

Strategies of Managing Urban Tree Vegetation: A Study of Cities in Taiwan

Technical Report

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Project: ER3DS – Emission Reduction in Smart Cities Using 3D Spatial Sensing and Analysis

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Summary

Urban regions are particularly affected by increasing heat waves due to climate change. Vegetation, particularly trees, are an important factor to the local climate (i.e. microclimate) within cities. However, urban trees are subject to increasing heat stress during hot summers, which may impede their positive effects on the urban climate and – worst case – lead to dying of trees. With increasing requirements to curate trees and limited resources (e.g., water, human power) there is increasing relevance to develop new strategies, for example, using digital geotechnologies for urban tree management. Cities in geographic regions with overall hotter climate (than in central Europe) are already more adapted to conditions of strong heat than German or central-European cities. This study gathers insights about strategies of urban tree management in Taiwan. This entails a survey of literature and publicly available resources, and direct interviews. Interviews are conducted with two scientific partners from Taiwan. In the frame of this survey, it was not possible to conduct interviews with stakeholders (formal requests were made to several city governments).

According to public resources and the information gained with the interviews, urban trees in Taiwan play an important role for different aspects: they have a function for aesthetics and culture, but also for thermal comfort and provision of shade during periods of high temperatures. There is increasing awareness of the importance of trees in the population in the environmental context. Linked to this, an increasing number of actions to avoid the removal of trees, for example, for construction can be observed. The management of urban vegetation is handled by different departments in the cities. Generally, the maintenance of urban trees, particularly trimming and irrigation, are outsourced to contractors. Irrigation mainly relies on watering trucks and human power, and may be limited in dry periods when there is low availability of water. Mostly fresh water is currently being used, some cities already changed to using gray water for irrigation.

So far, in Taiwanese cities the deployment of geotechnology in urban vegetation management regards mapping of trees for cadasters, with additional in-situ measured structural parameters. In current research projects in cooperation with city planning, meteorological data is recorded for monitoring the urban microclimate. These existent monitoring setups could be integrated for an improved understanding on the status of urban trees, by linking to new observation parameters, such as soil humidity at the position of individual trees or spatial information on the vitality of trees via (airborne) image acquisition. Similar to the current standard approach of urban tree management in Germany, there seems to be large potential for adopting new strategies of monitoring and managing trees. The situation in Taiwan shows various similarities to current strategies of tree management, mainly irrigation, in German cities. For example, in most cases watering trucks and expert-based scheduling of irrigation at street level are used. Therein, the capacity of irrigation during dry periods is limited by the availability of water and the capacity of human power. Both countries may hence greatly benefit from investigating new strategies of integrating digital geotechnologies to monitor urban vegetation for more targeted requirements of water and further maintenance.

1. Introduction

Urban regions are particularly affected by increasing heat waves due to climate change. Vegetation, particularly trees, are an important factor to the local climate (i.e. microclimate) within cities, for example by contributing to air quality or thermal comfort of people in public spaces (Foshag et al., 2020). Urban trees are subject to increasing heat stress during hot summers, which may impede their positive effects on the urban climate and – worst case – lead to dying of trees. In Germany, urban tree management strongly relies on experience of city managements and expertise of responsible persons. With increasing requirements to curate trees and limited resources (e.g., water, human power) it is becoming important to be able to manage trees with new strategies. This could entail the use of digital geotechnology, such as local sensors of soil humidity or remote sensing observation of vegetation health. Such technologies could be integrated in vegetation management, for example, by triggering targeted irrigation for single trees or streets, which require water (most urgently). Vegetation monitoring throughout the year could also help to take measures earlier on, for example if irrigation or other types of curation before the onset of stress periods would help to render trees more resilient.

Cities in other geographic regions with overall hotter climate are already more adapted to conditions of strong heat than German or central-European cities. This could either mean that the types of vegetation that are (predominantly) present in these urban regions are made out for warmer climate. But it could also entail already advanced urban vegetation management techniques, from which we can learn for adaptation of strategies in Germany.

The objective of this study is to learn about current and/or planned strategies of urban vegetation management, especially trees, in Taiwan. This entails a survey of (i) literature and publicly available resources, and (ii) interviews with stakeholders from Taiwan.

Three questions are central to the objective of the study:

- 1) How is urban vegetation currently being managed (mainly irrigated)?
- 2) How do vegetation management processes work, how are decisions, e.g. for irrigation, made?
- 3) What kind of digital (geo-)technologies are used for vegetation management? And which technologies are planned or intended for the future?

The synthesis of information obtained from our partners in Taiwan will provide the basis for developing new strategies of urban vegetation management in German cities under consideration of increasing heat stress. The exchange in the frame of interviews further prepares for potential future collaboration with partners from Taiwan on this research topic.

2. Approach

As a first step, we perform a survey of literature and public resources about urban vegetation, particularly its management, in Taiwan. In the second step, the main part of the study regards interviews with collaborators in Taiwan, i.e. persons providing information and their perspectives about urban vegetation management and planning of management strategies.

Interviews were conducted with two scientific partners:

- Interview 1: Professor Wang from the department of geomatics of the National Cheng Kung University (NCKU) and two of his PhD students
- Interview 2: Professor Lin from the department of architecture of the NCKU and one of his PhD students.

The interviews were conducted online and, in both cases, took one hour of time. Two persons performed the interview of which one was the main interviewer and one the main recorder who took notes in an online Excel sheet, which was visible to all participants during the interview meeting.

As to the manner of conduction of the interview: Before the interview, an Excel sheet with all the questions was prepared and sent to the interview partners. During the interview the sheet was made visible to the interview partners by screen sharing, so that they could see what was being noted. After the interview, the sheet was made available for approx. two weeks to the interview partners for corrections or additions.

In the frame of this survey, it was not possible to conduct interviews with direct stakeholders in Taiwan. Formal requests were made to different city governments by Kuei-Chia Chen (member of Prof. Wang's research group). The city officials from Taipei, New Taipei, Taichung, Tainan, and Kaohsiung provided some information, mainly pointing to publicly available resources. These are integrated in the subsequent results.

3. Results

In this section, the main findings are presented based on information gathered from the interviews with scientific partners, as well as literature and online research. The input by the interview partners is provided as supplements to this report, as the final version of the online interview tables (Suppl. 1: "Interview1", Suppl. 2: "Interview2"). The detailed compilation of public resources is contained in the Appendix of this report (referenced throughout the subsequent result sections).

3.1 How is urban vegetation currently being managed?

3.1.1 Function and Meaning of Urban Vegetation

According to the interview partners, vegetation has various meanings in the urban context in Taiwan. It is valued as an aesthetic feature adding to the city landscape. It plays an important role in making the city more inhabitable by mitigating floods and heat, providing shade, acting as a barrier to sound and preventing dust. It further provides a venue for activity for the citizens and has also cultural significance, e.g., in fengshui.

Generally, people perceive trees as positive and care for their protection. In recent years, there is an increasing number of actions where people protest against removal of trees or over-trimming. If multiple trees are to be removed, mostly because of building projects, petitions will be started, leading to project delays (Int. 1).

3.1.2 Influence of Heat Stress and Other Extreme Weather Events on Urban Vegetation

In general, irrigation of urban vegetation in Taiwan is required throughout the entire year, especially in southern cities like Tainan, where there is a pronounced dry season in the winter months (cf. climate diagrams in App. A). Although the climate in Taiwan is characterized as hot and humid subtropical climate, periods of drought occur particularly in the South (cf. App. A.2).

For trees, especially extreme weather events like typhoons pose a severe challenge. During typhoons, trees may fall and damage infrastructure and property, and hinder traffic. Therefore, trees falling due to typhoons are a larger concern than trees dying from drought. Management, particularly irrigation, of trees during droughts are described in Section 3.1.4.

3.1.3 Management of Urban Trees by the City Government

In Taiwanese cities, each city government has a department which is in charge of vegetation management. The organization of city departments are contained in Appendix B for the cities of Tainan (App. B.1) and Taipei (App. B.2). The responsibilities for different aspects of urban trees differ between the cities, according to informal information from the city governments of Taipei, New Taipei, Taichung, Tainan, and Kaohsiung. In some cities, one office manages all urban trees. In other cities, responsibilities are divided between departments, e.g., for trees in parks and street trees.

Actual activities of curating trees, such as irrigation, pruning and trimming, are typically outsourced to contractors. Based on statements from the city governments, companies are contracted to plant and curate trees with several years of warranty. If trees die, the company needs to replace them, i.e. plant new trees.

3.1.4 Concept for Irrigation of Urban Trees and Consideration of Weather Extremes

For irrigation, all cities use watering trucks. Water pipelines for irrigation are not considered as an option because most trees are located in areas where it is difficult to install pipelines, for example

in the middle of the road. Apart from irrigation, watering trucks are used to refill water towers in the mountain areas, rinsing the streets and squares, and cleaning urban areas in the after typhoons mainly from silt sediments (Taipei City Government, 2016).

The interview partners are not aware of other specific concepts or strategies in urban vegetation management. It is assumed to be mostly pursued using minimal time and labor resources, since budget and human resources are an important issue. For example, according to interview partner 1, trees may not be irrigated to their full needs since water and also the watering trucks cannot be sufficiently funded. Generally, more budget is available in wealthy cities (i.e., Taipei, and maybe New Taipei City), which will be able to irrigate even daily during summer. In contrast, contractors in Tainan irrigate monthly or even less frequently.

3.2 How do vegetation management processes work? How are decisions, e.g. for irrigation, made?

3.2.1 Coordination of Irrigation for Urban Tree Management

Management of urban trees in Taiwanese cities commonly follows an official schedule, which is provided on the city government websites (App. C). The information provided for Taipei, for example, mainly regards workflows and schedules for irrigation and trimming of trees. Based on information from the New Taipei city government, the trees normally would be trimmed three times per two months. Trimming is increased in the rainy and typhoon seasons (April to May and July to August).

The aspect of increasing irrigation during dry periods is described differently by the scientific interview partners in the context of water scarcity. According to Interview 2, water is almost always available due to precipitation of typhoons. Water scarcity occurs only in La Niña years, which are usually tough drought years. The view reflected in Interview 1 is that hardly any water is available for irrigation in any dry season, i.e. every year, because the water is needed to cover the demand of the population. In this context, the type of water used for irrigation is of relevance. In Taipei and New Taipei City reclaimed water is used for irrigation of urban trees. However, there was no information provided that the frequency or amount of watering is increased during dry periods. An important factor here is the budget of city governments, which may not allow to fund additional water resources and/or watering trucks. Consequently, trees tend to be left to drought stress or dying during dry periods. Other big cities like Taichung, Kaohsiung and Tainan use fresh water for irrigation. The use of fresh water is prioritized for the needs of the population in periods of scarcity, so that no water may be available for irrigation.

3.2.2 Reacting to Heat Stress

Irrigating in reaction to heat stress is possible if water and budget are available. In this, the interview partners (Int. 1) see the biggest weaknesses of the current approach, since water is scarce and also fresh water is being used for irrigation – which will always be prioritized to be

used for population demands. Furthermore, incidents of over-trimming before the typhoon season emerged, which leaves trees more vulnerable to typhoons. To improve management, higher budgets would be required to be spent on contractors for vegetation management.

Heat stress and other effects of climate change are gaining increasing awareness. New approaches are being developed and tested in experimental projects, e. g. replacing asphalt with more permeable materials so that water can reach the soil or enlarging the root pits for newly planted trees. The latter is probably mostly to remove root pressure to the asphalt but it also has benefits for the trees. The implementation of such innovations into practice will take several years and it is not yet clear which project ideas will be successful in the long run. An important aspect of successful innovations is that the positive effect of innovative measures can be demonstrated (e.g. to official decision makers), such as mitigating effect of trees on urban heat islands.

3.2.3 Choice of Tree Species

Tree species in the city are currently often native trees or selected for cultural reasons. Sometimes diversity of species is a motivation, or provision of shading. In the past, trees were selected out of aesthetic considerations, meaning they were often non-native species. Native trees are well adapted to Taiwan's diverse weather conditions, and are more tolerant to drought and heat than in high latitude areas. The interview partners are not aware of an urgent need or specific actions to change the composition of urban trees.

3.3 What kind of digital (geo-)technologies are used for vegetation management? Which technologies are planned or intended for the future?

3.3.1 Monitoring of Urban Climate

Urban micro climate is being measured by the Central Weather Bureau (CWB), who mostly record meteorological variables. No specific sensors are being used to monitor vegetation-related variables, such as soil humidity (Int. 2). Interview 1 mentions that the government may acquire and analyze geodata, mainly remote sensing data, when budget is available. Satellite imagery, therein, is used by the government mostly for planning and monitoring of agricultural areas. Satellite imagery may sometimes be used to decide in which areas outside of city centers trees are needed. No specific use of remote sensing or other data is known for the analysis of vegetation health or the status of trees.

Not directly related to vegetation management, Prof. Lin's lab maintains an IoT (Internet of Things) sensor network for monitoring how the local urban climate affects humans (cf. Int. 2). So far, their monitored micro-climate parameters are provided to the city government for urban planning purposes (ongoing project). These data might be used for tree management in the future, but no specific purpose is foreseen at the moment.

3.3.2 Sensors and Technical Systems for Vegetation Monitoring and Management

Technical systems used for vegetation management mostly regard web-based Geographic Information Systems (GIS). For example, Taipei City provides an online tree cadaster with information on the location of trees and parameters such as their species, height and diameter at breast height (Fig. 1). Trees are mapped in-situ with handheld GPS devices by persons employed for this task (information regards Tainan but probably applies to other cities as well, cf. Int. 1).

The interview partners are not aware of any technical solutions for tree irrigation. There is a strong focus on the use of water trucks and manpower for irrigation, since this approach is comparably low-cost (cf. Section 3.1.4). In some urban parks, irrigation systems are installed, for example water sprinklers. On road sides, retention bricks are increasingly installed to hold water for trees after heavy precipitation (Int. 1). This can be an important improvement for urban trees in Taiwan because of extreme periods with high water surplus, on the one hand, and strong lack of water, on the other hand.



Figure 1: Web view of tree cadaster for Taipei with information for an example tree. A full description of displayed information (translations) are provided in Appendix D.1. Source: <https://geopkl.gov.taipei/> (20 May 2022).

Generally, new technologies are mostly being tested in specific areas in Taiwan, but hardly implemented for entire cities. Only if a technology would prove to be successful and feasible, it might be fully implemented. In the long term, the current goal is to adopt the concept of the sponge city (cf. Qingmu & Hsueh-Sheng, 2021), which is being developed for pilot sites (Int. 2). Obstacles for realizing this, and for implementing technical solutions in general, are foremost the limited availability of money. Further, it is difficult to measure the success of new technologies based on

solid key performance indicators, which would be required to convince the government to invest in new strategies (cf. Int. 2).

3.3.3 Involvement of Citizens

Direct involvement in urban vegetation management is difficult for citizens because urban trees are government property. Therefore, there may be fees if modifications are made to public trees, even watering. Generally, a special license is required for being allowed to repair urban trees. Some of the city governments offer courses to people who want to work on curating or repairing trees.

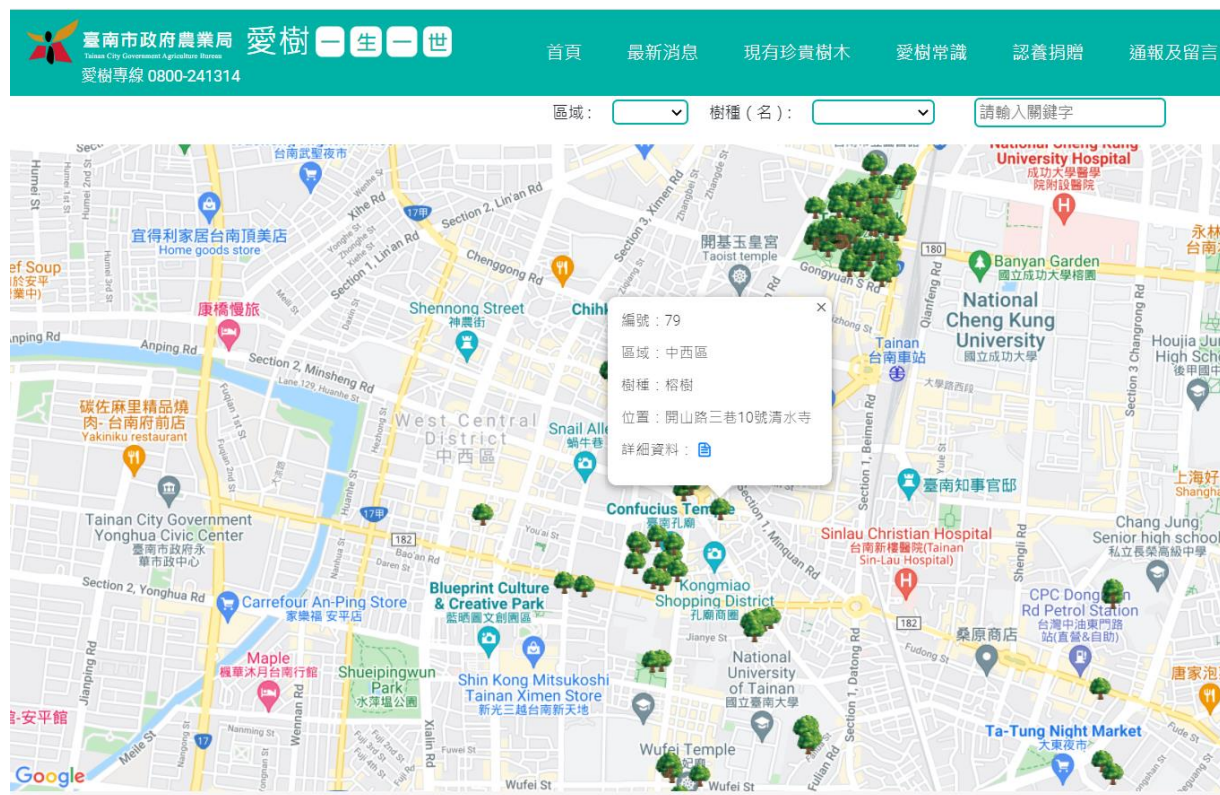


Figure 2: Web-based cadaster of valued trees in Tainan. A full description of the displayed info and requirements to submit trees as 'valued' are given in App. D.3. Source: <https://oldtree.tainan.gov.tw/> (20 May 2022).

Private parties, which are mostly companies or investors, can adopt tree areas or parks (cf. Int. 2). This means they provide money for maintenance, so that a contractor is hired to manage the respective trees. The benefit for companies is to obtain additional permissions, for example, for additional floors when constructing new buildings. It is hence an incentive to support government funds for maintaining urban vegetation.

A form of citizen involvement is the reporting of valued trees (i.e. mostly old trees, cf. App. D.2 and D.3), which are displayed on a public website of the Tainan City Government (Fig. 2). A

further web platform is used to apply for the removal of trees, for example if space is needed on private property or for the construction of other infrastructure, such as bus stops (cf. App. E).

4. Conclusion

So far, in Taiwanese cities the deployment of geotechnology in urban vegetation management regards mapping of trees for cadasters, with additional in-situ measured structural parameters. In current research projects in cooperation with city planning, meteorological data is recorded for monitoring the urban microclimate. These existent monitoring setups could be integrated for an improved understanding on the status of urban trees, by linking to new observation parameters, such as soil humidity at the position of individual trees or spatial information on the vitality of trees via (airborne) image acquisition.

Similar to the current standard approach of urban tree management in Germany, there seems to be large potential for adopting new strategies of monitoring and managing trees. The situation in Taiwan shows various similarities to current strategies of tree management, mainly irrigation, in German cities. For example, in most cases watering trucks and expert-based scheduling of irrigation at street level are used. Therein, the capacity of irrigation during dry periods is limited by the availability of water and the capacity of human power. Both countries may hence greatly benefit from investigating new strategies of integrating digital geotechnologies to monitor urban vegetation for more targeted requirements of water and further maintenance.

References

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Qingmu, S. & Hsueh-Sheng, C. (2018): Evaluation System of Sponge City Construction in Taiwan Metropolitan System under the Impact of Climate Change. *Modern Environmental Science and Engineering*, 4 (6), pp. 516-521. DOI: 10.15341/mese(2333-2581)/06.04.2018/004.

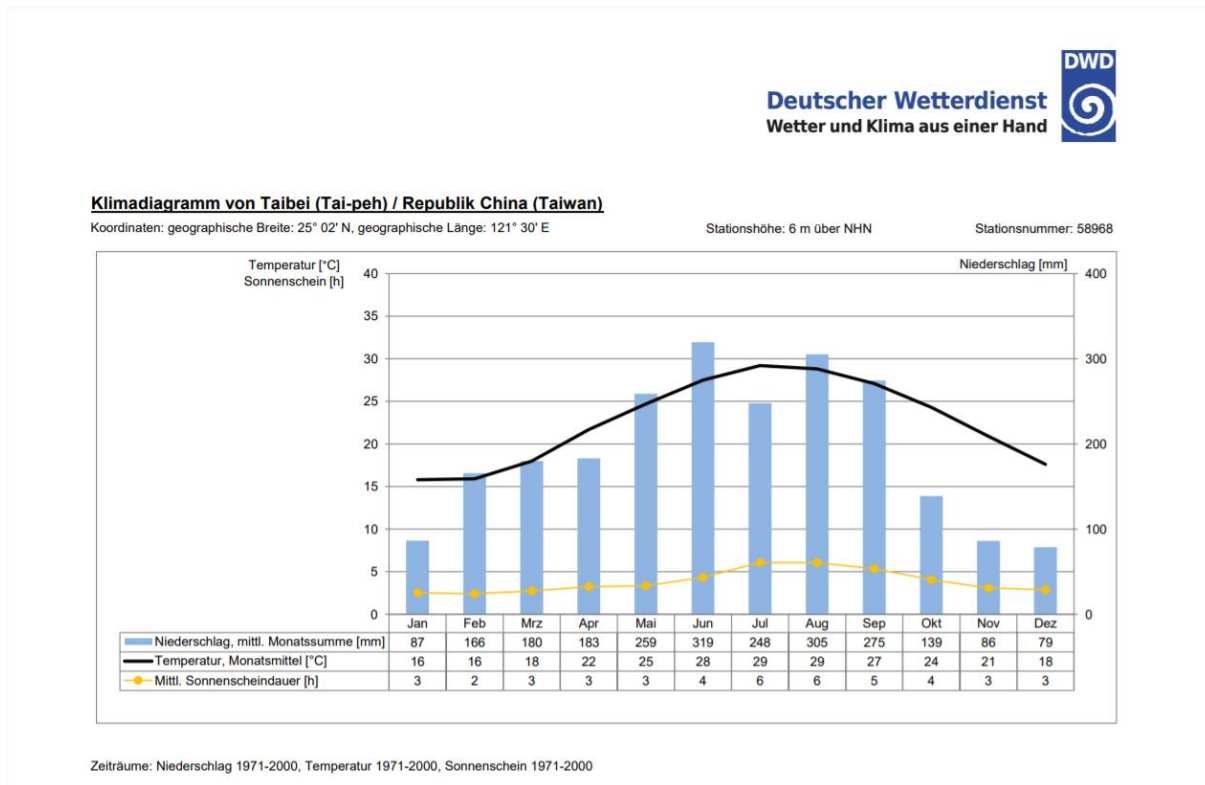
Taipei City Government (2016): 幫路樹解渴 水車每日里程從台北到高雄 (Daily water trucks from Taipei to Kaohsiung; translation of contents by T. Weise). URL: https://pkl.gov.taipei/News_Content.aspx?n=43E05059FCC72525&sms=72544237BBE4C5F6&s=97949172160486A9 (05 April 2022).

Acknowledgements

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Appendix A: Climatic Conditions in Taiwan

A.1: Climate Diagram of Taipei



Climate diagram of Taipei showing average precipitation, temperature and sunshine. Source: Deutscher Wetterdienst (https://www.dwd.de/DWD/klima/beratung/ak/ak_589680_di.pdf, 2022-05-20).

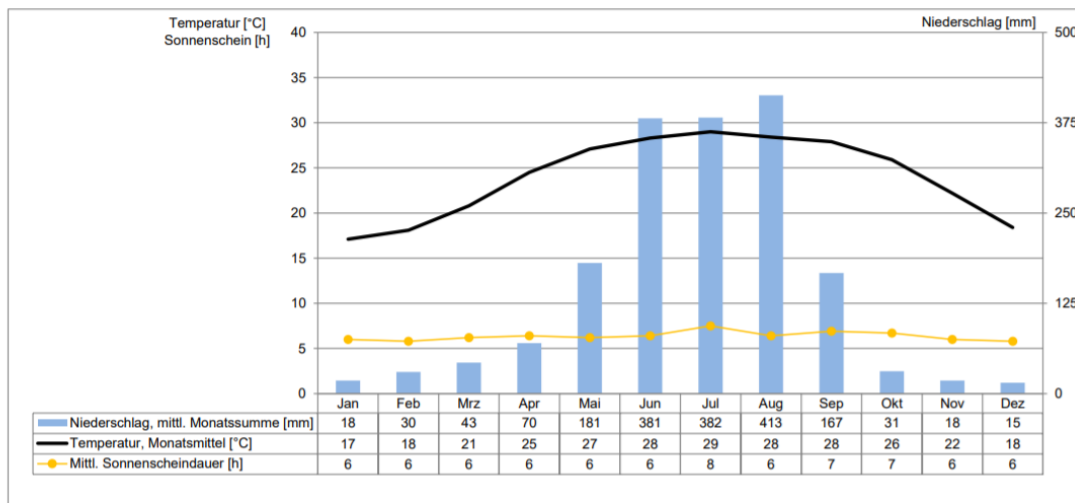
A.2: Climate Diagram of Tainan

Klimadiagramm von Tainan (Tai-nan) / Republik China (Taiwan)

Koordinaten: geographische Breite: 23° 00' N, geographische Länge: 120° 12' E

Stationshöhe: 14 m über NHN

Stationsnummer: 59358

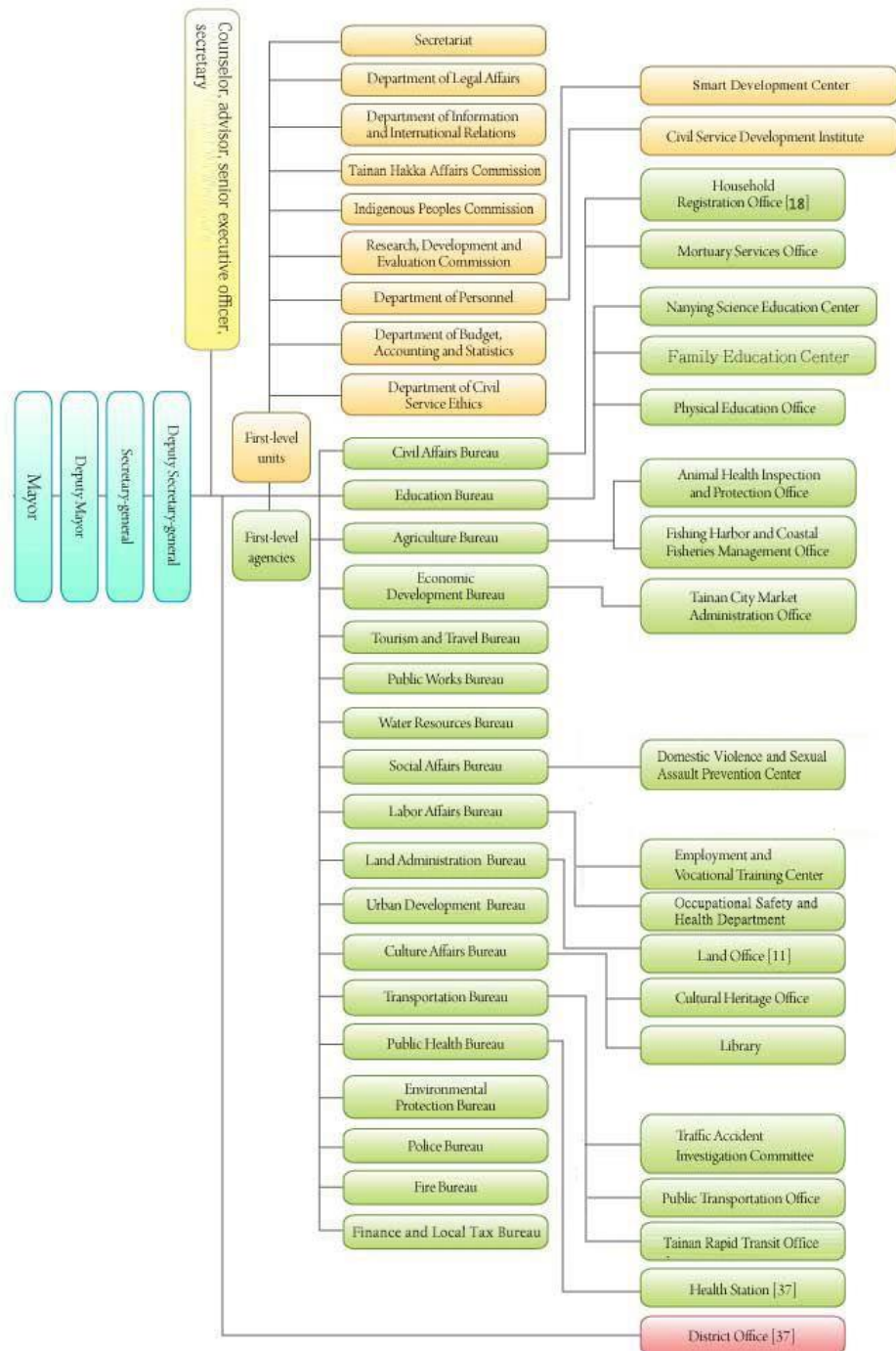


Zeiträume: Niederschlag 1897-1990, Temperatur 1892-1940, Sonnenschein 1971-1990

Climate diagram of Tainan showing average precipitation, temperature and sunshine. Source: Deutscher Wetterdienst (https://www.dwd.de/DWD/klima/beratung/ak/ak_593580_di.pdf, 20 May 2022).

Appendix B: Structure of City Departments in Taiwan

B.1: Tainan City Government Organization



Source: Tainan City Government Organization (URL: <https://www.tainan.gov.tw/en/cp.aspx?n=13211>, 04 April 2022).

B.2: Taipei City Government Organization

The “Public Works” department is responsible for vegetation management in Taipei, whose substructure is visualized in B.2.1. Directly executing the vegetation management is the substructure “Parks and Street Light Office”, which is visualized in B.2.2.

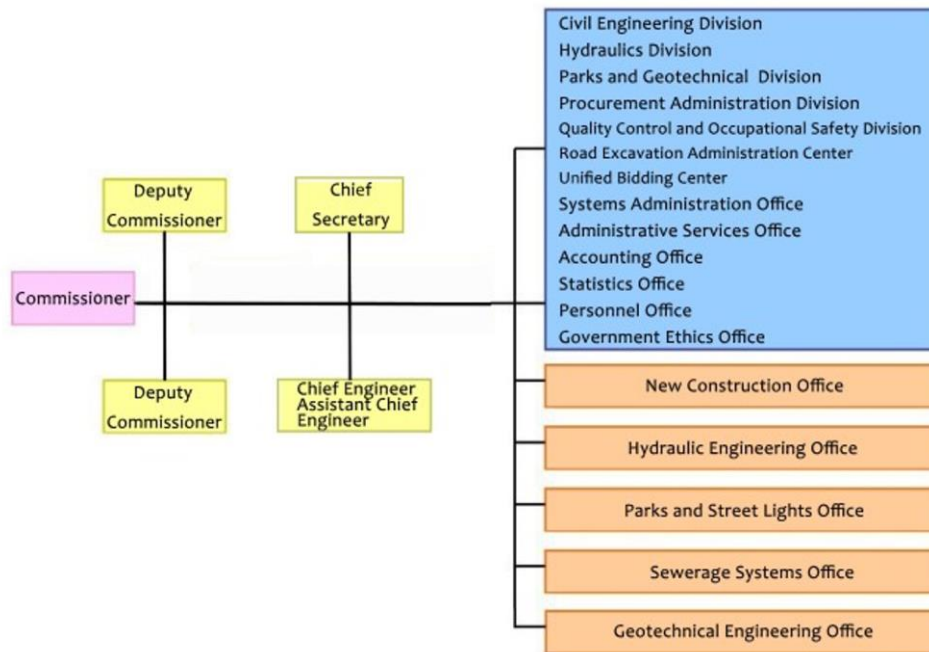
General structure of the Taipei City Government:

台北市府組織 Taipei City Government

- 民政局 Civil Affairs
- 財政局 Finance
- 地政局 Land
- 法務局 Legal Affairs
- **工務局 Public Works**
- 交通局 Transportation
- 社會局 Social Welfare
- 勞動局 Labour
- 警察局 Police
- 消防局 Fire Department
- 教育局 Education
- 兵役局 Military Service
- 體育局 Sports
- 資訊局 Information Technology
- 文化局 Cultural Affairs
- 翡翠水庫管理局 Feitsui Reservoir Administration
- 環境保護局 Environmental Protection
- 產業發展局 Economic Development
- 都市發展局 Urban Development
- 捷運工程局 Rapid Transit System
- 觀光傳播局 Information and Tourism
- 秘書處 Secretariat
- 人事處 Department of Personnel
- 主計處 Department of Budget
- 政風處 Department of Government Ethics
- 公務人員訓練處 Department of Civil Servant Development
- 都市計畫委員會 Urban Planning Commission
- 客家事務委員會 Hakka Affairs Commission
- 原住民族事務委員會 Indigenous Peoples Commission
- 研究發展考核委員會 Research, Development and Evaluation Commission

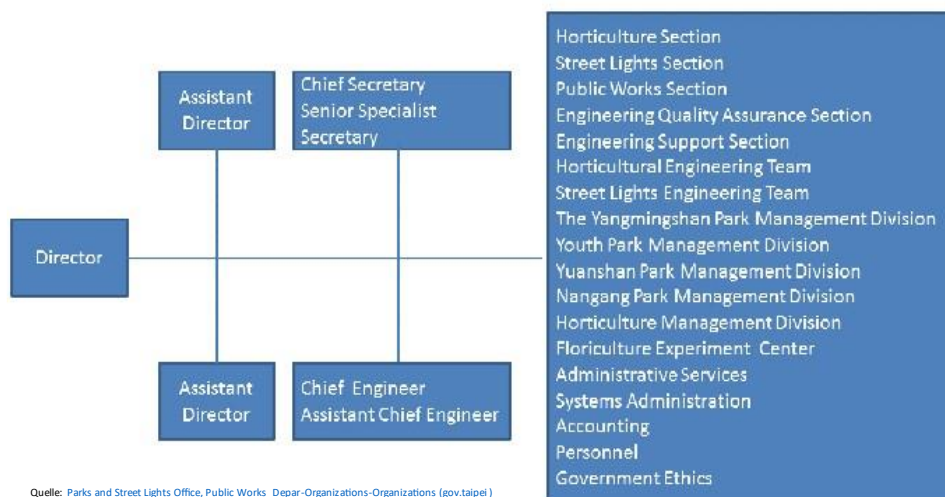
Source: Taipei City Government (URL: https://english.gov.taipei/News_Content.aspx?n=991C4C5B9571315F&sms=37F5ADE5D6397558&s=DD66CE8E89850074, 04 April 2022).

B.2.1: Organization of the Public Works Department



Source: Public Works Department, Taipei City Government (URL: https://english.pwd.gov.taipei/News_Content.aspx?n=DE8FD02E403A2FE1&sms=37F5ADE5D6397558&s=5BF8567F8EF986C3, 04 April 2022).

B.2.2: Organization of the Parks and Street Light Office



Quelle: [Parks and Street Lights Office, Public Works Department Organizations \(gov.taipei\)](https://english.pkl.gov.taipei/News_Content.aspx?n=C91DE93D025698CA&sms=37F5ADE5D6397558&s=E0BF10FF9BC76B34)

Source: Parks and Street Lights Office, Taipei City Government (URL: https://english.pkl.gov.taipei/News_Content.aspx?n=C91DE93D025698CA&sms=37F5ADE5D6397558&s=E0BF10FF9BC76B34, 04 April 2022).

Appendix C: Watering Schedule

Example on the watering schedule for Taipei in October 2021:

網站導覽 回首頁 ENGLISH 單一陳情 常見問答 雙語詞彙 台北通

請輸入關鍵字 進階搜尋

臺北市政府公園路燈工程管理處
工務局公園路燈工程管理處
Parks and Street Lights Office, Public Works Department, Taipei City Government

公告資訊
機關介紹
業務資訊
工程建設
政府資訊公開
經費報支專區
申請案件
公園處SOP
優良事蹟

首頁 > 公告資訊 > 行道樹、公園樹木預定修剪及澆灌行程
行道樹、公園樹木預定修剪及澆灌行程

公園處預定澆灌一覽表

公園處預定澆灌一覽表

※ 以下為預排行程，實際澆水量視當天狀況及

日期 Tag	單位 Behörde	項次	澆灌地點 Ort der Bewässerung	執行單位 Ausführende Einheit	趟數 Anzahl an Trips	澆水量 Wassermenge (噸數) in Tonnen	澆水面積 Fläche an Bewässerung swasser (m2)
	青年所	1	青年、228及本處	自辦	1	4	480
		2	民族公園	自辦	1	2	240
		3	林森、康樂公園	自辦	1	4	480
	關山所	4	藍山公園	自辦	1	2	240

製表日期: 11/10/2021

Source: Parks and Street Lights Office, Taipei City Government
(https://pkl.gov.taipei/News_Content.aspx?n=EBBD7C86561BDECF&sms=6C795C257A5AC781&s=881C4ED1C5E8D18F, 20 May 2022)

Example on the watering schedule for Taipei on 31 January 2022:

<div> 網站導覽 回首頁 ENGLISH 單一陳情 常見問答 雙語詞彙 台北通 </div>								
公園處預定澆灌一覽表								
製表日期: 111年1月27日								
※ 以下為預排行程，實際澆水量視當天狀況及天氣而定。								
日期	單位	項次	澆灌地點	施作單位	趟數	澆水量 (噸數)	澆水面積 (m2)	
1月31日	青年所	1	青年、228、本處及大安森林公園	自辦	1	4	480	
	陽明所	2	大豐公園、本所、忠誠公園、石牌公園	自辦	1	4	480	
		3	北投公園、親水公園、七星公園、社子公園	自辦	1	4	480	
	南港所	4	南港公園-玉東-六福-市民廣場-松壽廣場-五常-信義安康	自辦	1	3.5	420	
	花卉中心	5	碧山公園	自辦	1	2	240	
		6	湖山6號公園	自辦	1	2	240	
		7	西康公園	自辦	1	2	240	
		8	東湖4號公園	自辦	1	2	240	
	園工隊 西區分隊	9	仁愛路	自辦	1	5	600	
		10	中華路鰻鯉大道	自辦	1	5	600	

Source: Parks and Street Lights Office, Taipei City Government
https://pkl.gov.taipei/News_Content.aspx?n=EBBD7C86561BDECF&sms=6C795C257A5AC781&s=881C4ED1C5E8D18F, 20 May 2022)

Appendix D: Online Tree Cadasters

D.1: Tree Cadaster of Taipei City

A tree cadaster of Taipei City is available online (<https://geopkl.gov.taipei/>). An example tree entry is provided in the screenshot below. The number on each tree in the map denotes which tree species the tree belongs to. For example, “1” are Banyan trees, “2” are Camphor trees.



Screenshot of Taipei City tree cadaster. Source: <https://geopkl.gov.taipei/> (20 May 2022).

The following information is provided per tree (list from top to bottom, according to example in screenshot above):

- Serial Number of the tree
- Administrative district
- Location Street
- Number of tree species
- Name of the tree species
- Diameter at breast height (in m)
- Height (in m)
- Date of the survey.
- X coordinate
- Y coordinate
- Picture of the survey

D.2: Cadaster of Valued Trees in New Taipei City

New Taipei City provides an online tree cadaster designated for valued trees:
https://www.landscaping.ntpc.gov.tw/cht/index.php?act=precious_trees&code=sear

The definition of valued tree is given as:

- higher than 1.3 m and diameter of more than 90 cm
- more than 50 years old
- having a local, historical or academic value.

The website gives the opportunity to citizens to report potentially valued trees.

The information gathered and provided for each tree are (see screenshot below):

- Species name
- Scientific name
- Serial number
- Tree height (in m)
- Diameter at breast height and possibly at the bifurcation(s) (in cm)
- Location of the tree (coordinates)



Screenshot of New Taipei City tree cadaster for valued trees. Source: https://www.landscaping.ntpc.gov.tw/cht/index.php?act=precious_trees&code=sear (20 May 2022).

D.3: Cadaster of Valued Trees in Tainan City

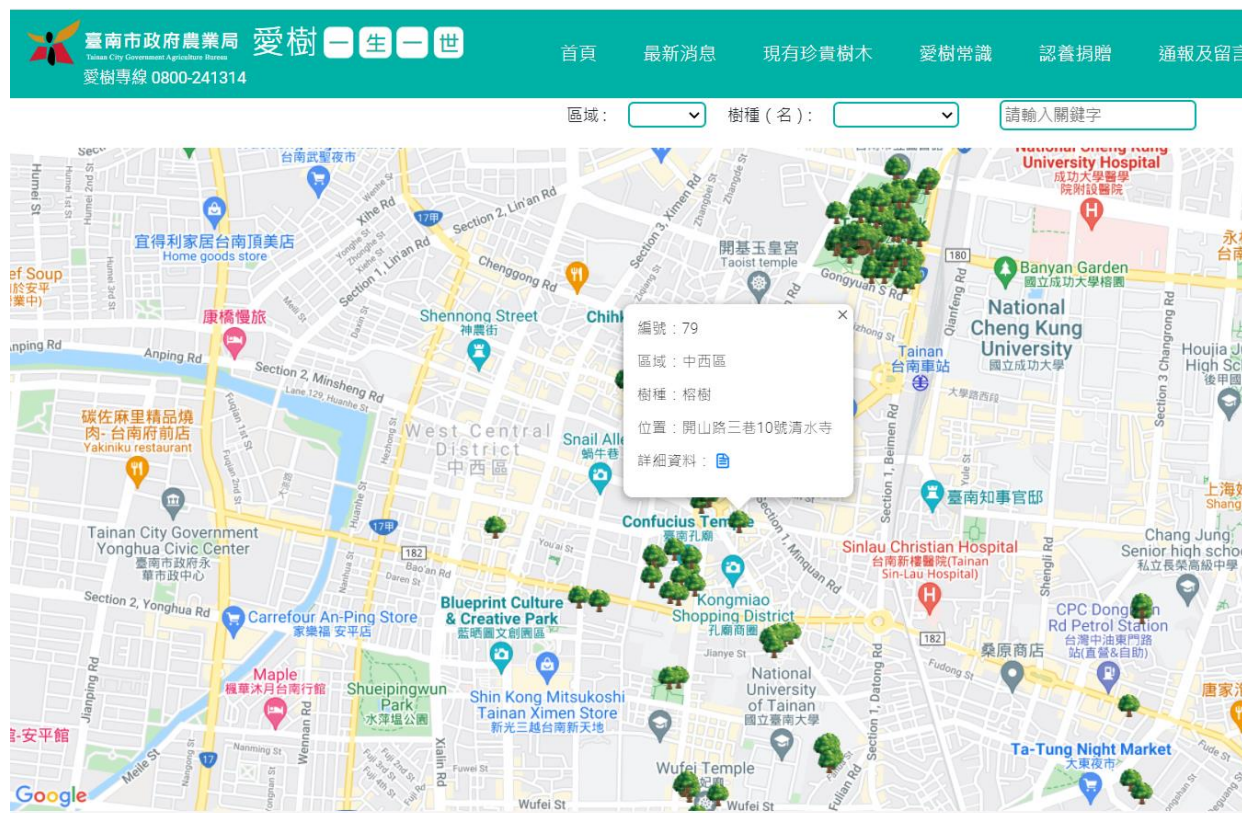
Tainan City provides an online tree cadaster designated for valued trees:
<https://oldtree.tainan.gov.tw/nowtree>

The requirements to designate a tree as valued according to the website are:

- Circumference larger than 3.8 m
- Age over 80 years
- Crown coverage of more than 300 m²
- Special meaning of the tree for the district

The information given for each valued tree on the website are (see example in screenshot below):

- Serial number of the tree
- District and street (address) of its location
- Tree species
- Circumference and age of the tree
- Short explanation of the meaning, value, or history of the tree



Screenshot of Tainan City tree cadaster for valued trees. Source: <https://oldtree.tainan.gov.tw/> (20 May 2022).

Appendix E: Involvement of Citizens in Tree Management

This website is a media platform revolving around transplanting and removing trees. The Parks and Street Light Office is responsible for this website. There are two units designated: one is the supplying tree unit, the other is the demanding tree unit. If you can supply trees, it means, that you want to remove a tree from your property. In this case you can fill out an online form asking you to give the location of the tree, how many trees should be removed and which species they are, which is the optimal environment for this kind of species, start and end date of the removal, and personal information of the applicant. Also, it is asked to upload pictures of the trees in question. Reasons for removal can be the development of the area, other usage e. g. for a bus stop, residential area etc.

供樹資料登記

如果您有樹木移出需求，請將相關資料登錄於下

樹木種植地點

樹木種植地點所屬地段地號

供給樹種與數量(請以下列格式填寫，每個樹種填一列)

1. 樹種: 雀榕, 數量: 1

2. 樹種: 樟樹, 數量: 2

.....

適合種植環境簡要敘述

我們的位置



公園路燈工程管理處

🏠 地址: 臺北市懷寧街109號

☎ 電話: (02) 23815132 轉 319

Screenshot of the form to apply for tree removal in Taipei City. Source: <https://treesmatch.gov.taipei/trees/index.php?r=officialmatch/supplyview&eid=1515> (20 May 2022).

There also exists an online form for people who can provide land for planting trees. They have to describe the conditions of their land and to which tree species their land might be suitable. Moreover, start and end date and personal information must be given.

Further, the website has a section about the legal framework of removal and plantation of trees.

Supplement 1 (Interview 1)

Survey on Urban Vegetation Management Strategies under Consideration of Heat Stress

Interviewers: Katharina Anders, Teresa Weise (Heidelberg University, Germany)

Related project: <https://www.uni-heidelberg.de/er3ds>

Interview partners: Prof. Chi-Kuei Wang, Kuei-Chia Chen, Dr. Chung-Cheng Lee

Date of meeting: 29th Nov 2021

1) How is urban vegetation (mainly trees) currently being managed (mainly irrigated)?

What is the function and meaning of urban vegetation (and trees in particular) in your area?

- preventing dust (especially trees along the roads)
- sound barrier
- shading
- aesthetics (makes the city more beautiful)
- fengshui (is like the qi of the city), example: the wind blows though the city (much as the qi flows through houses); Yinyang: banyan trees are like yin and therefore it has deeper shade; Problem with Fengshui: people might ask to remove a tree in front of their house because of bad qi/fengshui, on the other hand: people who are really into fengshui will protect and care for the trees (also water them) because when the tree dies it brings bad luck, especially true for really old trees (because there are ghosts in it)

How do heat stress or other extreme weather events (e.g. rainstorms) affect urban vegetation in your area?

- Trees are important to mitigate the urban heat island effect (Example: da'an park 大安森林公園 in Taipei is a "cooling island"?)
- drought periods are most stressful for trees
- taifuns mostly destroy trees (the important problem is damage to cars, infrastructure, etc., loss of tree itself is less of an issue as a new tree may be planted)
- insects and disease are also a stress factor

Who is responsible for irrigation of trees within the city? Which department, which persons/capacities?

The Parks and Street Lights office is in charge of the parks and road lamps, they are also in charge of irrigation.

What times of the year is vegetation management/irrigation especially important or challenging?	<ul style="list-style-type: none"> - Tainan: in the last dry season (winter, almost half a year) hardly any water was available to irrigate trees, because the available water was needed for the demands of the people (first priority); if budget is lacking, trees are not irrigated (the watering truck is quite expensive to rent, and water itself is expensive) - Taipeh: the dry season is less pronounced (because of the monsoon), maybe just a short period
What is the concept for managing urban vegetation? How is increasing influence of climate change considered? Example: Heat stress, rainstorms...	<ul style="list-style-type: none"> - Water scarcity is a problem, but (currently) not accounted for in urban vegetation management (low priority over other demand for water). - After a tree has fallen, e.g. due to taifun, a new, young tree is planted (depending on available budget).
Is there a document/publication available on this topic?	No public document, answers to specific question may be provided by the city government upon formal inquiry

2) How do vegetation management processes work, how are decisions, e.g. for irrigation, made? What adaptations are (expected to be) required considering increasing heat stress?

How is irrigation currently being coordinated?	No specific knowledge. Water trucks are deployed (seen during night) to irrigate trees. No information on schedule or strategy.
What is the process for reacting to heat stress (in certain periods, areas)?	<ul style="list-style-type: none"> - Water scarcity is a problem in dry periods. No water may be available for irrigation of trees (low priority over other water demands). - In Taipei (Nangang district?) there is a recent project (experiment) where asphalt is replaced with more permeable materials, so that rain water can pass through and reach the soil/roots - Further, there is a new policy to give the roots more space (horizontally and in depth). For older trees, the pit where the trees were planted is often too small and narrow when the tree has grown for many years. This also leads to damage of the asphalt / road (root pressure), which is why the asphalt problem is being solved by giving more space for the roots of newly planted trees.
What do you see as strengths or weaknesses of the current approach?	<ul style="list-style-type: none"> - Problems will be known/ become apparent, when an extreme situation/weather event is occurring. There is no information from observation, but this is not possible to obtain due to lack of techniques and budget. - Some incidents of mismanagement occurred, example: trees need to be trimmed before taifun season, but sometimes the trees are trimmed too much and cannot survive the influence of the taifun then (there is a rule as how to many leaves/ branches have to be cut). This overtrimming is known but hard to immediately account for because trimming it is an experienced-based task and depending on the person who is doing it (not the city manager, who is aware of the problem).

Do you observe an increase in heat stress, i.e. more irrigation being required?	The taifun wind is getting stronger, so there are more fallen or damaged trees (perceived by 2 of the 3 interview partners, 1 does not perceive an increase)
Do you see an issue of water scarcity in the (near) future, so that water might not be sufficiently available to adequately irrigate vegetation?	- Water scarcity is a current issue and may be increasing. When people need water, the government will prioritise them over irrigation of trees - there is no conflict or issue seen there.
How are tree species in the city chosen (when planting new trees)? Examples: growth rate, cost, cultural significance (if applicable), resistivity to heat or water scarcity, ...	In the past, trees were selected because they were beautiful (aesthetics), meaning they were often non-native tree species
Are there plans or discussions about changing the composition of urban vegetation to more adapted species? Example: Lower water needs, ...	- Recently (some years), there is a shift to select more native tree species, when planting new trees (or having to replace trees)

3) What kind of digital (geo-)technologies are used for vegetation management? And which technologies are planned or intended for the future?

How is the urban/micro climate being measured or monitored?	No specific knowledge, recommendation to refer to Prof. Lin
What kind of sensors are currently being used to monitor the status of urban vegetation?	No current / standard use is known. When budget is available, the government may acquire and analyze geodata, e.g. satellite imagery (which is a relatively cheap option).
What technical systems are being used for vegetation management? Examples: tree cataster, GIS, ...?	<p>- In Tainan City (administrative area, which is the size of the whole county since 5 years) the trees are being managed/mapped to be provided openly (GIS/cataster) with information on their location (handheld GPS), height, and other parameters. Mapping is done in-situ by persons employed for this job. Currently mapping is only done in the core city, the entire county is much larger but not yet available.</p> <p>- In Taizhong they wanted to map around 100,000 trees in a certain area and offered the task to Prof. Wang, but with the proposed budget it was not possible to perform TLS/MLS surveys with digital analysis of tree locations and parameters. The city government has a GIS layer of trees since around 10 years, the current task is to update the trees (e.g. which were removed); using "RFID technology"</p>

What technical solutions are being used for tree irrigation? Examples: Local water storage, tree bags, ...	Only water trucks are used to irrigate urban trees on the road. Irrigation systems are installed in parks (e.g. water sprinklers). - Making the root pits larger might lead to overall better soil humidity
What sensors, technologies, or strategies are planned or being discussed for the future?	None are known, due to lack of budget. Some trees in parks have QR codes, which contain information about the tree species (website link).
If so, what could be obstacles for implementing them? Example: cost, missing expertise or resources, ...	<i>not applicable</i>
Do you know of commercial supplier / firm offering irrigation systems (with or without monitoring component)? If so, are they of interest regarding the technique and cost? Are they implemented somewhere?	None are known, likely because of the limited budget of the city government of Tainan. It could be that there are more activities in Taipei (might inquire with the city government).
(How) are citizens being involved in urban vegetation management? Example from Germany: Watering buddies	<ul style="list-style-type: none"> - People can adopt trees or entire parks, meaning provide money (for maintenance, including watering?); works like charity. - Maybe older people care more about trees (cultural aspect) - In face of climate change more people alter their opinion of trees (certain groups), example: when building a sports stadium (name?) a lot of trees had to be removed to which people objected. Nowadays, if a lot of trees have to be removed, there will be people protesting and petitions will be started, leading to the project being delayed (but maybe not cancelled). - Example of building construction on NCKU campus: some old trees were transferred to another place and when the construction was finished, the trees were relocated to their original position. - Nowadays, when removing trees due to construction, the responsible persons need to compensate for the additional carbon (calculated from the properties and age of the tree, may ask Prof. Lin about this topic)
Who are further relevant stakeholders for your city/region, who are included in the management/irrigation process? Or who should be included?	Parks and street lights office of the city government is mainly responsible. They will consult with external persons, mostly university professors or retired professors, as well as local groups who are concerned with trees and have expertise.

Supplement 2 (Interview 2)

Interviewers: Katharina Anders, Teresa Weise (Heidelberg University, Germany)

Related project: <https://www.uni-heidelberg.de/er3ds>

Interview partner: Prof. Tzu-Ping Lin, Si-Yu Yu

Date of meeting: 2021-12-02

1) How is urban vegetation (mainly trees) currently being managed (mainly irrigated)?

What is the function and meaning of urban vegetation (and trees in particular) in your area?	<ul style="list-style-type: none"> - landscape, activity, urban flood mitigation, heat mitigation - regarding the question, how the population values vegetation: right now the maintenance effort is in focus, maybe with more knowledge and awareness about microclimatic effects in urban areas the value will increase
How do heat stress or other extreme weather events (e.g. rainstorms) affect urban vegetation in your area?	<ul style="list-style-type: none"> - mostly extreme weather events: drought vs. flood - government/contractors reacting to these events - typhoons pose an additional challenge because no plant can survive with high certainty - trees falling due to typhoons are the biggest concern (rather than dying through drought)
Who is responsible for irrigation of trees within the city? Which department, which persons/capacities?	<ul style="list-style-type: none"> - Taipei City: The Parks and Street Lights Office of the Public Works Department - Tainan City: Parks Management Division of the Bureau of Public Work - Irrigation is mostly done by contractors (companies) who are paid (i) for regular work throughout the year and (ii) for exceptional work, e.g. reaction to extreme event with short response time - Pruning and trimming are also part of the contract (besides irrigation) and are more pressing during typhoon season because of damage to property and infrastructure and affecting traffic (road blocking)
What times of the year is vegetation management/irrigation especially important or challenging?	<ul style="list-style-type: none"> - Irrigation is always important - Droughts may occur every year in southern Taiwan, but there is usually high water availability due to typhoons - La Nina years are typically tough drought years; lack of water is a huge problem then

What is the concept for managing urban vegetation? How is increasing influence of climate change considered? Example: Heat stress, rainstorms...	<ul style="list-style-type: none"> - Urban vegetation management is mostly pursued to be fast and easy (no targeted effort for specific strategy) - Budget and effort are always a consideration - Water logistics is organized by contractors; they use fresh water for irrigation (no requirement or laws from official side) - Heat stress and other effects of climate change are becoming more common knowledge, and vegetation is becoming important in the context of mitigating heat and other ecological functions/benefits - But before new approaches are implemented one would need to convince the government that vegetation is useful for making people feel better (e.g. mitigation of urban heat islands)
Is there a document/publication available on this topic?	Some information online, no specific documents

2) How do vegetation management processes work, how are decisions, e.g. for irrigation, made? What adaptations are (expected to be) required considering increasing heat stress?

How is irrigation currently being coordinated?	<ul style="list-style-type: none"> - Taipei City: Contractors that irrigate conditionally (see 1.3), even daily in summer - Tainan City: Contractors and officers/ employees at scheduled times within a month
What is the process for reacting to heat stress (in certain periods, areas)?	<ul style="list-style-type: none"> - When air temperature is rising, the city government might deploy watering trucks - Since high temperatures are common, contractors are used to irrigating every day, which is regulated in the contract
What do you see as strengths or weaknesses of the current approach?	<ul style="list-style-type: none"> - Water scarcity and the fact that fresh water is being used - More money would need to be spent on the contractor for better management
Do you observe an increase in heat stress, i.e. more irrigation being required?	yes (see above)
Do you see an issue of water scarcity in the (near) future, so that water might not be sufficiently available to adequately irrigate vegetation?	yes (see above)

How are tree species in the city chosen (when planting new trees)? Examples: growth rate, cost, cultural significance (if applicable), resistivity to heat or water scarcity, ...	<ul style="list-style-type: none"> - some cities have rules or recommendations for tree species - urban trees are often native or selected for cultural reasons - sometimes diversity of species is a motivation, or provision of shading (e.g. in parks on NCKU campus with large crown areas)
Are there plans or discussions about changing the composition of urban vegetation to more adapted species? Example: Lower water needs, ...	<ul style="list-style-type: none"> - native trees in Taiwan are adapted to hot / humid, and variable conditions, so there is no urgent need to change - no discussions currently known - referral to example in the USA working on "low maintenance trees" in the frame of the LEED program (Leadership in Energy and Environmental Design)

3) What kind of digital (geo-)technologies are used for vegetation management? And which technologies are planned or intended for the future?

How is the urban/micro climate being measured or monitored?	<ul style="list-style-type: none"> - Central Weather Bureau CWB - IoT sensors: sensor networks (from bclab of Prof. Lin) are used for monitoring how the climate affects humans (thermal comfort) - So far, monitored micro-climate parameters by Prof. Lin's lab have been passed on to the city government for urban planning purposes (current project); in the future, data might be used for tree management
What kind of sensors are currently being used to monitor the status of urban vegetation?	Mostly meteorological variables, no soil humidity sensors or similar so far
What technical systems are being used for vegetation management? Examples: tree cataster, GIS, ...?	<ul style="list-style-type: none"> - GIS - Remote sensing imagery is used by the government for agriculture planning and monitoring; sometimes to decide in which areas (outside city centers) trees are needed
What technical solutions are being used for tree irrigation? Examples: Local water storage, tree bags, ...	<ul style="list-style-type: none"> - Strong focus on manpower (comparably low cost) for irrigation, rather than technical solutions - Some cities (e.g. Taoyuan) use retention bricks to hold water for the trees, which are a good solution for Taiwan because there are periods with water surplus and with lack (opposite extremes) - New technologies/strategies are being tested / experimented in certain cities or areas, but cannot be known if successful and if they will be implemented in other places
What sensors, technologies, or strategies are planned or being discussed for the future?	<ul style="list-style-type: none"> - nothing specific is known - one future goal is the concept of sponge cities

If so, what could be obstacles for implementing them? Example: cost, missing expertise or resources, ...	<ul style="list-style-type: none"> - The biggest obstacle is limited money - It is difficult to measure the success of new technologies (would need solid key performance indicators), which is required to convince the government to invest
Do you know of commercial supplier / firm offering irrigation systems (with or without monitoring component)? If so, are they of interest regarding the technique and cost? Are they implemented somewhere?	<ul style="list-style-type: none"> - No specific knowledge of any - Irrigation is done by contractors, who manage the details of how irrigation is done (they will try to do it as cost-efficiently as possible, see note on manpower)
(How) are citizens being involved in urban vegetation management? Example from Germany: Watering buddies	<ul style="list-style-type: none"> - not really involved, though the perception of trees is positive (people perceive it as sad if a tree is destroyed during typhoon season) - involvement is difficult for citizens because urban trees are government property (there might be fees if any modification is made, even watering) - there are actions where people protest against cutting of trees or overtrimming (raising government awareness that trees are not only an ornamentation, but important for the wellbeing of the population) - public participation is partly invited in the frame of urban planning, e.g. a new part or area - Companies/investors can adopt tree areas/parks to obtain permissions, e.g. to add floors to newly constructed buildings (incentive to fund urban vegetation to receive benefits); they will hire a contractor to manage the tree area/park
Who are further relevant stakeholders for your city/region, who are included in the management/irrigation process? Or who should be included?	Government and contractors are most important; at the moment citizens are not really involved