Risk Assessments of Trees and Urban Spaces under Attacks of Typhoons: A Survey and Statistical Study in Guangzhou, China

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Abstract. Typhoon, as one of the extreme climatic disasters, attacks the southeast coastal cities in China every year. To countermeasure the risk of a typhoon on urban tree safety, we established a cooperation research team including professions on urban design and city planning, wind engineering, and tree health assessment and management. This paper presents some statistical studies on the data of the damaged urban trees causing by the typhoons in Guangzhou and some other cities in Pearl River Delta (PRD), China in 2016 - 2018. The data of the damaged trees is imported in a geographic information system (GIS) database and a local climate zone (LCZ) map to analyze the distribution of damaged trees in different urban morphologies and underlying surface patterns. Results show a series of high-risk tree species such as Ficus microcarpa, Ficus virens var.sublanceolata, and Bauhinia variegata in typhoons. Then, six LCZ typologies and four main typologies of urban space are figured out basing on the statistical analysis of the damaged trees. Preliminary results reveal that some kinds of tree species and urban space are at a higher risk level during the typhoons. Current works will support the research on urban tree management, risk management and forecasting, urban planning, and landscape design.

1. Introduction

According to Sustainable Development Goals 13 (SDG 13), countries should take urgent action to combat climate change and its impacts. Recent reviews have provided some assessments that the globe warming and the El Niño-Southern Oscillation (ENSO) phenomenon had effects on tropical cyclones (TC) and sea level rising[1][2]. Southeast coast of China was attacked by typhoons, which are mature TCs in the region of the Indian or western Pacific oceans, by Ave. 27 times and mainly during June and November each year[3]. Guangdong is one of the provinces in south China that has the highest typhoon landfalling frequency of 2.9 times per year[4]. Typhoons and their accompanying disasters such as seawater intrusion and heavy rainfall has caused a huge threat to human safety and economics. To countermeasure these risks, a series of forecasts and early warning systems for typhoons has been built up to avoid the loss in recent years in China.
However, the strong wind effects on urban trees during and even after the typhoons in lots of cities still cause a sequence of secondary disasters such as stem damages and tree fallings that reinforce the harms on the pedestrian safety, urban facilities, buildings, and vehicles (figure 1a). The phenomenon is relevant to multiple research areas such as meteorology, wind engineering, forestry, and urban planning. Some researchers have discussed the strong wind effects in different urban environments and the aerodynamics roughness in different downscale surface layers[5], space-time variation effects of typhoons on buildings and structures[6], and tree structure and wind response effects with the tree risk assessment (TRA) [7]-[8]. However, much more integrated research on urban trees under the effect of a typhoon is still lacked. From a perspective of urban safety, a better understanding of typhoon effects on the specific urban environments and local urban trees is still needed to promote in the urban tree management, urban planning, and risk forecast and alarm.

To countermeasure the risk of typhoons on urban safety, we focused on the problems of the typhoon effects on urban trees and established a cooperated research team including professionals on urban design and city planning, wind engineering, and tree risk assessment and management (figure 1b). A preliminary study is conducted basing on statistical analysis with the data of the damaged trees under typhoon attacks in three years (2016 - 2018) in cities in the Pearl River Delta (PRD), China. Furthermore, a geometry information system (GIS) and a local climate zone (LCZ) database of Guangzhou (GZ), China, which is the central city in PRD, are introduced to give some analysis on the relevance of the urban canopy and the distribution of damaged trees during the typhoons. Consequently, a risk assessment of typhoon effects on different urban environments and urban trees could be figured out and further studies on urban trees management as well as landscape and urban design could be improved considering the effects of typhoon risks in the future.

Figure 1. Photo of a fallen tree after the typhoon Hato, 2017 (a) and the diagram of the cooperation research framework (b)

2. Methodology

2.1. Urban trees data source

As a part of the work of urban safety management, a fast report - response system for tree rescue has been set up in the main cities in the PRD in recent years to deal with the emergent problems during the disasters. Tree rescue and risk assessment works are mainly conducted during and after the typhoon in the urban area and some of the main roads. Thus, the data of urban trees in this study had been collected in the above rescue works in 2016 - 2018. However, different rescues and investigations still have some differences in data information. For example, the data of GZ in three years includes a much more precious record on the location of the damaged trees. The data of other cities only records the
tree species, TRA levels, and the names of the roads (table 1). Thus, the tree species analysis is based on all the data in six cities and the geographical analysis is only based on the data of GZ.

Composite indices have been developed to evaluate the tree risk in an urban environment, including tree health status record, proximity to buildings and artifacts[9], parameters of the scale of a tree and the stems, and root rot[10]. However, a much more simple and fast classification, which only divides into three levels such as fallen trees (Level A), main trunk inclining (Level B), and branches breaking (Level C), is applied in the rescue works.

Table 1. Description of the data of the damaged trees in different typhoons

| Typhoon                  | Year | Quantity of trees | Tree Species* | TRA levels* | Location         | Cities*       |
|--------------------------|------|-------------------|---------------|-------------|------------------|--------------|
| Nida (No. 1604)          | 2016 | 74                |               |             | Precise location | GZ           |
| Hato (No. 1713) & Pakhar (No. 1714) | 2017 | 351               |               |             | Precise location | GZ           |
| Hato & Pakhar            | 2017 | Approx. 300       |               |             | Road name        | ZH           |
| Mangkhut                 | 2018 | 144               |               |             | Precise location | GZ           |
| Mangkhut                 | 2018 | Approx. 25,000*   |               |             | Road name        | GZ, ZH, SZ, HK, MC, Macau, JM, Jiangmen |

* Data of 2018 includes a larger scale investigation for urban trees after the typhoon Mangkhut; “●”, means the data includes in the data record; GZ, Guangzhou; ZH, Zhuhai; SZ, Shenzhen; HK, Hongkong; MC, Macau; JM, Jiangmen.

2.2. GIS database platform
GIS is widely applied in urban planning, land use management, and forest management[11]. In this study, a GIS database including the building footprint, building floors, and the central lines of the roads in GZ was established for current and future works for urban trees assessment and management. The software ArcGIS 10.2[13] was applied to record the damaged trees’ information in recent three years. In the GIS database, the information of a damaged urban tree includes the tree species, the TRA level, the precise location, and the name and number of the typhoon. The GIS database of both buildings and trees information gives an opportunity to analyse the relevance of the urban space and damaged trees in different scales.

2.3. Local climate zone (LCZ) and the world urban database and access portal tools (WUDAPT)
To describe the strong wind effects on different urban canopies as well as the urban trees, an aerodynamic roughness length ($z_0$), which is defined as a parameter for some vertical wind profile equations that model the horizontal mean wind speed near the ground, of a specific urban morphology is better to be known. Shen et al.[12] have estimated that the $z_0$ of the urban and built-up land is higher than 2.0. However, a $z_0$ is normally described a much larger urban scale. A more detail analysis for urban environment with buildings and trees in different urban morphologies and urban canyons under a scale of 1 km is still lacked. Thus, the LCZ map that gives a better resolution of urban environment is introduced to this study.

LCZ was developed by Steward and Oke to redefine and quantify the urban heat island (UHI) effects, which includes 10 built types and 7 land cover types[17]. The method named WUDAPT[14] is an approach designed to recognize the LCZ classification. WUDAPT has been created to collect the urban morphology and activity data globally and provide a universal, simple, and objective data for the urban climate study. The WUDAPT data was built with free satellite images and free software of Google Earth[15] and SAGA-GIS[16]. Different levels of the LCZ include different precision of urban data[14].

As different patterns of the underlying surface are defined, an LCZ map also shows the possibilities for the analysis of other problems relating to the urban morphologies and the underlying surface patterns. In this study, a Level 0 LCZ map (resolution of 100 - 300 m) of GZ is collected via the open-source database[14], imported to the GIS database, and overlapped with the coordinates data of
damaged trees to analysis the relevance of the urban underlying surface patterns with the strong wind effects.

3. Results

3.1. Damaged trees species analysis

Statistical results of damaged trees (table 2) reveal that some of the local urban tree species such as Ficus microcarpa, Ficus virens var.sublanceolata, and Broussonetia papyrifera are the high-risk tree species under the typhoon attacks. The data could support the improvement of tracing, recording, and protecting some high-risk species in urban tree management.

As the data of the damaged trees were collected during the rescue works, field observations also reveal that the problems are not only related to the tree health but also the plant environment. Most of the Ficus microcarpas were damaged due to the soil problems such as the limited size of the tree pools, the mixed soil with construction wastes, and the artificial cutting of roots preventing an expanded growth. The dense building environment is also the main reason for the tree damage because many trees are forced to grow aslant to avoid the buildings and get the daylighting. The inclining growth will increase the risk of the tree falling during the typhoons. In this aspect, the urban tree management should be cooperated with urban facility management, urban infrastructure management, and urban planning to provide a better growth environment for trees.

Table 2. Main tree species damaged in typhoons

| Tree Species                              | Nida in GZ, 2016 | Hato & Pakhar in GZ, 2017 | Hato & Pakhar in ZH, 2017a | Mangkhut in GZ, 2018 | Mangkhut in 6 cities, 2018b |
|-------------------------------------------|------------------|---------------------------|---------------------------|---------------------|-----------------------------|
| Ficus microcarpa                          | 16               | 112                       | ●                         | 15                  | ●                           |
| Ficus virens var.sublanceolata            | 80               | ●                         | 24                        | ●                   | ●                           |
| Bauhinia variegata                        | 3                | 44                        | 14                        | ●                   | ●                           |
| Broussonetia papyrifera                   | 4                | 16                        | 15                        | ●                   | ●                           |
| Ficus altissima                           | 11               |                           | 6                         | ●                   | ●                           |
| Cinnamomum hurmanni                      | 11               |                           |                           |                     |                             |
| Mangifera indica                          | 10               |                           |                           |                     |                             |
| Melaleuca leucadendron                    | 8                | ●                         | 5                         | ●                   | ●                           |
| Bombax malabaricum                       | 3                | 8                         | 9                         | ●                   | ●                           |
| Syzygium kainanense Chang et Miu          | 3                | 8                         |                           |                     |                             |
| Ficus benjamina                           | 5                |                           | 13                        | ●                   |                             |
| Chukrasia tabularis                       | 9                |                           | 11                        | ●                   |                             |
| Eucalyptus robusta Smith                  | 5                |                           | 4                         | ●                   |                             |
| Khaya senegalensis                        | 10               |                           |                           |                     |                             |
| Delonix regia                             | ●                |                           |                           |                     |                             |
| Erythrina variegata                       | ●                |                           |                           |                     |                             |
| Ficus elastica                            | ●                |                           |                           |                     |                             |
| Other                                     | 16               | 43                        | 28                        |                     |                             |
| Total                                     | 74               | 351                       | 144                       |                     |                             |

* GZ, Guangzhou; ZH, Zhuhai; a & b, two data of the risk trees have been analyzed with a clustering method; “●” means the data includes in the data record.

3.2. GIS database for urban tree management

As a part of urban tree management, a damaged tree database was established. It offers an opportunity to couple the trees’ information with the urban information in order to evaluate the strong wind effects on different urban areas. On the other side, it also gives a guide for urban disaster safety monitoring and forecasting.

Results of three years in GZ reveal that the damaged trees are mainly located in the downtown area (figure 2), some of whose planting environment is much worse than the newly developing area due to
the lack of green land. It should be noticed that some damaged trees in the urban parks and open space were ignored in the database because the tree rescue works are much more emergent in the living area and main roads. A more comprehensive record of the damaged trees should be improved in future investigations.

3.3. Data analysis with the LCZ map
Overlapping with the damaged urban tree geographic information with the LCZ map (figure 3), results reveal that LCZ 2 (Compact mid-rise), LCZ 5 (Open mid-rise), LCZ 8 (Large low-rise), LCZ B (Scattered trees), LCZ 1 (Compact high-rise), and LCZ 10 (Heavy industry) are the most serious areas, in where most of the damaged trees located, in recent typhoons (table 3). Zones of LCZ 2 and LCZ 5 are mainly the downtown area of GZ. It warns that the trees planted in past decades in the existing urban environment should be assessed and monitored in future management.

3.4. Data analysis with different typologies of urban space
As the positions of the damaged trees were recorded in the GIS database, further analysis with the information of building footprint, building height, and roads could be added later. Four main typologies of urban space were figured out via the statistical analysis of the damaged trees in GZ in three years (table 4 and figure 4): a. High-density and low-rise buildings area (10.7%); b. In-between the compact and open space (7.9%); c. Urban space around the high-rise buildings area (2.8%); d. Urban space around the overpasses area (17.6%).

Results imply that some typologies of urban space and facilities may have a higher sensitivity to the strong wind effects in the urban environment. It also gives a warning that people should avoid staying outdoor in the above typologies of urban space during typhoon disasters.
Figure 3. LCZ map of GZ overlapped with the GIS database of damaged trees (2016 - 2018)

| LCZ catalogue | 2016 Quantity | Ratio (%) | 2017 Quantity | Ratio (%) | 2018 Quantity | Ratio (%) | Summary Quantity | Ratio (%) |
|---------------|---------------|-----------|---------------|-----------|---------------|-----------|-----------------|-----------|
| LCZ 1         | 6             | 9%        | 8             | 2%        | 9             | 7%        | 23              | 4%        |
| LCZ 2         | 27            | 42%       | 213           | 63%       | 73            | 60%       | 313             | 60%       |
| LCZ 5         | 5             | 8%        | 52            | 15%       | 12            | 10%       | 69              | 13%       |
| LCZ 8         | 13            | 20%       | 8             | 2%        | 6             | 5%        | 27              | 5%        |
| LCZ 10        | 8             | 12%       | 8             | 2%        | 6             | 5%        | 22              | 4%        |
| LCZ B         | 2             | 3%        | 17            | 5%        | 10            | 8%        | 29              | 6%        |

Table 4: Quantity and ratio of damaged trees in four specific urban space typologies

| Year | Type A Quantity | Ratio (%) | Type B Quantity | Ratio (%) | Type C Quantity | Ratio (%) | Type D Quantity | Ratio (%) |
|------|----------------|-----------|----------------|-----------|----------------|-----------|----------------|-----------|
| 2016 | 16             | 21.6      | 5              | 6.8       | 2              | 2.7       | 14             | 19.0      |
| 2017 | 38             | 10.8      | 22             | 6.3       | 11             | 3.1       | 59             | 16.8      |
| 2018 | 7              | 4.9       | 18             | 12.5      | 3              | 2.1       | 27             | 18.8      |
| 3 years | 61             | 10.7      | 45             | 7.9       | 16             | 2.8       | 100            | 17.6      |

* Type A: High-density and low-rise buildings area; Type B: In-between compact and open space; Type C: Around high-rise buildings area; Type D: Around overpasses area.

4. Discussion
This study tempts to establish a GIS database platform to support the tree management and risk assessment for the typhoons in GZ, China. Some preliminary studies coupling with urban canopy have been conducted and reveal that the trees in and around some special kinds of urban space and facilities are under high risk during the typhoon attacks. However, some limitations and improvements in this study should be discussed.

4.1. Parameters of the urban space
This paper tries to discuss the relationship between the urban environment and trees under the effects of typhoons. However, some parameters such as surface albedo, sky view factor (SVF), ground emissivity, and urban surface aerodynamics roughness, is still lacked in this study. Respectively, the information of building height, which the level 0 LCZ map lacks, gives an opportunity to have a more detail analysis for the wind tunnel or computational fluid dynamic (CFD) studies in the future.
4.2. **Impact factors on the tree falling**

This research gives some absolute numbers of the damage tree species in recent typhoons. However, it should be noticed that some of these tree species such as *Ficus microcarpa* have a large cardinal number in the city and there are some differences of the urban tree species planning in different areas and decades in the city. Theses factors would impact the results of statistical results. A proportion study on different tree species is lacked in the current works but could be improved and compared with the urban tree planning data in later research.

Basing on the field investigations, some empirical impact factors on tree damage could be discussed such as the tree health and risk as well as the climactic factors during the typhoons. We find that lots of old trees in the downtown area are lacked tree health assessment in past years and some environmental factors increase the risk of tree damage such as the insufficient planting pool and the densely built environment harming the growth of roots and tree crown. Respectively, some climatic disaster occurs accompanied by the typhoons. Heavy rain is one of the factors that reduce the density of the soil and increase the risk of the tree falling. Some field reports after the rescue works pointed out that many trees fell at the end of the typhoons due to both effects of strong wind and heavy rains. The wind orientation of the typhoon normally changes with time and causes a continuous force on the tree crown that lets the trunk incline in changing angles and reduce the compactness of the soil. Then heavy rains may much easier to wash out the soil and cause the tree falling after the landing of typhoons. From this perspective, multiple factors may impact on tree damage and falling during the typhoons. Thus, a much more comprehensive record for the field investigations is still needed to improve in future studies.

5. **Conclusion**

This paper shows the framework of the cooperation research and some statistical studies basing on the data of the damaged trees causing by the typhoons in GZ and some other cities in PRD, China in 2016 - 2018. Preliminary results reveal that some kinds of tree species and urban space are in the higher risk level during the typhoons. Related to SDG 13, current works will support the urban trees management, tree safety tracing, city facilities maintenance, and urban and landscape planning within the city developing. It’s an important issue to strengthen the urban resilience and reduce the damage and risk to people and city facilities during the typhoon disasters in the background of global climate change.
and fast urbanization. Future works of this research will develop some more comprehensive field measurements as well as continuous health assessments on different tree species in the city. A better risk-based and safety-orientated guidelines or policies on urban trees management and urban landscape design would be developed in future.

Acknowledgments
This research is supported by National Natural Science Foundation of China (No. B51478188).

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