The Variation of Air Purification Benefit Provided by Street Tree Assemblages in Shenyang, China

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Abstract

Background: Street trees assemblage is a widespread natural component in the cities and provides a wide range of ecosystem services to the cities. However, the distribution of street trees assemblage within a city is inequal. In this paper, we took air purification benefit provided by street trees for example to examine how urban form, urban geography and drivers of vegetation management affect the variation of ecosystem services provided by street trees in metropolitan Shenyang, Northeastern China. The i-Tree Street (2018) was utilizing to evaluate air purification benefit provided by street trees.

Results: We analyze the results using 2 indices: per kilometer benefit and average tree benefit. The results showed us that (1) both indices didn't vary along the population gradient. (2) The per kilometer benefit had a decreasing trend along the urban-suburban gradient. (3) The districts which had the highest per kilometer benefit and average tree benefit are neither the old ones nor the newest one, but the districts start to develop from around 2002 and 2003.

Conclusions: We infer that the public policy is a main driver of vegetation management, especially for street trees, because street tree is closely related to road/street development which is closely related to economic development of a region. Besides, there could be a time lag effect for ecosystem services provided by trees.

1 Introduction

Urban ecosystem is different from other natural ecosystems (e.g., river ecosystem, forest ecosystem, wetland ecosystem et.). It is an ecosystem consisting of natural and social-economic components, while predominated by one species, human being. Therefore, it is a severely impaired ecosystem deemed to be a trashed or damaged habitat by bio-ecologist. Even so, some bio-ecologist point out that it is more likely to be fixed if it can "localization" or "regional self-reliance" by properly introducing natural components which provide cities ecosystem services (Wu 2014). According to the study of Stockholm by (Per Bolund and Hunhammar 1999), there are seven types of locally natural components and street tree is listed as the first one (the other six are lawns and parks, urban forests, cultivated land, wetlands, lakes and sea, and streams).

Street trees assemblage is the foundational natural component in the city because street trees would be everywhere provided there is a road or street et. (Berland and Hopton 2014). Although it just accounts for a relatively small fraction of the entire urban natural components, it provides prominent ecosystem services for urban habitants (Mullaney et al. 2015, McPherson et al. 2016). Street trees can improve urban dwelling environment not only by environmental beautification and ornamentation (Silvera Seamans 2013), but also by air purification, stormwater reduction, energy conservation, noise reduction, carbon storage, shade providing and so on (Silvera Seamans 2013, Mullaney et al. 2015).

However, the distribution of street trees assemblage within a city is inequal and in most cases, is affected by social-economic development more than any other factors such as natural ones (Pham et al. 2017), except for some cases where physical geography is various (Lowry et al. 2011, Berland et al. 2015). In generally, the factors related to social-economic development can be divided into 3 categories: urban form (e.g., population density and urban morphology), urban geography (e.g., urban sprawl), and drivers of vegetation management (e.g., public policies, life style). According to the population density theory, the higher population density will lead to less physical space available for vegetation. Some researchers find negative relationship between population density and vegetation cover (Mennis 2006, Conway and Hackworth 2007, Troy et al. 2007, Luck et al. 2009). But recently, Bigsby et al. (2013) finds that there is a paradox in the result between Baltimore and Raleigh. (Pham et al. 2017) also found that there is a negative relationship between tree cover and population density, but a positive one between street tree cover and population density. That is probably some new situation coming out along with social-economic development. There is a need of more researches about the relationship between vegetation cover and population density to renew the population density theory. Nevertheless, we still concern about the relationship between vegetation cover as well as its associating benefit and population density when we explore the distribution characters of vegetation cover, especially when we focus on the ecosystem services provided by vegetation, because we want to know whether the demand of people is satisfied.

The distribution of urban natural component is also reported to be affected by spatiotemporal urban variation (Howe et al. 2017, Malkinson et al. 2018, Xing et al. 2018). In generally, because the urban core area is more affected by human disturbance than suburban area, the natural characteristics of the natural component in urban core area is more severely disturbed than in suburban area (Ren et al. 2012, Ossola and Hopton 2018). Concerning to the relationship between urban geography and urban green space, the degree of fragmentation of green space is increasing along with urban-suburban gradient (Shrestha et al. 2012, Inostroza et al. 2013, Malkinson et al. 2018), and the area of urban green space shows a decreasing trend with urbanization (Berland 2012). However, Berland and Hopton (2014) found that the street tree assemblage doesn't significantly change along with urban-suburban gradient. He inferred that the management practices are relatively more important drivers of street tree characteristics than urban form.

As a natural component in cities where dominated by human, urban trees would be affected by policies made by human. However, how policies affect either urbanization or urban trees remains an issue to be explored (Wu 2014). Some researches found that policies would promote urban tree canopy cover increasing (Berland and Hopton 2014, Krafft and Fryd 2016). While Galenieks (2017) in their research about the comparison between city Loma Linda and Redlands, California suggested that policies are not always leading to positive effects on urban trees if the commitments to preservation and to practice management principles are not fulfilled. Hill et al. (2010) found some policies would effectively help to improve the status of urban trees and others not, even though all of them are initiated to improve trees conservation and planning. More researches on urban forest management and relation between urban forest benefits and existing policies (e.g. city planning policy, climate change adaptation, energy policy) are needed in the future (Krajter Ostoić and Konijnendijk van den Bosch 2015).

In this paper, we examined air purification ecosystem service which provided by street tree assemblage at the subdistrict scale, and explore its relationship with population density, urban sprawl and public policy respectively, to address the three following questions: (1) how does air purification benefit vary across the city at the subdistrict scale? (2) Whether the benefit of street tree assemblage varies along with the population density and urban-suburban gradients? (3) Does the public policy have a positive effect on the street tree benefit? From these questions, we intent to improve our understanding about the characteristics of street tree benefit distribution within a city and how urban form and urban geography influence the urban ecosystem services distribution, as well as how human modify urban natural component, thus urban ecosystem services, by public policy system.

2 Study Area And Methods

2.1 Study area

We carried out this study in metropolitan Shenyang, Liaoning Province, northeast China (41^{o}11'51" ~ 43^{o}02'13"N,122^{o}25'09" ~ 123^{o}48'24"E, Fig. 1A). Shenyang city is a capital city of Liaoning province and had an estimated 2017 population of 5,864,912 people (Chinese Census Bureau, 2017). The urban built-up area of Shenyang is within the third beltway and about 758.6 km^2. Shenyang is an inland city with an average altitude of 51 meter, belonging to the temperate semi-humid continental climate zone. Its average annual temperature and annual precipitation are 8.6℃ and 721.9 millimeter respectively. There are 7 districts and 76 subdistricts within the third beltway of Shenyang city (Fig. 1B).

2.2 Methods

Field data collection and modelling

We obtained road data, including data on highways and smaller streets, from Google Maps, using ArcGIS 9.3. Field data were collected from June to September 2017. Six percent of all street segments were included during data collection for each sub-district, in accordance with the *I-Tree Street User Manual*, which requires that sample inventories include 3–6% of all street segments to achieve a standard error of ~ 10%. Street segments were randomly selected from the road data set from each sub-district. For each tree, the main attributes we collected were DBH (diameter at breast height), crown size, health condition, LandUse and LocSite which were asked for i-tree street to assess air purification.

Modelling air purification

The i-Tree Streets Model (i-Tree, 2018) was used to assess air purification benefits in metropolitan Shenyang. We first used the method proposed by McPherson (2010) to select the best city match, i.e. to pick a “best fit” climate zone for this Asian city. The best match city for Shenyang was Queens, New York, so the “US northeast climate zone” was chosen for the modelling. To exam the effects of population density, city sprawl (urban-suburban gradient) and district development plans, i.e. government policy on the distribution of air purification ecosystem services provided by street tree assemblages, we regrouped the field data of sub-districts in 3 ways: (1) by population density (districts with population density > 10,000 persons/km^2 were grouped as P1, districts with 1,000–10,000 persons/km^2 were assigned to P2, and districts with < 1,000 persons/km^2 were placed in group P3), (2) by beltways (sub-districts within the first beltway were grouped as B1, sub-districts between the first and the second beltway were assigned to B2, and the sub-districts between the second and the third beltway were places in B3 (Figs. 1B and 1C), (3) by districts (the districts named HG, HP, S, T, Y, HN and D respectively). We got 13 groups in total. We then ran the i-Tree Street Model on each group of field data, individually and got average tree benefit of air purification (ATB, $/tree) and total benefit of air purification for each group.

Statistical analysis

The index used in this paper are per kilometer benefit (PKB, $/km) and average tree benefit (ATB, $/tree), which indicate the ability of street trees assemblage and individual street tree for ecosystem services provision in a specified area respectively. We used PKB instead of the whole ecosystem services value of a specified area, because the lengths of different areas are various and the PKB would be more comparable.

First, we utilized Grouping Analysis (spatial constraints setting is NO_SPATIAL_CONSTRAINT, and distance method is EUCLIDEAN) in ARCGIS to categorize the subdistricts for the value of PKB and ATB into 3 categories respectively. Second, we categorized the subdistricts according to the factors we assumed to have effects on the distribution of ecosystem services provided by street trees assemblage (population density, city sprawl and public policy) and do the statistical analysis in Excel.

3 Results

3.1 General analysis

The distribution of the result of cluster analysis for PKB (Fig. 2 A) showed that there is a decreasing trend from northwest to southeast. While for ATB, there is no apparent trend (Fig. 2 B).

3.2 Analysis along population gradient and urban-suburban gradient

The per kilometer and average tree air purification benefit of P1, P2 and P3 were USD 1049.75 and 5.51, 1336.56 and 7.19, and 770.08 and 4.98 respectively (Fig. 3A). P2 had the highest air purification benefit both for per kilometer and average tree, but not the lowest population density. While the lowest population density group P3 had the lowest PKB and ATB. The highest population density group P1 had a medium value of PKB and ATB. The result is contrary to the population density theory. Also, there is no a decreasing or increasing trend along with population density gradient.

The per kilometer of air purification benefit and average tree of air purification benefit showed opposite trends along the urban-suburban gradient (Fig. 3B). The PKB of B1, B2 and B3 are USD 1310.56, 1183.94

and 985.00 respectively, showing a decreasing trend along the urban-suburban gradient. While the ATB of B1, B2 and B3 are USD 5.75, 6.07 and 6.13 respectively, increasing along the urban-suburban gradient.

3.3 Analysis among districts

District T and D had the highest PKB over USD 1300 among the 7 districts (USD 1374.32 and 1318.53 respectively, Fig. 3C). These two districts both are new industrial area. T is used to be a heavy industrial area. Industrial transfer and urban renewal was taken place from 2002. District D is identified by the government as a new industrial area for modern manufacturing industry, service industry and real estate industry from 2003. District Y and HG had the medium PKB over USD 1100 among the 7 districts (USD 1121.84 and 1116.48 respectively, Fig. 3C). District Y is a new district starting to develop modern agriculture and other new industries from 2010. While district HG is the third old district in Shenyang and known to be the education centre of Shenyang. The two oldest districts S and HP which are political, economic, cultural and education centers had the values of PKB lower than USD 1000 (USD 849.26 and 975.76 respectively, Fig. 3C). District HN which is the newest one among the study districts and was set up in 2014 had the lowest PKB among the districts (USD 585.03, Fig. 3C). The ATB of 7 districts keep a similar pattern with PKB (Fig. 3C).

4 Discussion

4.1 street tree air purification benefit and population density

Our result doesn't support the population density theory, and is also different from results found by Bigsby et al. (2013) and Pham et al. (2017), who found increasing trend of street tree cover along increasing population density gradient. In our result, there isn't certain trend of street tree air purification benefit along population density gradient. The highest benefit is neither in the area of the highest population density nor in the area of the lowest population density, but in the area of medium population density. While the lowest benefit is company with lowest population density. Luck et al. (2009) also found that the highest trees cover is in the mid-population density area. But they found the cover at the lowest population density is higher than cover at the highest density. The population density theory is not supported any longer in some cases, because the relationship between population distribution and green space is more complicated under new situation, such as the improvement of ecological consciousness which induced more investment on the green space construction in old town where population density is high (Harrington and Hsu 2018), the different characteristics of different city natural component (Per Bolund and Hunhammar 1999), and so on. The change of original green space in the city might be explained by the population density theory (Ren et al. 2012), while the artificially introduced ones would be explained by other factors (Pham et al. 2017). In theory, the area of lowest population density would have more space available for trees. However, in our case, low population density also relates to low economic development. We infer that is the main reason for the low street tree benefit in the low population density, because street tree assemblage is different from other conserved green space such as a park which is based on the original green space. Street tree assemblage is a natural element introduced totally artificially, and related to the development of street/road which is also closely related to economic development. Therefore, street tree assemblage development is dependent on the investment by the government for the construction of streets/roads and their related infrastructure.

4.2 street tree air purification benefit and urban geography

In most cases, along with the urban-suburban gradient, trees/green space is increasing (Berland 2012, Ren et al. 2012, Malkinson et al. 2018), but in our case, the PKB which indicates ability for providing air purification benefit by street trees of a specified area showed a decreasing trend. Berland and Hopton (2014) also found that street tree assemblage doesn't show an increasing trend. Actually, they even didn't find a decreasing trend along the urban-suburban gradient. They found the peak of stormwater interception benefit provided by street tree assemblage is in the inner-ring suburban area and the lowest one shows in the outer-ring suburban area. They thought the temporally lagged growth of the newly planted trees in the outer-ring suburban is the main reason for that. However, it isn't true in our case. The ATB which indicate the average ability for providing air purification of a tree showed an increasing trend along the urban-suburban gradient. That implies there are more big/old trees in the outer-ring suburban area than in the old town. The main reason for our case might be that there are more trees in the old towns than in the outer-ring suburban area (the amounts of street trees for per kilometer in B1, B2 and B3 are 228 trees/km, 194 trees/km and 160 trees/km respectively). That also probably reflects the fact that the investment of street trees planting in the old town is more than the outer-ring suburban area.

4.3 street tree air purification benefit and public policy

Public policy probably is a main driver of vegetation management.

Irga et al. (2017) in their research pointed out that policy could encourage green infrastructure installation in Australia. Harrington and Hsu (2018) also showed that policy would take the lead role in driving green infrastructure installation in US. Our results also support this statement. Shenyang start to redevelop old industrial area (district T) and develop new industrial in the selected areas (district D and Y) from 2002. The city planning of the old industrial area and new industrial areas at that time would aim to improve the environment and redevelop the old industrial areas as livable areas to attract more citizen to move in. Green infrastructure construction is an important mean to achieve the redevelopment target, therefore, the government would take political and economic action to promote the green infrastructure construction in these areas. As Hopkins et al. (2018) said, integrating green infrastructure into control plans by policy means is an important method to improve green infrastructure installation. It reflects that government plays a key role in promoting green infrastructure installation and improve ecosystem services in city. In another word, if the government has done nothing in green infrastructure construction, such as taking action to improve it, or preventing it from being occupied by building or something else, the green space in the city would substantially degrade and shrink (McWilliam et al. 2015).

Also, we should notice there is a time leg effect of public policy on development of green infrastructure because of trees needing time to grow up. The highest benefit values were found in district T and D,which were starting to redevelop in 2002 and 2003 respectively. The benefit value of district Y (starts to develop in 2010) were found around the average value (USD 1048.75 for PKB) of the 7 districts. The newest district HN which was set up in 2014 had the lowest value under the average value. But we noticed that the ATB of HN is not as low as its PKB among the 7 districts (Fig. 3C). That give us a caveat that when planting new trees in a developing area, the most important thing is preserving the high-quality heritage tree (in generally, the tree with DBH over 20cm should be preserved. That would be a good foundation to construct street tree landscape with rich layers, walkable pedestrians and livable environment for residents.

5 Conclusions

The distribution of street tree assemblage and its associated air purification benefit can't be explained by population density theory and don't vary along the urban-suburban gradient. That is probably due to the social characteristic of street trees. Street trees' installation is closely related to roads/streets' construction, and roads/streets' development is closely related to economic development. Therefore, where the government invests more for economic development and streets/roads, and promote more people to settle down, there would be more street trees and the associated air purification benefit. From the ecosystem services perspective, it is a good phenomenon that where there are more people, there is more ecosystem services. However, street tree assemblage is just one of the natural components in cities, we need further researches to illuminate the distribution patterns and the affected factors of other natural components and their associated ecosystem services in cities respectively, then we can modify and promote green infrastructure installation to meet the need of city dwellers.

Public policy is a main driver of street trees planting and government take lead role in promoting street trees installation. Therefore, it is important for city sustainable development that public policy maker conceive eco-consciousness when they are making decision and the environmental decision-making ability of a government should be strengthened.

Public policy would have a time leg effect on ecosystem services provided by street trees for trees needing time to grow up. High-quality heritage trees should be preserved during area redevelopment and city sprawl.

List Of Abbreviations

P1: districts with population density > 10,000 persons/km^2 were grouped as P1

P2: districts with 1,000-10,000 persons/km^2 were assigned to P2

P3: districts with < 1,000 persons/km^2 were placed in group P3

B1: sub-districts within the first beltway were grouped as B1

B2: sub-districts between the first and the second beltway were assigned to B2

B3: sub-districts between the second and the third beltway were places in B3

HG, HP, S, T, Y, HN and D are names for seven districts in our study respectively

PKB: per kilometer benefit for street tree assemblage of air purification

ATB: average tree benefit of air purification

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Yes

Availability of data and materials

We will share the data if the manuscript is accepted. And we will provide the data if the reviewer requires.

Competing interests

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled.

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Authors' contributions

Jing Yao, conceived and wrote the manuscript

Wei Chen and Miao Liu, main contributors of manuscript conceiving.

Xiaobo Wang, partial funding supported;

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Figures

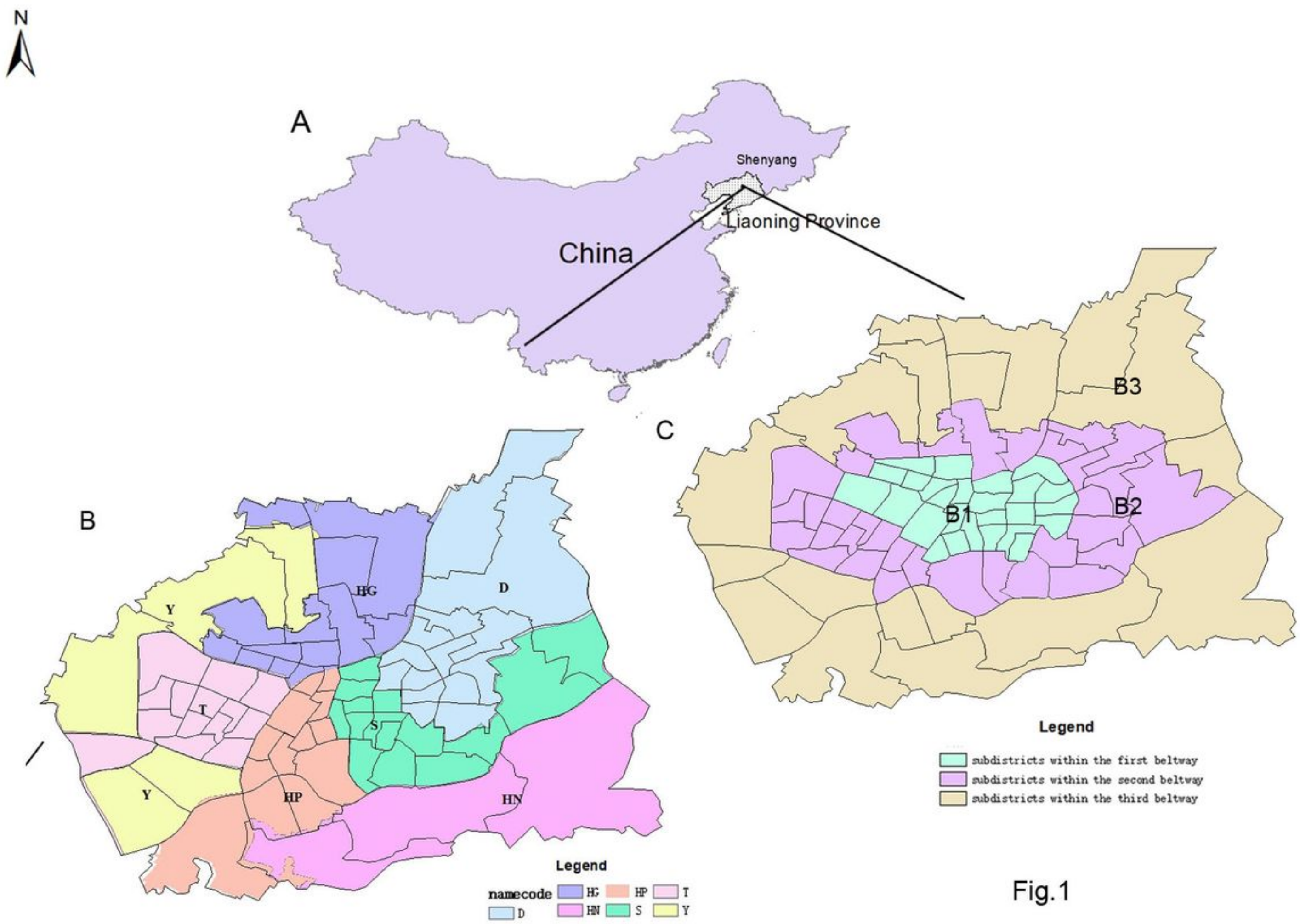

Figure 1

(A) Location of Shenyang in China; (B) Distribution of 7 districts and 76 subdistricts within the third beltway of Shenyang; (C) Distribution of 76 subdistricts and the three beltways of Shenyang. 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.

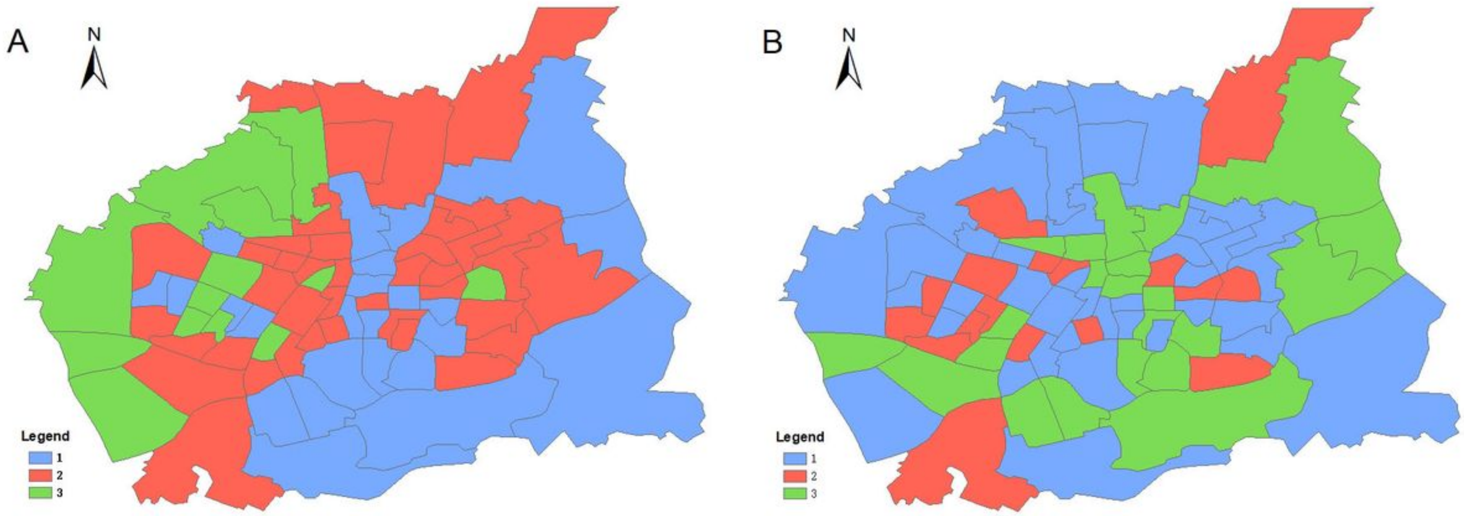

Fig. 2

Figure 2

Distribution of the results of K-means cluster analysis at the subdistrict scale: (A) per kilometer benefit (1- benefit value <1000 $/km, 2- 1000 $/km <benefit value < 2000 $/km, 3- benefit value >2000 $/km) (B) per tree benefit (1- 5$/tree <benefit value < 7.5 $/tree, 2- benefit value >7.5$/tree, 3- benefit value < 5$/tree) 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.

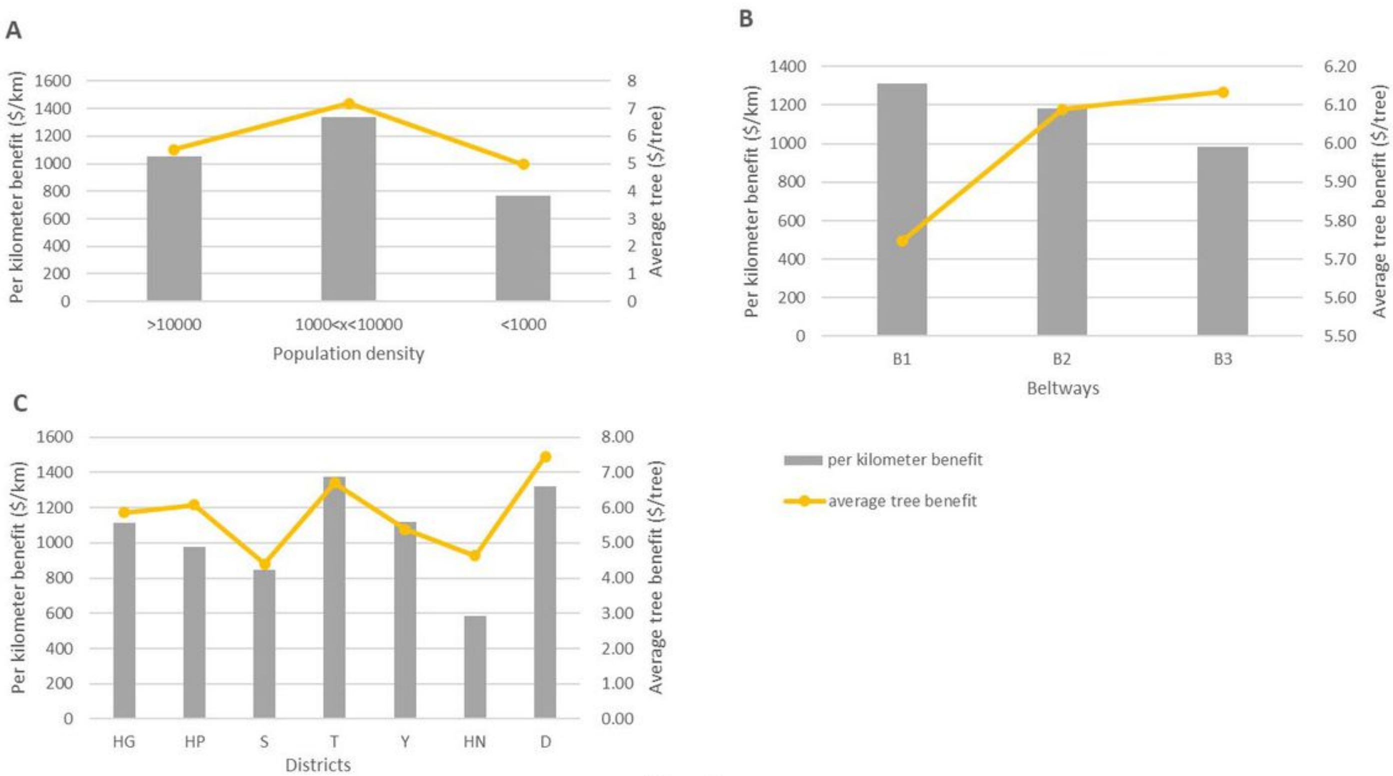

Fig. 3

Figure 3

Comparison of street trees assemblage associating air purification benefit according to (A) population density, (B) urban-suburban gradient, (C) public policy