Analysing the spatial distribution patterns of green infrastructures through network analysis

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Highlights

- Location-based networks of green infrastructures (GIs) are derived and used for clustering.
- The clusters vary in the number and density of GIs and delineate land parcels of various sizes.
- GIs are found to be unevenly distributed across various scales in Brooklyn, New York City, U.S.

Introduction

Green infrastructures (GIs) are small-scale semi-natural practices to manage stormwater runoffs, which are environmentally friendly alternatives to the conventional pipe drainage systems. They are also known as low impact development (LID) practices, sustainable urban drainage systems (SuDS), or water sensitive urban design (WSUD) in different contexts. GIs have been adopted in many cities globally, and their effectiveness in stormwater management has been widely recognized. For instance, more than 11,000 of GIs have been constructed or in construction in New York City, NY, the U.S. as of 2021 (NYC DEP, 2021).

GIs are commonly implemented throughout an urban catchment to provide on-site treatment to stormwater runoffs generated by different parts of a city. Therefore, it is important to analyse the spatial distribution patterns of GIs to better understand the catchment-scale effects of the GIs and the factors that affect the hydrological performances of GIs (Zhang and Chui, 2018). Various point pattern analysis (PPA) methods may be useful for solving these tasks, in which GIs are treated as points and the correlations among the points and between the points and the external environments are analysed. However, these methods commonly do not explicitly account for the combined effects of a group of GIs, and thus may be not suitable for studying GIs' effectiveness at a larger scale (e.g., at city scale), which involves thousands of points. Therefore, this study aims to demonstrate the feasibility of using network analysis methods to link individual GIs and analyse the group effects of GIs. The correlations between two individual GIs can be determined based on their spatial proximity. The structure of the networks allows for easier analysis of GIs' spatial distributions and their group effects at different spatial scales.

Methodology

As GIs are small-scale practices (compared to the scale of a city), it is reasonable to use points to represent GIs in a city-scale map based on their locations. The points can be used to define the nodes (also known as vertices) of a network, and edges (also known as links) can be created by connecting correlated nodes (Luke, 2015). The degree of correlations between two nodes may be measured by the distance between them. The links can be created by only connecting strongly correlated nodes or connecting each pair of nodes while "memorizing" their correlations. The nodes can then be clustered based on their locations in the network. For each cluster, the correlations between the nodes and the network structure can be further analysed to generate useful insights on the roles of each node in the network and how closely the nodes are related. Each cluster can also be used to delineate a land parcel as it contains a group of nodes that each corresponds to a specific location of the map. As the GIs in each parcel are assumed to be affected by similar environmental factors, the properties of the land parcels can be then analysed to understand the spatial distribution patterns of the GIs and the general conditions of the external environments surrounding the GIs of each cluster.

This study applies the network analysis-based methods to study the spatial distribution patterns of the GIs in Brooklyn, New York City, the U.S. There are currently (as of June 2021) 4,763 GIs that have been constructed, in construction, or planned (NYC DEP, 2021). The GIs are treated as nodes, and the links are created between two nodes if their distance is smaller than or equals to 100m. The nodes are clustered simply based on whether they are connected by a network of links, i.e., each connected component is treated as a cluster. The clusters are then used to define land parcels using the 2D Concave Hull Algorithm (Gombin et al., 2020). The number of nodes in each cluster, the area of the resulting land parcels, and the density of the nodes in the land parcels are analysed. The land use of the parcels can then be studied, which is useful for estimating GIs' effectiveness at city scale.

Results and discussion

The spatial locations of the GIs are shown in Figure 1a. It is apparent that they are distributed unevenly across Brooklyn. The distribution of the distance from a GI to the nearest GI is shown in Figure 1b, which confirms that some GIs are very far from the other GIs while some other GIs are very close to each other (note that x-axis is in logarithm scale).

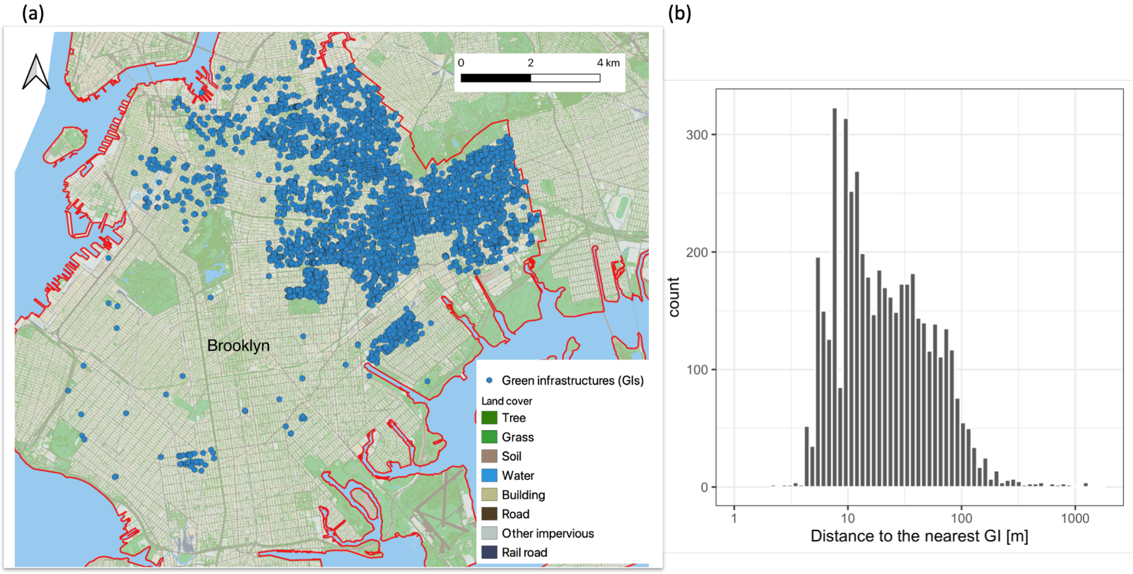

Figure 1. (a) GIs' locations in Brooklyn, New York City, U.S. (b) Distribution of the distance from a GI to the nearest GI.

Figure 2 shows the networks of GIs in a small region of Brooklyn. Several GI clusters (disconnected networks) are shown, and they vary in shape and sizes. Some GIs are not connected to the other GIs, and some other GIs are only connected to one GI. These results suggested that the distributions of the GIs are uneven at a smaller (than city) scale. Created from unevenly distributed GI clusters, land parcels as shown in Figure 2 also have different scales and shapes.

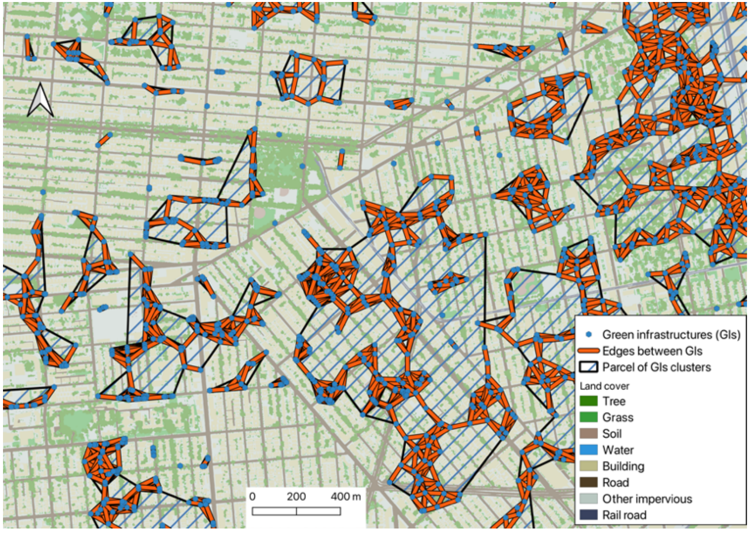

Figure 2. The networks of GIs. Each disconnected network defines a cluster. The corresponding land parcels are also shown.

The number of GIs in the clusters, the area of the resulting land parcels, and the density of GIs in the land parcels are computed, and their distributions are shown in Figure 3. In general, these quantities are found to be distributed unevenly for each cluster (note that x-axis is in logarithm scale). The GIs within a large network may have different hydrological performances to the GIs that are not connected to any other GIs, and the areas with different GI densities are expected to have different on-site treatment efficiencies to stormwater runoffs. Further studies on these topics are recommended.

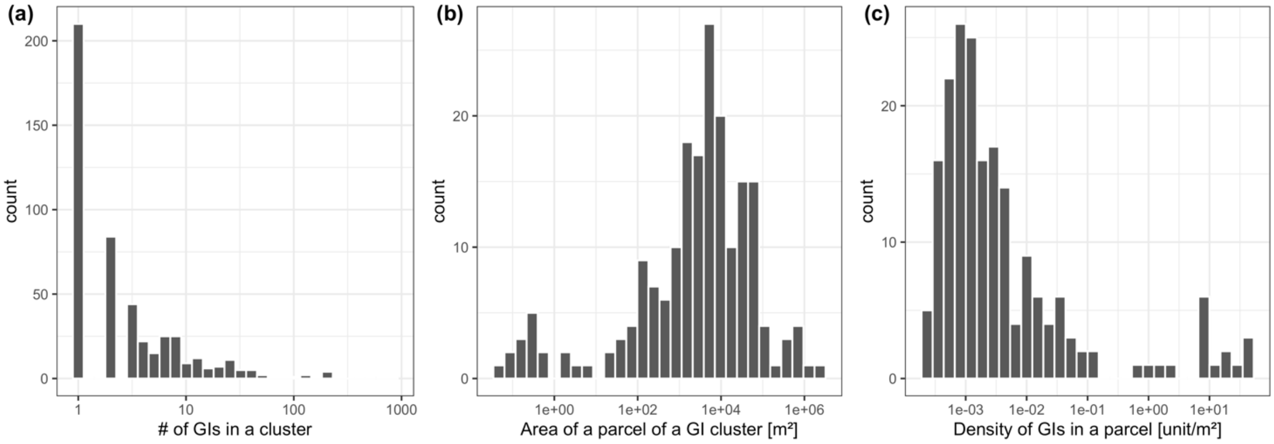

Figure 3. The distributions of (a) the number of GIs in a cluster, (b) the area of the parcel corresponding to a cluster, and (c) the density of GIs in a land parcel.

Conclusions and future work

This study presents a network analysis-based method to study the spatial distribution patterns of green infrastructures (GIs) in Brooklyn, New York City, the U.S. The GIs are found to be distributed unevenly at various scales. Networks of GIs are created based on their spatial locations, which are then used to cluster GIs and define the land parcels that are affected by different clusters of GIs. The uneven distributions of GIs may affect their hydrological performances and result in imbalanced stormwater management efficiencies across different areas of a city. The proposed network analysis-based methods enable the GIs' spatial distribution and hydrological performance to be more easily studied, which can be useful for assessing GIs' effectives at a city scale. This study also recommends exploring the applications of various methods for network analysis in GI-related studies.

Acknowledgement

The work described in this paper was partly supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. HKU17255516), and partly supported by the RGC Theme-based Research Scheme (Grant No: T21-711/16-R) funded by the Research Grants Council of the Hong Kong Special Administrative Region, China. The locations of the green infrastructures used in this research can be downloaded at: https://data.cityofnewyork.us/Environment/DEP-Green-Infrastructure/spjh-pz7h (Accessed 23 June 2021).

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