.00	Native	Deciduous	Summer	18
40	<i>Platanus orientalis</i>	2272	52	35.93 ± 10.23	11.97 ± 2.77	6.91 ± 2.67	Native	Deciduous	Spring	18
41	<i>Heteropanax fragrans</i> (Roxb.) Seem.	52	1	32.00 ± 0.00	9.00 ± 0.00	3.00 ± 0.00	Introduced	Evergreen	Autumn	12
42	<i>Populus nigra</i> var. <i>italica</i>	76	1	32.00 ± 0.00	13.80 ± 0.00	6.30 ± 0.00	Introduced	Deciduous	Spring	18
43	<i>Salix babylonica</i>	170	4.0	31.50 ± 8.38	9.67 ± 3.43	4.42 ± 1.86	Native	Deciduous	Spring	18
44	<i>Populus alba</i>	716	26	33.59 ± 9.02	14.15 ± 2.48	6.85 ± 1.22	Introduced	Deciduous	Spring	18
45	<i>Ginkgo biloba</i>	8397	119	23.76 ± 6.75	10.69 ± 2.50	4.31 ± 1.62	Native	Deciduous	Spring	18
46	<i>Celtis sinensis</i> Pers.	243	9	26.67 ± 9.86	12.89 ± 5.42	3.33 ± 1.89	Native	Deciduous	Spring	12
47	<i>Lindera megaphylla</i> Hemsl.	9	1	20.00 ± 0.00	8.00 ± 0.00	3.00 ± 0.00	Native	Evergreen	Spring	12
48	<i>Machilus chinensis</i>	324	6	16.88 ± 6.15	8.50 ± 1.60	3.38 ± 1.06	Introduced	Evergreen	Spring	8
49	<i>Cinnamomum septentrionale</i>	1295	21	23.64 ± 4.42	9.36 ± 2.88	4.88 ± 1.43	Native	Evergreen	Spring	18
50	<i>Cinnamomum japonicum</i> Sieb.	1908	45	19.82 ± 4.86	7.03 ± 2.29	4.88 ± 1.62	Native	Evergreen	Spring	12
51	<i>Cinnamomum camphora</i> (L.) Presl.	3124	79	28.24 ± 7.26	10.06 ± 3.61	5.12 ± 2.43	Native	Evergreen	Spring	12
52	<i>Jacaranda mimosifolia</i>	100	3	24.50 ± 2.89	10.00 ± 3.46	4.50 ± 0.58	Introduced	Deciduous	Spring	2
53	<i>Corypha umbraculifer</i>	6	1	22.00 ± 0.00	4.00 ± 0.00	3.00 ± 0.00	Introduced	Evergreen	Spring	12
54	<i>Livistona chinensis</i> (Jacq.)	5	1	25.00 ± 0.00	6.00 ± 0.00	4.00 ± 0.00	Introduced	Evergreen	Spring	12
55	<i>Phoenix hanceana</i>	28	2	32.00 ± 0.00	11.00 ± 0.00	5.00 ± 0.00	Introduced	Evergreen	Summer	12
56	<i>Cocos nucifera</i>	120	1	25.00 ± 0.00	9.00 ± 0.00	5.00 ± 0.00	Introduced	Evergreen	Summer	12
57	<i>Trachycarpus fortunei</i>	625	13	22.38 ± 12.18	6.50 ± 2.19	3.22 ± 1.54	Introduced	Evergreen	Spring	12

Results are means ± standard deviations (SD).

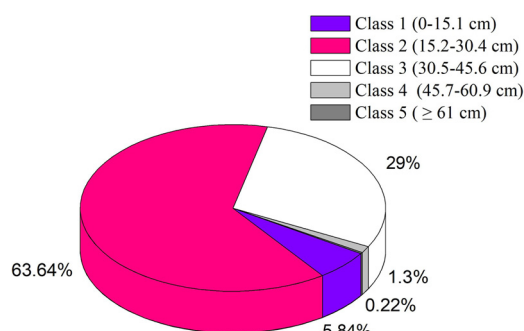


Fig. 3. The DBH distribution of street trees.

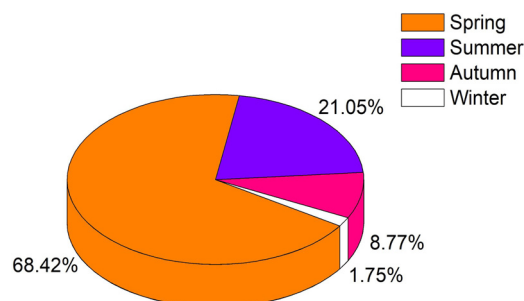


Fig. 4. The percentage shares of street trees in respect to flowering season.

correlation was observed between I_{UGZA} scores and species richness (i.e., SHDI and the total number of species).

4. Discussions

Chengdu City has always been considered as the “livable city” in China, and is renowned for its rich plant resources (Liu et al., 2008) and superior green coverage rate (45 %). The first stage of street greening finished over the past ten years; however, large-scale replacement or replenishment plantations (of more than 6000 trees) of street trees has been carried out every two years since 2016 (Report on the Work of the Chengdu Government, 2019). Still, despite the street greening is mature in Chengdu City, it is still fast changing qualitatively in accordance with the demands of international metropolises.

4.1. The characteristics of streets trees

In Chengdu City, the number of street trees per capita is 0.06, which is clearly lower than the 0.28–0.30 for 50 US cities (McPherson et al., 2016) and 0.16 for four Mediterranean cities (Maya Manzano et al., 2017; Soares et al., 2011). Moreover, this is slightly less than the data of a number of other Asian cities, such as Bangkok (0.17) (Thaiutsa et al., 2008), Bangalore (0.10) (Nagendra and Gopal, 2010), and Daegu (0.07)

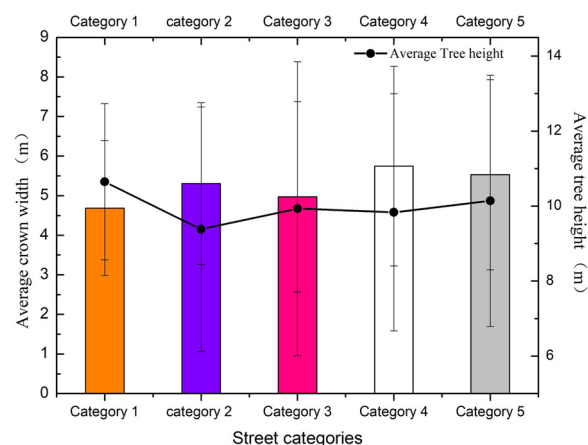


Fig. 5. The tree characteristics of different street categories.

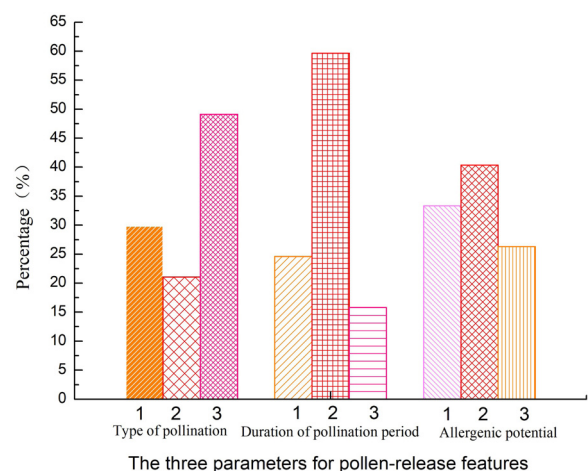


Fig. 6. The rate of pollen-release parameters of tree species.

(Yoon et al., 2013). It is necessary to consider that the population base of these cities is much less than that of Chengdu City. However, this value is much higher than that of many Chinese cities, notably, Qingdao (0.02), Guangzhou (0.02), Shanghai (0.03), and Beijing (0.02) (Zhang et al., 2013; Wei, 2016; Tang et al., 2016).

With regard to species diversity, the species identified in this study (57 species) are less than those identified in Hong Kong (70 species) (Jim and Zhang, 2013), Gran Mendoza (75 species) (Breuste, 2013), and Bangalore (108 species) (Nagendra and Gopal, 2010). That could be due to the research areas of these cities are much bigger than that of Qingyang District. However, it is higher than that of New York with 15 species (Cowett and Bassuk, 2014), Singapore City with 32 species (Ghosh et al., 2016), and Kuala Lumpur with 35 species (Sreetheran

Table 3
Characteristics of street.

Street category	Number of Street	Number of trees	Number of tree species	The total length of the streets (m)	Average tree spacing (m)	Tree density	Area ratio (Si/St)	SHDI
1	5	1427	7	20,400	7.36 ± 2.79	0.07 a	0.02 a	0.94
2	13	1565	11	19,165	6.25 ± 2.21	0.08 ab	0.05 a	1.97
3	34	4016	20	32,776	5.45 ± 2.02	0.12 ab	0.08 a	3.16
4	336	29,128	51	205,298	5.60 ± 2.11	0.14 b	0.20 b	3.70
5	74	4565	25	32,613	5.88 ± 2.05	0.14 b	0.29 b	3.84
Total	462	40,701						

Results are means ± standard deviations (SD). Values followed by different letters indicate there is statistically significant difference among the treatment groups at $p \leq 0.05$ (5%) according to one-way ANOVA test, followed by Duncan's post hoc test in SPSS. The common letters indicate that no significant difference is observed among groups.

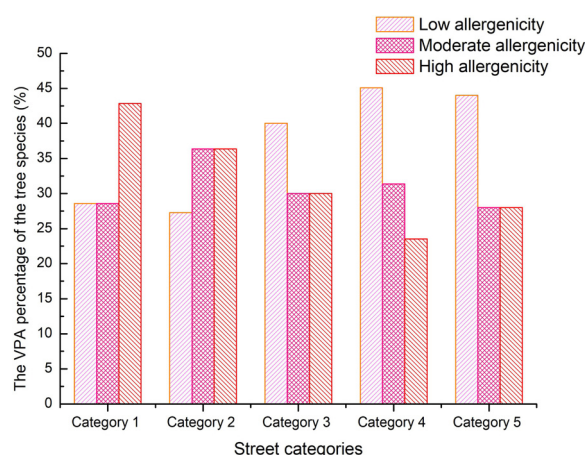


Fig. 7. The VPA percentage of the tree species in each street category.

et al., 2011). Moreover, the data is much higher than that of many cities in China, such as Beijing (12 species) (Tang et al., 2016), Lasha (24 species) (Yang et al., 2012), Shenzhen (49 species) (Wu et al., 2010), and Shengyang (24 species) (Li et al., 2003). As indicated by Liu et al. (2008), because of the huge topographic differences and obviously vertical differentiation of climate, Chengdu City is the area where has the most native plant species in China. Additionally, the two species, *F. concinna* and *G. biloba*, represented more than 20 % of the entire population each, and the sum of them comprises nearly 50 % of the total population. Previous research has proposed that the most dominant species should not surpass 10 % to retain an even species distribution (Nagendra and Gopal, 2010; Maya Manzano et al., 2017). Therefore, the species distribution of street trees here appears to an uneven feature. This feature is very similar to other highly populated cities, such as Singapore City, where the five most common species constitute 61 % of the entire population (Ghosh et al., 2016), Bangkok, where one dominant species constitutes more than 40 % of the tree number (Thaiutsa et al., 2008), and Beijing, where one dominant species, *Sophora japonica* L., accounts for more than 50 % of the tree population (Tang et al., 2016).

In this study, about 63.64 % of trees in Qingyang District have a moderate diameter (15.2–30.4 cm). The situation is completely opposite of the US, where the planters advocate the planting of small-sized trees on the streets to reduce tree maintenance costs and increase species diversity (McPherson and Rowntree, 1989). Additionally, there is no significant difference in the average DBH, tree height, and crown width among the different street categories. This is due to the movement of “transplanting big trees into cities” in China since 2000. While, big trees may achieve the purpose of shortening the greening cycle, benefits associated with the biomass of these large, mature trees may be partially negated by their low survival rates (McPherson et al., 2016).

4.2. The I_{UGZA} of street trees

Previous research indicated that the value of I_{UGZA} above 0.3 may

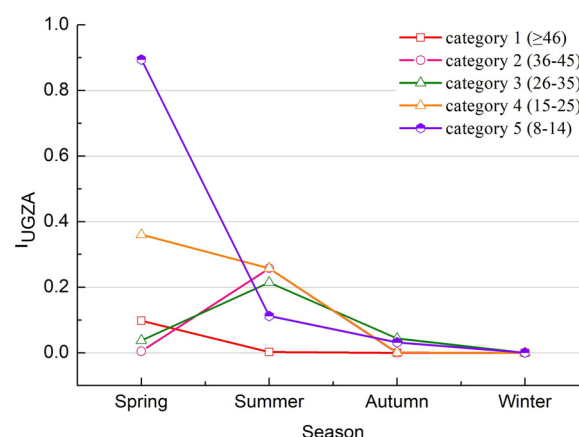


Fig. 8. The seasonal I_{UGZA} of street categories.

thus be considered indicative of high allergenicity, and thus indicative of urban green space causing discomfort and adverse symptoms for an allergic population (Cariñanos et al., 2014, 2017, 2019). The data of the present study shows that street category 4 and 5 greatly exceed the threshold value of 0.3. Moreover, the values of both street category 3 and 2 are slightly below the threshold. This finding indicates the high allergenic risk of street trees of Qingyang District. Several popular tree species with a high VPA (18), such as *G. biloba*, *P. orientalis*, and *Cinnamomum camphora* (L.) Presl., are the main causes of pollen allergy, which are not very suitable for the design of allergy-friendly green spaces in Chengdu City. These tree species are different with that in Central Europe, where about 30–50 % of people with pollen allergies manifest sensitivity to *Betula* pollen (Kuchcik et al., 2016). However, it is a little similar to Spain and France, where the roadside tree responsible for most pollen allergies is *P. orientalis* (Cariñanos and Casares-Portel, 2011). Thus, it is necessary to build a local database for city designers to characterize the potential allergenicity of street tree species to minimize the impact of pollen allergens on the local inhabitants. Furthermore, due to its abundant quantity, *F. concinna* highly contributes to the final I_{UGZA} value, although it is a species with low allergenic potential. It indicated that the excessive use of low-allergenic tree species could also increase the allergenic risk. This finding verified the speculations that abundant use of lowly (Mrdan et al., 2017) or moderately (Ciferri et al., 2006) allergenic plants could intensify their allergenic effect on the inhabitants. In addition, the seasonal difference of the allergic risk of streets reflects that spring-flowering trees are used excessively in this district. Therefore, this study suggests to integrate the season parameter into the I_{UGZA} formula.

Cariñanos et al. (2017) reported a significant correlation between the value of I_{UGZA} and tree density and tree number of urban parks. In this study, correlation analysis reveals that area ratio and tree density are the crucial factors affecting the I_{UGZA} of street green spaces, while no relationship was also observed between tree number and I_{UGZA} . In addition, SHDI of street green space shows no any positively correlated with I_{UGZA} . It is different with the results which reported by Cariñanos et al. (2019) for Mediterranean urban parks. Interestingly, the same

Table 4

The I_{UGZA} and the contribution of the dominant species to I_{UGZA} .

Street category	I_{UGZA}	Contribution of the dominant species to I_{UGZA}
1	0.1002 a	<i>G. biloba</i> (0.0773), <i>B. javanica</i> (0.0194)
2	0.2626 a	<i>G. biloba</i> (0.2337), <i>C. septentrionale</i> (0.0140), <i>F. concinna</i> (0.0095)
3	0.2959 a	<i>G. biloba</i> (0.1468), <i>P. orientalis</i> (0.0412), <i>C. camphora</i> Presl (0.0339)
4	0.6166 ab	<i>P. orientalis</i> (0.1793), <i>G. biloba</i> (0.09769), <i>F. concinna</i> (0.0656), <i>S. japonica</i> (0.0423), <i>P. alba</i> (0.0391)
5	1.0391 b	<i>G. biloba</i> (0.2577), <i>C. camphora</i> Presl (0.2342), <i>K. paniculata</i> (0.0767), <i>P. alba</i> (0.0697)

Values followed by different letters indicate there is statistically significant difference among the treatment groups at $p \leq 0.05$ (5%) according to one-way ANOVA test and Duncan's post hoc test in SPSS. The common letters indicate that no significant difference is observed among groups.

Table 5
Pearson's correlations between I_{UGZA} of street categories and characteristics of street.

Characteristics	I_{UGZA} of category 1	I_{UGZA} of category 2	I_{UGZA} of category 3	I_{UGZA} of category 4	I_{UGZA} of category 5	Average I_{UGZA}
Area ratio	0.99**	0.22	0.55**	0.50**	0.47**	0.52*
Tree density	0.79*	0.42	0.48**	0.42**	0.41**	0.42*
SHDI	-0.43	0.36	-0.03	0.06	0.20	0.05
Number of trees	0.64	0.70	0.19	0.18	0.12	0.09
Number of tree species	-0.17	0.14	-0.05	0.04	0.26*	0.04

All values followed by * are significantly different at $p \leq 0.05$, by **are significantly different at $p \leq 0.01$.

authors pointed out no significant correlation between I_{UGZA} and SHDI for Spanish urban parks (Cariñanos et al., 2016). Such radically different results could be due to the balanced diversity among species with different flowering and allergenicity attributes. Previous researches for urban parks suggested that the value of I_{UGZA} ranges between 0 and 1 (Cariñanos et al., 2014, 2016, 2017, 2019; Jochner-Oette et al., 2018). However, in the present study, community streets shows an average I_{UGZA} value of 1.0391, which exceeds the upper limit. This is because the two key factors (area ratio and tree density) effected on I_{UGZA} simultaneously show the highest values in this street category. Together with the highest tree density and the largest and high crowns of trees, the smallest surface of streets generates a large volume of emitted allergens, which prompts the value of I_{UGZA} beyond its maximum.

4.3. How to control the allergenic risk of street trees in Chengdu City

The presented comparative analysis indicates that the large surface area of tree crowns, the high rate of spring-flowering trees, and the excessive tree density are important causes of the high allergy of street trees in Chengdu City. In addition, as indicated by Damialis et al. (2005), pollen concentration and its allergic effect were significantly correlated with local climate, especially the wind speed in urban area (Zhang et al., 2015). Moreover, cross-reactivity of pollen and fog seems causing exacerbation of allergic risk of inhabitants (Tsabouri et al., 2015). Due to calm winds prevail and perennially foggy in Chengdu City, the allergy risk of street trees could be accumulated in urban area for a long time, and difficult to mitigate.

Thus, actions are required to minimize the volume of allergens produced by the street trees in Chengdu City. There are several greening strategies to achieve this goal. Firstly, street trees with high VPA, such as *G. biloba*, *S. japonica*, *Cedrus deodara* (Roxb.) G. Don, *P. alba*, and so on, should be partially removed and replaced by low VPA species, such as *Prunus serrulata*, *Ficus virens*, and *Magnolia grandiflora*, to decrease the potential allergenicity. Secondly, it is worth noting that Chengdu City is the region with the lowest solar radiation intensity of China (Luo et al., 2015). Streets here need more sunshine instead of excessive shade during all seasons. Therefore, replacing trees with

umbrella-shaped crown (*Ailanthus altissima*, *F. altissima*, and *F. concinna*) with trees with cylindrical crown, which's branching angles is less than 40° , such as *Paulownia fortuneia*, *Machilus chinensis*, and *Ficus benjamina*, or increasing tree spacing, could decrease the area ratio to minimize the volume of pollen release. Thirdly, under the premise of retaining the current species diversity, male trees individuals of dioecious species should be partially replaced by female individuals or male sterile individuals. A good example can be found in *G. biloba* in this study. *G. biloba* has been the iconic tree species in Chengdu City since 1987. That is the reason why it is one of the most abundant urban trees in this area, with proven high allergenicity of its pollen (Hong, 2015; Cariñanos et al., 2016). Moreover, previous research revealed an excessively high proportion of 80 % of male of *G. biloba* in urban greening space (Del Tredici, 2007; Cariñanos and Casares-Porcel, 2011). Fourthly, adjusting the proportion of street trees with balancing blossoming throughout all four seasons will be beneficial for relieving the aggregated allergy stress. Finally, adopting appropriate management and gardening strategies (e.g., pruning and chemistry medicine) could reduce pollen emission. For instance, due to inflorescences occur in greater numbers in the upper parts of the tree crown (Dudek et al., 2018), heavy pruning of the crown top of street trees at winter, could inhibit the number of inflorescences.

5. Conclusions

Although Chengdu City is widely renowned as the "livable city" of China, and rapidly gains importance as a global city, little is known about the urban street environment and its allergenicity risk. This research indicates that street trees in Chengdu City pose a high allergenicity risk for local residents, especially in spring and early summer. The I_{UGZA} of streets trees even exceeds the upper limit (1.0). That be due to the large surface area of tree crowns, the excessive tree density, the popular use of high VPA trees, and unbalancing blossoming of street trees in this city. Moreover, the scale of allergy incidence is growing with the increasing green area of Chengdu City. As suggested by the World Allergy Organization, avoiding contact with allergens is more important than pharmacological treatment (Pawankar et al., 2013).

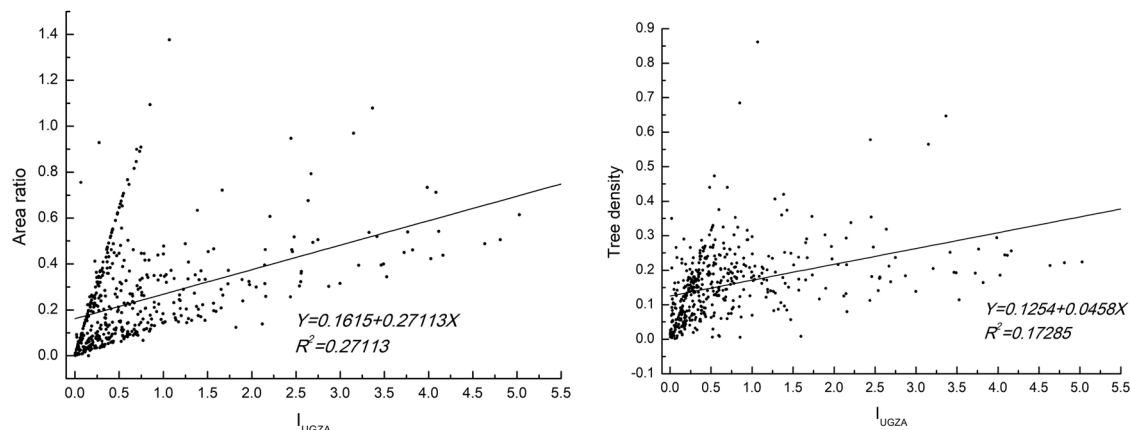


Fig. 9. One-dimensional linear regression equation.

Thus, this study can provide certain recommendations for urban designer, resident, and visitor. Healthy urban design requires the co-operation of not only the landscaper, but also experts from botany, aerobiology, epidemiology, ecology, meteorology, and geography. When planning outdoor activity in Chengdu City, residents are less exposed to the impact of pollen in urban expressway, main and secondary streets than that in precinct and community streets. Residents with pollen allergies should wear masks when they have to pass precinct and community streets in spring and early summer. Visitors with pollen allergies should avoid traveling to Chengdu City in spring and summer. The best time for them recreation here is autumn and winter.

Urban microclimate significantly affects the concentrations of tree pollen. The next research will be involved in the spatial or temporal variability in urban tree phenology, expect to deepen the understanding of the street tree responses to the urban heat island (UHI) effect, and improve urban well-being using scientific landscape design.

Funding information

This work is supported by the National Natural Science Foundation of China (grant numbers: 31971716), the 13th five year plan of social science research in Sichuan Province (grant numbers: SC19B138), and the Sichuan science and technology plan project (grant numbers: 2020JDR0036).

Declaration of Competing Interest

The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with this work submitted.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.ufug.2020.126747>.

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