Urban Tree DBH Response to Fast Urbanization— A Case from Coastal City Zhanjiang, China

Xia-Lan Cheng
Lingnan Normal University
Mir Muhammad Nizamani
Hainan University
Kelly Balfour
Algoma University
Salman Qureshi
Humboldt-Universität zu Berlin: Humboldt-Universitat zu Berlin
Shuang Liu
Lingnan Normal University
Zhi-Xin Zhu
Hainan University
Si-Si Wu
Bureau of urban Management
Huafeng Wang (279745044@qq.com)
Hainan University

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Abstract

Trees perform various ecosystem functions within urban green space, yet little is known about the magnitude of change in urban tree DBH, and its potential response to urbanization. Field investigation was used to determine current tree DBH within Urban Function Units (UFUs) in the coastal city Zhanjiang in China. The cover of each UFU was determined via visual interpretation of satellite images. We recorded 12,434 individuals within Zhanjiang green space belonging to 185 species, 137 genera, and 51 families. The dominant DBH range was 5-15 cm, which accounted for 43.72% of the total stems. The DBHs of 33 individuals were larger than 90 cm - 20 of these individuals were *Ficus* species. The average tree DBH within commercial areas was (32.29 cm ±1.74 cm), which was the highest among all UFU types, and lowest within woodland areas (7.11 cm ± 0.56 cm). Tree DBH was significantly positively correlated with imperious surface rate, and significantly negatively correlated with green space surface rate. Variation partitioning analysis showed that impervious surface rate had the highest explanatory power, followed by construction age, then patch density. These three prediction variables, however, only explained 20% of the total observed variation - this suggests that DBH was strongly influenced by several additional factors. Understanding urban tree DBH structure and its influencing factors can promote the stable development of the urban forest.

1. Introduction

The benefits of access to local green space are well documented, including, among many others, those related to physical health (Maas et al., 2006), stress recovery (Van den Berg etal., 2007), mental well-being (Fuller et al., 2007), social cohesion (Coley et al., 1997), provision of ecosystem services (Bolund & Hunhammar, 1999), and biodiversity conservation. Urban green spaces (UGSs) are becoming increasingly important in developing countries (Thaiutsa et al., 2008). Trees, especially those of maturity, are considered “key elements” within urban areas (Lindenmayer et al., 2012; Stagoll et al., 2012); trees contribute to various ecosystem functions, such as habitat function (maintenance of biological and genetic diversity) and information function (spiritual enrichment, mental development and leisure) (McKinney, 2002; Dobbs et al., 2011).). Urban trees can also have a stronger effect on carbon budgets than non-urban trees (Dearborn & Kark, 2010), in addition to playing a high impact role in reducing the intensity of urban heat island effects (UHI) (Chow & Roth, 2006).

Current studies of urban trees largely focus on the following aspects: (1) The ecological service of urban trees: mitigating urban heat island effects (Nowak et al., 2017; Zhao et al., 2018; Fan et al., 2019; Ow et al., 2019), aerodynamic characterization of urban trees (Rafael et al., 2018; Yuan et al., 2017; Zeng et al., 2020), and the impact of urban trees on air pollutants (Sicard et al., 2018; Yli-Pelkonen et al., 2018; Chen et al., 2019; Lai & Kontokosta, 2019; ; Xing et al., 2019; Mukherjee et al., 2020; Sgrigna et al., 2020) are still research hotspots, although some negative ecological services related to human health have also attracted much attention, such as pollen (Sicard et al., 2018; Cariñanos et al., 2020; Aerts et al., 2021) and plant (Lara et al., 2019) allergies; (2) Urban tree management: maintenance and assessment practices, including the health (North et al., 2017; Stravinskienė et al., 2018; Abbas et al., 2020; Großmann et al., 2020; Schollaert et al., 2020), survival (Ossola & Hopton, 2018; chollaert et al., 2020), and protection (Morgenroth et al., 2017; Guo et al., 2018; Lin et al., 2020) of urban trees and urban forestry policy (Breger et al., 2019; Namin et al., 2020; Quinton et al., 2020) have been researched to establish a healthy and rational urban forest structure; (3) Physiological and morphological responses of urban trees to human disturbance and other environmental stresses were studied (Cobley & Pataki, 2019; Moser-Reischl et al., 2019; Wang et al., 2019; Kuzmin et al., 2020) to guide urban tree planting; and (4) Research on urban forest structure and diversity, with tree canopy, species composition (Chimaimba et al., 2020; Dangulla et al., 2020) and diversity (Kendal et al., 2012; Bentsen et al., 2010 Sjöman et al., 2016; e Silva et al., 2020) being studied in detail.

Few studies, however, have assessed urban tree DBH and its influencing factors – in fact, little is known about the magnitude and dynamics of urban tree DBH. This measure is considered to reflect the age structure of an urban forest, and also infers urban vegetation dynamics. The DBH structure is the most basic stand structure for a forest community, and could reflect the relationship between trees and their habitat. Typically, the greater the DBH, the greater the ecological benefits associated with trees (e.g., carbon storage, carbon sequestration, and air purification), but the maintenance costs for trees with large diameters is often higher than for smaller trees. Both the size and the age of a tree affect characteristics such as the tree mortality. Typically, tree-level data are needed for maintaining the urban tree reserve. To maximize the ecological benefits of urban green space, the DBH structure of trees should be reasonably configured. Therefore, we ask two key questions: (1) What is the magnitude of tree DBH in Zhanjiang UGS? (2) Which factors could contribute to changes in urban tree DBH? We expect that trees with smaller DBHs would be more abundant than trees with larger DBHs, due to rapid urbanization and increased attention towards urban tree planting in recent decades.

2. Materials And Methods

2.1 Study area

Zhanjiang has a subtropical oceanic monsoon climate; the summer season is hot and wet, with the mean daily maximum air temperature often exceeding 34°C in July and August. Thunderstorms and heavy rain occur frequently from May to October, during which typhoons (tropical cyclones) may take place. The relatively cool and dry winter runs from December to February, with temperature occasionally dropping below 10°C.

Our study area was located on the Eastern side of Zhanjiang (Fig. 1).

2.2 Field investigation

We divided a Google Earth image of Zhanjiang's main urban area into 273 grids with an edge length of 650 m. In each grid, we choose one UFU within which to carry out our field work. The field work was carried out from June to August, 2017. The definition of UFU used in this study was based on Wang &

López-Pujol, (2015). A UFU has distinct boundaries, and the management and maintenance of green space within them was typically consistent. In each UFU, we set up three 20 m^2 plots.

All woody plants with a DBH ≥ 2 cm were inventoried within each plot. DBH was measured at 1.30 m from the ground using calipers or a diameter measuring tape. Woody plants with forks below 1.3 m were considered multi-stemmed; for trees with multiple stems, the aggregate DBH of individual stems was obtained from the square root of the sum of the squared DBHs of individual stems (Mauro et al., 2019). All tree species present and the number of individuals of each were recorded. All recorded trees were identified into species level in the field with the help of regional floras (South China botanical garden, 2009; Guangxi Institute of Botany, 1991–2016). The trees were classified into several groups according to the DBH: 2 ≤ DBH 5, 5 ≤ DBH 15, 15 ≤ DBH 30, 30 ≤ DBH 45, 60 ≤ DBH 75, 75 ≤ DBH 90, DBH ≥ 90.

Urban vegetation is subject to biophysics and economic-social factors; with reference to previous work, several influential factors were selected for study: land cover rate, landscape indices, soil qualities, green space maintenance, UFU type, and the construction age of each UFU (Cilliers & Bredenkamp, 1999; Wang et al., 2013; Amici et al., 2015; Zhu et al., 2019 Anderson & Minor, 2019; Kumar et al., 2021; Jim, 2021). The landscape cover was divided into four types including green surface, wasteland, water body, impervious surface based on visual interpretation of the Systeme Probatoire d’Observation de la Terre (SPOT) image. The landscape indices were conducted using Fragstats 4.2. The 0–10 cm of surface soil samples were collected at each plot by foil sampler. The litters and stones were on the soil surface were removed before we collected soil sample. And the soil qualities were later measured in the lab. Green space maintenance information was acquired through interviews with associates of each UFU. UFU types and the construction age of each UFU were determined via the official web site of each UFU, during interviews, and/or through assessments of historical Google Earth image.

2.3 Data analysis

A linear regression model was adopted to choose prediction variables for analysis (Table 1), while non-significant ($p > 0.05$) prediction variables were removed. The response variable was the average DBH of each plot. Greening rate and impervious rate were significantly correlated, which means there is multicollinearity between greening rate and impervious rate. Then we removed greening rate and kept impervious rate according to the high p value of impervious rate. Five prediction variables were chosen for further analysis according to linear regression model (Table 1). We implemented an all-subsets regression with the five prediction variables to select the best subset of predictor variables. We used the regsubsets() function from the leaps package (Lumley, 2017**)** in R, the model with the highest predictive power was chosen according to adjusted R^2 (Schwarz, 1978). After the best subset of prediction variables was identified, variation partitioning analysis was used to identify the relative variations in average DBH in relation to these prediction variables.

Table 1
Five prediction variables were chosen for further analysis

Variable	**Definition**
Land cover rate	green surface rate, wasteland rate, water body rate, **impervious surface rate**
Landscape indices	NP, Patch number **PD**, Patch density, Indicates spatial heterogeneity SHEI, Shannon's Evenness Index, Indicates even degree of different landscape types LSI, Landscape shape index, A basic and straightforward measure of overall shape complexity. Superior to PARA and PAFRAC, LSI solves the problems of patch size influence by adjusting for a square standard CONTAG, Contagion Index, Expresses the agglomeration degree among different landscape types
Soil qualities	water content, organic matter, total nitrogen content, available potassium, available phosphorus
Maintenance frequency	the sum of trimming, weeding, pesticide, fertilization and watering frequency each year
UFU types	farmland, institutional, transportation, utility, commercial apartments, factory, commercial area, park, urban village, vacant, woodland
Construction age	2017 minus the year the UFU constructed

3 Results:

3.1 Tree DBH classes of urban green space in Zhanjiang

We recorded 12,434 individuals within Zhanjiang's urban green space, belonging to 185 species, 137 genera, and 51 families. Of the tree DBH classes measured, 5–15 cm DBHs dominated UGSs with 5346 (43.72%) individuals, while large trees with DBHs ≥ 75 cm accounted for 67 (0.54%) of the total individuals sampled (Fig. 2). The DBH of 33 individuals exceeded 90 cm, 20 of which were *Ficus* species: *F. altissima*, *F. benjamina*, *F. elastica*, *F. macrocarpa* and *F. virens*. The remaining 13 individuals exceeding 90 cm were *Antiaris toxicaria*, *Casuarina equisetifolia*, *Ceiba speciosa*, *Celtis sinensis*, and *Mangifera indica.*

The average tree DBH in commercial areas was 32.29 cm (± 1.74 cm), which was the highest average among all UFUs, whereas the lowest average DBH recorded (7.11 cm ± 0.56 cm) was in woodland areas (Fig. 3). The average tree DBH within commercial areas was significantly higher than within vacant land, farmland, and woodland.

3.2 The drivers of tree DBH within UGS

Tree DBH was significantly positively correlated with imperious surface rate (adjust R^2 = 0.12, P = 2.18e-07), and significantly negatively correlated with green space surface rate (adjust R^2 = 0.12, P = 2.98e-07) according to our linear regression model (LM) (Fig. 5).

Tree DBH was significantly positively associated with the construction age of each UFU. Urban villages typically had older construction ages, whereas commercial apartments, commercial areas, vacant areas, and woodlands typically had younger construction ages (Fig. 6).

According to the results of an all-subset regression, adjusting R^2 values for construction age, UFUs, and patch density resulted in the highest predictive power for tree DBH (Fig. 7).

A variation partitioning analysis (Fig. 8) showed that, impervious surface rate had the highest explanatory power, accounting for about 5.68%, while construction age accounted for about 5.14%. At 1.58%, the explanation power of PD was the lowest.

4. Discussion

4.1 DBH size

The DBH pattern observed within the UGS of Zhanjiang was an inverted "J" type, wherein the dominant urban trees were young. In accordance with studies from a few decades ago, we found that most urban trees were relatively small in size and had DBHs smaller than 15.24 cm (Dorney et al., 1984; Nowak, 1993; Nowak, 1994; McGarigal & Cushman, 2002). Similarly, Dorney et al. (1984) recorded that 67% of urban trees had DBHs ≤ 15.24 cm in Shorewood, Wisconsin. The dominance of trees with DBHs typically ≤ 28.67 cm indicates that the majority of trees within UGSs are relatively young, and may have been planted within the last decade or so (Muthulingam & Thangavel, 2012). During this time period, Zhanjiang experienced rapid urbanization. From the view of landscape ecology, urbanization is the process in which the land cover of the landscape changes from natural to manmade (Merlotto et al., 2012), simultaneously, natural vegetation stands are replaced by human vegetation stands. As time passes in a natural community dominated by young trees, the community is actively renewed and approaches its climax due to low external interference. Urban habitats, however, are usually subject to drought, inadequate soil volumes, environmental pollutants, and warmer temperatures (Guo et al., 2015; Mullaney et al., 2015), which can all amount to poor performance and hastened death of individuals comprising urban communities. High urban tree stress and mortality would prevent most individuals from reaching large DBHs, older trees would instead be periodically replaced by younger ones.

The mean DBH was lowest within woodlands and highest within commercial areas – this may be attributed to the planting of Eucalyptus within woodlands for commercial purposes. Eucalyptus trees are not natural vegetation, and are cut down every 4–10 years to harvest their wood. Due to this frequent interference, it is not surprising that DBH was lowest within woodlands. Commercial areas are located within the city center, and have thus experienced urbanization for long periods of time. Similar to Macau, China, most of Zhanjiang's older trees are located in the oldest and most densely built-up areas of the city (Zhang et al., 2017). To protect these older, larger trees, China published a Regulation on the Protection and Management of Ancient and Famous Trees in 2001. Therefore, larger trees have remained within commercial areas for a long time as a result of human protection. The large amounts of impervious areas within commercial areas, however, means thatfew new trees are planted. Overall, the few large trees remaining in commercial areas, and the rare occurrence of smaller trees, has contributed to the large mean DBH observed. Again, our results confirm that anthropogenic variables are important drivers of species diversity patterns of older, larger trees (Lindenmayer & Laurance, 2017; Zhang et al., 2017).

Of 33 individuals with a DBH ≥ 90 cm, 22 were *Ficus* species. *Ficus* species have been widely planted in south China cities due to their reasonably good growth despite environmental stresses (Jim & Liu, 2001). As in Guangzhou and Hongkong, the largest trees in Zhanjiang were *F. microcarpamacrocarpa*, which became popular across Southern China long ago for the shade offered by its thick canopy cover. *F. macrocarpa* is also highly tolerant of chronic urban environmental stresses, allowing it to recover well after damage (Adetona et al., 2013) and, in some cases, live for over 500 years (Taylor et al., 1997).

4.2 The different effects of greening surface and impervious surface on urban tree DBH

Contrary to expectation, urban tree DBH was significantly positively associated with impervious surface rate and significantly negatively associated with greening area rate. Our results indicate that large trees were usually found growing where there was high impervious surface, such as within urban villages and commercial areas. The largest tree in our investigation was located in urban village. Long-settled regions support more old trees mainly due to the positive effects of human management activities (Liu et al., 2019). Small trees, on the other hand, were usually found growing within parks and woodlands, which are some of the largest green space surfaces in Zhanjiang. As mentioned previously, during urbanization, some older, larger trees were protected by the government, so they were maintained over time rather than being removed. Newer, younger trees were increasingly planted in parks as people recognized the important ecological services of urban trees.

Impervious surfaces are generally poor areas for tree growth; trees surrounded by impervious surfaces have much shorter life expectancies than trees grown in parks or natural areas (Watson et al., 2014), and they tend to be more water-stressed due to higher temperatures, less soil moisture availability, and increased transpiration - these conditions and their combined effects can reduce overall tree growth and health (Cregg & Dix, 2001). Furthermore, impervious surface reduces the potential for future natural regeneration (Nowak & Greenfield, 2020). Therefore, maintaining an appropriate impervious surface relative to green space surface is important for preserving urban trees.

4.3 Construction age and patch density

Typically, the DBH of urban trees is significantly affected by the construction age of green space, as humans allocate more resources towards greening measures, such as tree planting. Our results, however, indicate that the construction age of a UFU did not strongly affect the DBH. While new trees may be planted regularly as construction age increases (e.g., for aesthetic value or other ecosystem services), trees do not reach the full capacity of their natural lifespan due to environmental stress. Similar to urban tree cover, urban tree DBH is constantly changing as a consequence of many natural (e.g., regeneration, growth, storms) and anthropogenic (e.g., development, planting, tree removal) forces (Nowak & Greenfield, 2020). Therefore, tree planting may have no lasting impact on the average DBH observed within a UFU when there are other natural and anthropogenic forces at play.

PD is considered an indicator of landscape configuration (Chen et al., 2020) and fragmentation. In our research, we found that greater PD was associated with greater average DBH. Large trees do not necessarily need large areas to grow, as suitable habitats such as abundant water and nutrients, lower pollution are more important. Older UFUs within Zhanjiang registered higher values of PD, and tended to have more green space patches overall – although these were usually small and highly fragmented (Cheng et al., 2020). Habitat fragmentation resulting from urbanization separates and reduces the available space for tree species, thus, the survival of species that require larger growing spaces becomes less likely (Jian-feng et al., 2005). In the future, cities should consider allocating green spaces of various sizes to better aid the growth of natural species, such as native species *Ficus* species always needed large space as they have a lot of aerial roots to support the big thick crown.

5. Conclusion

The construction age, impervious surface rate, and patch density of UFUs are important habitat elements for urban trees, and are significantly correlated with urban tree DBH. The adjusted R^2 values of all three factors were low, however, indicating that DBH may be strongly influenced by several additional factors, both biotic and abiotic, at multiple scales in the urban environment. Further research is needed to identify these factors. The compact development mode may not always militate against the nurturing and preservation of large urban trees; as long as some suitable niches are left by design in the built-up matrix, whether meritorious trees can fill such sites is contingent upon human activities. The results of this study can aid management and policies related to urban trees, specifically the appropriate abundance of DBG classes, in addition to facilitating discussions regarding improvement to urban forest structure.

Declarations

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Author Contributions:

Dr Xia-Lan Cheng: Formal analysis (Lead); Investigation (Lead); Methodology (Lead); Resources (Lead); Software (Lead); Writing-original draft (Lead); Writing-review & editing (Equal). **Mr Mir Muhammad Nizamani:** Formal analysis (Equal); Writing-original draft (Equal). **Miss Kelly Balfour:** Writing-review & editing (Equal). **Dr Salman Qureshi:** Funding acquisition (Equal); Writing-review & editing (Equal). **Dr Shuang Liu:** Visualization (Equal). **Dr Zhi-Xin Zhu:** Writing-review & editing (Equal). **Dr Si-Si Wu:** Visualization (Equal). **Dr Hua-Feng Wang**: Conceptualization (Lead); Data curation (Lead); Funding acquisition (Lead); Project administration (Lead); Resources (Equal); Supervision (Lead); Validation (Lead); Writing-review & editing (Equal).

Data availability statement:

All of the data used in this paper are included as Supplementary Data.

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Figures

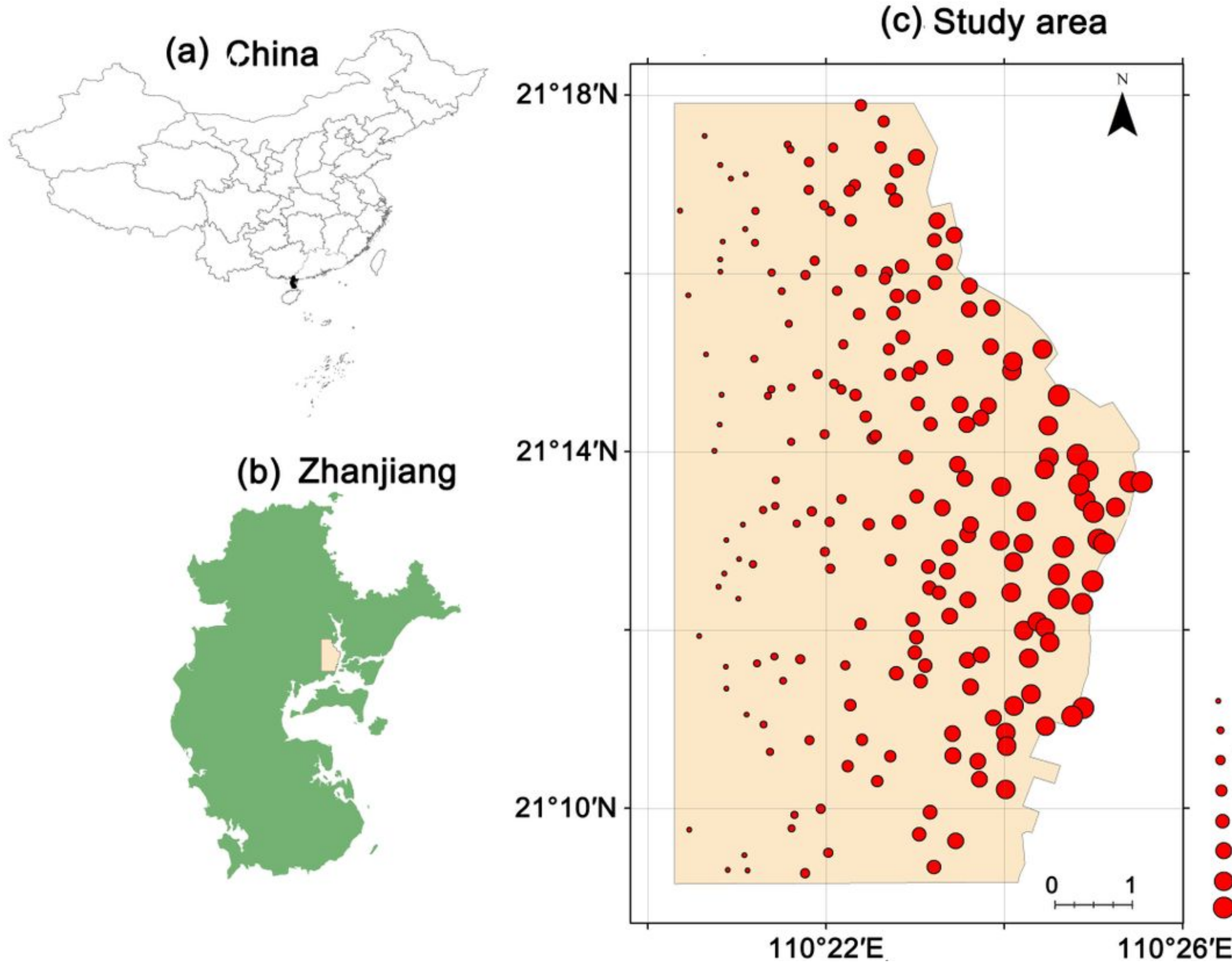

Figure 1

A map of China where a black spot (a) indicates the location of Zhanjiang (b), and a yellow shaded section (b) indicates the location of our study area. Red spots within our study area (c) indicate the locations of our sampling plots, where the size of each red spot reflects the average DBH recorded. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

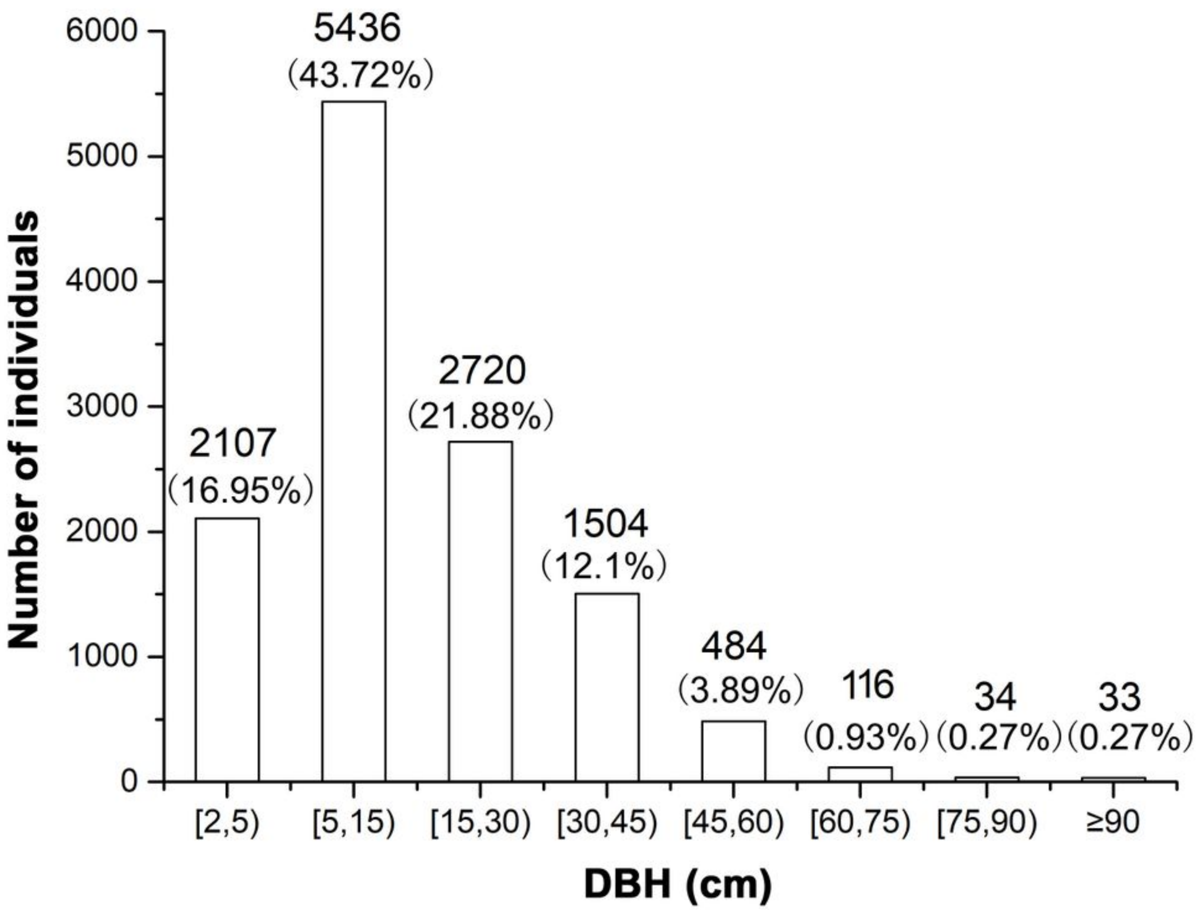

Figure 2

The distribution of individual trees sampled within Zhanjiang with DBHs ranging between 2 cm and exceeding 90 cm.

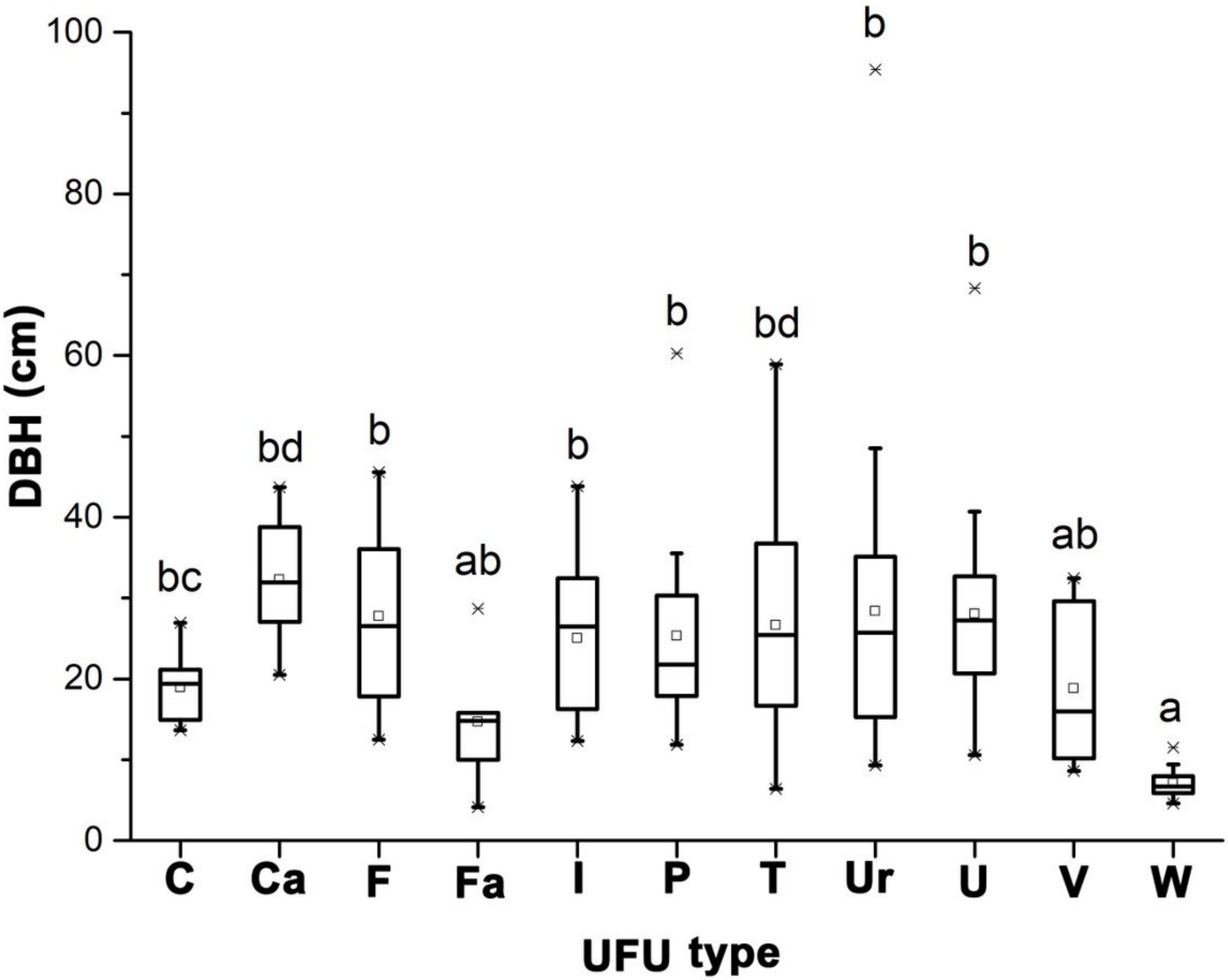

Figure 3

The distribution of DBH measurements according to each UFU type. C: Commercial area; Ca: Commercial apartments; F: Factory; Fa: Farmland; I: Institutional; P: Park; T: Transportation; Ur: Urban Village; U: Utility; V: Vacant; W: Woodland.

Figure 4

Images of the green spaces of Zhanjiang: (a) A commercial apartment (Baoliyuanjing Garden); (b) A woodland with small DBH Eucalyptus species; (c-d) An urban village with old large trees and large impervious surface (c is Wenbao Village d is Nanliu Village).

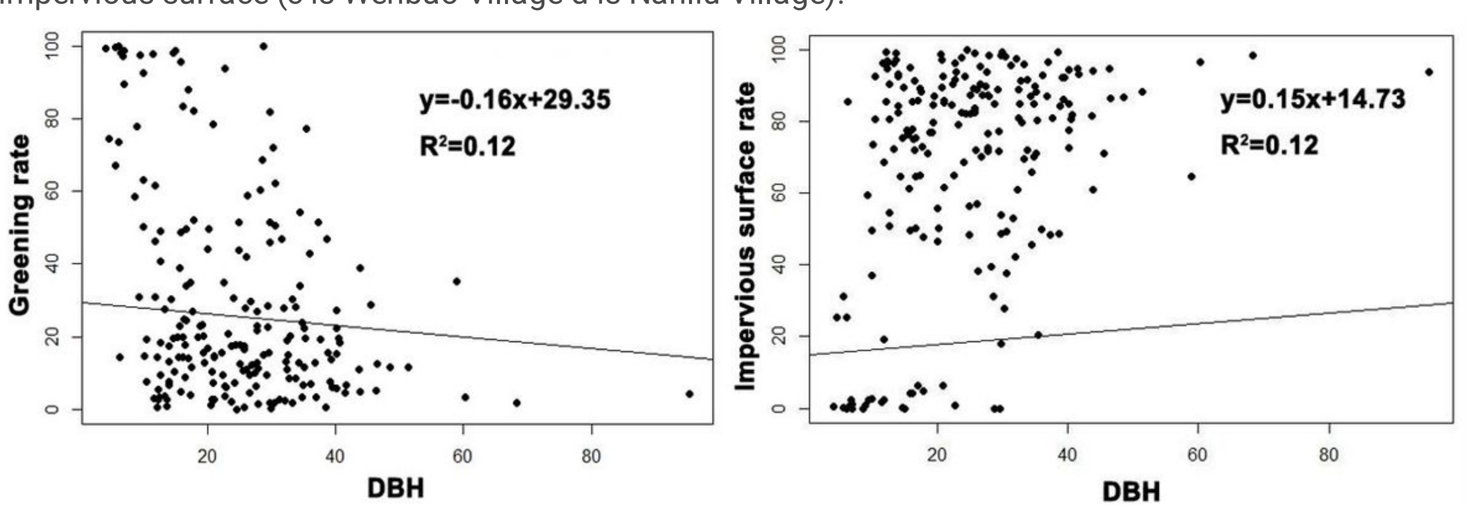

Figure 5

Results of a linear regression model comparing DBH to a) greening rate and b) impervious surface rate.

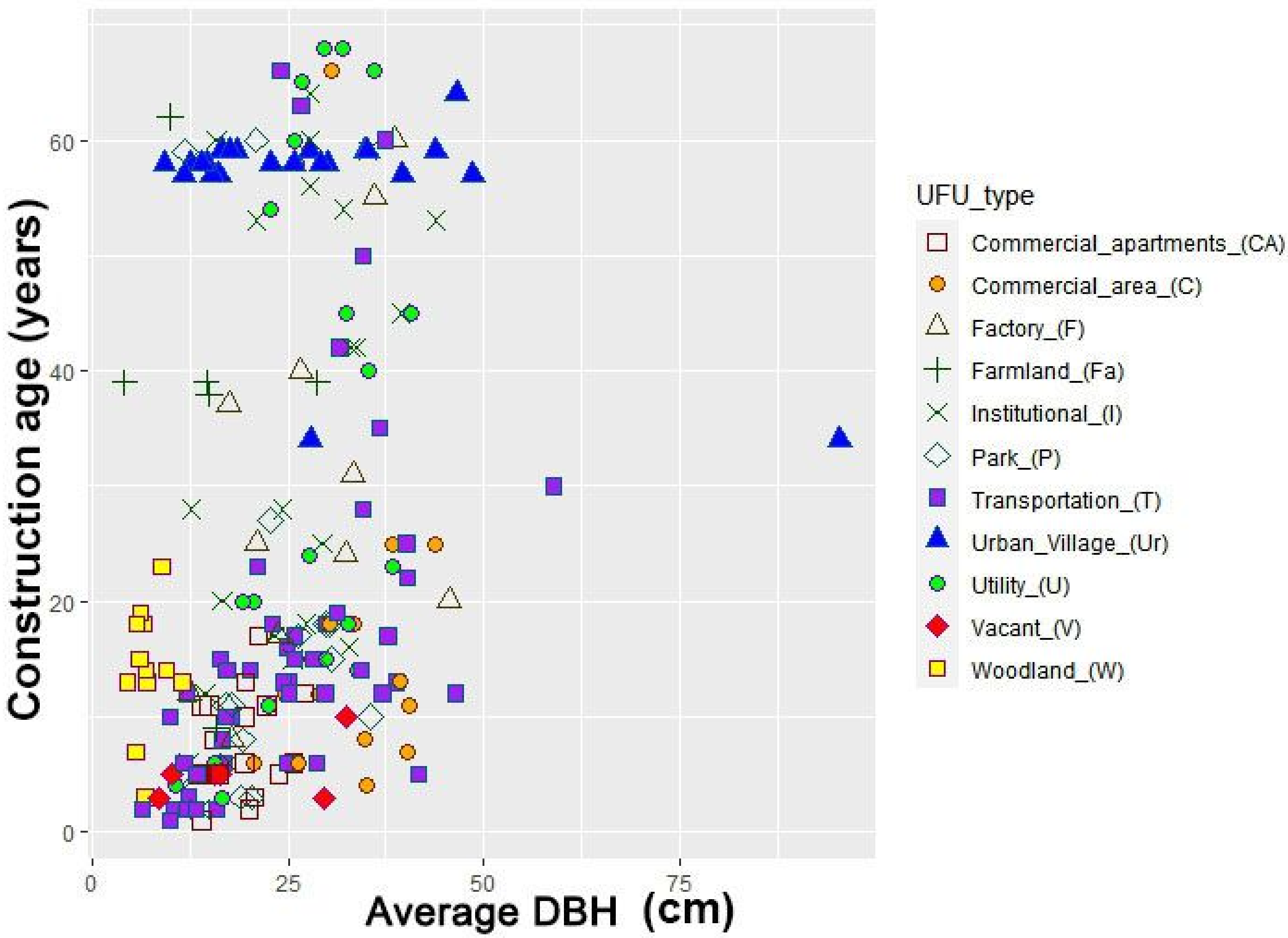

Figure 6

A scatterplot comparing the construction age and average DBH according to UFU type.

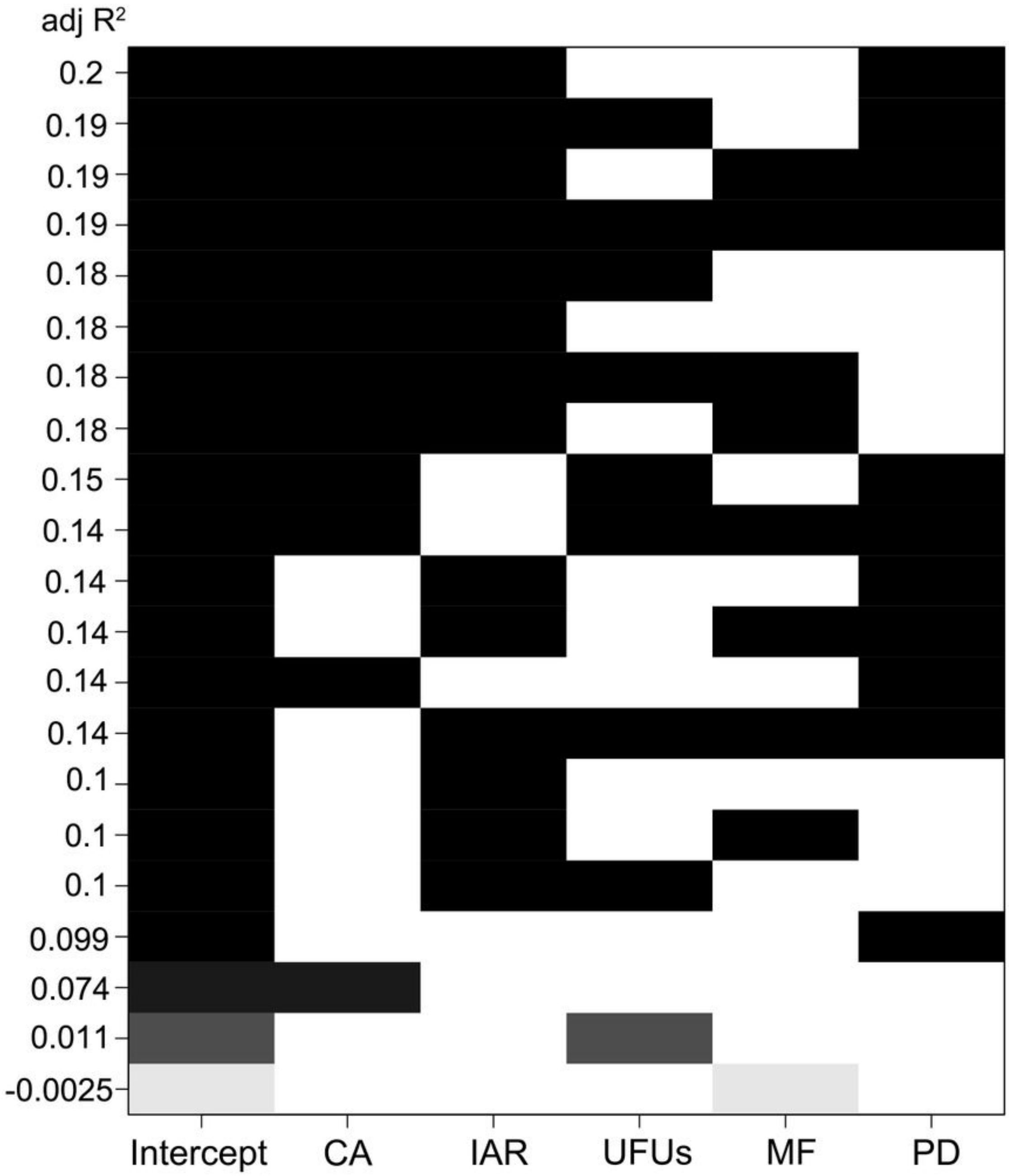

Figure 7

All possible subset regression models for tree DBH, the best was the one with the highest adjusted R2 (adjusted R2 = 0.2). CA: construction age; IAR: impervious surface rate; UFUs: Urban function units; MF: maintenance frequency each year; PD: patch density.

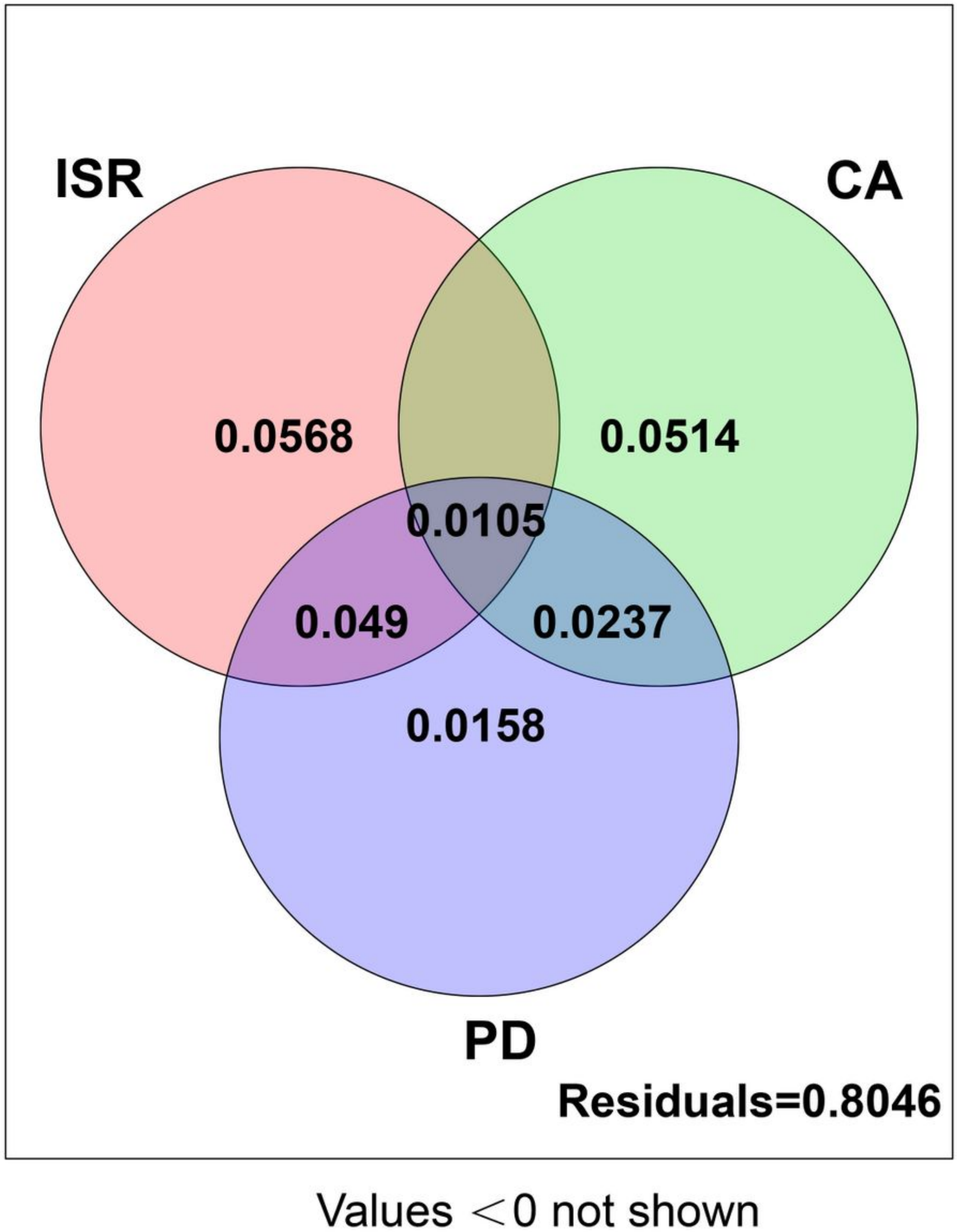

Figure 8

Results of a variation partitioning analysis. ISR: Impervious surface rate; CA: Construction age; PD: Patch density.