A GEOSPATIAL APPROACH TO MAPPING JACARANDA TREE DISTRIBUTION IN JOHANNESBURG, SOUTH AFRICA.

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November 2023

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Declaration

I declare that this dissertation is my own, original work, except where otherwise acknowledged. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted previously for any degree or examination, at this, or any other university.

_____________________________ 24 November 2023_

Rohini Chelsea Reddy Date

Abstract

Accurate mapping of the spatial distribution of invasive species is vital for the implementation of effective monitoring and management strategies. In countries where resources are scarce and costly, citizen science provides a cost-effective and accurate alternative for large-scale data collection. Citizen's familiarity with their environment contributes to aspects such as accurate identification of features on the landscape. Advances in a geographic information system (GIS) together with open-sourced photography from Google Street View, provide accurate methods for in-field and remote validation of citizen science data for invasive mapping and assists with the creation and compilation of maps to visualize the spatial distribution of invasive plants upon the landscape. In this study, the first spatial distribution maps for invasive tree species, *Jacaranda mimosofolia* (common name: Jacaranda), are created for the City of Johannesburg (CoJ). Jacaranda trees are well-known by citizens in the CoJ for their district purple flowers which blanket the landscape during springtime. A combination approach using citizen science, GIS, and Google Street View for data collection, analysis, and creation of the first spatial distribution map of exact location and prevalence of Jacaranda trees within certain suburbs of the CoJ, is produced. A total of 8,931 ground-truthing geopoints together with extensive Google Street View validation for Jacaranda tree presence, formed the basis of accurate spatial distribution maps. The first research question of this study focused on the spatial distribution of Jacaranda trees in the CoJ and was answered as a total of 54 suburbs were confirmed as having a large presence of Jacaranda trees in the CoJ. Citizen science data collected a total of 488 geotags for possible Jacaranda tree presence in the CoJ, over a 75-day online survey collection period. Although citizen science data provided a lower spatial resolution compared to successful fieldwork and

Google Street View approaches, citizen science data provided very high accuracy for the identification and geolocation of Jacaranda tree presence in the CoJ which answers the second research question based on the effectiveness of the geospatial approach towards citizen science, ground-truthing and Google Street View as data collection methods.

Since the accuracy of citizen science resulted in 66% of collected geotags within the categories of 'very high', 'high' and 'moderate' accuracy ranges of between <7-24m from a confirmed Jacaranda tree, together with the accuracy of 8,931 in-field collected geolocation of Jacaranda trees and Google Street View's accuracy and capability of collecting street view imagery – it is concluded that the combined approach of ground-truthing, citizen science and Google Street View contribute not only to effective data collection, but also towards the successful mapping of Jacaranda tree presence in the CoJ.

Acknowledgements

First and foremost, I would like to thank my supervisor, Prof. Jennifer Fitchett. Prof, thank you for seeing the potential in me from my Honours year and for providing the best teaching support I have received throughout my entire academic career. You have always been patient, understanding and kind from the time I changed my entire focus four months into the year, right the way through to my final days of submission whilst I juggled moving to a new city. Your passion is admirable.

I would like to thank the *South African National Space Agency* for awarding me a bursary that provided the funding for my Masters studies. I would also like to acknowledge the support and assistance from the fantastic team at *Esri South Africa*. To Lizette Rust for offering me an abundance of resources and support. To Cameron Muller for being the best Mentor and now one of my role models in the GIS field. To Deon Lengton for helping with *Esri* devices and providing support during fieldwork. To the *Esri* Interns who kept me smiling (and dancing). Specifically, I would also like to acknowledge Lindokuhle Nhlabathi, Shelton Ndlovu, Basil Rabophala, Tears Rankapole, and Linda Mabeso for accompanying me on data collection during my fieldwork campaigns, you each made the fieldwork component one of the best experiences of my academic career. To everyone from the *Esri* Durban office for sharing this academic journey with me.

I would like to acknowledge all anonymous respondents involved in the survey aspect of my research project. I would also like to thank Dean Peters and Dale Carter from the *City of Cape Town* for the ongoing support and motivation towards the completion of my studies.

Last, but certainly not least, I would like to thank my entire family for their immeasurable support. To my grandparents – Ma and Pa, thank you both for ensuring I get away from my desk with weekly brunch and coffee outings which were always filled with laughter and wise words of encouragement. To my little brother, Kieron, for always offering warm hugs, funny faces, and constant reminders to make time for fun.

To my parents, Sangita and Noel, this research project is dedicated to the both of you. I would never have made it this far if it wasn't for the fighting spirit you have instilled in me. Thank you for the endless amount of love, guidance, understanding, support, and patience you both continue to offer.

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List of Acronyms and Abbreviations

CoJ: City of Johannesburg

EVI: Enhanced Differential Vegetation Index

GIS: Geographic information system

GLONASS: Global Navigation Satellite System

GPS: Global Positioning System

GUIDs: Globally Unique Identifiers

KML: Keyhole Markup Language

LAI: Leaf Area Index

LHWP: Lesotho Highlands Water Project

NDVI: Normalized Differential Vegetation Index

PPGIS: Public Participation GIS

PSHB: Polyphagous Shot Hole Borer

QR: Quick Response

SABAP: The South African Bird Atlas Project

SQL: Structured Query Language

TOD: Transit-oriented Development

VGI: Volunteered Geographic Information

Glossary

Capture: This is a single frame which is captured from a desired perspective using Google Street View. This single frame, or capture, has embedded geographic co-ordinates from which the street view was captured.

Citizen Science: “The collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists” (Oxford 2016). In this study, the general public were not actively engaged in the analysis of data, but rather with data collection only.

Crowdsource: Is to “obtain (information or input into a particular task or project) by enlisting the services of a large number of people, either paid or unpaid, typically via the Internet” (Oxford 2016). In this study, the term ‘crowdsourced’ must be read with an understanding of the citizens of the City of Johannesburg (CoJ) as the unpaid volunteers who obtained Jacaranda tree information for the purpose of this study.

Esri: *Esri* is a private company, started in 1969 where the first commercial geographic information system was developed. Today, *Esri* is a world leader in GIS software.

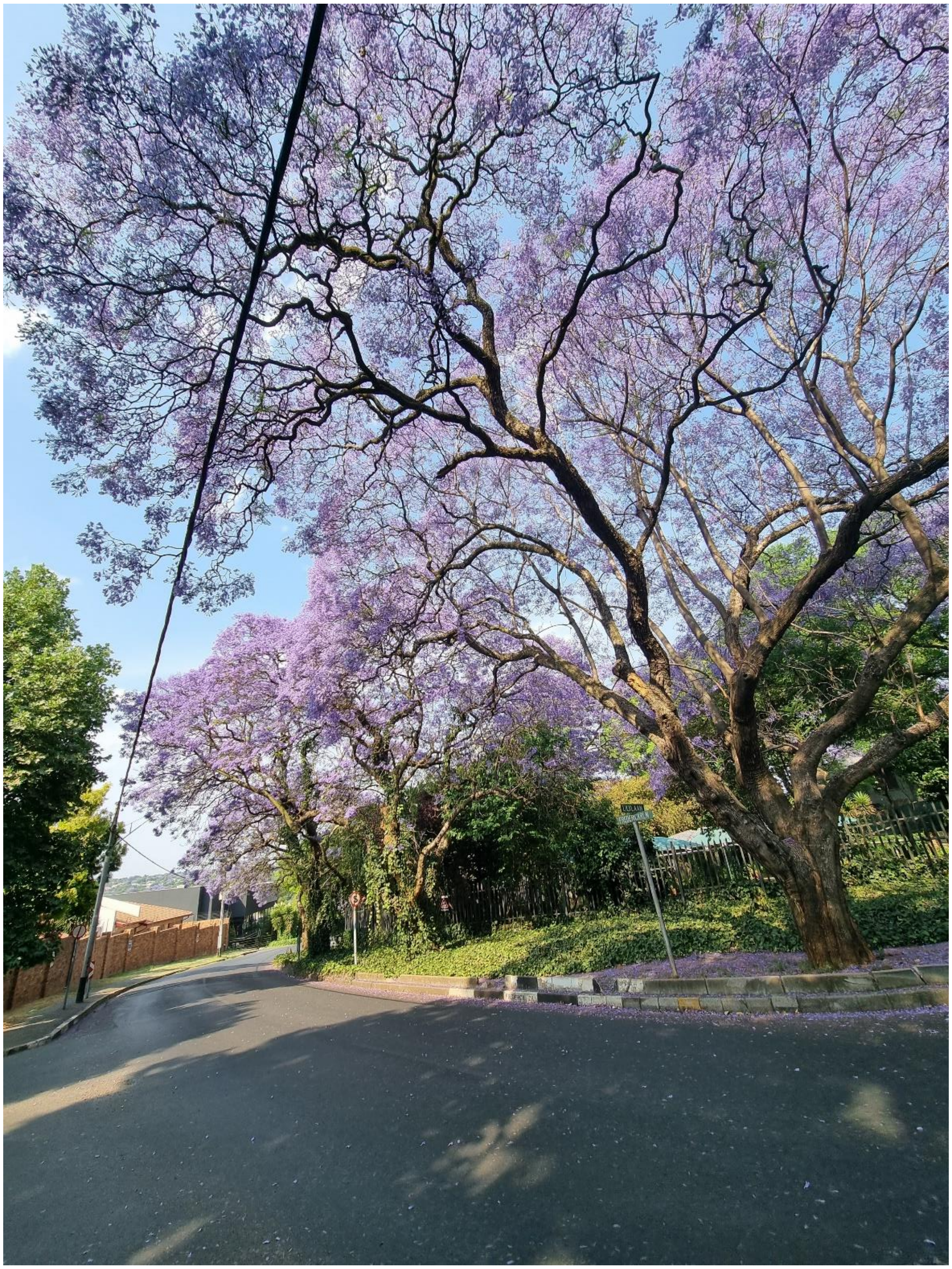
Geographic information system (GIS): A geographic information system produces maps and manages and analyzes a wide variety of types of data. In this study, a GIS assisted with the successful mapping of Jacaranda tree presence and distribution in the CoJ, whilst simultaneously providing the mapping platform for citizen science data collection.

Geopoint: These points represent the exact geographic co-ordinates of a Jacaranda tree collected through two field-campaigns in the months of August and October, using *Esri's Quickcapture* application.

Geotag: This tag represents a single citizen science capture of a Jacaranda tree using *Esri's Survey123 Connect,* which is a sophisticated geocoded survey platform.

Ground-truth(ing): This process involved ground-based validation of Jacaranda tree presence whereby physical visits to Jacaranda tree locations were done.

CHAPTER 1: INTRODUCTION



Own photograph taken in the suburb of Northcliff, on 12 October 2022.

1.1 Background

The City of Johannesburg (CoJ) agglomerates more than one third of the Gauteng City-region population (Schäffler and Swilling, 2013). The CoJ is one of the fastest growing cities in South Africa with the highest numbers of migrants (Rasmeni and Mudia, 2019). South Africa's history of apartheid posed urban pressures which are still seen today (Risimati and Gumbo, 2018). Segregation of ethnic races lead to the CoJ having division of northern suburbs of the CoJ as affluent and southern suburbs as poor (Rasmeni and Mudia, 2019). The division of suburbs influenced a tree planting boom where many invasive tree species were planted predominantly in these affluent areas in an effort to reduce dust, air, heat, and noise pollution in the CoJ (Schäffler and Swilling, 2013). One of these many tree species was the *Jacaranda mimosifolia* (common name: Jacaranda).

Jacaranda is a deciduous tree belonging to the Bignoniaceae family (Xie *et al.* 2021). Jacaranda trees were brought to South Africa from Brazil in the 1800s not only to address pollution from increased mining in the CoJ, but also to beautify the landscape (Gachet and Schuhly, 2009). Jacaranda trees are identifiable by their bright purple flowers which blossom in spring and form a large part of the urban identity and urban forest of the CoJ (Schäffler and Swilling, 2013).

Apart from the excitement which springtime Jacaranda flowering offers to citizens, these trees are also notorious for their conservation status. Jacaranda trees hold category 3 alien-invasive status and hold a unique position as an "invasive flagship species" (Fitchett and Fani, 2018, p. 470). Owing to this status, Jacaranda trees are prohibited from being replanted, transplanted, or sold – as a result, the aging population of Jacaranda trees will not always be part of the urban fabric of the CoJ (Schäffler and Swilling, 2013). Spatial information on the distribution of

Jacaranda trees around the CoJ is scarce, with only one remote sensing-based study to have identified the location of Jacaranda trees in the CoJ, with limited accuracy (Newete *et al.* 2022). Owing to this, it is imperative to know the spatial distribution of invasive Jacaranda trees, as stated in the primary and secondary aims of this study. The aim to produce the first Jacaranda distribution map in the CoJ using a three-way combined data collection approach ensures accurate and efficient data collection points and resulting maps, as seen later in this dissertation.

Citizen science, in this context, has been defined as “the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists” (Oxford 2016). In this study, the general public were not actively engaged in the analysis of data, but rather with data collection only. Citizen science has been used in vegetation distribution mapping as data is collected at a fine spatial resolution over a large geographic area, at a very low cost (Chandler *et al.* 2017). There is an increased use of citizen science for invasive tree mapping (although often for their removal), providing data outputs which are both reliable and accurate in complex urban environments (eg. Hawthorne *et al.* 2015; Seiferling *et al.* 2017). This provides a framework for mapping Jacaranda trees which both contributes to the growing literature on mapping invasive species and assists those in monitoring the current distribution of this more unique flagship invasive. Moreover, as stated in the secondary aims, a citizen science approach for invasive species mapping in the CoJ is useful for both data collection and for quantifying the accuracy of citizen science data (eg. Hawthorne *et al.* 2015).

Citizen science data collection is limited by issues of accuracy in the identification of specific tree species by non-specialists; these are addressed by ground-truthing through physical fieldwork and the use of digital imagery such as Google Street View (Visser *et al.* 2014). Cross referencing of citizen science logged geopoints with trees identified on Google Street View, together with ground-based fieldwork – permits both an assessment of accuracy of citizen science as an approach, and a more comprehensive and accurate Jacaranda distribution map as explored in the research questions of this study - as linked to the spatial distribution of Jacaranda trees in the CoJ as well as the effectiveness of the geospatial approach towards citizen science, ground-truthing and Google Street View as data collection methods.

1.2 Rationale

One of the many purposes of invasive mapping is to represent their distributions across both local and global landscapes and environments (Pedrotti 2012; Seiferling *et al.* 2017). Knowledge about the main features of a landscape, such as invasive presence, is imperative for efficient and effective maintenance and monitoring (Qiu *et al.* 2019; Choi *et al.* 2022). Repeated mapping of vegetation or individual species over time permits a collection of data which may offer information such as rate of growth, phenological changes, direction of growth and population presence – to name a few (Pedrotti 2012; Dujardin *et al.* 2022). Furthermore, it provides a visual interpretation of any trends which occur long-term and assists with possible future trend analysis (Masocha and Skidmore, 2011; Buldrini *et al.* 2015).

There is an urgent need for accurate mapping of the spatial distribution of invasive species as their presence leads to a loss of biodiversity and ecosystem services (Visser *et al.* 2014). Jacaranda trees as an invasive species share similar needs for their spatial distribution to be mapped for the CoJ (Newete *et al.* 2022). Additionally, given the importance of Jacaranda trees to the identity of the CoJ, and the use of Jacaranda lined streets in photography and videography during the spring season, a map of their distribution has social and cultural value. These maps provide vital location information for citizens to experience well-known Jacaranda blooms, whilst simultaneously allowing for improved monitoring of these invasive trees for both ageing analysis and the presence of *Polyphagous Shot Hole Borer* (PSHB) – an invasive insect which burrows through tree bark, weakening the tree's ability to transport moisture – presenting great risk to many urban trees (Paap *et al.* 2018; Newete *et al.* 2022).

Remote sensing has been widely used for invasive species mapping; however, challenges arise when mapping heterogeneous landscapes which are vegetation dense (Fonji *et al.* 2014). These challenges include cost – as ground-truthing is expensive and time-consuming, spectral mixing – as similar spectral reflectance from other land cover types skew the dataset, and misclassification – as coarse spatial resolution results in several land cover types as classified into a single type (Huete *et al.* 2002). Citizen science presents the opportunity for large-scale ground-validation of invasive Jacaranda trees, at a high spatial resolution and low cost (Tang and Liu, 2016). Ground-truthing by field-visits are reduced in time as geolocation of Jacaranda trees are collected through citizen science, providing random sampling sites for ground-validation (Hawthorne *et al.* 2015). Moreover, Google Street View is a free platform compiling street-level views of roads and pavements across the world, which is useful for the identification of streets where these urban trees are located, without being physically present in-field (Visser *et al.* 2014).

1.3 Aims and Objectives

The primary aim of this study is to produce the first map of the distribution of Jacaranda trees in the CoJ using a geospatial approach through a combination of citizen science, ground-truthing and Google Street View. The secondary aim is to explore the accuracy of citizen science in mapping distinct tree species. This will be achieved through the following objectives:

1) To use a citizen science approach to crowd-source data on the location of Jacaranda trees in the CoJ and to compare this data to ground-truthing and Google Street View data on confirmed Jacaranda tree presence in the CoJ, to then map all three data collection methods through an integrated geocoded survey and GIS platform.

2) To use both a GIS and Google Street View to validate ground-truthing data of both reported and un-reported Jacaranda tree locations in the CoJ, as reported from citizen science.

3) To perform an accuracy assessment of the citizen science derived data and map the level of accuracy on the final product.

1.4 Research Questions

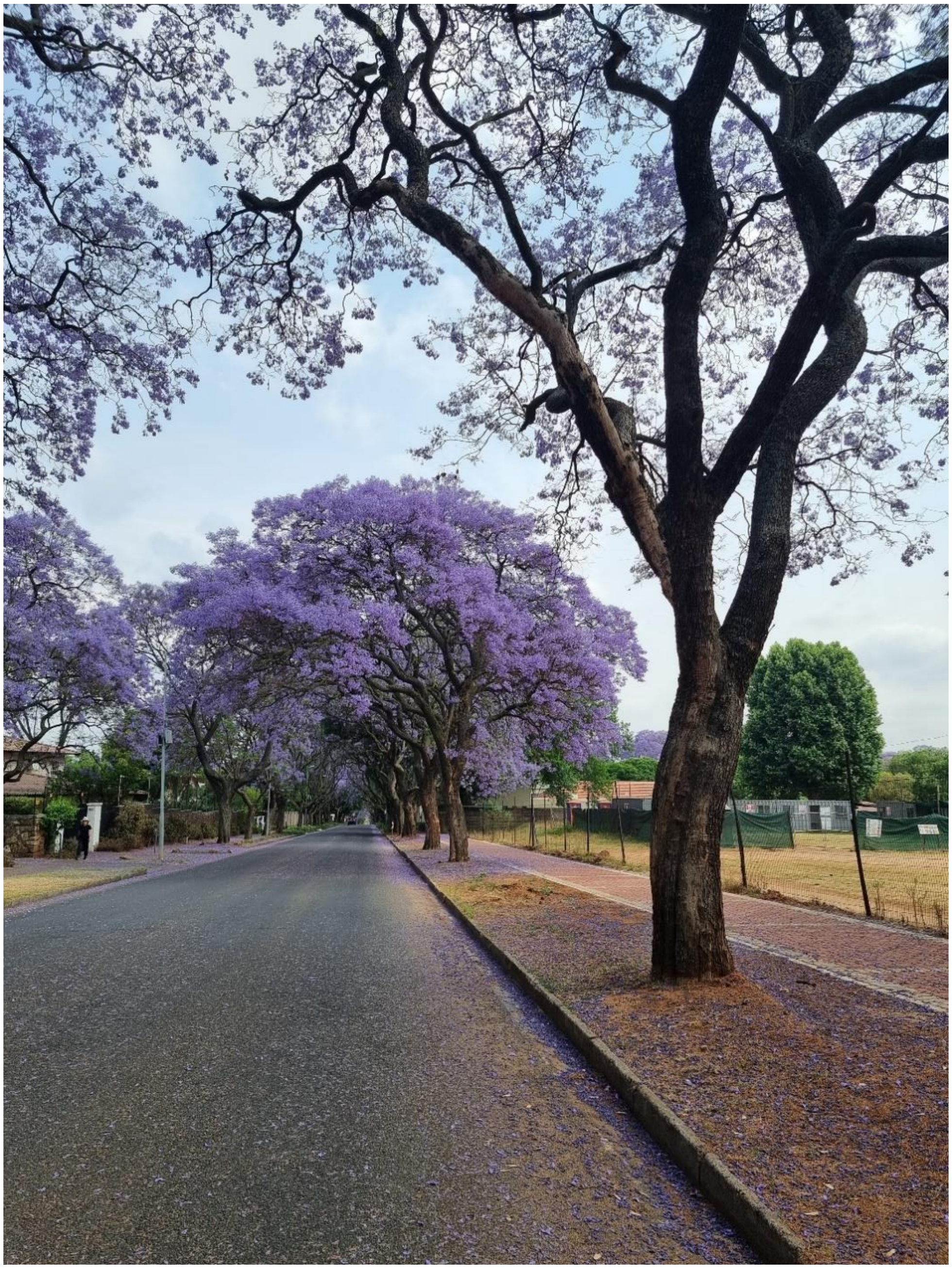
1) What is the spatial distribution of Jacaranda trees in the CoJ?

2) How effective is the geospatial approach in the combined citizen science, Google Street View, and ground-truthing methods of data collection?

1.5 Structure of the Dissertation

This dissertation comprises seven chapters. Chapter two explores studies that have engaged a GIS, citizen science and Google Street View as tools for successful vegetation mapping, together with the pertinent literature on the CoJ's urban forest. Chapter three provides contextualization of the study site with reference to the climate, geography, urban forest, and population dynamics. Chapter four provides a detailed breakdown of the methods used in this research project, with reference to studies which have either engaged in similar or alternate methodological approaches. Chapter five provides a critical analysis of all core data components and presents these results along with their limitations. Chapter six provides a detailed discussion of each core component of this study where individual data sources are analyzed for trends and patterns on significant discoveries and their implications for this study and for future applications. The final chapter concludes with a synthesis of the study and achievement of the aim and objectives, followed by future research avenues and implications fostered from this research study. Due to the hierarchy of sections, sub-sections, and sub-sub-sections, to allow for ease of identification of figures and tables, figures and tables are numbered according to the subsection in which they fall.

CHAPTER 2: LITERATURE REVIEW



Own photograph in the suburb of Waverley, taken on 17 October 2022.

2.1 Introduction

Vegetation mapping is of importance as it provides spatial information on the location, type, direction, and rate of spread of plant species (Bois *et al.* 2011). In the CoJ, where the urban forest is one of the world's most extensive, a spatial understanding of various urban forest species is imperative for effective monitoring and management of invasive species (Fitchett and Raik, 2021; Newete *et al.* 2022). This is especially significant for effective conservation efforts to manage and plan for future trends (Jordan *et al.* 2012; Thompson 2016). The literature review provides an overview of the published research reflecting tools that are used in recording vegetation, with a focus on the effectiveness of the geospatial approach towards the combined use of citizen science, Google Street View, and ground-truthing as data collection sources, as stated in the research question. In addition to reviewing existing studies that map vegetation, this literature review also critically reflects on methodologies employed to assess the accuracy of each of the data collection sources used, along with capabilities for spatial distribution mapping of invasive species in both the CoJ and other cities with heterogeneous urban forests.

2.1.1 Background and Previous Research

Today, alien invasive Jacaranda trees are mostly found in the northern suburbs of the CoJ, as these were typically the wealthy suburbs during post-colonial times (Newete *et al.* 2022). Although Jacaranda trees are abundant in the CoJ's landscape, studies linked to spatial distribution are few, with many existing studies focusing on remote sensing mapping approaches (Jombo and Adam 2018; Abutaleb *et al.* 2021; Newete *et al.* 2022). Newete *et al.* (2022) present spatial distribution mapping of Jacaranda tree presence in the CoJ using remote sensing efforts revealed four main suburbs of Saxonwold, Houghton, Parkview, and Parkwood as high prevalence Jacaranda tree suburbs. Though remote sensing is a commonly used tool, this study highlighted two research gaps linked to spectral mixing and misclassification of tree canopies when mapping a heterogeneous landscape such as the CoJ.

The first research gap presented is towards the exclusion of smaller suburbs within the CoJ with potential Jacaranda tree presence as remote sensing efforts were unable to detect the small-scale tree canopy cover of these suburbs (Newete *et al.* 2022). Since Jacaranda trees are a category three invasive species, it is important to identify all suburbs for their presence and to utilize both small and large-scale mapping techniques. A secondary data collection technique through fieldwork was aimed at collecting Jacaranda tree data using a hand-held GPS device, however, areas visited were few in numbers, chosen at random, and included major parks and suburbs only (Newete *et al.* 2022). To achieve a spatial distribution map which is accurate, all areas of the CoJ must be visited or considered irrespective of suburb size and independent of known areas for Jacaranda tree presence.

By this, citizen science as a tool is effective to crowd-source data on both Jacaranda tree location and known presence as citizen science data is sourced at a fine spatial resolution, over the geographic area in focus (Chandler *et al.* 2017). Citizen science data can form the foundation for other spatial distribution mapping efforts to confirm or validate Jacaranda tree presence. This coincides with the use of ground-truthing and Google Street View as two capable tools for the validation, confirmation, and mapping of the spatial distribution of Jacaranda trees in the CoJ

(Ives *et al.* 2017; Seiferling *et al.* 2017). Ground-truthing and Google Street View data collection methods can be compared to citizen science data collection for a measure of accuracy to be produced, together with providing an assessment of the effectiveness of using a geospatial approach in this regard (Bois *et al.* 2011). These three data sources combined will address any gaps which may present themselves in the data collection period.

Therefore, it is important to highlight areas where data has not been collected, as well as to consider additional data collection methodologies to curb these research gaps for more accurate spatial distribution mapping.

2.2 Tools for Recording Vegetation

Vegetation has been observed and recorded by both scientists and members of the general public for hundreds of years (Marsham 1789; Sparks and Carey 1995). This has a range of applications from tracking phenological shifts to monitoring invasive species and identifying biomes. The current toolbox of methods used in recording vegetation includes the use of citizen science, a combination of Google Earth with Google Street View, as well as social media. Each tool provides fundamental opportunity for high-resolution data collection, at varied geographical scales, which is explored in this section.

2.2.1 Citizen Science as a Tool

Citizens as volunteers provide support for sampling activities which are essential for both biodiversity monitoring and public awareness of ecological changes (Miller-Rushing *et al.* 2012; van der Wal *et al.* 2015). Citizen science, in this context, has been defined as "the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists" (Oxford 2016). These citizens were not actively engaged in the analysis of data, but rather with data collection only. Volunteers for citizen science projects are made up of the public with a focus on the connection of people to science (Wright *et al.* 2015; Vahidi *et al.* 2021). When citizens participate, it empowers the public to make direct contributions to scientific research (Dickinson *et al.* 2012; Miller-Rushing *et al.* 2012).

Citizen science can encompass 'crowdsourcing' and 'public participation' (Brown and Kytta 2014; Fonji *et al.* 2014; Vahidi *et al.* 2021). However, there are distinct differences between these terms. Public participation is the participation by the public-at-large to scientific research, as well as political decision making, urban planning and other applications (Cooper *et al*. 2018). Here, scientific research is argued to have never been the exclusive domain of professional scientists as many 'amateur' scientists have been successful in this regard (Cooper *et al*. 2018). Scientific research is mostly involved in routine with documenting, monitoring, analysis and writing as mundane tasks which almost anyone can make useful contributions towards – if they are careful and stringent to protocol (Cooper *et al*. 2018). In citizen science, a citizen scientist is concerned only with science and not scientific research. In this study, citizens did not have to be literate to the scientific process, but merely capable of using simple data tools, such as user-friendly geocoded surveys. An example of citizen science in this regard is seen in studies from the data logging tool named *CyberTracker*. *Cybertracker* was tested in the Karoo National Park, South Africa, where two citizens could not read or write but were successful in the thorough data collection and monitoring of endangered Desert Black Rhino through the *CyberTracker* field computer (Liebenberg *et al*. 1999).

Crowdsourcing is commonly used to "obtain information or input (into a particular task or project) by enlisting the services of a large number of people, either paid or unpaid, typically via the Internet" (Oxford 2016). Therefore, the complexity and ambiguity between the terms of citizen science, crowdsourcing, and public participation as three separate concepts, must be acknowledged (Cooper *et al*. 2018). Though citizen science, crowdsourcing and public participation are similar by the involvement of the public for data collection, each term clearly differs by the level of which participants are expected to engage on (Harvey 2012). Therefore, citizen science is the most correct term for this study as the participation of the public-at-large for the purpose of science was evident. Moreover, the public in this study must be understood as citizens of the CoJ who each participated on a voluntary basis without the enlistment of their services or benefit of an income nor an incentive as crowdsourcing approaches would offer.

In vegetation recording, a citizen science technique assists with the cross-validation of professional data collection as a larger database consisting of both professional ground-control data and citizen observation data is created (Roman *et al.* 2017; Roy-Dufresne *et al.* 2019). These multiple stakeholder collaborations present new opportunities not only for database management, but also for vegetation distribution modelling (Roy-Dufresne *et al.* 2019; Azzurro and Cerri, 2021). Information extracted from citizens who live near the environmental region of interest often complements or even replaces professional methods of ecological sampling (Ives *et al.* 2017; Azzurro and Cerri, 2021). These diverse uses of citizen science have each assisted in increasing public awareness of science by incorporating local knowledge of citizens into scientific research (Wright *et al.* 2015; Roman *et al.* 2017). This promotes advocacy among citizens as more learning opportunities are presented and diverse views are considered (Cooper *et al.* 2008; Vahidi *et al.* 2021). However, most of these citizen science programs are carried out in North America or Europe, with few programs found in Africa, Asia, and Central and South America (Chandler *et al.* 2017).

2.2.1.1 Citizen Science Projects

Globally, Citizen science projects in biodiversity and conservation management have attracted increased attention due to awareness of citizen science programs (Newman *et al.* 2012; Nugent 2018). Two global programs, among many others, are those of *iNaturalist* and the *Global Coral Reef Monitoring Network* (Chandler *et al.* 2017). *iNaturalist* is a mobile application which serves the global community for nature observation and identification by means of photography with embedded information on the date and location of the photograph for scientists and society to learn from (Nugent 2018). The *Global Coral Reef Monitoring Network* is an initiative which provides updated scientific information on the status and trends of coral reef ecosystems throughout the world (GCRMN 2020). Locally, a range of citizen science programs have been implemented by the *Animal Demography Unit* (ADU), based at the University of Cape Town. *The South African Bird Atlas Project* (SABAP) project is another well-known local citizen science project whereby bird species distribution and abundance are mapped across several countries in southern Africa through digital mapping (SABAP2 2023). *Cape Citizen Science* is a project based in the City of Cape Town, supported by the *Forestry and Agricultural Biotechnology Institute*, with a focus on utilizing citizen science to collect information on plant diseases and insect pests, to protect the flora of the greater Cape floristic region (Cape Citizen Science 2023).

These are but a few of the many other well-known projects which use citizen science for data collection. Though the above-mentioned projects are successful on both global and local scales, certain data collection projects may require location specific information. In the projects listed above, a mobile application is commonly used as the platform for users to collect data, however, these applications lack a geospatial component whereby a device's precise location can be accurately and immediately provided therefore shadowing the location data from where the user is situated. This automated accuracy-controlled approach has proven to drastically increase data accuracy – as opposed to a user manually inputting their location – where a spatial component is necessary for reporting (Atzmanstorfer et al. 2014). Hence, a margin for location error, based on citizen inaccuracy, must be considered.

Moreover, many of the above-mentioned projects depend on the aggregated answers from citizen science reports as a marker for validity and accuracy of true recordings (Swanson 2016). This too provides margin for error as additional validation tools are not utilized to leverage possibilities of inaccurate identification by citizens (Hara *et al.* 2013). Ground-truthing by field work campaigns provide the most accurate form of data validity since citizen science reports can be visited physically to confirm the presence or abundance of the research area in focus (Hawthorne *et al.* 2015). Further, the validation of citizen science points in-field contributes to accuracy measurements where citizen science collected data may be directly compared and assessed to control data in-field (Thompson 2016; Wakie *et al.* 2016). Similarly, the combined use of aerial imagery and digital street views – as accessed through open-source platforms such as

Google Earth and Google Street View – promotes validation opportunities to remotely confirm the presence or abundance of the research area in focus (Ives *et al.* 2017; Seiferling *et al.* 2017). Hence, any inaccuracies found in citizen science data can be validated or confirmed to ensure data accuracy within these large citizen science projects.

2.2.2 Google Earth and Google Street View as a Tool

Google Earth's aerial imagery together with Google Street View imagery, are two views which complement each other when tasked with recording both vegetation and infrastructure components (Berland and Lange, 2017). Google Earth and Google Street View are publicly available and easily accessible geospatial technologies which are cost-effective and offer precise alternative methods for identifying trees and buildings at local and global scale (Li *et al.* 2015; Choi *et al.* 2022).

Google Earth constructs pictures of the surface of the earth by downloading satellite imagery in a user-friendly interface to allow both the public and researchers to 'zoom-in' to locations of interest whilst still viewing the satellite image (Lisle 2006). Google Street View is an interface within Google Earth and Google Maps which provides a streetscape view using individual photographs which are 'stitched' together to form a continuous view (Li *et al.* 2015). This continuous view is achieved through vehicles with mounted cameras, which physically drive through the streets of cities, towns, and villages across the world to supply these photographs (Li *et al.* 2015). Google Street View is a type of platform which provides on-the-ground street imagery at a high spatial resolution, for visual validation of sites close to roads (Visser et al. 2014;

Qiu et al. 2019). Google Street View offers an interactive approach for users to manually ‘drag and drop’ a virtual pin from the software directly onto virtual streets which have been previously mapped using vehicle platforms with photography instrumentation (Anguelov et al. 2010; Li et al. 2015). Users can then maneuver in all directions across a virtual 2D, and 3D plane to identify features along streets such as trees and buildings (Berland and Lange, 2017; Ives et al. 2017).

In scientific research, Google Earth can be used to capture geographic information such as the exact coordinates of individual land features to entire polygon areas which define perimeter (Fonji *et al.* 2014; Ferreira-Rodriguez *et al.* 2021). Google Street View enables researchers to capture geographic coordinates of individual street-level features, validated through 2D and 3D imagery viewing (Qiu *et al.* 2019; Choi *et al.* 2022). Google Street View is especially useful for the virtual identification of urban street trees as the presence and species of specific trees at multiple locations can be validated against citizen collected data (Ives *et al.* 2017; Seiferling *et al.* 2017). Google Street View in tree identification, assists with identifying numerous factors such as location of trees, number of trees, size of trees and species – to name a few (Visser *et al.* 2014; Berland and Lange, 2017).

However, studies which use Google Street View as a remote validation tool of street-level features also utilize additional data collection tools to ensure data collection is accurate. Citizen science is a common tool used in conjunction with Google Street View as citizens act as ‘sensors’ to both collect large amounts of data from the geographic area in focus whilst also assuming the role of fieldworkers since citizens are often required to walk various streets to validate Google Street View collected data (Hara *et al*. 2013). Hence, citizens are not only engaging in digital data collection through online surveys, but also serving as fieldworkers since certain streets are physically visited and features are validated or confirmed by citizens often through means of photographic or digital survey verification (Clark 2014; Wegner *et al*. 2016). Projects such as *Opentreemap* aim to create a publicly available tree inventory for each city in the world by utilizing a combined approach of open-source street view data together with citizen science to catalogue street trees (Wegner *et al*. 2016; Hamilton *et al.* 2018). The addition of citizen science to Google Street View has been proven to enhance data quality, specifically for cases where tree species identification or validation is imperative (Clark 2014; Crall *et al.* 2015; Roman *et al.* 2017).

2.2.3 Social Media as a Tool

The widespread use of social media as a valuable tool in vegetation recording has recently been discovered. Social media platforms which lead in photography and visual representation are the forefront of capturing and sharing visible vegetation with the public (Silva *et al.* 2018).

Common social media sites such as Facebook, Instagram and Twitter can, when granted permission, capture user's GPS location from their mobile devices, based on either the user's physical location or the location at which the photograph was taken (Brown and Kytta, 2014; Sullivan *et al.* 2014). This function is particularly useful as distinct phenological stages, such as peak flowering, may be identified through photography ensuring correct species identification (Silva *et al.* 2018).

There are many geotagged photographs on social media sites which circulate across the world through the flexibility of the internet (Wegner *et al.* 2016; Yang *et al.* 2019). The inter-site variability encourages the public to participate and therefore supports the citizen science approach since these social platforms make engagement and accessibility seamless for data collection (Clark 2014; Fonji *et al.* 2014). This interactivity encourages users to support the creativity, diversity, and openness of various fields – including those focused on biodiversity and ecosystem monitoring as associated with plant and tree mapping (Hawthorne *et al.* 2015; Wakie *et al.* 2016; Li *et al.* 2015).

2.3. Combined Citizen Science and Geospatial Approaches

In urban environments, citizens as sensors or ground-collectors of vegetation data are a great help towards successful identification of various species across the landscape (Qiu *et al.* 2019; Dujardin *et al.* 2022). The fast-growing data source of citizen science provides reliable and accurate invasive species plant mapping data outputs, from both simple and complex urban environments (Hawthorne *et al.* 2015; Roman *et al.* 2017; Seiferling *et al.* 2017). Combined citizen science and geospatial approaches have the potential to accumulate large amounts of data, over a wide geographic region all within a short timeframe, which may otherwise be difficult to collect (Fonji *et al.* 2014; Ferreira-Rodriguez *et al.* 2021; Dujardin *et al.* 2022). The accurate identification provided by citizen science assists with the creation and compilation of maps to visualize the spatial distribution of invasive plants upon the landscape (Hawthorne *et al.* 2015; Thompson 2016). This is highly advantageous in regions or countries which are underdeveloped and limited in resources (Thompson 2016; Ferreira-Rodriguez *et al.* 2021).

2.3.1 Spatial Distribution Mapping

Combined citizen science and geospatial approaches in invasive species mapping grants opportunity not only for effective biodiversity and ecosystem management, but also towards community awareness and education (Theobald *et al.* 2015; Maynard-Bean *et al.* 2020). This awareness bridges the gap between citizens, researchers, and policymakers, as each person shares responsibility in the project as it provides an opportunity for stakeholders to engage with and educate the public on scientific research in the community, whilst simultaneously encouraging citizens to express their knowledge on the local environment (Schlossberg and Shuford, 2005; Dickinson *et al.* 2012; Brown and Kytta, 2014; Fonji *et al.* 2014). Scientists and researchers support the aid of combined citizen science and geospatial approaches towards invasive species mapping as data accuracy is resoundingly higher when collected by citizens who are familiar with their region as a higher citizen participation is observed since citizens show increased concern towards projects which may directly impact their community (Bois *et al.* 2011; Jordan *et al.* 2012; Fonji *et al.* 2014; Theobald *et al.* 2015). This data accuracy reflects on the secondary aims of this study which explores citizen's accuracy in data collection of invasive Jacaranda tree species in the CoJ.

Scientists and researchers further support the use of internet-based platforms in combined citizen science and geospatial approaches since digital surveys, websites, and mobile applications permit large-scale instant collection, storage and sharing of both geolocation and attribute data (Bois *et al.* 2011; Hawthorne *et al.* 2015; Tang and Liu, 2016; Wakie *et al.* 2016). Developments in geospatial technology allow digital surveys to access Global Positioning System (GPS) location information from the device used to take the survey, to produce an exact geographic coordinate location in real-time (Buldrini *et al.* 2015; Wright *et al.* 2015; Berland and Lange, 2017; Joy *et al.* 2019). In biodiversity and ecosystem monitoring and management, this GPS-approach with geospatial technology is highly beneficial for locating and mapping out high-risk areas and assists with the identification of any patterns or future trends (Salem 2003; O'Donoghue *et al.* 2010). This GPS information can be stored on a geospatial database where several analysis tools may be used simultaneously to output information on spatial distribution, rate of spread, affected areas or resources, and possible monitoring solutions – to name a few (Le Maitre *et al.* 2002; Hawthorne *et al.* 2015). This reflects on the research question of this study whereby geospatial approaches assist with the analysis and visualization of data collected from citizen science, Google Street View and ground-truthing. Studies which use these real-time combined citizen science and geospatial approaches for data collection stem from various fields, which include but are not limited to; disaster management mapping, trend prediction mapping, biodiversity monitoring and ecosystem monitoring (Salem 2003; O'Donoghue *et al.* 2010; Joy *et al.* 2019). The combined citizen science and geospatial approaches in these fields assist with real-time monitoring, mapping, and management networks for the identification of affected areas and potentially affected areas (Tran et al. 2009; O'Donoghue et al. 2010; Joy et al. 2019; Yang et al. 2019).

Invasive species mapping projects are varied and may include careful selection and training of volunteers to correctly identify specific invasive species (Jordan *et al.* 2012; Wakie *et al.* 2016). Selection and training of volunteers increase the accuracy of positively identified invasive plant species, whilst also producing much larger sample sizes (Jordan *et al.* 2012; Thompson 2016). Training may also involve volunteers' engagement with GPS devices when capturing ground control points (Thompson 2016; Wakie *et al.* 2016). Though training increases the accuracy of data collected from citizens, the uncertainty of training time needed often compromises planned timeframes for project start and completion (Fuccillo *et al.* 2015). This is a major disadvantage for projects which depend on seasonality for the successful identification of invasive plant species (Bois *et al.* 2011; Clark 2014).

Well-known projects which use a combined citizen science and geospatial approach for distribution mapping and monitoring include *eBird*, SABAP, *OpenStreetMap*, *OakMapper*, *Abandoned Developments* and *CoCoRaHS* (Sullivan *et al.* 2014; Tang and Liu, 2016). All six projects use volunteer collected data over online platforms to collect user inputs over a large geographic and temporal scale (Haklay and Weber, 2008; Tang and Liu, 2016). *eBird* is a web-interface that records recreational and professional bird observations from the Western Hemisphere and beyond (Sullivan *et al.* 2014). This is similar to our local SABAP Bird mapping program in South Africa. *OpenStreetMap* is a web-based interface which allows citizens to report on the built environment and street conditions on a global scale (Sullivan *et al.* 2014). *OakMapper* uses an interactive map to record sudden oak tree death in California (Connors *et al.* 2012). *Abandoned Developments* records abandoned residential construction sites throughout the south-eastern United States using an interactive map (Tang and Liu, 2016). *CocoRaHS* is an interactive website used to quickly record precipitation observations across North America (Tang and Liu, 2016; Qiu *et al.* 2019).

Two major kinds of interactive platforms were evident from these six combined citizen science and geospatial approach projects: direct and indirect (Tang and Liu, 2016). The indirect approach as used by *eBird,* SABAP and *CocoRaHS* involved indirect submission of data through a checklist, whilst the direct approach as used in *OpenStreetMap*, *OakMapper*, and *Abandoned Developments*, involved a direct submission of data on an interactive map (Tang and Liu, 2016; Qiu *et al.* 2019). *eBird,* SABAP and *OpenStreetMap* resulted in the highest interaction rates because citizens were attracted to the project since they belonged to specific interest groups (Dickinson *et al.* 2012; Tang and Liu, 2016). *eBird* and SABAP attracted 'Birders' who are typically people with an interest in birdwatching, whilst *OpenStreetMap* attracted people who were interested in mapping the built environment (Sullivan *et al.* 2014; Tang and Liu, 2016). The *Abandoned Developments* and *OakMapper* projects did not have specific interest groups – which resulted in low levels of participation towards these projects from citizens (Haklay and Weber, 2008; Tang and Liu, 2016).

There are often concerns around the quality of citizen science data, however, studies show that data quality can be maintained when monitoring programs are well developed and carefully implemented (Atzmanstorfer *et al.* 2014; Crall *et al.* 2015). Volunteers may be specified or selected based on factors around the project scope to ensure data integrity (Joy *et al.* 2019; Dujardin *et al.* 2022). The specification of volunteers within citizen science projects is imperative to reduce issues around distribution of observers versus distribution of species as high concentrations of data points may represent higher population responses of observers rather than higher research sample data from species (Crall *et al.* 2015; Van de Wal *et al.* 2015).

Additionally, the layout of surveys, websites, and applications contribute to a higher data quality from combined citizen science and geospatial approaches in invasive species mapping (Fonji *et al.* 2014). Many online surveys follow a common approach which either requires the citizen to identify an invasive plant species from a list of pre-configured invasive species options, or to identify a single invasive plant species only (Fonji *et al.* 2014, Ferreira-Rodriguez *et al.* 2021). Questions within surveys, websites and applications often require details on the count of invasive species seen and a geo-tagged point of location from where the sighting was made (Tang and Liu, 2016; Wakie *et al.* 2016). Geo-tagged points collected from these online surveys of specific invasive species can be represented as spatial distribution maps using a GIS as a tool (Hawthorne *et al.* 2015; Ferreira-Rodriguez *et al.* 2021).

2.4 Synthesis

Many conservation decisions made by cities and countries are based on imperfect or varied data (Bird *et al.* 2014*;* Barnard *et al.* 2017). Reliant policymaking is dependent on updated and accurate data on biodiversity, to predict species' responses to local and global change (Bled *et al.* 2013; Altwegg *et al.* 2014). Although phenological and remote sensing mapping efforts exist within the CoJ, spatial distribution mapping of Jacaranda presence has yet to be accomplished. Spatial presence of invasive trees is pivotal not only towards effective management, planning and monitoring, but is also key towards the identification of suburbs and regions which may be at risk for high invasive tree presence. This offers an additional opportunity to re-model the existing conservation and land management plans of the CoJ, to consider key areas which may pose future risk.

CHAPTER 3: STUDY SITE

Own photograph taken in suburb of Saxonwold, on 12 October 2022.

3.1 Introduction

The mapping of Jacaranda tree distribution using a combined citizen science and geospatial approach in this study, is focused on the CoJ, within the Gauteng province of South Africa. In late spring, the CoJ is a well-known location to experience the distinct purple flowering of invasive Jacaranda street trees (Fitchett and Raik, 2021). The CoJ is rapidly developing with high-rise buildings and industrial zones taking over vegetated areas, leaving the urban forest at risk due to poor monitoring and management practices (Newete *et al.* 2022). It is important to identify high risk areas where old Jacaranda trees may die from invasive pest species attack or may fall onto private property. This chapter describes the CoJ's history, general geography, climate and population.

3.2 History

The CoJ is one of the largest and fasting growing cities in Africa, with one of the world's largest urban forests assets which require attention (Schäffler and Swilling, 2013). The CoJ experienced an apartheid regime past whereby segregation and land separation of different races, each contributed to shaping to landscape of the CoJ today (Schäffler and Swilling, 2013). This segregation led to those of the white race residing in northern suburbs of the CoJ with the black races occupying the southern regions (Turton *et al.* 2006).

The CoJ started major mining interventions from the 1800s with the discovery of gold in the Rand area (Turton *et al.* 2006). An influx in mining activities led to a tree-planting boom in the late 19th century to address the increase in dust, air, noise, and heat pollution in the CoJ (Schäffler and

Swilling, 2013). Quick-growing species were selected such as Eucalyptus, Black Wattle, London Planes, Oaks, and Jacaranda – to name but a few of the Colonial familiar species which were planted (Turton *et al.* 2006). Resultantly, major greening efforts were abundant in northern affluent suburbs of the CoJ, forming greenbelts and public parks (Schäffler and Swilling, 2013). Today, these trees form large parts of the CoJ's urban forest with well over 10 million trees which occupy approximately 16.1% of the CoJ's area as covered by both native and alien species (Schäffler and Swilling, 2013; Hardy and Nel, 2015).

3.3 General Geography

The CoJ is classified as part of the South African highveld, located in the Gauteng province of South Africa (Crétat *et al.* 2012). The CoJ is the largest City in South Africa with an area of 1,645 km^2 and is commonly referred to as ''The City of Gold'' after gold was discovered in the Rand region in 1886 (Vearey 2010, p.37; Harrison and Zack, 2012). The CoJ is the economic and transport hub of South Africa and contributes to approximately 10% of Africa's economic activity (Risimati and Gumbo, 2018).

The main regions of the CoJ are those of Diepsloot, Midrand, Sandton, Alexandra, Inner City, Johannesburg South, Ennerdale, Soweto, Diepkloof, Rosebank, and Roodepoort (Risimati and Gumbo, 2018). The CoJ is administratively divided into seven regions, namely A, B, C, D, E, F, and G, which each consists of several suburbs (Risimati and Gumbo, 2018). The exact boundaries of these regions are regularly changed and therefore difficult to map. The CoJ promotes transit-oriented developments (TODs) in previously marginalized areas by focusing on development of economic and business sectors within Regions F, B and E. Regions G and D are defined as medium to low-income residential spaces whilst regions A and C are defined as medium to high income residential spaces with some commercial activities (Risimati and Gumbo, 2018). The CoJ is a metropolitan City, with two neighboring metropolitan cities, namely City of Tshwane (Commonly known as Pretoria) and City of Ekurhuleni (Fitchett and Raik, 2021).

The CoJ is situated along the watershed of the Witwatersrand and depends on the Lesotho Highlands Water Project (LHWP) transboundary transfer scheme as the main water supply source (Mguni *et al.* 2022). The Witwatersrand is at the headwaters of two major river basins, namely the Lesotho and the Orange River basins, where any pollution occurring in these basins impact activities downstream (Turton *et al.* 2006). Hence, capping of the LHWP transboundary transfer scheme, by means of a maximum water capacity limit, until the second phase of the LWHP is completed – adds to water availability pressure in the CoJ (Mguni *et al.* 2022). The CoJ has a highly variable topology with the central regions of the CoJ found at an altitude of 1,763 m above sea-level and northern regions found at lower altitudes, resulting in different air temperatures between these regions (Newete *et al.* 2022; Souverijns *et al.* 2022).

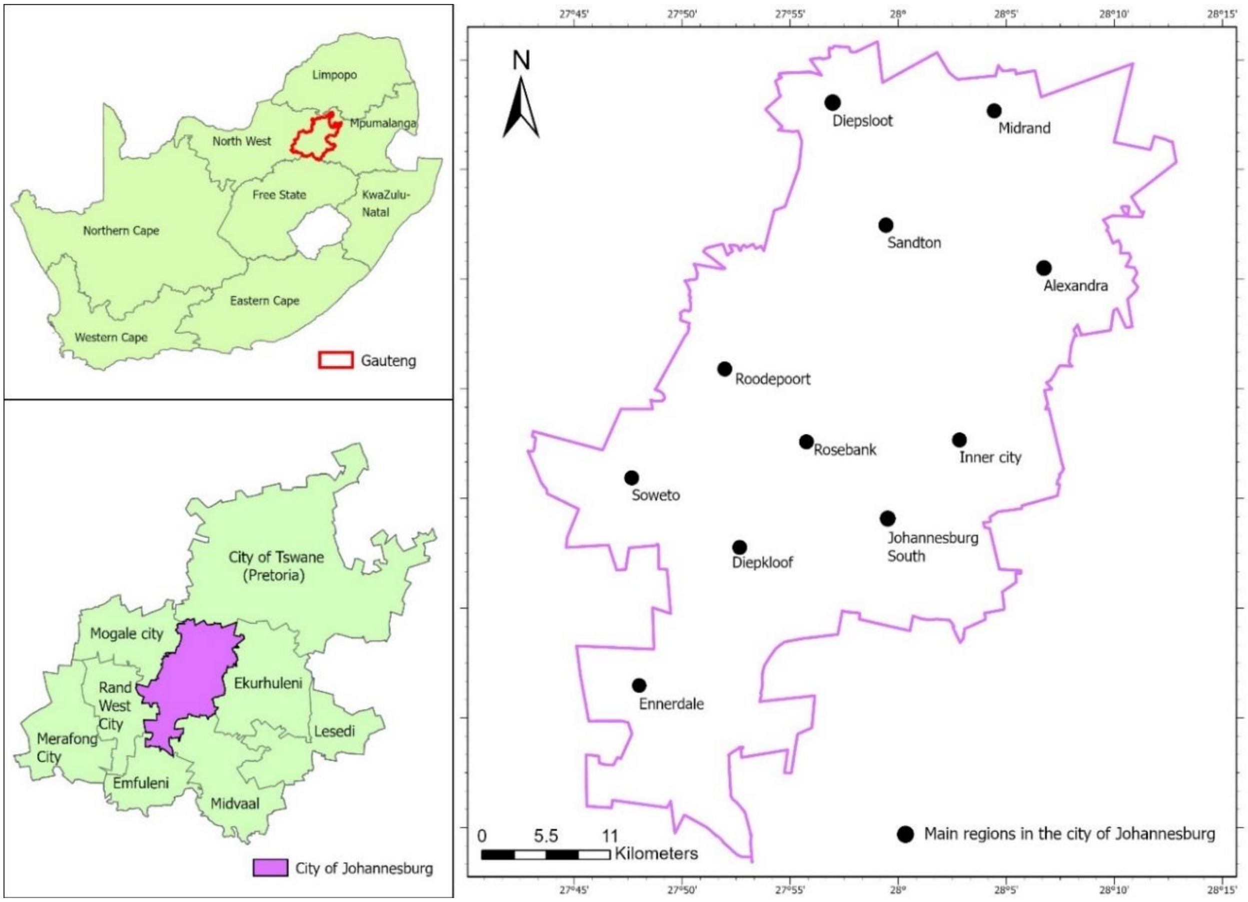


Figure 3.1: Study site map of the CoJ showing the main regions of Diepsloot, Midrand, Sandton, Alexandra, Inner City, Johannesburg South, Ennerdale, Soweto, Diepkloof, Rosebank, Roodepoort and adjacent municipalities.

3.4 Climate

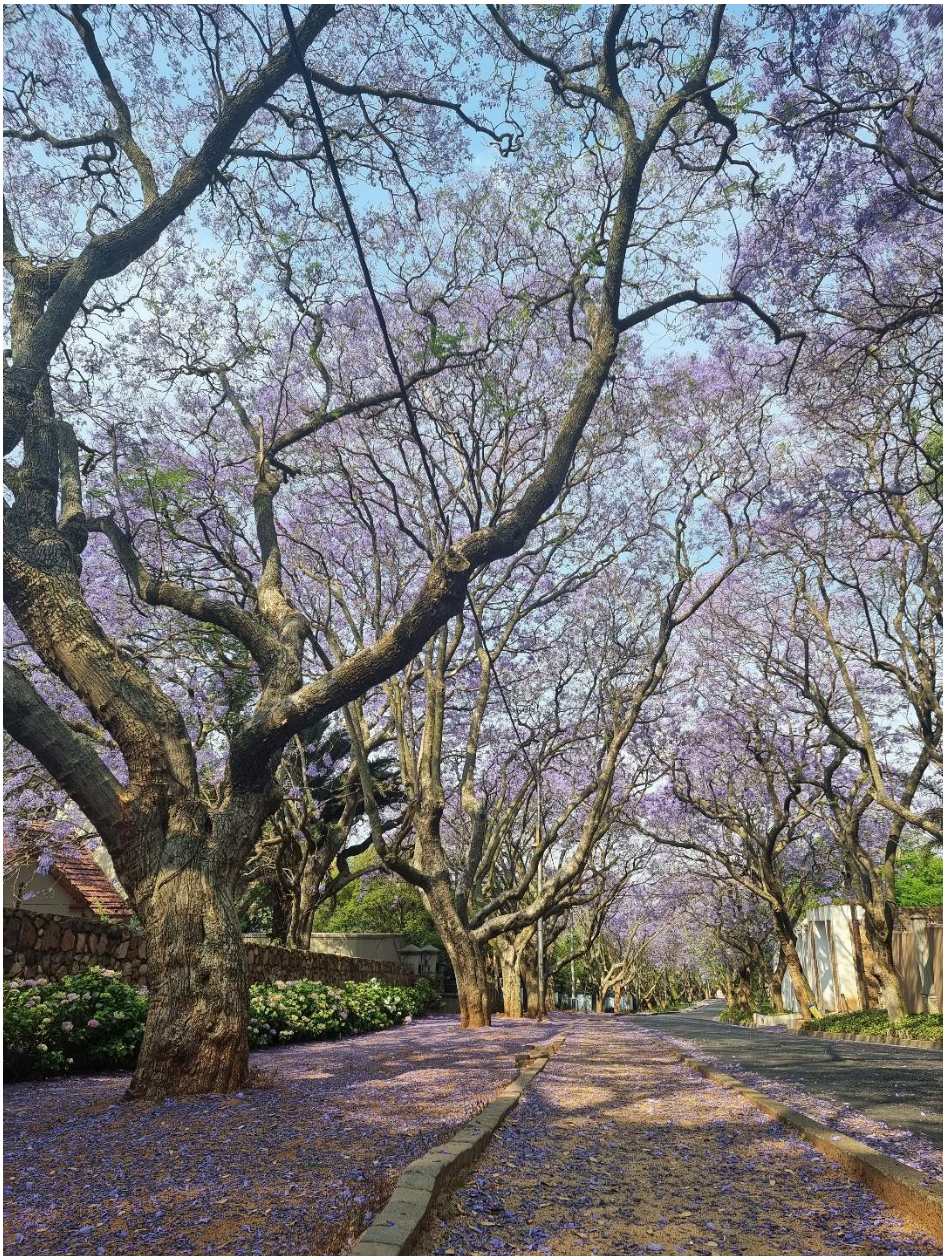
The CoJ has a temperate climate with mean annual temperatures of 22°C (Dyson *et al.* 2015). Solar radiation and air temperatures are the largest influencers to heat stress in the CoJ, compared to humidity (Souverijns *et al.* 2022). The variable topology of the central suburbs found at higher altitudes than northern suburbs contribute to different air temperatures experienced across these regions (Hardy and Nel, 2015). The central regions of the CoJ emit the highest concentrations of heat due to high building density, increased anthropogenic activity and low vegetation presence (Souverijns *et al.* 2022). Urban heat island stress is counteracted by the presence of vegetation which assists with detoxifying the air and providing shaded cover which lowers temperatures in the vicinity (Hardy and Nel, 2015).

The CoJ experiences a mean annual rainfall of approximately 600 mm annually, with most of the rainfall during the summer months of October and March (Crétat *et al.* 2012). Rainfall decreases from east to west of the country as influenced by the warm Agulhus current and presence of the Indian ocean on the east and cooler Benguela current from the Atlantic Ocean on the west (Crétat *et al.* 2012). Summer rainfall may lead to intense Highveld thunderstorms which may cause hazardous flash flooding due to poor infiltration rates of the urban environments artificial surfaces (Schäffler and Swilling, 2013). The low mean annual rainfall of the CoJ, combined with high evaporative potential and the variability of rainfall, results in South African rivers having among the lowest conversion of mean annual rainfall to mean annual runoff (Turton *et al.* 2006).

3.5 Population

The CoJ has a current population of approximately 6 million people with an approximate annual growth rate of 2% (United Nations 2022). Population growth and urbanization in the CoJ contributes to changes in the quality and quantity of urban green spaces (Abutaleb *et al.* 2021). The result of a rapidly growing population leads to decreased availability of land space as 'green spaces' in the City (Rasmeni and Madyira, 2019). An increase in population is translated to a mounting demand for service infrastructure to meet growing needs of the City, which is contributed by both domestic and international immigration (Abutaleb *et al.* 2021). The spatial distribution of highly populated suburbs in the CoJ is influenced by apartheid, where urban growth was controlled, and the City was segregated by racial lines (Todes 2012). Spatial change in the CoJ has been rapid after 1994. In the CoJ, northern and western edges of the City house higher population density with the development of popular residential complexes (Todes 2012). Resultantly, suburbs which are highly populated, usually offer reduced vegetation cover. Rapidly developing suburbs within the CoJ such as Sandton, Melrose Arch and Midrand are just a few examples of areas where increased urbanization leads to reduced presence of vegetation (Mudede *et al.* 2020).

CHAPTER 4: METHODOLOGY



Own photograph in the suburb of Northcliff, on 12 October 2022.

4.1 Introduction

This dissertation is the first to map ground-level Jacaranda tree spatial distribution in the CoJ. The primary aim of this study is to map the spatial distribution of Jacaranda trees in the CoJ, through a combination of citizen science, ground-truthing using a GIS, and Google Street View techniques. The secondary aim is to explore the accuracy of citizen science in mapping distinct tree species. This is followed by two research questions: First, "what is the spatial distribution of Jacaranda trees in the CoJ?". Second, "how effective is the geospatial approach in the combined citizen science, Google Street View, and ground-truthing methods of data collection?" The combined approach requires the integration of processes to ensure harmony between the three data sources.

This chapter outlines the data acquisition process from two field campaigns, Google Street View efforts and survey responses collected from citizen science, as supported by *Esri South Africa*. Thereafter, methodological processes for each dataset will be discussed to determine any relationships between data acquisition procedures and resulting patterns or trends. Additionally, the calculation process for citizen science data accuracy will be discussed.

4.2 Data Collection

As this research study aims to produce the first spatial distribution map of Jacaranda tree presence in the CoJ, initial ground-based data acquisition was imperative to the success of the study since this would form the foundation to identify any data gaps or inaccuracies from citizen science collected data (*Section 2.2.1*). Two field campaigns for ground-data collection were necessary for the collection of control points for validated Jacaranda tree presence in the CoJ. In the absence of research studies which use geospatial technology as a tool for invasive tree mapping in the CoJ, a secondary data collection technique to address any missing data from fieldwork campaigns was important. Google Street View for virtual data collection of confirmed Jacaranda trees in the CoJ assisted here (*Section 2.2.2*). These two data collection techniques ensured digital standardization of data, so geopoints could be processed and integrated into digital maps (Crall *et al.* 2015). Citizen science data collection was carried out through the use of digital surveys (Vahidi *et al.* 2021). This digital component granted seamless transition of both attribute and spatial data, which were collected from individual users and stored on online geospatial databases (Figure 4.1).

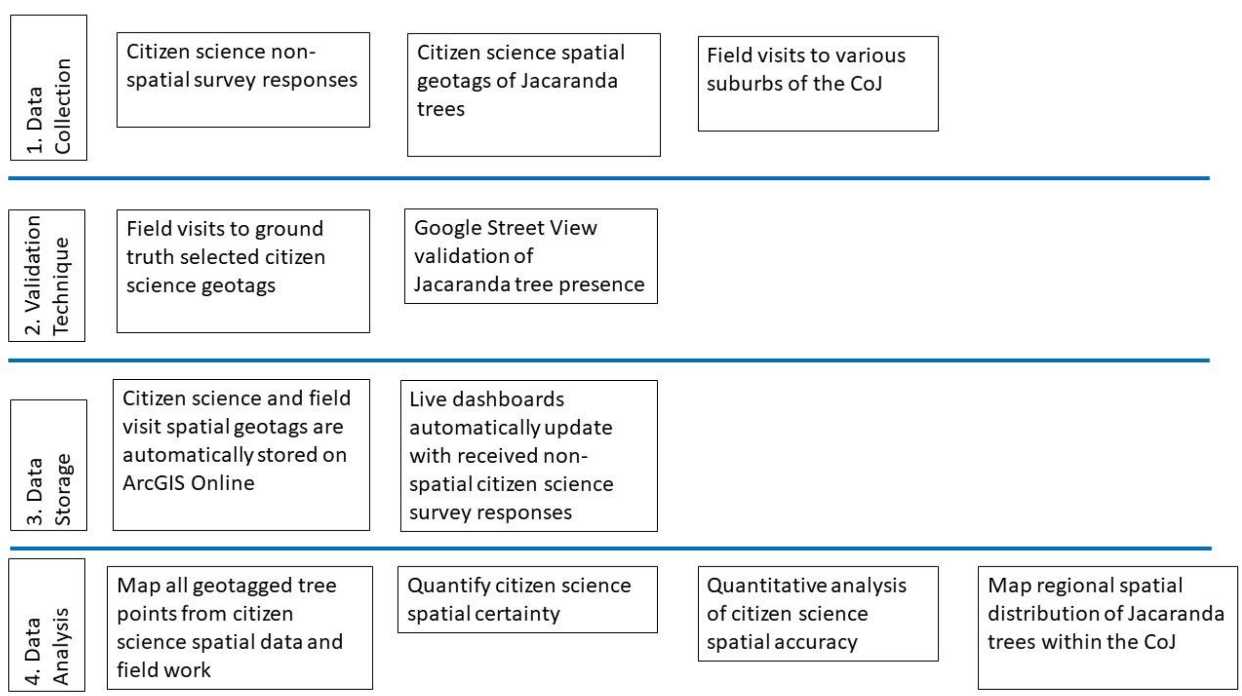


Figure 4.1: Methodology diagram

4.2.1. Ground-truth Data

Two field campaigns were carried out from 5-11 July 2022 and 11-17 October 2022 to collect validated Jacaranda tree location. Based on extensive research prior to field campaigning, a preselection of suburbs with a large number of Jacaranda trees guided the first field campaign in July 2022 (*Section 2.1.1*; Newete *et al.* 2022). Jacaranda tree prevalence varies per suburb with some suburbs having a high prevalence, with Jacaranda trees lining either side of multiple streets, whilst other suburbs have a very low prevalence with Jacaranda trees located sporadically across the suburb. Some suburbs, especially the more recently developed suburbs, do not have any Jacaranda trees at all. Since the two field campaigns were conducted during the seasons of winter and spring, Jacaranda trees vary is physical appearance. In winter, Jacaranda trees are identified by lush green bipinnately compound leaves which made these trees stand-out against the dry winter landscape and were identified by their distinct appearance (Figure 4.2). Similarly, field campaigns during spring blossoming of Jacaranda trees facilitated easy identification of the trees as Jacaranda trees blossom with bright purple flowers.

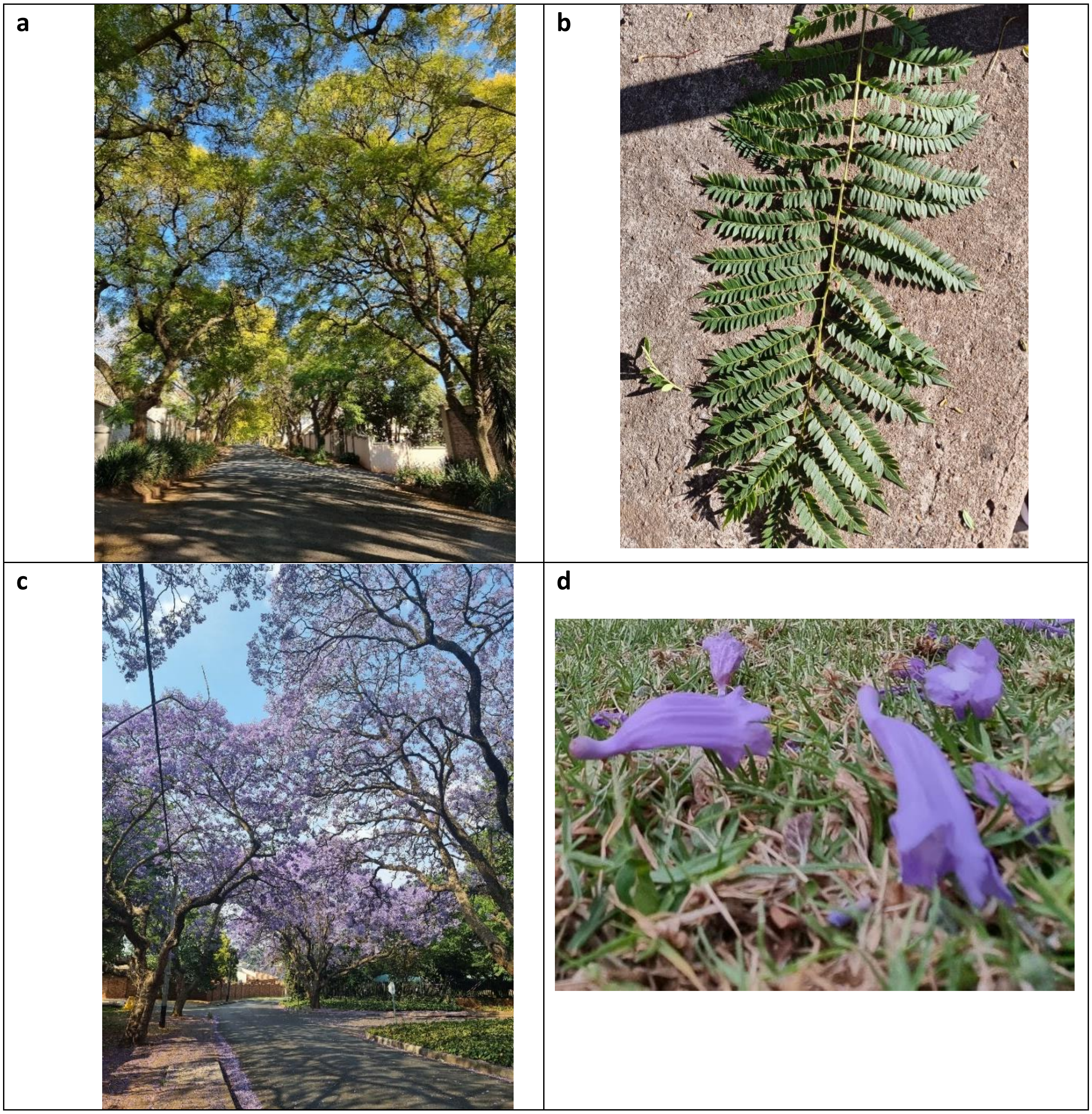


Figure 4.2: Own photograph during fieldwork showing a) winter-time green tree, b) winter-time green leaf c) spring-time purple tree, and d) spring-time purple flower of Jacaranda trees.

Data from field campaigns were captured as geopoints using software and hardware provided by *Esri South Africa*. Observations for Jacaranda tree presence was made through physically driving to and walking along individual streets per suburb and capturing exact coordinates of Jacaranda tree presence using both the *Cedar CT8 Rugged Tablet* (CT8 Tablet) and *Garmin Glo* (Garmin) GPS device, together with *Esri ArcGIS QuickCapture* software (Figure 4.3).

Figure 4.3: Own photograph of CT8 Tablet and Garmin device provided by Esri South Africa.

A manual log was updated of individual street names which were not completed during the allocated day of fieldwork. These incomplete streets would either be visited the next day or validated remotely using Google Street View. In-field navigation to different streets was assisted by navigation services provided by Google Maps (Fonji *et al.* 2014). Up to six individual street names were added as 'stops' within a single Google Maps journey for routes of 'best travel' to be mapped. The first and last 'stop' or street name within Google Maps assisted as anchor points to ensure fieldwork was conducted within the boundary of the suburb in focus, as navigation without Google Maps became disorientating in larger suburbs or within streets with similar names to others. The extensive field campaigning for control points of confirmed Jacaranda trees formed part of this study's main objective to have enough control points of known Jacaranda tree presence to measure citizen science data against, and therefore test for accuracy of citizen science data.

4.2.1.1 Field Devices and Software

The CT8 Tablet, which is commonly used with *Esri ArcGIS* products, is a durable field device powered by Android 8.1 with Google mobile services included (Juniper systems 2019; Esri 2022a). The CT8 Tablet has renowned GPS accuracy between 5-8m under a dense tree canopy, due to an external GNSS Antenna attachment (Juniper systems 2019). The handheld Garmin device boosts GPS accuracy of the CT8 Tablet with space-based global navigation satellite system (GLONASS) receivers (Garmin 2023). The Garmin device has a GPS accuracy of between 1-3m under a dense tree canopy (Garmin 2023). The Garmin device connects wirelessly through Bluetooth to the CT8 Tablet, and these devices together form the hardware to collect accurate ground-truthing averaging between 1-3m under a dense tree canopy.

Esri's QuickCapture application was used for the rapid collection of individual geopoints. *QuickCapture* is an application which can be easily configured by the user for a tailored fieldwork experience (Esri 2023a). For this study, a template for reporting was used and configured as an application where one-touch button activations were utilized. This configuration process involved the deconstruction of a reporting template, and reconstruction which was fine-tuned and tailored for optimal user functionality for this research study. The first button activates a drop-down list of pre-filled regions within the CoJ, so a specific region could be selected during fieldwork. The second button would capture the exact geographic co-ordinates from where the button was pressed in-field. Thereafter, a secondary screen would open to display a high-resolution aerial imagery map, sourced from *Esri South Africa*, within the application. The LANDSAT8 aerial image map would display every recorded point for Jacaranda tree presence in the form of geopoints. This application layout was chosen for its high efficiency and simplicity to easily capture a large number of geopoints in-field with very high accuracy.

A third button provided a live-tracking route option. This tracking option was a valuable guide at the end of each day of fieldwork, to keep a record of streets and suburbs visited. All geopoints with live tracking routes were then configured to automatically save every 30 seconds. Automatic uploads at 5-minute intervals were configured for all geopoints to upload onto *Esri's ArcGIS Online* for storage, management, and analysis. *ArcGIS Online* is a cloud-based mapping and analysis solution used for map creation, data analysis, and sharing of data whether in-field on behind a machine (Esri 2023b; Figure 4.4).

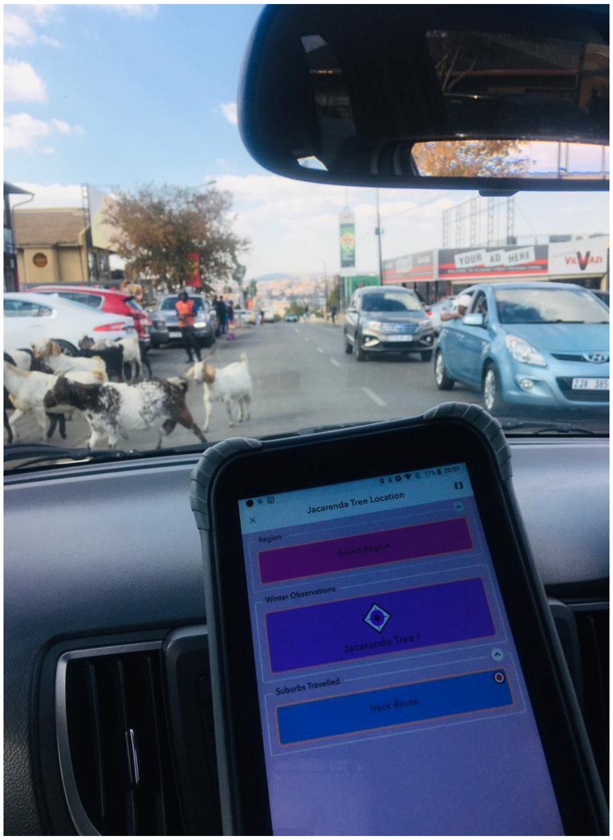


Figure 4.4: Own photograph during fieldwork in Soweto, showing three-button layout of QuickCapture application.

All collected geopoints were accessed through *ArcGIS Online* at the end of each day of fieldwork. In cases where streets were covered more than once (*Section 6.6*), these duplicated geopoints were filtered and removed using *Esri's Map Viewer*. *Map Viewer* is an interactive web mapping and data visualization application for creating, exploring, and saving web maps which is available through *ArcGIS Online* (Esri 2023c). Live route tracking data was removed from the geopoint dataset to appear as its own separate dataset. Geopoints were processed for geographic projection to comply with decimal degree standardization throughout the project (Fonji *et al.* 2014).

4.2.2 Virtual Campaign Data

Virtual campaigns were carried out intermittently from August 2022 to November 2022 using Google Street View was the chosen tool for virtual validation of Jacaranda trees along streets in the CoJ (*Section 2.2.2*).

In this study, a single Google Street View capture contained at least one Jacaranda tree (*Section 5.3*). Once a capture was taken, it was named chronologically on the software, and the spacebar button on a keyboard was pressed once, to maneuver in equal intervals down a virtual street. If a view did not contain Jacaranda trees, this capture was still taken and instead named "None" to ensure a log existed for streets visited without Jacaranda tree presence. This process was repeated until the entire street was covered, and ended when an entire suburb was complete. Google Street View captures were manually categorized into virtual folders which were named after the suburb in which they were captured. Entire virtual folders per suburb were saved automatically on Google Earth Pro software.

The digital file format of completed suburbs was that of Keyhole Markup Language (KML) files within Google Earth Pro (Ives *et al.* 2017). KML files are a universal format used for storing geographic data, however these file types are not easily read through *ArcGIS* products (Esri 2023d). Instead, KML files were uploaded to *Esri's ArcGIS Earth* where they could be saved as compressed files known as KMZ files. *ArcGIS Earth* is an interactive 3D experience similar to Google Earth Pro, except it does not yet have functionality for street-level analysis (Esri 2023d). In this study, *ArcGIS Earth* was useful as a conversion and sharing tool since converted KML files could be uploaded to *ArcGIS Online* for storage. This ensured data integrity and standardization across *Esri* products since field campaign and virtual campaign data were uploaded to an online geodatabase and could be accessed through *ArcGIS Online* (Ferreira-Rodriguez *et al.* 2021).

This systematic approach to the rapid collection and efficient storing of Google Street View captures assists with accuracy assessment efforts since these Google Street View captures form part of the control points from which citizen science data will be compared to. Moreover, the segregation of Google Street View captures as stored per suburb name, assists with detailed accuracy comparisons in cases where citizens have captured Jacaranda tree locations in suburbs which were not covered by ground-truthing efforts. Hence, careful attention is paid towards mapping spatial distribution of possible Jacaranda tree presence in these suburbs since ground validation points may not exist.

4.2.3 Citizen Science Data

Citizen science data was obtained through digital surveys which were purpose-built, refined, and tailored for this research project. These digital surveys were produced using *Esri's Survey123 Connect*. *Survey123 Connect* is a sophisticated desktop application which permits the user to author surveys using Microsoft Excel, which is alternatively coded with questions, instructions, restrictions, geotagging, and prompts each enabled through the advanced technological capability of *Survey123 Connect* (Esri 2023e). In this study, an advanced survey format was required whereby each question required tailored styling and functional formatting to guide the user through a series of geospatial instructions. This formatting included 'drop-down' lists, 'select one' or 'select many' options, 'required questions' with prompt or instruction messages for the user, accuracy warnings for geotag questions, among others. Therefore, template survey layouts which exist on *ArcGIS Online* could not be used.

Survey123 Connect automatically creates the digital survey with styling and layout as prompted from the coded spreadsheet program which is linked to the *ArcGIS Online* portal for all responses from users to be stored and managed digitally (Esri 2023e). Furthermore, *Survey123 Connect* can be restricted with GPS warnings to ensure a user can only capture a geotag once their device is in a specific accuracy zone. To ensure geolocation accuracy in this study, surveys were configured with a 7m accuracy and would not allow the user to capture a geopoint if their accuracy was out of this range.

Survey123 Connect automatically generates both a survey link which can be accessed using any web browser, together with a Quick Response (QR) code which smart devices may scan from either a paper or digital based source to automatically redirect the user to a web browser to view the survey (Esri 2023e). Both digital links and QR codes assisted with the dissemination of the survey to a wide and varied sample of respondents through both snowball-sampling and convenience-sampling approaches and is in-line with this study's objective to make this survey accessible through social media platforms for citizens of the CoJ to participate in Jacaranda tree data collection (*Section 2.2.3*). Snowball-sampling was useful in cases where a single user passed the survey link to others, while convenience-sampling was useful since social media formed a major part of attracting a wider audience and increased attention for survey completion. The five social media platforms of WhatsApp, Instagram, Facebook, LinkedIn, and Twitter would each result in different trends of responses from citizens of the CoJ since each of the above-mentioned social media platforms distribute website links uniquely. Instagram was the preferred platform to share digital survey links as accompanying Jacaranda photography could be posted along with main headings or attractive text directed at the CoJ audience, in an effort to easily attract a CoJ citizen's attention. Additionally, physical posters were created for residents of the CoJ to scan the QR code and access the survey. Since surveys were coded and created for this research project, and as geotagging was a key component of the survey, a decision was made to target smart devices for survey collection instead of paper-based approaches. The use of social media platforms and QR codes to disseminate the survey ensured most users who received the survey had access to smart devices that could enable their participation.

4.2.3.1 Social Media Data

Social media assisted with identifying the best days and times of day to share survey links which correlated with increased user activity of Jacaranda photography. These data trends were collected through manual logging in a Microsoft Excel spreadsheet. Select Jacaranda season inspired events such as the "Jacaranda In Your Pocket" photo competition, "Johannesburg Free Walking Trails" for Jacaranda season walks in the City and "I Heart Jhb" for information on Jacaranda markets – among others – were logged in Microsoft Excel, capturing key dates for upcoming public events, competition open and close dates, and any information on the location of events. These dates formed the framework for the social media drive ensuring that survey links were shared in-line with upcoming dates of interest.

The trend analysis of dates which corresponded to key interest from users was an iterative process which required constant monitoring not only for key dates and events, but also for the on-time creation of posts. These posts assisted with sharing the survey link to users whilst simultaneously assisting with increased attention to the 'Jacaranda Mapper' Instagram account which had unique and attractive Jacaranda content linked to the survey for this research project. Response count from users on days where survey link was shared was monitored on an online dashboard, accessible through *ArcGIS Online. Survey123 Connect* intertwines with *ArcGIS Online* not only with automatic saving of user's submitted responses, but also provides a virtual dashboard where survey response statistics are updated in real-time (Esri 2023e). The strategic monitoring of social media trends resulted in a total of 203 responses and 488 geotags for Jacaranda tree location collected during the 75-day survey collection period.

4.3 Data Analysis

Data standardization was insured since all data from field campaigns, Google Street View, and citizen science surveys were stored and managed entirely on *ArcGIS Online.* Although data was manipulated from Google Earth Pro to *ArcGIS Earth,* the strict decision to stay within *Esri's* product suites not only ensured data integrity, but also ease of access across the several *Esri* products and applications used in this study (Ferrara 2020). This was further driven by use of *Esri's* well-known *ArcGIS Pro* software which was pivotal for data analysis and visualization within this study as it served as an integration and analysis platform of all collected geopoints from citizen science, Google Street View and ground-truthing efforts.

4.3.1 Geoprocessing

ArcGIS Pro is a powerful single desktop GIS application which includes world-leading geospatial tools for data visualization, advanced analysis, and map creation (Esri 2023f). *ArcGIS Pro* hosts a diversity of built-in spatial analysis tools which each assisted in the analysis of data collected from citizen science, Google Street View and ground-truthing efforts for the successful creation of several high-resolution spatial distribution maps for Jacaranda presence in the CoJ.

4.3.1.1 Structured Query Language

Structured Query Language (SQL) is a tool widely used for spatial modelling and database management in a GIS (Lei 2021). SQL expressions in *Esri's ArcGIS Pro* adhere to standard SQL syntax with common use of Boolean statements (Esri 2022b). SQL is particularly useful for relational databases, which was the format used to relate attribute citizen science data to spatial citizen science data collected from geotagging efforts (Aufaure-Portier 1995). Here, several 'select layer by attribute' SQL expressions were used to isolate data in unique pairs which were specific to this study. The use of SQL was essential in this study since attribute questions and respective unique answers per user (as adopted from citizen science survey responses), could be selected in isolation or cumulatively with associated spatial information. This resulted in unlimited data combinations for deeper regression analysis (Aufaure-Portier 1995).

4.3.1.2 Joins and Relates

Data collected from citizen science surveys were exported from *ArcGIS Online* in Microsoft Excel format. Hereafter, the Excel spreadsheet was cleaned and standardized to meet formatting requirements for use in *ArcGIS Pro*. Three Excel spreadsheets were compiled from citizen science responses. The first spreadsheet with attribute information, the second with spatial information of collected geotags from the citizen's street and other streets, and the third with spatial information from geotags linked to exact location tags. The separation of these datasets was imperative for analysis of citizen science accuracy where non-spatial data such as citizen's 'length of stay' or 'suburb of residency' in the CoJ could be isolated and directed compared to the same user's geotagging accuracy to find any trends which support the study's secondary aim.

A series of spatial joins were made between the three spreadsheets based on both Global IDs and Globally Unique Identifiers (GUIDs) which each represent an individual user through a unique identity code (Esri 2023e). These identity codes were extracted and linked across all three spreadsheets ensuring spatial analysis ability for single or multiple users simultaneously (Godfrey and Stoddart, 2018). These advanced spatial joins provided an opportunity to cross-compare answers from various users who contributed to the citizen science dataset, for new trend possibilities to be identified.

4.3.1.3 Spatial Analysis

Once all spreadsheets were linked based on a Global IDs or GUIDs, geometric analysis to correct spatial co-ordinates from the three datasets were done (Suzuki 2005). Since ground-truth geopoints were collected in-field and configured through *QuickCapture*, and citizen science data were collected through *Survey123 Connect;* geometric analysis ensures spatial standardization between the datasets before spatial analysis can be carried out (Breytenbach 2016). In this study, the *Lo29* reference system based on the *WGS84* reference ellipsoid was the geo-reference framework of choice since *Esri* software re-projects *Lo29* co-ordinates with accuracy, whilst enforcing strict pixel-to-pixel registration with the gridded reference provided from ground-truthing data (Breytenbach 2016).

Several spatial analysis tools such as proximity, intersect, distance, X-Y to line, buffer, and near-distance, among others, were used. *Esri* offers extensive and advanced geoprocessing tools built on various statistical approaches such as Pearsons's correlation coefficient, Cohens kappa coefficient, Multiple regression, and Thiessen Polygon, among others (Esri 2022b). Geoprocessing tools are selected and applied on a case-by-case basis. In this study, several geoprocessing toolboxes were utilized such as the 'Spatial Statistics Toolbox', 'Geostatistical Analyst Toolbox' and 'Spatial Analyst Toolbox', to name a few. Each toolbox contains an array of individual tools which each perform advanced statistical analysis once the dataset has been formatted correctly from the initial collection, cleaning, filtering, and storage of data (Esri 2022b). *ArcGIS Pro* automatically processes individual or multiple spatial analyses at any given time, as a supervised classification (Esri 2023f).

Proximity analysis from citizen science geotags to nearest ground-truth geopoints from both ground-truthing and Google Street View datasets were completed. For this, a new dataset was created and comprised of combined ground-truth geopoints and Google Street View geotags, as control points for validated Jacaranda tree presence. This would form the basis of accuracy as the nearer the distance a citizen science geotag to a validated Jacaranda tree (as validated through Google Street View and ground-truthing), the more accurate the citizen. Hence, these Euclidean distance tools assisted with calculations to the nearest control point (confirmed Jacaranda tree) to then separate into 'bins' of accuracy.

To categorize distances into 'bins' of accuracy, SQL expressions were used to isolate distances which were <7 m, 8-14 m, 15-24 m, 25-100 m, 101-199 m, and >200 m from control points (*Section 5.7*). These SQL queries supported the study's objective and aim, which is to explore and measure accuracy of citizen science. Geotags which fell within one of the six 'bins', were first exported as a new standalone table, and then exported as a feature class. The result was two new datasets, comprising six new standalone tables and six new feature classes for each rank of accuracy. These feature classes were then symbolized and created into maps within *ArcGIS Pro.* Each feature class was shared to *ArcGIS Online*, for storage, whilst completed map layouts were exported as high resolution .JPG image format.

A similar process was carried out for the separation of citizen science geotags which were tagged per location. Each categorization was colour coded after being isolated from SQL queries, with colours of red for the 'citizen's street', orange for 'other streets', and yellow for 'exact location'. The reason for this separation was to compare the six 'bins' of accuracy to any trends in the citizen's location as influencing accuracy of geotags. These new categorizations were also exported as standalone tables and feature classes before final map layouts were exported as high resolution .JPG images for certainty analysis. Each citizen science geotag was processed through an SQL expression which was custom and purpose-built on *Model builder* where new standalone tables and feature classes were created for each measure of certainty (*Section 5.6*), facilitating further analysis where detailed SQL expressions can be processed concerning specific datasets (Figure 4.5).

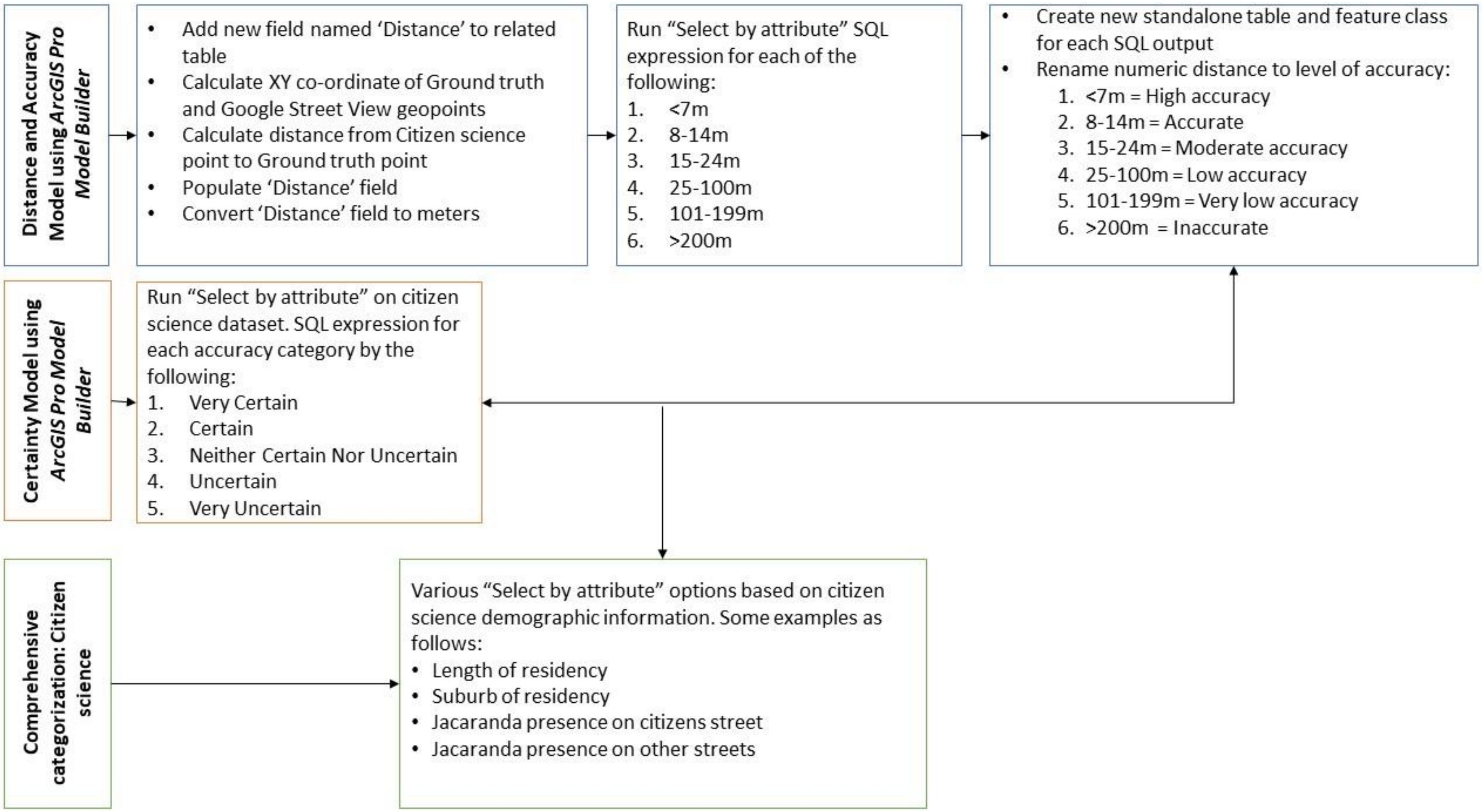


Figure 4.5: Model builder workflow showing custom built SQL queries for data filtering and analysis.

4.3.1.4 Accuracy Assessments

Once maps were created for citizen science geotags per categorization of the citizens' street, other streets, or exact location, a field validation was undertaken for accuracy purposes. The creation of maps in *ArcGIS Pro* created a dynamic environment for 'zoom-in' actions to detect street and suburb names for a single geopoint. In-field accuracy assessments were conducted during the final fieldwork campaign in October 2022.

From the total citizen science geotags collected up until 13 October 2022, nine of which could be visited in-field as these geotags were in reasonable driving distance for validation efforts. A validation survey was created on *Survey123 Connect* with integrated navigation services provided by Google Maps (Fargher 2018). This dynamic survey was different to the one created for citizen science data collection, as the field validation survey had a purpose of providing efficient travel routes to the selected nine geotags. The purpose-built validation survey was configured to a 7m accuracy warning. The validation survey was linked to the selected nine geotags collected from citizen science data. These nine outliers were unique by both Global ID and GUID as these tags ranged from geotags collected on the citizen's street, other streets, and as exact locations.

The advanced navigation survey was configured to order the nine outliers in order of nearest distance from any live location point. The best driving route to navigate to the closest geotag was displayed on Google Maps (Randall *et al.* 2022). Upon arrival at the geotag, the survey was configured to present two custom-built options for validation, and one configured option for accuracy corrections. The first validation option was a one-button approach to validate if a tree (of any species) was present at the exact location. The second validation option was a one-button approach to validate if the tree species (if one was present) is a Jacaranda tree or not. If a

Jacaranda tree was present at one the nine outlier geotags, the accuracy correction option was used. Here, an exact location of Jacaranda tree presence was captured in-field, using the *Survey 123 Connect*. Notably, all nine geotags were located within the 7 m accuracy threshold and were classed as 'high accuracy'.

The purpose of conducting these field visits to geotags which were seen as outliers 9when compared to previous Google Street View and ground-truthing), was to ensure that these data points were in fact accurate, before incorporating into the overall accuracy assessment for this study.

4.4 Synthesis

Spatial distribution maps produced in this research study involved data collection through a combination of ground-truthing, Google Street View and citizen science approaches. Validation of Jacaranda tree presence through ground-truthing and Google Street View confirms all data collected from citizen science as useful for purposes of this research study, as highlighted in this study's objectives. Additionally, the successful separation and analysis of citizen science data is in-line with the study's third objective whereby accuracy assessments for several variables can be considered influencing a citizen's geotagging accuracy.

CHAPTER 5: RESULTS

Own photograph taken in suburb of Melville, on 13 October 2022.

5.1 Introduction

This chapter presents the results of data on Jacaranda tree presence obtained through extensive ground-truthing using a GIS, Google Street View, and citizen science. The mapping of data collected from these three sources of confirmed Jacaranda tree presence addresses the primary aim of this study which is to produce the first map of the distribution of Jacaranda trees in the CoJ. Second to this, the study aimed to explore the accuracy of citizen science in mapping this distinct tree species, whereby citizen science efforts were assessed against validated Jacaranda tree location with further analysis on possible factors which may contribute to lower or higher counts of accuracy and certainty for Jacaranda tree presence.

5.2 Ground-truth Validation of Jacaranda Tree Presence

A total of 5,928 confirmed geopoints for Jacaranda tree presence was collected during the 7-day winter field campaign from 5-11 July 2022. A total of 3,003 confirmed geopoints for Jacaranda tree presence were collected during the 7-day spring field campaign from 11-17 October 2022 (Table 5.1). The extensive collection of ground-truth geopoints for Jacaranda tree location contributes to this study's objectives to create a spatial distribution map of known Jaranda tree presence, whilst also comparing citizen science data accuracy of collected geopoints for Jacaranda tree presence to that of confirmed presence.

Table 5.1: Number of validated Jacaranda tree geopoints collected from both field campaigns carried out in winter and spring seasons.

Dates of Fieldwork	**Number of ground-based geopoints**	**Suburbs Visited**	
5-11 July 2022	5928	Atholl Atholl Gardens Athollhurst Braamfontein Constantia Kloof Dunkeld Dunkeld West Killarney Melrose Melrose Estate Melrose North Observatory Parkhurst	Parktown Parktown North Parkview Parkwood Randpark Rosebank Orange Farm Ennerdale Soweto Halfway House Ferndale Saxonwold
11-17 October 2022	3003	Blackheath Blairgowrie Bryanston Craighall Douglasdale Emmarentia Greenside Halfway House Houghton Estate Melville	Northcliff Northwold Norwood Oaklands Sunninghill Waverley Weltevredenpark Westcliff Westdene
Total	**8,931**	**44**	

An initial spatial distribution map of confirmed Jacaranda tree presence in the CoJ was produced (Figure 5.1) – as per the study's primary aim. It is important to note that Jacaranda trees are often street trees, and these 8,931 total geopoints are collected from Jacaranda trees which only lined streets (*Section 4.2.1*), since access was not permitted into private property where Jacaranda trees occupied gardens and park spaces.

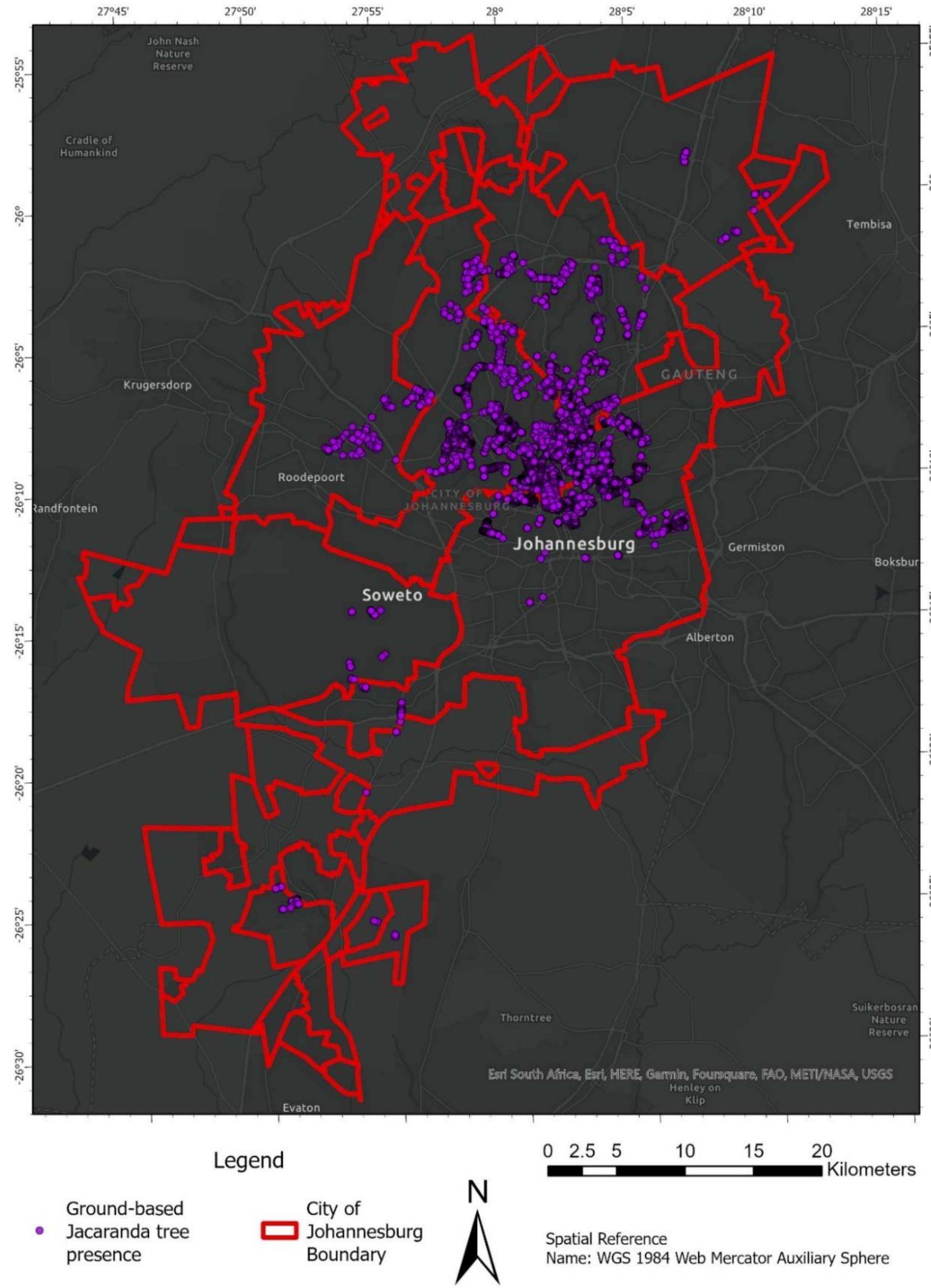


Figure 5.1: Map showing ground-based validation of a total of 8,931 geopoints where a single geopoint represents Jacaranda tree presence in the CoJ.

Ground-truthing further revealed insight on high-prevalence Jacaranda tree suburbs where trees were planted with an equidistant pattern of one another and neatly lined many streets as displayed in the suburb of Saxonwold. In contrast, other suburbs displayed a sporadic distribution of Jacaranda trees found either in clusters on one end of a street or as single trees dispersed at random points along streets with other tree species sharing the area as was evident in the suburb of Killarney. Jacaranda trees were particularly sporadic in suburbs such as Soweto, where two or three Jacaranda trees were found at random locations. This ground-truth map is not a comprehensive map of all Jacaranda trees in the CoJ, in that an absence of Jacaranda trees on the map does not necessarily mean an absence in reality. However, every one of the 8,931 purple geopoints on the map is indicative of high accuracy Jacaranda tree presence at that point in reality.

5.3 Google Street View Validation of Jacaranda Tree Presence

Google Street View imagery was used for desktop remote validation of Jacaranda tree presence in the CoJ. Google Street View imagery also confirmed high numbers of Jacaranda tree presence in the central and northern suburbs of the CoJ. As this study's second objective is to use Google Street View to validate both reported and unreported Jacaranda trees, all collected GPS coordinates of Jacaranda trees were processed to produce a map where a single Google Street View capture represented a single geopoint (*Section 4.2.2*). Depending on the prevalence of Jacaranda trees which line a street, a single Google Street View capture and corresponding single geopoint, may contain one to six Jacaranda trees (Figure 5.2).

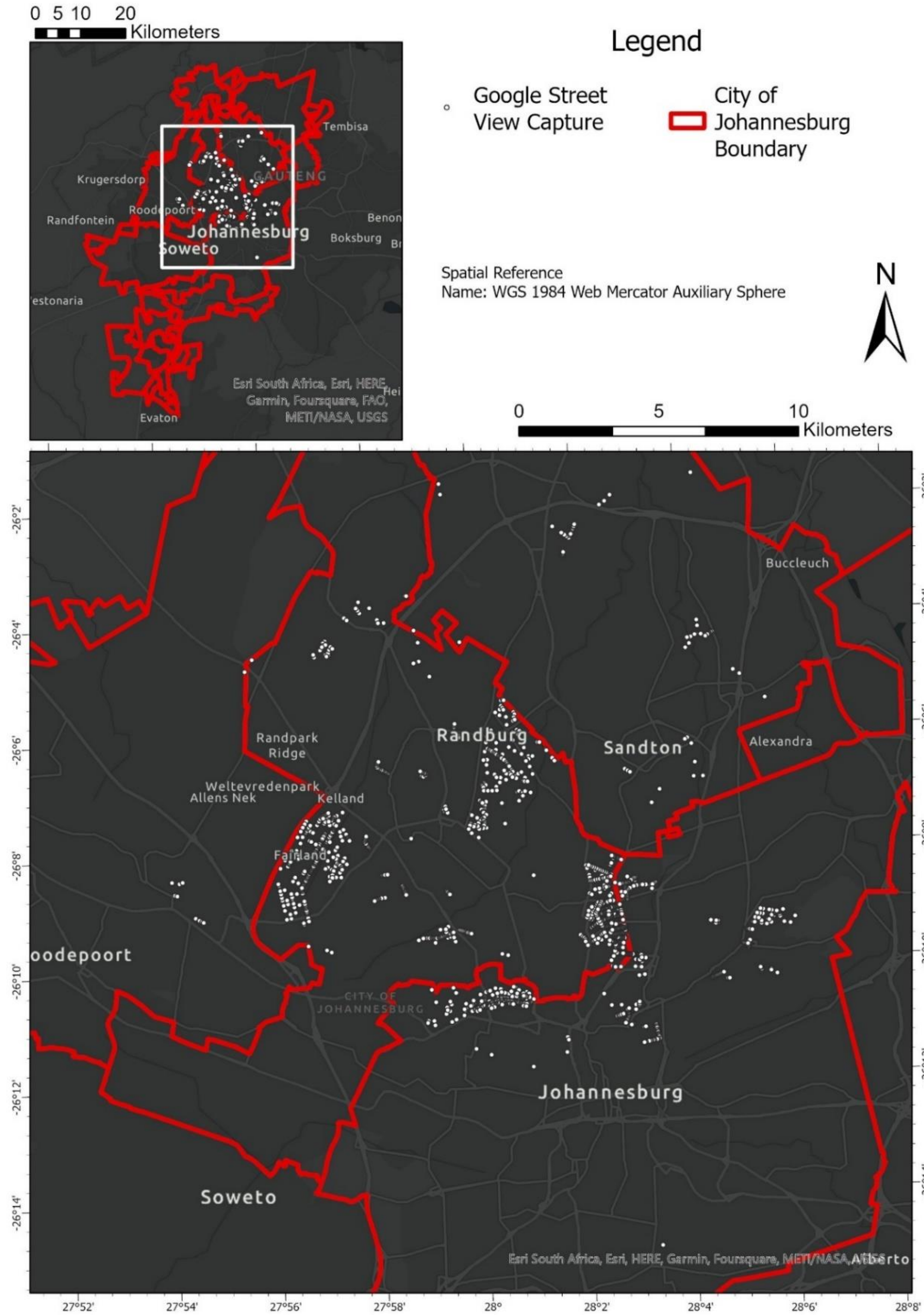
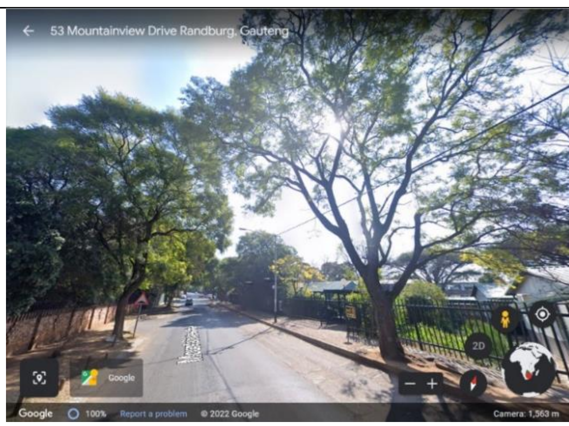


Figure 5.2: Map showing Google Street View captures of Jacaranda tree presence in the CoJ, where a single white geopoint represents between 1 - 6 Jacaranda trees.

Google Street View imagery indicates three different Jacaranda tree appearances of bare, green leaf, and flowering. All three appearances were clearly identifiable on Google Street View, along with young Jacaranda trees which had not yet produced full branches and leaves. Google Street View capturing commenced from August 2022 with two key goals in the data collection process. First, to validate regional 'gaps' for entire suburbs and specific areas of suburbs that were not visited during the July 2022 field campaign, and second to validate any suburbs or streets where citizen scientists geotagged Jacaranda tree presence, which is in-line with this study's objectives (Figure 5.3).

a



b

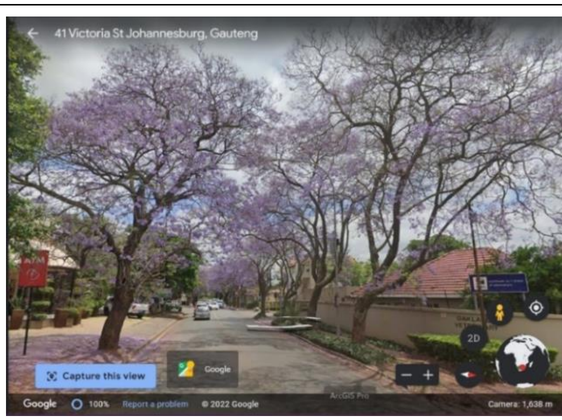


Figure 5.3: Google Street View capture showing a) two green and b) five flowering Jacaranda trees in a single capture.

For the suburbs of Atholl, Atholl Gardens, Athollhurst, Bryanston, Douglasdale, Dunkeld, Dunkeld West, Emmarentia, Killarney, Melrose, Melrose Estate, Melrose North, Melville, Northcliff, Northwold, Norwood, Observatory, Parkhurst, Parktown, Parktown North, Parkview, Parkwood, Pine Park, Rosebank and Saxonwold both Google Street View and ground-truthing were conducted to facilitate the comparison of results for the two methods. The focus on these suburbs were made based on previous studies identifying high prevalence of Jacaranda tree suburbs but were further guided during both field and virtual campaigning as nearby streets were noticed with high Jacaranda tree prevalence (*Section 4.2*). Resultantly, the decision was made to venture along these newfound high Jacaranda tree prevalence streets. At the end of these campaigns, data revealed many smaller suburbs to have been covered during these ventures. This was particularly resourceful for this study's second objective, as the control data points of ground-truthing and Google Street View were larger in numbers than anticipated. Hence, a more detailed and high spatial resolution foundation existed to compare citizen science geotagging against – which is also in-line with the first objective and primary aim of this study.

Google Street View further assisted with identification of Jacaranda trees in suburbs and streets where ground-truthing was not conducted due to time and logistical constraints. Jacaranda presence in the suburbs of Bordeaux, Fairland, Kensington, Linden, Linksfield, Montgomery Park, Morningside, Orange Grove, Orchards, Pine Park, Randburg, Riviera, Rivonia, and Sydenham was validated using Google Street View. Google Street View presented geotagging patterns which were more structured when on map display than those collected from ground-truthing (*Section 4.2.2*). Owing to the uniformity of Google Street View captures, new observations of the land topology were identified such as clear street intersections, sections where Jacaranda trees were found on alternate streets and suburbs where gridded planting versus random planting was implemented (Figure 5.3).

5.4 Citizen Science Survey Responses

Five social media platforms were used to encourage participation of residents with the 'Jacaranda Mapper Survey' (*Section 4.2.3*). The analysis of these responses is significant as it links to the efficiency of using citizen science as a data collection tool, together with identifying the best platforms to effectively engage with the public at large, to then attract a specific audience. In the case of this study, citizens of the CoJ formed part of the target audience.

The number of survey responses reflected interest in and relevance of Jacaranda tree flowering, with an increase in citizen responses recorded closer to and during Jacaranda tree flowering events. A total of 203 Jacaranda tree mapping survey responses were obtained during the 75-day survey collection period, spanning 08h30 on 25 August 2022 to 08h30 on 07 November 2022 (Figure 5.4).

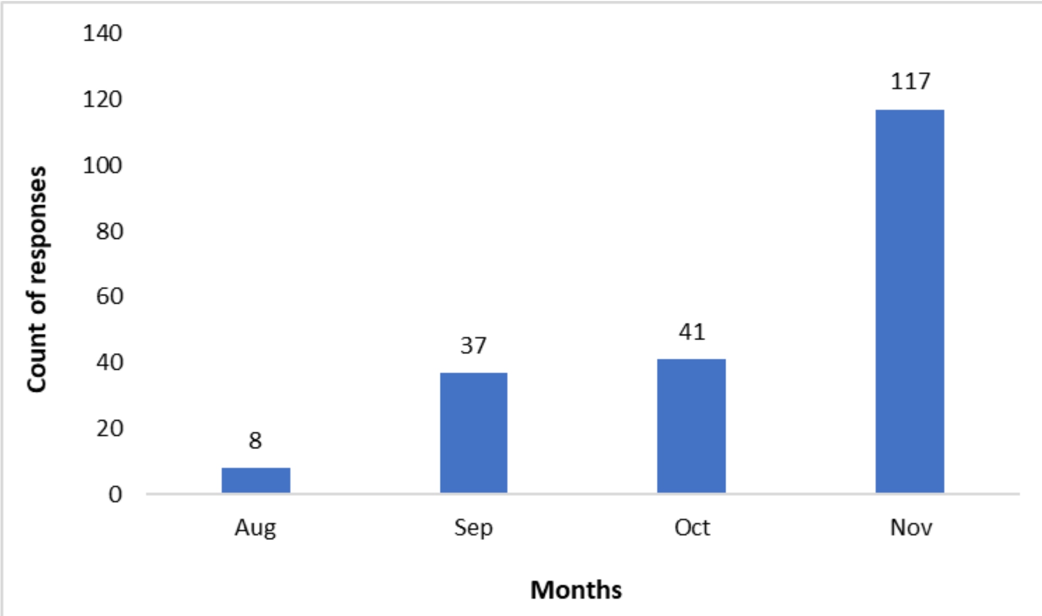


Figure 5.4: Count of online survey responses collected per month from citizens of the CoJ, over the 75-day survey collection period.

Notably, 29 of the total 203 survey responses could not be included in the results which follow, as these respondents indicated in the first question that they were not residents of the CoJ, at which point the survey was configured to end. Therefore, analysis and results from 174 survey responses follow in the sections hereafter. The month of August marked a slow start to the initiative with a total of eight responses. The survey link was shared only through the platform of WhatsApp, by means of direct messages to personal friends and relatives who were known residents of the CoJ as well as sharing of the survey link on the WhatsApp status platform.

The number of responses began to increase steadily with a count of 37 responses for the month of September, which is also the month associated with springtime (Van der Walt and Fitchett, 2020). The month of October had a total of 41 survey responses (Figure 5.4). The final month of the survey initiative measured the highest number of responses as seen by a total of 117 survey responses obtained in November (Figure 5.4). Jacaranda trees are still in peak flower during this month but begin to lose their flowers rapidly during the middle of November. This unexpectedly high number of responses was collected from 1-7 November 2022.

5.4.1 Social Media Posting Dates for Survey Responses

Both snowball-sampling and convenience-sampling approaches displayed positive results with snowball-sampling as the most effective when coupled with platform WhatsApp. This direct approach collected a steady number of responses, but the overall count was low since a smaller audience is reached. Comparatively, convenience-sampling was helpful in attracting a larger audience for a higher response count.

Since sharing survey links through WhatsApp presented a lower yield, Facebook and Instagram user accounts for the project were created on 12th and 13th September 2022, respectively, to attract larger audiences. Hereafter, the number of survey responses increased rapidly as the digital survey was distributed using hashtags and mentions which were aimed at Jacaranda-specific audiences (Figure 5.5).

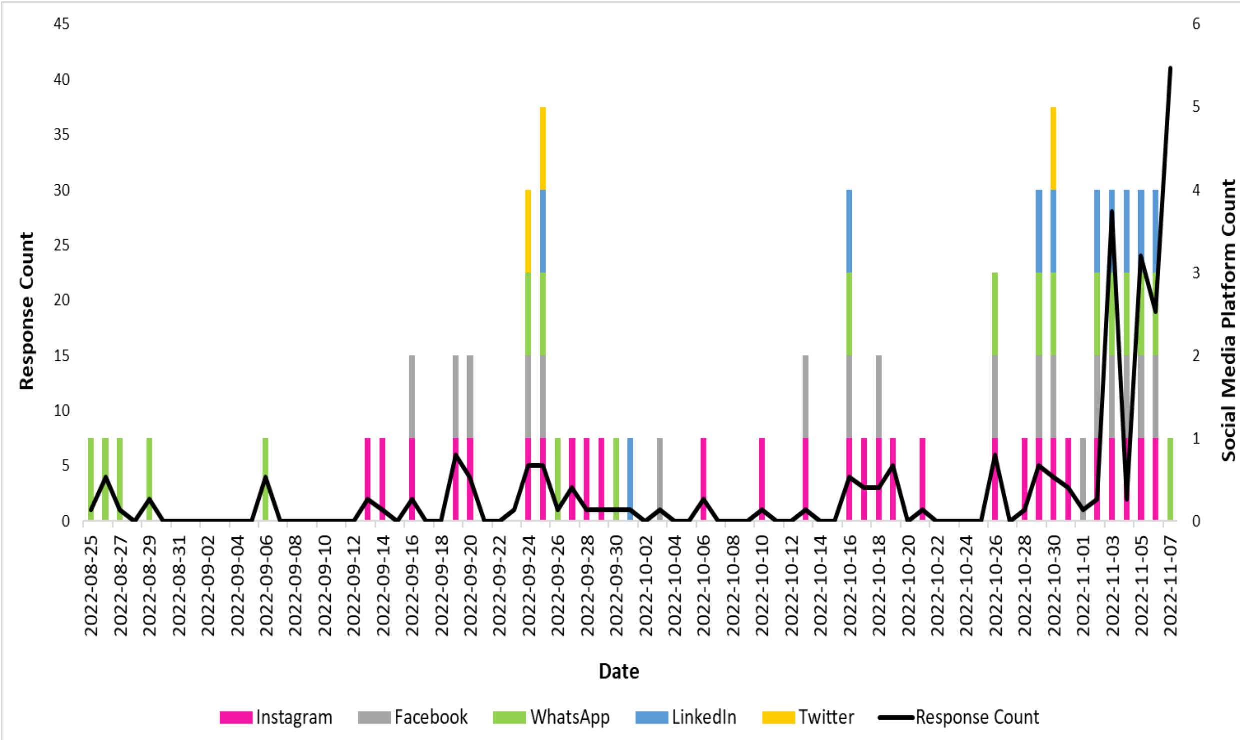


Figure 5.5: Response count per day as influenced by posting days on five social media platforms of Instagram, Facebook, WhatsApp, LinkedIn, and Twitter.

Since Instagram reaches a general audience, with hope of attracting CoJ residents the use of hashtags, tags, and comments were chosen based on factors related to 'Jacaranda season' (Table 5.2). Jacaranda photography posts from the public were analyzed, and common words and phrases formed part of my many posts. An example where both hash-tagging and tagging is used is observed with the "Jacaranda in your pocket" photography competition where photograph entries must be posted with the #Jacarandainyourpocket and @Johannesburginyourpocket hashtag and tag, respectively. Moreover, whenever a survey link was re-shared, it was guaranteed for at least one survey response to be collected for that day. Therefore, reference to hashtags, tags, or comments which citizens of the CoJ are attracted to, are found to increase the participation rate of citizens in the survey.

Table 5.2: List of hashtags, tags and mentions which were used in Jacaranda posts on social media.

Hashtags used:	**Mentions used:**
#Jacaranda	@CityofJohannesburg
#Jacarandas	@CityofJoburg
#Jacarandaseason	@LoveJohannesburg
#Jacarandatree	@Johannesburginyourpocket
#Johannesburg	
#Joburg	
#Jozi	
#Spring	
#Purple	
#Johannesburgphotographer	
#Jacarandainyourpocket2022	

5.5 Citizen Demographic Information

The Jacaranda mapping survey captured demographic information on citizens' duration of residency in the CoJ, suburb of residence within the CoJ, as well as citizen's certainty ratings linked to geotagging on their awareness of Jacaranda tree presence in their suburb, street, and other streets. Responses were collected from a total of 69 suburbs across the seven regions of the CoJ with a total of 488 citizen science geotagged locations for possible Jacaranda tree presence in the CoJ. The demographic information of a citizen is an important influence towards this study's third objective and second research question as these variables may contribute to the accuracy of data collected by the citizen on Jacaranda tree presence.

5.5.1 Citizen Familiarity with the CoJ

Citizen science responses were collected from a range of residents who live in the CoJ for a minimum of 0-11 months to more than 10 years. The most responses (44%, n=174) were received from citizens who have lived in the CoJ for more than 10 years followed by the least responses (8%, n=174) from citizens who have lived in the CoJ between 0-11 months (Figure 5.6). The most responses are significant to the analysis based on the third objective of this study since research shows that the accuracy level of data collect from citizens, increases based on citizen familiarity (or length of stay) in the region in focus (*Section 2.2.1*).

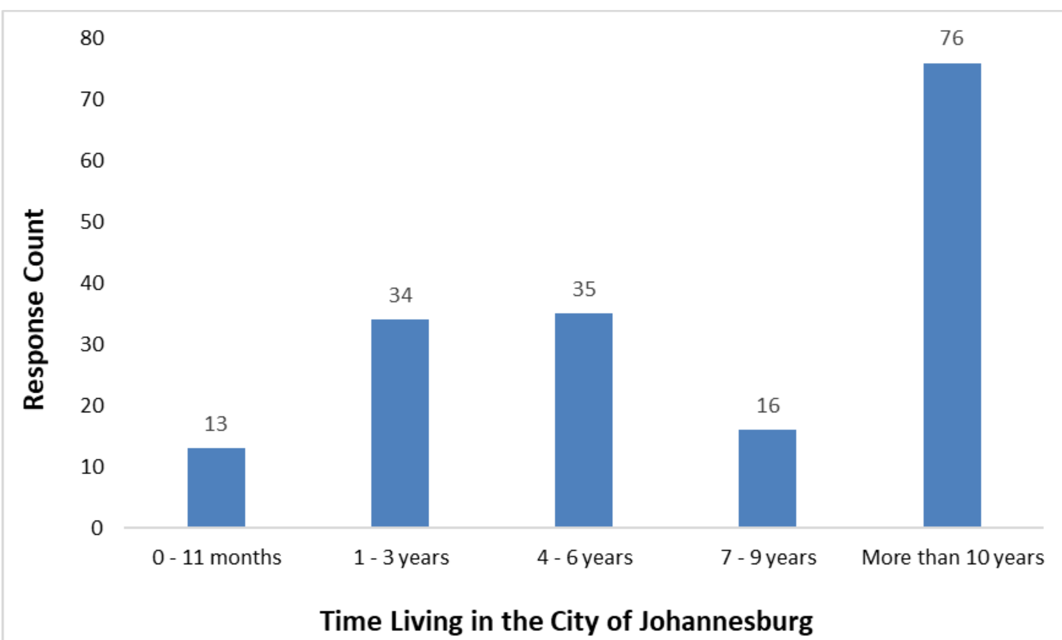


Figure 5.6: Response count of each citizen's timeframe for which they have lived in the CoJ.

5.5.2 Citizen Suburb of Residence

Citizen science responses were collected from a total of 69 suburbs in the CoJ (Figure 5.7). The largest number of responses collected were from 43 citizens who reside in the suburb of Parktown. This is unsurprising as three of the University of the Witwatersrand campuses are based in Parktown, together with a number of student residences including the largest Postgraduate residence, the *Wits Junction*. As the questionnaire was distributed through social media, it is not unexpected that the largest uptake would be from users within a close social network, along with students who are willing to complete questionnaires for their fellow Postgraduates. The second highest response counts were shared between the suburbs of Montgomery Park and Northcliff, with seven citizens each. Six responses were obtained from citizens who have lived in each of the suburbs of Blairgowrie, Melrose, and Melville. The least responses were counts of one which were found across a total of 43 suburbs.

The spatial distribution from which citizen science responses were collected are significant towards the first objective of this study as many citizens were willing to collect data for a study based in their city.

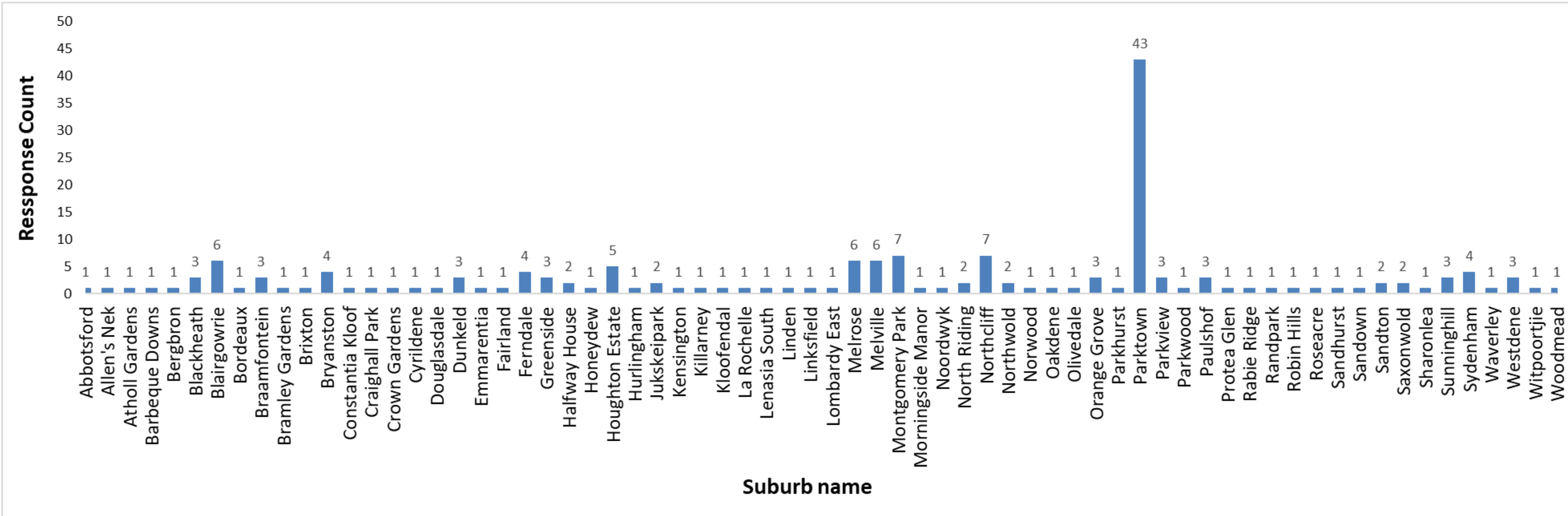


Figure 5.7: Citizen science online survey responses per Suburb in the CoJ, ordered alphabetically.

5.6 Citizen Science Certainty Ratings

Citizens were required to answer certainty questions on Jacaranda tree presence in their suburb, on their street, and on other streets. A five-scale certainty rating measured from ‘very certain’, ‘certain’, ‘neither certain nor uncertain’, ‘uncertain’ and ‘very uncertain’ was provided when citizen’s selected either ‘yes’ or ‘no’ for Jacaranda presence in their suburbs. A ‘very certain’ rating was the common response across Jacaranda presence in citizen’s suburb, their street or other streets, indicating for citizens to show high awareness of the Jacaranda tree species within their suburbs.

The majority of citizen science responses displayed the highest certainty rating of ‘very certain’ for Jacaranda tree presence in their residing suburb (66%, n=174; Figure 5.8). The least responses were those of the fourth rating ‘uncertain’ of Jacaranda presence in their suburb. Certainty ratings were then analyzed according to suburb. Interestingly, the suburb of Parktown, with the highest count of overall citizen science responses (Figure 5.7), displayed a majority count of 38 of the 43 responses as ‘very certain’ for Jacaranda presence in Parktown suburb. The suburbs of Montgomery Park and Northcliff which displayed the second highest response count (Figure 5.7), also displayed high certainty responses (Figure 5.8).

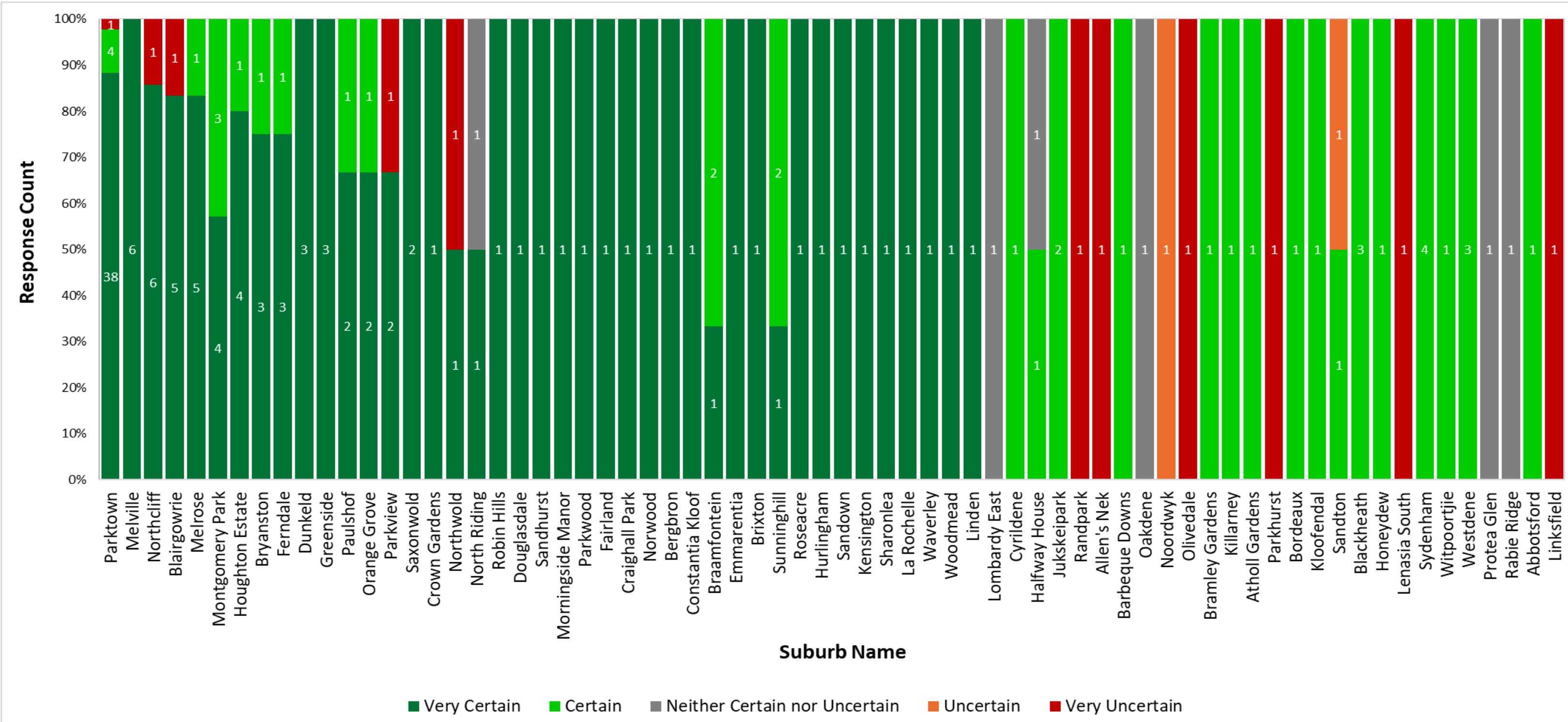
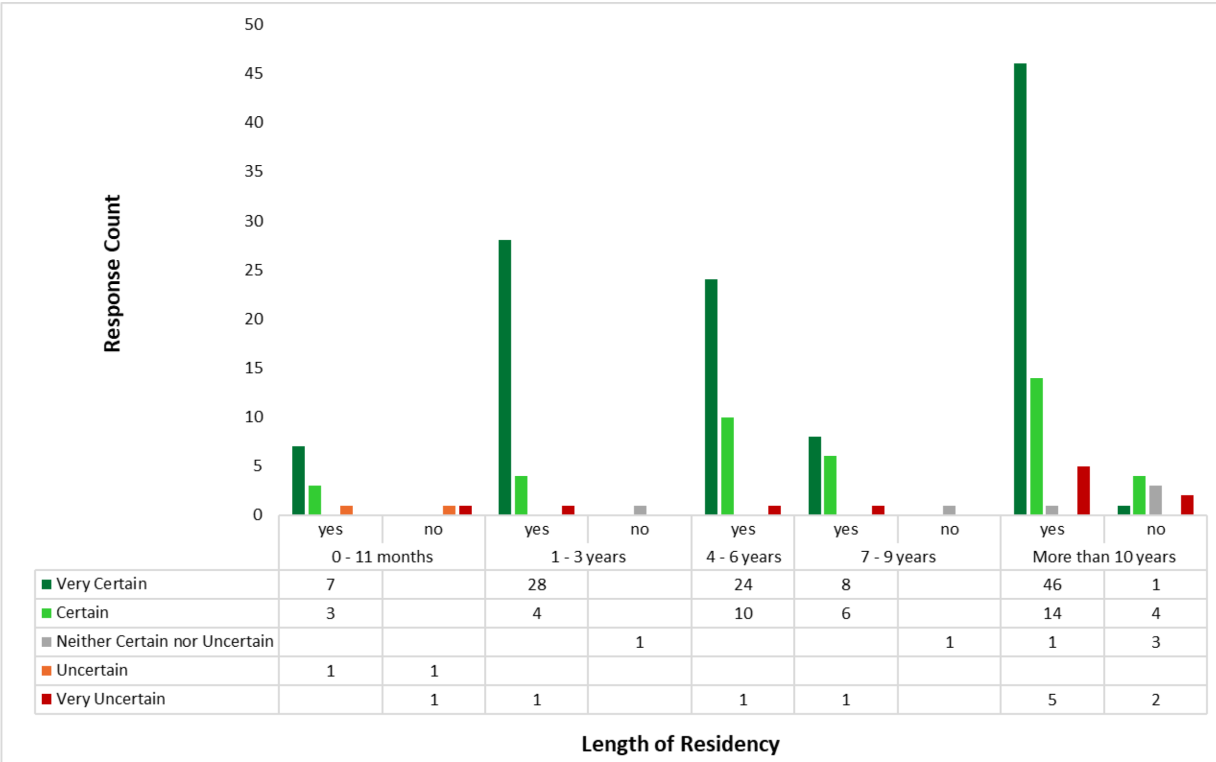


Figure 5.8: Certainty rating of total citizen science responses per suburb, ordered from 'Very certain', 'Certain', 'Neither certain nor uncertain', 'Uncertain', and 'Very uncertain'.

5.6.1 Certainty Ratings Linked To Citizen Length of Residency in the CoJ

Five options classifying the period of length of residency in the CoJ were available for citizens to select in the digital survey (Figure 5.9). The fewest responses across all survey responses were from the 0-11 months category with most responses as 'very certain' for Jacaranda tree presence in their suburbs. Notably, zero certainty ratings were collected for the category of 'neither certain nor uncertain'.

The second length of residency option was between 1-3 years and third option of between 4-6 years displayed similar trends (Figure 5.9). The majority of the responses collected from both options were from the 'very certain' and 'certain' ratings for Jacaranda tree presence, with few ratings collected across other certainty options. The fourth length of stay option between 7-9 years and fifth length of stay option of more than 10 years, showed similar trends. Most of these responses were from the 'very certain' and 'certain' ratings for Jacaranda tree presence. Notably, zero certainty ratings were collected for the category 'uncertain' for both length of residency options with very low counts for categories 'neither certain nor uncertain' and 'very uncertain'.



	0 - 11 months: yes	0 - 11 months: no	1 - 3 years: yes	1 - 3 years: no	4 - 6 years: yes	7 - 9 years: yes	7 - 9 years: no	More than 10 years: yes	More than 10 years: no
Very Certain	7		28		24	8		46	1
Certain	3		4		10	6		14	4
Neither Certain nor Uncertain				1			1	1	3
Uncertain	1	1							
Very Uncertain		1	1		1	1		5	2

Figure 5.9: Certainty ratings of Jacaranda tree presence in citizen's suburbs, as influenced by citizen's residence in the CoJ.

Citizen science respondents' level of certainty of the accuracy of geotags on the citizen's own street was compared to the certainty of their geotags for trees on other streets. A total of 433 certainty ratings were collected cumulatively from Jacaranda tree presence on citizen's streets and on other streets (Table 5.3). Notably, most responses (54%, n=433) collected certainty ratings from other streets, instead of the citizen's street (46%, n=433). The 'very certain' and 'certain' ratings were dominant across both citizen's streets and other streets with 117 and 124 responses, respectively (Table 5.3). The 'very uncertain' category was lower for Jacaranda tree presence on 'my street', accounting for five of the 198 tags compared to this category in the 'other streets' with four of the 235 responses. Although a low count of Jacaranda trees was geotagged from the ‘my street’ category, certainty ratings for Jacaranda tree presence appear higher than those for ‘other streets’.

Table 5.3: Certainty ratings of Jacaranda tree presence from citizen’s street and other streets.

	My street	**Other streets**
Very Certain	117	124
Certain	71	92
Neither Certain nor Uncertain	2	8
Uncertain	3	7
Very Uncertain	5	4
Total	**198**	**235**

5.7 Citizen Science Geotagging

A geotagging accuracy buffer for the digital survey was set to 7m, as the survey could be accessed from any smart device with a built-in GPS. A single user could capture up to 200 individual geotags for Jacaranda presence on ‘my street’, ‘other streets’ and ‘exact location’. Hence, a maximum of 600 geotags could be captured in a single survey. A total of 448 individual geotags were collected from citizen scientists (Figure 5.10).

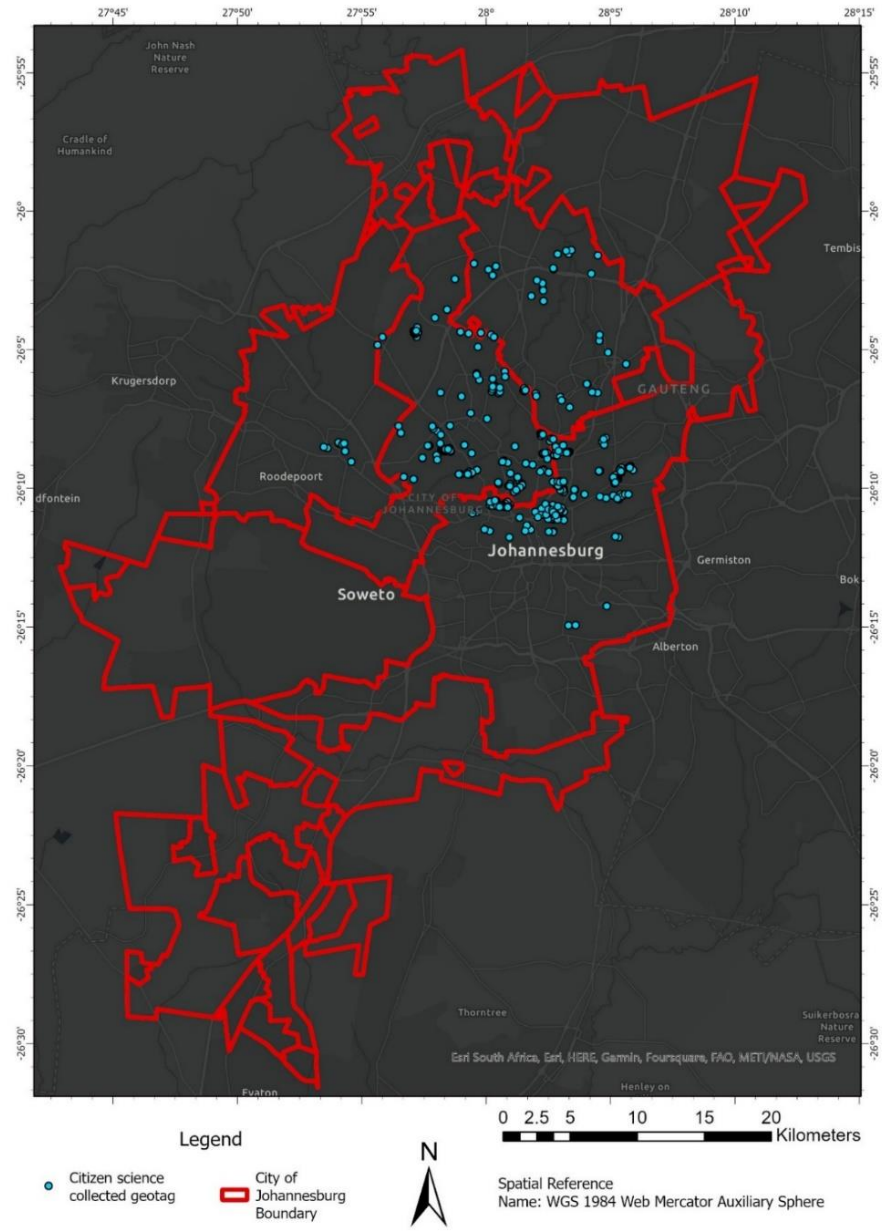


Figure 5.10: Map showing all captured citizen science geotags for Jacaranda tree presence in the CoJ.

The complete set of citizen science collected geotags were then categorized into three categories: geotags which were tagged on the citizens street, on other streets, and those which were geotagged as exact locations (Figure 5.11). Of the total 488 geotags, 198 geotags were collected from ‘my street’, 235 from ‘other streets’ and 55 were ‘exact location’ for Jacaranda tree presence. Notably, the majority of citizen science geotags were collected from ‘other streets’ as opposed to ‘my street’.

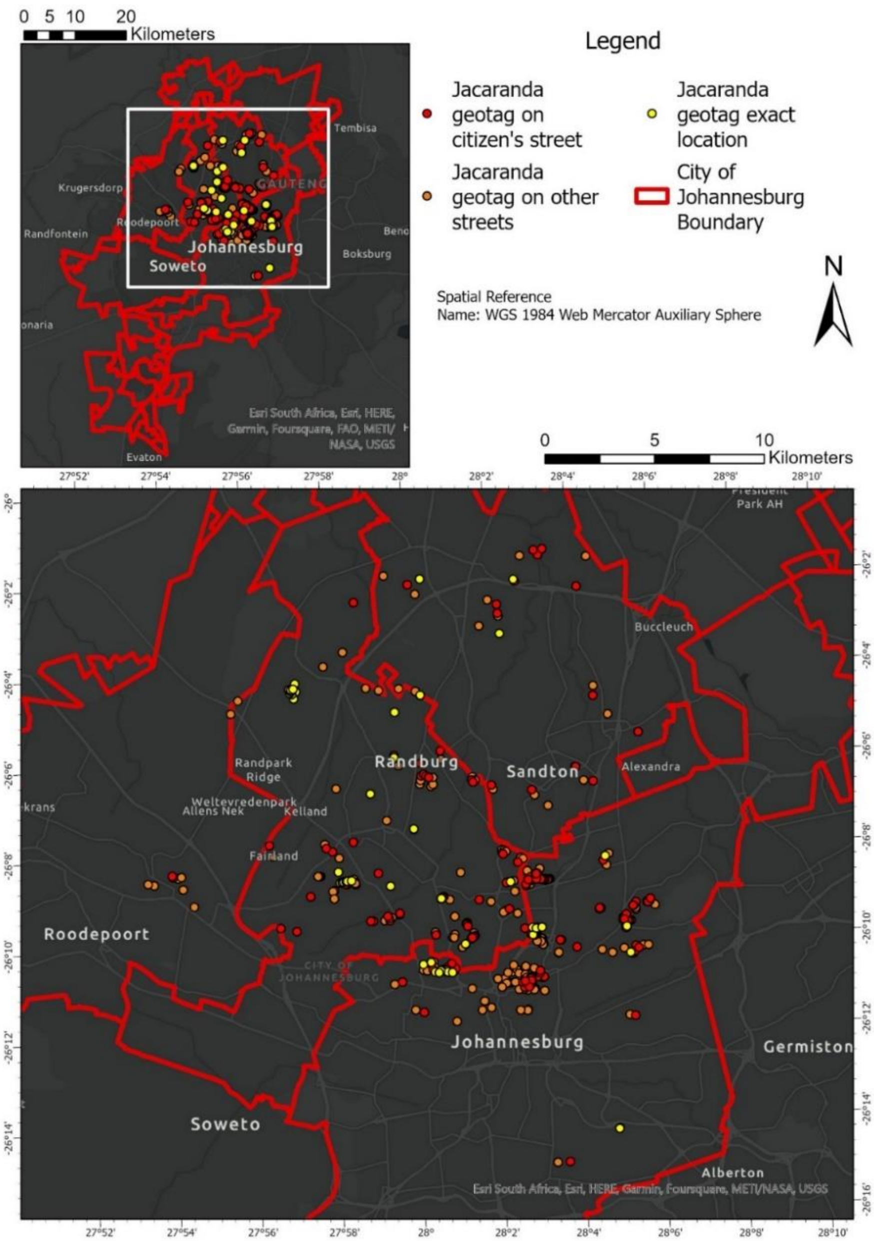


Figure 5.11: Map showing total citizen science geotags categorized by ‘my street’, ‘other streets’ and ‘exact location’ of Jacaranda tree presence in CoJ.

Citizen science collected geotags were also categorized by levels of accuracy and were compared to ground-based and Google Street View geopoints of confirmed Jacaranda tree presence (*Section 4.3*). After analyzing all measured citizen science geotags from ground-based and Google Street View geopoints, threshold 'bins' of measured accuracy were created. Six levels of accuracy were classified (Table 5.4).

Table 5.4: Six categories for level of accuracy of citizen science geotags from confirmed Jacaranda tree presence.

Measure of accuracy	Accuracy description
<7m	Very high
8-14m	High
15-24m	Moderate
25-100m	Low
101-199m	Very low
>200m	Inaccurate / Unconfirmed

5.8 Citizen Science Geotag Accuracy

The largest percentage (30%, n=488) of citizen science geotags were within the 'very high accuracy' category as these geotags were <7 m of confirmed Jacaranda tree presence (Table 5.5). Interestingly, citizen science geotags begin to decrease in accuracy with the second highest total of 24% (n=488) of geotags within the 'low accuracy' category, followed by 22% (n=488) of geotags within the 'high accuracy' category.

Table 5.5: Citizen science geotags categorized by six levels of accuracy. Accuracy levels were analyzed for the total geotag count, geotags on 'my street', geotags on 'other streets' and 'exact location'.

	All geotags	**My street**	**Other streets**	**Exact location**
<7m	148	67	68	13
8-14m	106	54	43	9
15-24m	70	27	36	7
25-100m	115	33	61	21
101-199m	23	7	13	2
>200m	26	10	14	3
Total	**488**	**198**	**235**	**55**

Citizen science collected geotags were then split into the three categories for 'my street', 'other streets', and 'exact location' (Table 5.5). A total of 198 geotags were collected from the on 'my street' category. Notably, most geotags fell within the 'very high accuracy' range (34%, n=198) and 'high accuracy' range (27%, n=198) with the fewest geotags (4%, n=198) within the 'very low accuracy' range. Resultantly, citizens are remarkably aware and accurate of Jacaranda tree presence on their streets.

A total of 235 geotags were collected from the 'other streets' category. Notably, this category showed similar trends to the cumulative accuracy of total geotags. Most geotags fell within the 'very high accuracy' range (29%, n=235), followed by 26% (n=235) of geotags as 'low accuracy'. The third highest count of 18% (n=235) of geotags had a 'high accuracy' for Jacaranda tree presence. This fluctuating trend indicates that citizens were either very accurate or not accurate when locating Jacaranda trees in other streets.

A total of 55 geotags were collected from the ‘exact location’ category. This category showed unexpected results. Most geotags (38%, n=55) were within the ‘low accuracy range’ of within 25-100 m of confirmed Jacaranda tree presence. This was followed by the ‘very high accuracy’ range with 24% (n=55) of geotags of <7 m of confirmed Jacaranda tree presence. The third highest count of 16% (n=55) of geotags had a ‘high accuracy’ for Jacaranda tree location. Notably, the ‘very high’ and ‘high’ accuracy combined has a count of 22 geotags compared to the combined 23 geotags for ‘low’ and ‘very low’ accuracy. It can be argued for the ‘exact location’ category accuracy to show as a ‘gray area’ since geotags are split between the top two accurate ratings and bottom two inaccurate ratings depending on the device used by citizens to capture these geotags. The accuracy range with geotags which fall within 101-199 m of confirmed Jacaranda tree presence, displayed the same trend throughout all categories of ‘my street’, ‘other street’, and ‘exact location’. Here, the lowest count of geotags of 4% (n=198), 6% (n=235), and 4% (n=55) respectively, are each owed to the ‘very low accuracy’ range. Resultantly, citizen science geotagging indicates few counts for low accuracy and more counts for high accuracy.

5.8.1 Inaccurate, Unconfirmed, or Invalid Geotags from Citizen Science

A total of 26 citizen science geotags fell within the >200 m range for distance from confirmed Jacaranda tree presence. Three citizen science geotags with invalid geometry were excluded from the total count of geotags (Table 5.6). These three geotags did not have geographic coordinates attached to them and measurement for accuracy could not be calculated.

Further analysis was conducted for the 26 geotags which fell within the >200 m range of confirmed Jacaranda tree presence to better understand possible reasons for inaccuracy (Table 5.6). These geotags were confirmed using Google Earth composite imagery to identify nearby streets with confirmed Jacaranda tree presence, for new conclusions on Jacaranda tree likelihood on the street in question. A total of 31% (n=26) of citizen science geotags were correctly tagged Jacaranda trees (Table 5.6).

Table 5.6: Description of 29 citizen science collected geotags which lie within the 'inaccurate', 'unconfirmed' or 'invalid' accuracy range for >200m of confirmed Jacaranda tree presence.

Geotag ID	Street name	Suburb	Geotag category	Tree presence	Jacaranda tree presence	Distance to nearest Google Street View/ground	Notes
1	Eckstein Street	Observatory, Johannesburg	Citizen's street	Yes	No	268m	Satellite imagery confirms geotag placement on Eckstein Street, outside of private property. No Google Street View data available. Satellite imagery confirms tree species directly beneath the geotag. Tree species unknown.
2	Eckstein Street	Observatory, Johannesburg	Citizen's street	Yes	Unconfirmed	289m	Satellite imagery confirms geotag placement within private property but is located along vegetated fencing at the back of the property. No Google Street View data available. Tree species unknown.
3	Eckstein Street	Observatory, Johannesburg	Citizen's street	Yes	Unconfirmed	305m	Satellite imagery confirms geotag placement within private property but is located along vegetated fencing at the back of the property. No Google Street View data available. Satellite imagery confirms trees surrounding the private property and lining one side of Eckstein Street. Tree species unknown.
4	Republic Road	Cresta, Randburg	Citizen's street	Yes	No	306m	Google Street View confirms no Jacaranda tree presence at geotag. Republic road does have Jacaranda trees, but none are located near this geotag.
5	Daisy Street	Rosettenville, Johannesburg	Citizen's street	Yes	No	484m	Google Street View confirms no Jacaranda tree presence at geotag. Daisy street does have Jacaranda trees, but none are located near this geotag.
6	Murray Avenue	Morningside Manor, Sandton	Citizen's street	Yes	No	415m	Google Street View confirms no Jacaranda tree presence at geotag. Murray avenue does have Jacaranda trees, but none are located near this geotag.
7	Komari Avenue	Paulshof, Sandton	Citizen's street	Yes	No	<blank> (988m, this is a whole other suburb)	Google Street View confirms no Jacaranda tree presence at geotag. Komari avenue does not have Jacaranda trees.

8	Komari Avenue	Paulshof, Sandton	Citizen's street	Yes	No	<blank> (856m, this is a whole other suburb)	Google Street View confirms no Jacaranda tree presence at geotag. Komari avenue does not have Jacaranda trees.
9	Unnamed road, parallel to Komari Avenue	Paulshof, Sandton	Citizen's street	No	No	<blank> (1,191m, this is a whole other suburb)	Satellite imagery confirms geotag placement within private property, resembling farm or crop lands. No Google Street View data available.
10	Riverside Road	Sandton	Citizen's street	Yes	Unconfirmed	396m	Satellite imagery confirms geotag placement within private property. Google Street View data is only available up until the entrance of the gate to this private residential estate. Satellite imagery confirms tree species directly beneath the geotag. Tree species unknown.
11	Frederick Street	Observatory, Johannesburg	Other street	Yes	Yes	242m	Satellite imagery confirms geotag placement within citizen's private property. Google Street View data is available for the majority of Frederick Street, confirming high prevalence of Jacaranda tree presence lining the street. Tree species is identified as *Jacaranda mimosofolia*.
12	Inyoni Road	Roseacre, Johannesburg	Other street	No	No	2,875m	Google Street View confirms no Jacaranda tree presence at geotag. Satellite imagery confirms geotag placement upon a house, with no tree species nearby.
13	Hospital Street	Hillbrow, Johannesburg	Other street	Yes	Yes	201m	Satellite imagery confirms geotag placement within private property. Google Street View data is available for surrounding roads of the property, confirming high prevalence of Jacaranda tree presence lining the street. Tree species is identified as *Jacaranda mimosofolia*.
14	Hospital Street	Hillbrow, Johannesburg	Other street	Yes	Yes	203m	Satellite imagery confirms geotag placement within private property. Google Street View data is available for surrounding roads of the property, confirming high prevalence of

							Jacaranda tree presence lining the street. Tree species is identified as *Jacaranda mimosofolia.*
15	Republic Road	Cresta, Randburg	Other street	Yes	No	318m	Google Street View confirms no Jacaranda tree presence at geotag. Republic road does have Jacaranda trees, but none are located near this geotag.
16	Cavendish Street	Morningside	Other street	Yes	Yes	276m	Google Street View data not available for Cavendish Street. Google Street View data is available for surrounding streets, confirming high prevalence of Jacaranda trees. Satellite imagery confirms geotag placement directly on tree species. Tree species is identified as *Jacaranda mimosofolia*.
17	Jacaranda Lane	Chislehurston, Sandton	Other street	Yes	Yes	320m	Google Street View data not available for Jacaranda Lane. Street view data is available for surrounding streets, confirming high prevalence of Jacaranda trees. Satellite imagery confirms geotag placement directly on tree species. Tree species is identified as J*acaranda mimosofolia*.
18	Jacaranda Avenue	Meadowhurst, Randburg	Other street	No	No	556m	Google Street View confirms no Jacaranda tree presence at geotag. Jacaranda avenue does have Jacaranda trees, but none are located near this geotag.
19	Empire Road	Johannesburg	Other street	Yes	Unconfirmed	268m	Google Street View data not available for this section of Empire Road. Satellite imagery confirms geotag placement very near a moderate prevalence of tree species. Tree species is unknown.
20	Unnamed road, parallel to Komari Avenue	Paulshof, Sandton	Other street	Yes	Yes	727m	Google Street View data not available. Satellite imagery confirms geotag placement directly on tree species. Google Street View data is available for surrounding streets, confirming high prevalence of Jacaranda trees. Tree species is identified as *Jacaranda mimosofolia*.
21	Amethyst Avenue	Roodepoort, Johannesburg	Other street	Yes	Yes	201m	Google Street View data not available. Satellite imagery confirms geotag placement directly on tree species. Tree species is identified as *Jacaranda mimosofolia.*

22	Amethyst Street	Roodepoort, Johannesburg	Other street	Yes	Yes	202m	Google Street View data not available. Satellite imagery confirms geotag placement directly on tree species. Google Street View data is available for surrounding streets, confirming high prevalence of Jacaranda trees. Tree species is identified as *Jacaranda mimosofolia*.
23	Yolande Drive	Constantia Kloof	Other street	Yes	No	241m	Google Street View confirms no Jacaranda tree presence at geotag. Yolande drive does have Jacaranda trees, but none are located near this geotag.
24	Inyoni Road	Roseacre, Johannesburg	Exact location	No	No	2,873m	Google Street View confirms no Jacaranda tree presence at geotag.
25	Eckstein Street	Observatory, Johannesburg	Exact location	Yes	Unconfirmed	205m	Satellite imagery confirms geotag placement within private property but is located along the vegetated area of the property. No Google Street View data available. Tree species unknown.
26	Saint Audely Road	Bryanston	Exact location	Yes	Unconfirmed	340m	Satellite imagery confirms geotag placement within private property but is located along the vegetated area of the property. No Google Street View data available. Tree species unknown.
27	Unknown	Unknown	Invalid	Unknown	Invalid	Unknown	No geometry collected. This geotag had geographic co-ordinates of (0;0) indicating a user error
28	Unknown	Unknown	Invalid	Unknown	Invalid	Unknown	No geometry collected. This geotag had geographic co-ordinates of (0;0) indicating a user error
29	Unknown	Unknown	Invalid	Unknown	Invalid	Unknown	No geometry collected. This geotag had geographic co-ordinates of (0;0) indicating a user error

A total of 46% (n=26) of geotags in the >200 m range for confirmed Jacaranda tree presence was incorrect. Satellite imagery and available Google Street View data revealed common reasons for incorrect tagging of Jacaranda trees. This was largely owed to misidentification of Jacaranda tree species. Two cases of misidentification were apparent. The first was misidentification of tree species to another common tree in the CoJ landscape, the London Plane tree (Figure 5.12).

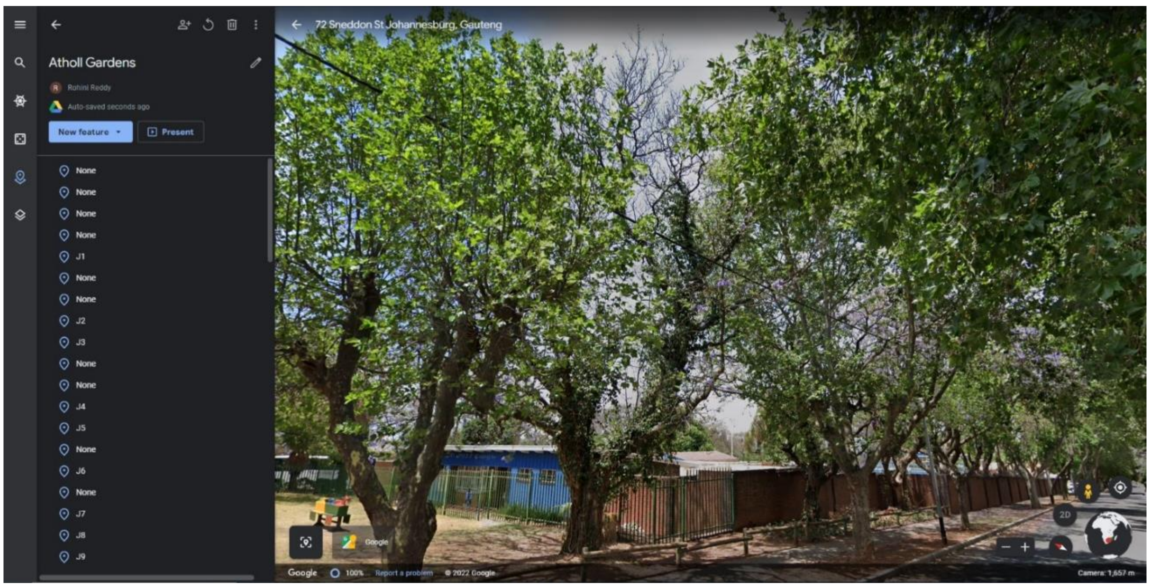


Figure 5.12: Screen capture from Google Street View of misidentification of Jacaranda tree to the common London Plane tree in the CoJ.

The second was misidentification of similar purple-coloured flowering trees, either with blossoms of pink or purple (Figure 5.13). In cases where misidentification was not the result of an incorrect geotag new conclusions about citizen's geotagging accuracy can be drawn as these geotags are placed in areas where there is no Jacaranda tree presence in the citizen's street, other streets, or the suburb.

Figure 5.13: Screen capture from Google Street View of misidentification of Jacaranda tree to similar purple-coloured flowering trees of differing tree species.

A total of 23% (n=26) of geotags were unconfirmed. These were cases where both Google Street View and ground-based data was not available for validation of Jacaranda tree presence and Google Earth composite imagery could not identify nearby streets with Jacaranda tree presence to confirm the likelihood of a geotag as a Jacaranda tree (Figure 5.14).

Figure 5.14: Screen capture from Google Street View of streets with available Google Street View imagery shown in blue. Streets without a blue highlight, do not have Google Street View imagery available.

Aside from cases where both ground-based and Google Street View data were not available for Jacaranda tree identification, unconfirmed cases also arose from pixelated or distorted Google Street View imagery (Figure 5.15).

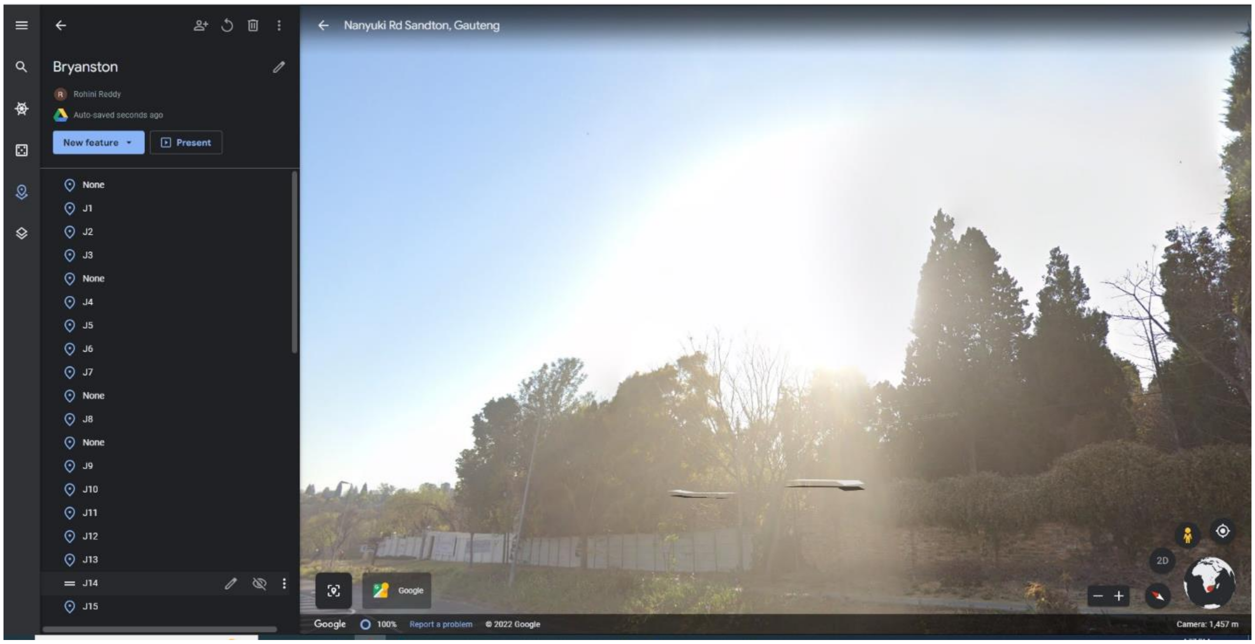


Figure 5.15: Screen capture from Google Street View of blurred Google Street View imagery due to strong sunlight limiting visibility of tree species in this capture.

5.8.2 Accuracy of Geotagging Certainty from Citizen Science

Certainty ratings collected from geotags on 'my street' and 'other street' were compared to the six levels of accuracy. The 'very high' accuracy ranges from the 'my street' category, displayed a majority of certainty geotags within the 'very certain' and 'certain' ratings (Figure 5.16). This is significant to the third objective of this study as citizens are showing a very high accuracy for geotagging ability. Interestingly, citizens indicate to be 'very certain' and 'certain' for Jacaranda tree presence even in cases where these geotags were of 'very low' accuracy and 'inaccurate or unconfirmed'.

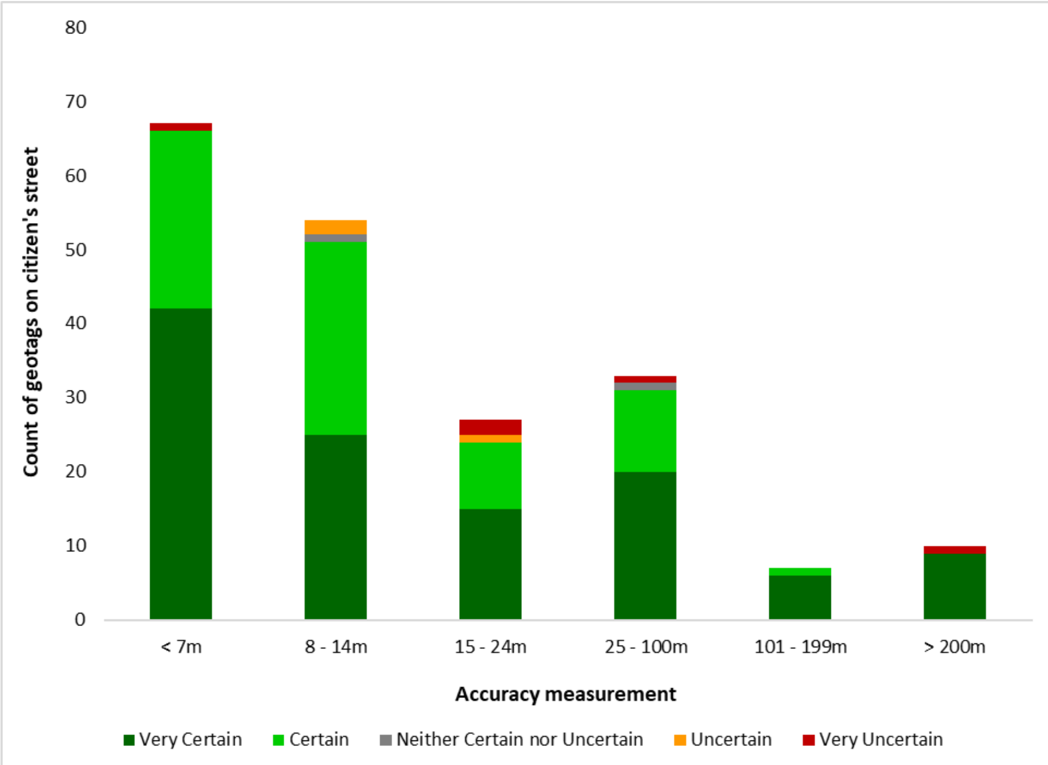


Figure 5.16: Accuracy of citizen science geotagging compared to certainty ratings for Jacaranda tree presence on citizen's streets.

The 'very high' accuracy range from the 'other streets' category, displayed ratings of 'very certain' and 'certain' only (Figure 5.17). This is significant to the study as it is in-line with the third objective where citizens show trends of high certainty and high accuracy on the data collected for Jacaranda tree presence. Similar to the 'my street' category, citizens indicate to be 'very certain' and 'certain' for Jacaranda tree presence even in cases where these geotags were of 'very low' accuracy and 'inaccurate or unconfirmed' for Jacaranda tree presence.

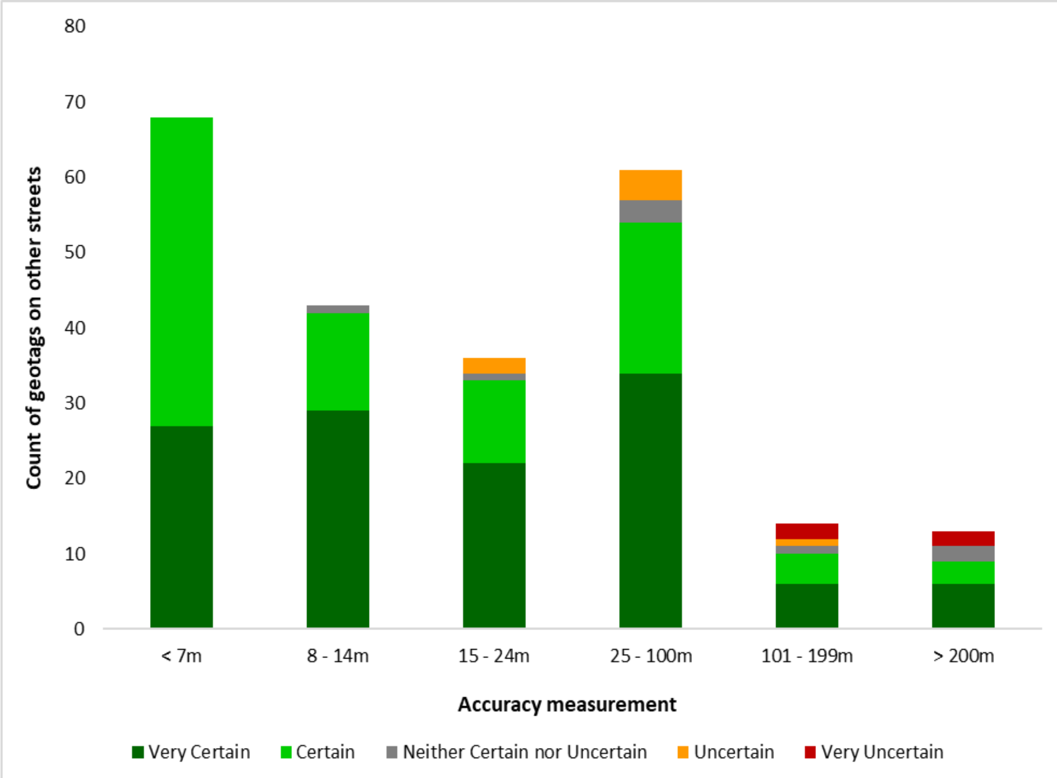


Figure 5.17: Accuracy of citizen science geotagging compared to certainty ratings for Jacaranda tree presence on 'other streets'.

5.9 Spatial Distribution of Jacaranda Trees

Combining the three sets of data, the first spatial distribution maps for known Jacaranda tree presence as derived from a combination of ground-truth geopoints, Google Street View geotagging and citizen science geotagging, were created (Figure 5.18).

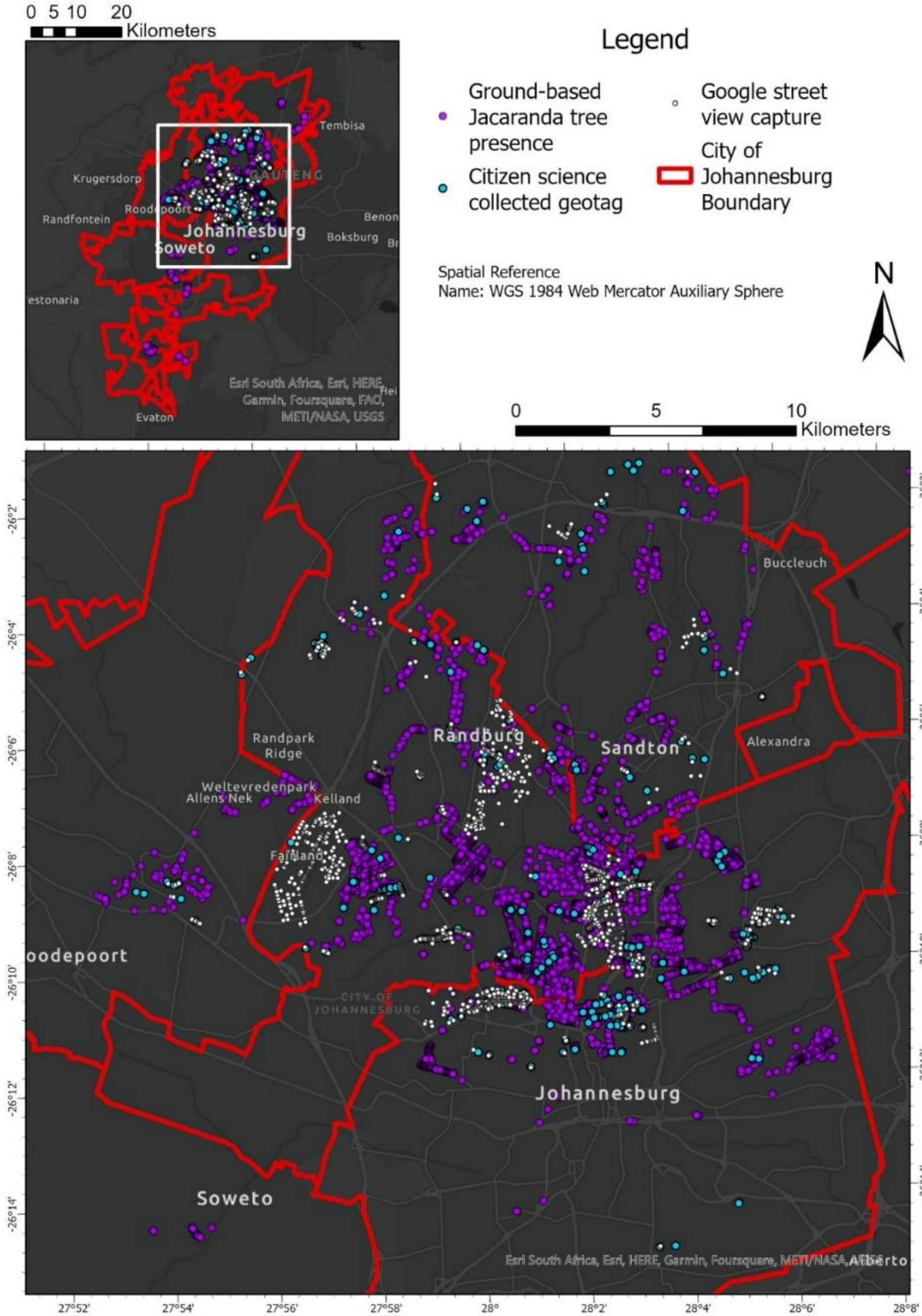


Figure 5.18: Map showing combined geopoints of ground-based validation, Google Street View validation and citizen science geotags for Jacaranda tree presence in the CoJ.

A high concentration of geopoints indicate suburbs where Jacaranda trees are found in very high numbers where trees line streets on both sides (Figure 5.19). The spatial distribution map for Jacaranda tree presence revealed for the northern and central suburbs of the CoJ to have high numbers of Jacaranda trees, and for these suburbs to also form part of many citizen science geotags (Figure 5.19). Additionally, a density map displays the overall presence of confirmed Jacaranda trees as concentrated in the northern and central regions of the CoJ (Figure 5.20). Though gaps for geopoints exist on the map, it is important to note that an absence of Jacaranda tree geopoints on the map does not necessarily mean an absence of Jacaranda trees in reality. Instead, these gaps indicate areas where further analysis for sporadic trees location can be identified.

Figure 5.19: Zoomed-in map showing select suburbs with large numbers of Jacaranda trees where ground-based geopoints, Google Street View geotagging, and citizen science geotagging data is abundant.

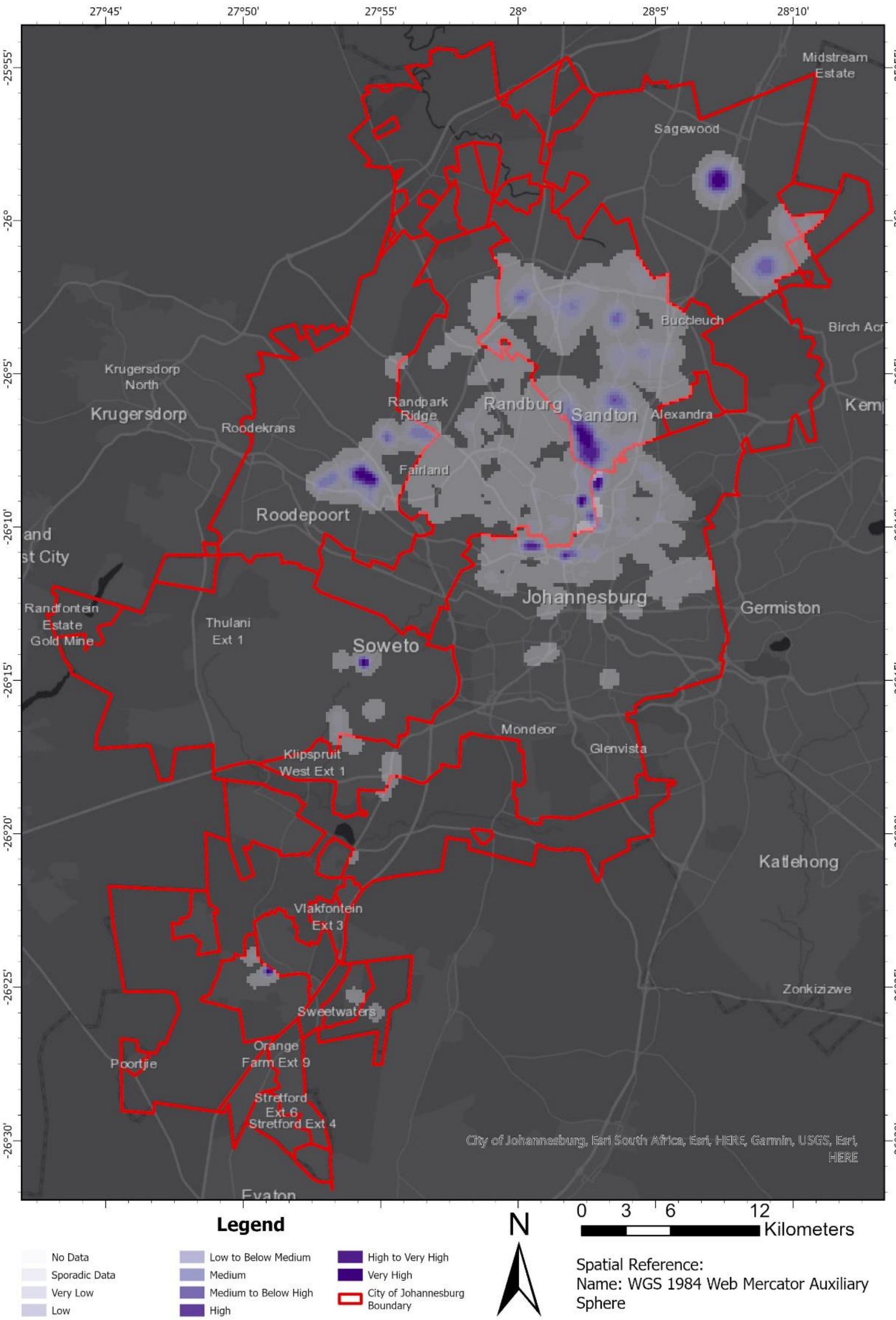


Figure 5.20: Density map showing regions with large numbers of confirmed Jacaranda trees, as supported by ground-based and Google Street View validation.

These maps provided the basis for the compilation of a list of confirmed suburbs with high Jacaranda tree presence. Spatial distribution of Jacaranda trees within these suburbs ranges from trees which line either side of the street for consecutive streets in the suburb, versus suburbs where trees are found on alternate streets (Table 5.7). Citizen science geotagging of Jacaranda tree presence was collected in a total of 41 of these 54 suburbs of confirmed high prevalence for Jacaranda trees.

*Table 5.7: Suburbs with large numbers of Jacaranda trees, as confirmed from field campaigns (highlighted in pink) and Google Street View (highlighted in green), citizen science (indicated with an *). Suburbs where both field campaigns and Google Street View were used are highlighted in purple.*

Suburb Name:	Region:
1. *Atholl Gardens	E
2. Atholl	E
3. Athollhurst	E
4. Berario	B
5. *Blackheath	B
6. *Blairgowrie	B
7. *Bordeaux	B
8. *Bryanston	E
9. *Constantia Kloof	C
10. Craighall	B
11. *Douglasdale	B
12. *Dunkeld	B
13. *Dunkeld West	B
14. *Emmarentia	B
15. *Fairland	C
16. *Greenside	B
17. *Houghton Estate	E
18. Kensington	F
19. *Killarney	E
20. Linden	B
21. *Linksfield	E
22. Martindale	B
23. *Melrose	E

24. *Melrose Estate	E
25. *Melrose North	E
26. *Melville	B
27. *Montgomery Park	B
28. *Morningside	E
29. *Northcliff	B
30. *Northwold	C
31. *Norwood	E
32. Oaklands	E
33. Observatory	E
34. *Orange Grove	E
35. *Olivedale	C
36. Orchards	E
37. Parkhurst	B
38. *Parktown	B
39. *Parktown North	B
40. *Parkview	B
41. *Parkwood	B
42. *Pine Park	B
43. *Randpark	B
44. *Riviera	E
45. Rivonia	E
46. *Rosebank	B
47. *Saxonwold	B
48. *Sunninghill	A
49. Sophiatown	B
50. *Sydenham	E
51. *Waverley	E
52. *Weltevredenpark	C
53. *Westcliff	B
54. *Westdene	B

5.10 Synthesis

Ground-truthing and Google Street View combined, produced a map with a wider spatial distribution of Jacaranda tree presence in the CoJ compared to data collected from citizen science geotagging. Results of citizen science geotagging were accurate with most of the geotags within the ‘very high’ to ‘high’ accuracy of confirmed Jacaranda tree presence. Spatially, citizen science data did not provide enough geotags to cover the area which extensive ground-truthing and Google Street View efforts covered. The spatial distribution and count of geopoints from ground-truthing alone provided thorough validation in suburbs which were visited. The addition of Google Street View assisted with capturing suburbs where ground-truthing was not completed and provided a thorough spatial distribution in suburbs which were virtually visited. Citizen science was not effective for identifying many new suburbs for Jacaranda tree presence since these suburbs were previously identified through extensive and high-resolution ground-truthing and Google Street View efforts. However, citizen science was effective towards identifying a quantitative measure of the accuracy of citizen science data. Therefore, citizen science data can be trusted as a reliable and convenient data collection source.

Lastly, the high prevalence of Jacaranda tree presence as a category 3 alien-invasive tree were identified to both street and suburb level within the greater CoJ. This high-resolution distribution provides the first opportunity for conservationists and the public to locate Jacaranda trees towards effective conservation monitoring and management.

CHAPTER 6: DISCUSSION

Own photograph taken in the suburb of Houghton Estate, on 11 October 2022.

6.1. Introduction

The primary aim of this study is to produce the first map of Jacaranda tree distribution in the CoJ through data collected from a combination of citizen science, ground-truthing using a GIS, and Google Street View. This contributes to existing bodies of research around invasive tree species mapping in urban environments (Visser *et al.* 2014; Buldrini *et al.* 2015; Hawthorne *et al.* 2015; Tang and Liu, 2016). Jacaranda trees are classified in South Africa as a category 3 alien-invasive species and therefore require strict monitoring and management practices (Newete *et al.* 2022). By mapping and locating suburbs with large numbers of Jacaranda trees, we can identify areas and streets which require urgent attention so water consumption models can be created on the effect of Jacaranda trees on the landscape. Additionally, Jacaranda trees are prohibited from being replanted or transplanted (Fitchett and Raik, 2021). This creates cause for concern of current old Jacaranda trees which may be at risk of dying or falling over. Hence, locations of these trees can help with monitoring and preventative management for any destruction to nearby property since Jacarandas are street trees which are found near homes and schools.

Various studies have used citizen science, ground-based data collection or Google Street View imagery as tools to map vegetation, however, none have engaged in a combined approach or triangulation of tools of this nature. This discussion critically analyses the performance, capability, and results of each of the three techniques mentioned to collect data on Jacaranda tree presence in the CoJ which is followed by a critical assessment of the accuracy of citizen science geotagging to both ground-based and Google Street View data. The second section of this chapter explores the implications of the newfound trends and relationships of citizen science data as a tool for mapping, with analysis of the implications and future potential for citizen science as a tool not only for local invasive tree mapping, but for mapping of the greater environment for infrastructure, emergency, and health monitoring on a global scale. The final section of this discussion highlights the limitations in this study which are linked to data collection, citizen science accuracy and seasonal restrictions for Jacaranda tree flowering. Additional factors related to the snowball-sampling approach, digital survey responses and field-campaigning are assessed as potential influencers to the results.

6.2 Mapping Jacaranda Tree Distribution

Combined citizen science and geospatial approaches are helpful for data collection both in-field and remotely. The framework for comparison between the best data collection method from these three approaches may include factors of cost, logistical ease, level of accuracy, chances of a false positive, and chances of a false negative. However, a combined data collection method is best. A combination ensures that any data gaps which may exist in either of the three data collection methods can then be addressed by one of the remaining two data collection methods. This is significant to the first objective of this study as this triangulation approach of three data collection sources were successfully integrated into a geospatial approach whereby the balances brought about by these three data collection methods were instrumental in creating high levels of accuracy in ground-truthing and Google Street View data since citizen science assisted in identifying any areas which either required geotag validation or further data collection efforts.

The placement of citizen science geotags are found to occupy suburbs where extensive ground-truthing and Google Street View campaigning was completed. Though the spatial distribution of citizen science geotag placement was low, accuracy was high and citizen science proved to produce high accuracy Jacaranda presence maps, but this accuracy was camouflaged by extensive ground-truthing and Google Street View initiatives which also shared high accuracy. It is important to note that these maps are not comprehensive maps of all Jacaranda trees in the CoJ in that an absence of Jacaranda trees on the map does not necessarily mean an absence in reality. Instead, a data gap may represent suburbs which were either not visited by both ground-truthing and Google Street View methods or may represent suburbs where Jacaranda trees are present, but in scarce numbers where distribution is sporadic.

Data collected from citizens can be modelled for accuracy through ground-truthing and use of Google Street View which is in-line with the second objective of this study as both ground-truthing and Google Street View were valuable validating tools for both reported and unreported Jacaranda tree presence. Citizen science data collection has high accuracy and is influenced by citizen familiarity with the environment in focus (*Section 5.5*). Citizens who have lived in the CoJ for longer periods of time show higher accuracy for geotagging placement on their streets and other streets for Jacaranda tree presence which also reflects on the secondary aim of this study.

A high accuracy and resolution of ground-truthing geopoints for spatial distribution maps resulted in every one of the 8,931 purple geopoints as indicative of validated high accuracy Jacaranda tree presence at that point in reality. The only challenge from ground-truthing efforts is found with navigation and orientation of streets within suburbs. In cases where Jacaranda trees lined many streets in high numbers within suburbs, navigation along one street to the next became disorientating as many streets are similar in appearance. Resultingly, the structure of ground-truthing geopoints appeared less uniform to those collected through Google Street View.

Google Earth's aerial imagery together with Google Street View imagery, are two views which complement each other when tasked with vegetation mapping (Wegner *et al.* 2016; Berland and Lange, 2017). The success of tree species and canopy profile detection was largely owed to the ease of accessibility and high level of accuracy of Google Street View imagery to provide high spatial and temporal resolution of tree species (Ives *et al.* 2017; Choi *et al.* 2022). Furthermore, Google Street View imagery provided essential metadata of the date by which the image was captured, as well as the camera's geolocation at the time of capture (Choi *et al.* 2022). Some suburbs within the CoJ could not be covered within both field-campaign timeframes so the uniformity of 2D and 3D imagery from Google Street View successfully captured equidistant geopoints of Jacaranda tree location with high accuracy and resolution of tree species and count. This is significant to the study's second objective since both ground-truthing, and Google Street View were used effectively to validate both reported and unreported Jacaranda trees.

Google Street View offered a structured and time-efficient alternative method for Jacaranda tree validation (Ives *et al.* 2017; Seiferling *et al.* 2017; Li *et al.* 2015; Choi *et al.* 2022). The high resolution of Google Street View geopoints offered clear land topology patterns such as street patterns, road intersections, and presence of Jacaranda trees located on alternate streets as opposed to consecutive streets. Aside from Google Street View providing a structured mapping technique, issues with Google Street View performance were apparent. The first is Google Street View's poor ability to geopoint hundreds of location pins within the Google Earth software. Google Earth software begins to slow down and sometimes freeze when approximately 200 geopoints are captured and stored. This software performance issue consumed time, as the software cannot be used unless the system is shut down and rebooted. Additionally, some

Google Street View captures present blurred views due to camera malfunction or privacy concerns which distort or obstruct objects within the street in focus (Figure 6.1).

Figure 6.1: Google Street View of a blurred capture due to camera malfunction or privacy concerns.

A variety of seasons were captured within a single view of the same location (Figure 6.2). This variation contributed to either the ease or difficulty in Jacaranda tree identification as trees in flower are easier to identify than those which have lost their leaves and appear bare. Bare Jacaranda trees were often corrected by the analysis of an alternate available view which displayed the same tree when in flower, taken in a different year and month. However, working through different years of imagery to obtain a view of a photo taken during the flowering period was time consuming.

Figure 6.2: Google Street View capture of Kruger Street intersection in the CoJ where Jacaranda trees are captured when a) flowering and b) bare.

A third mapping approach using citizen science was used towards gathering additional data for Jacaranda tree presence in the CoJ. The use of citizen science to mitigate imperfect data and fill data gaps in Southern Africa has been supported by Barnard *et al.* (2017). Interestingly, citizen scientists did not assist with the mitigation of imperfect data or with gap filling of data in this research study. Instead, most citizen science geotagging data are located in suburbs and streets where extensive ground-truthing, and Google Street View validation were carried out. A collection of citizen science data reveals relatively low numbers of responses and low geotag count in comparison to the many geopoints collected during the field campaigns and through Google Street View data collection efforts. The spatial accuracy and resolution of an individual citizen was also difficult to map since individual citizen accuracy of collected geotags could not be analyzed due to time constraints inhibiting the manual selection of individual users. Instead, all geotags from combined citizen science efforts were analyzed cumulatively for accuracy. Hence, citizen science geotagging could have displayed a higher spatial resolution if individual users were analyzed for their average geotagging accuracy, count of geotags, and spatial distribution of geotag placement.

In cases where some geotags were located in suburbs where Jacaranda tree presence was unconfirmed, the use of Google Earth composite imagery assisted with confirmation of Jacaranda tree presence. Remote sensing is commonly used instead of Google Earth imagery as a valuable tool for the validation or identification of urban trees (Joshi *et al.* 2004; Delgado-Aguilar *et al.* 2019; Newete *et al.* 2022). However, in this research study, Google Earth composite imagery provided a high spatial resolution and accuracy for the identification of Jacaranda tree canopy from aerial imagery. Distinct purple tree canopies from aerial imagery were easy to single out from surrounding green vegetation. Although remote sensing is a popular tool used for the identification and validation of urban trees, Newete *et al.* (2022) were unsuccessful with detecting the purple hue of Jacaranda tree flowering in a heterogeneous landscape. The remote sensing techniques applied by Newete *et al.* (2022) failed to identify smaller suburbs in the CoJ such as Saxonwold, Houghton, Parkview, and Parkwood whereas this research study identifies these suburbs with large numbers of Jacaranda trees (*Section 5.9*). Aside from Google Earth composite imagery providing high resolution imagery, Google Street View was crucial for the discrimination of other vegetation species which had similar pink or purple colours of flowers. Here, both Google Earth composite imagery and Google Street View were beneficial for birds-eye and street level views of vegetation types and supports the second objective of this study.

6.2.1 Invasive Species Monitoring and Management

The identification of at least 54 suburbs with large numbers of Jacaranda trees in the CoJ assists with invasive species monitoring and management since spatial distribution maps of Jacaranda tree presence highlight areas which are at risk, such as destruction to nearby property since Jacarandas are street trees found near homes and schools. Maps provide a visual representation of invasive species for the identification of underserved areas, for future survey efforts to be aimed towards (Bois *et al.* 2011). The rate and direction of invasive species spread can be monitored with annual mapping campaigns to produce spatial distribution maps of the influence of invasive species to native species (Cavaleri and Sack, 2010). The current presence and projections of future invasive species spread is imperative for effective land use management and monitoring as preventative measures and conservation efforts can be implemented to protect native species from potential decline (Buldrini *et al.* 2015). In cities such as the CoJ, where the rate of urbanization increases annually, invasive species location directly contributes to knowledge of available land space in the CoJ which may potentially be affected by invasive species spread (Buldrini *et al.* 2015). The early detection for invasive species and consistent monitoring over time can only be done with up-to-date spatial management (Johnson *et al.*

2020). Though 54 suburbs were identified in this study, many suburbs were not validated and could contribute to further Jacaranda tree presence.

The combination of the CoJ depending on the LHWP transboundary transfer scheme, experiencing a low mean annual rainfall, high evaporation rates, variable precipitation, and location on the Witwatersrand watershed, each exerts water stress (Turton *et al.* 2006). The confirmed presence of category 3 invasive Jacaranda trees present opportunities for water-use modelling which are vital for the management of water availability towards the protection of biodiversity and species which are at risk of dying if they are near suburbs with large numbers of Jacaranda trees. As yearly temperatures increase with global warming, studies around ecohydrology with invasive ecology are at the forefront of biodiversity conservation efforts (Cavaleri and Sack, 2010). Additionally, studies linked to water balances can finally be calculated for suburbs with large numbers of Jacaranda trees to quantify water flow and water deficit which are influenced by the abundance of Jacaranda trees.

Apart from Jacaranda trees which are known for their high-water consumption, the newfound presence and largely unknown implications of the PSHB beetle is a cause for concern due to possible large-scale infestation of Jacaranda trees, especially since the category 3 invasive status of Jacaranda trees prohibits the replanting, transplanting, or selling of these trees (Schäffler and Swilling, 2013; Paap *et al.* 2018; Newete *et al.* 2022). As a result, the aging population of Jacaranda trees will not always be part of the urban fabric of the CoJ and now face earlier risk of extinction. Furthermore, the entire urban forest of the CoJ may be affected with PSHB and have associated effect on the City's ecosystem services as street trees assist with reducing the urban heat island effect, air pollution, noise pollution, potential storm water flooding, and soil erosion, among others (Akbari *et al.* 2001). Hence, the spatial distribution maps for Jacaranda tree presence produced in this study assist towards locating high prevalence Jacaranda suburbs and streets which are at higher risk of PSHB infiltration than others. The successful creation of this spatial distribution map is in-line with the study's primary aim as well as addresses the first research question.

6.2.2 Citizen Science Engagement

Azzurro and Cerri (2021), Bois *et al.* (2011) and Ferreira-Rodriguez *et al.* (2021) each take on a citizen science approach which support the engagement with targeted audiences in data collection as responses display higher accuracy when citizens are familiar with the area in focus. However, in the case of this research study, the exclusion of participants outside of the CoJ led to some disgruntled social media users who could not complete the survey since they lived outside of the CoJ. This was particularly noticed from users who reside in the City of Tshwane (commonly known as Pretoria), which also forms part of the Gauteng City-region and is abundant in Jacaranda trees (Fitchett and Raik, 2021). A comment received on Facebook from a user who did not reside in the CoJ but still wanted to participate in the survey is quoted as follows:

> *"I drive to JHB [City of Johannesburg] daily, I could help, but that means I must lie on the form to complete it. Loads of people from Pta* [City of Tshwane, commonly known as Pretoria] *and the East Rand* [City of Ekurhuleni] *are like me by the way."*

Our response to the user above was to not be dishonest on the survey as the integrity of the data was crucial. Fortunately, when a user indicates that they do not live in the CoJ the survey automatically ends, but it would be impossible to identify any users who were dishonest on this and subsequent questions.

The count of survey responses from residents of the CoJ is influenced by factors around Jacaranda tree peak flowering dates, Jacaranda tree peak flowering awareness, as well as Jacaranda tree inspired competitions and events which are aimed at the community. A total of 203 responses and 488 geotags were collected during the 75-day survey collection period, however, 29 of which could not be used. The survey was aimed at citizens of the CoJ only, and these 29 respondents indicated that they did not reside in the CoJ. The use of citizen science for urban tree geotagging is considered as ineffective as the response and geotag count is considered low in comparison to the 8,931 geopoints which were collected during a successful and extensive 14-day ground-truthing campaign (*Section 5.2*). Additionally, suburbs which citizens identified for Jacaranda tree presence were those which were previously validated through ground-truthing and Google Street View approaches.

The exclusion of non-residents to the CoJ may have contributed to low numbers of responses, however, this is juxtaposed against possible accuracy issues from non-residents. In this research study, the participation of citizens was in-line of views of both Bois *et al.* (2011) and Hawthorne *et al.* (2015) whereby citizens who reside in the area of focus for longer periods, find relatability or feel a sense of responsibility to partake in initiatives which are either aimed towards the citizen or involve the citizen's region of residence (*Section 5.5*).

Notably, most responses were received from citizens who reside in the CoJ for more than 10 years with overall 'very high' accuracy and 'very certain' to 'certain' degrees for Jacaranda tree presence in surrounding areas. Interestingly, the lowest count of responses was received from the shortest length of stay category of 0-11 months (Figure 5.9). Schlossberg and Shuford (2005), Atzmanstorfer *et al.* (2014) and Clark (2014) argue that citizen participation decreases when the citizen feels unfamiliar with the area and the task then poses as an obstacle for engagement. Similarly, new citizens may feel reluctant to participate in this survey due to unfamiliarity with the CoJ. Additionally, there is a high likelihood that citizens who have lived in the CoJ for less than a year may only just be experiencing their first sightings of Jacaranda tree flowerings in the CoJ and therefore be unfamiliar with Jacaranda trees.

The praiseworthy accuracy of citizen scientists in this research study revealed the potential and validity of citizen science as a reputable data collection source and addresses the secondary aim of this study. It must be noted that citizen attention to this research study was dependent on the Jacaranda flowering season. The survey link was shared again when Jacaranda flowering was over, to a large social platform with over 200,000 followers, and this received zero responses. It is evident for participation to dwindle when citizens are not enticed by data collection being relevant or apparent as it were when Jacaranda trees were in peak flowering stages.

6.2.3 Tourism Opportunities

Identifying suburbs with large numbers of Jacaranda trees assists with economic and social value to the CoJ since Jacaranda seasons inspired photography competitions, walking tours, markets, among others, each attract citizens and tourists alike. Since Jacaranda trees attract attention for their beautiful flowering, their invasive status and need for conservation management is often camouflaged. Therefore, spatial distribution mapping of these trees contributes towards identifying areas where Jacaranda trees which still occupy the landscape, for tourism revenue to continue for years to come. The monitoring of Jacaranda trees is made easier since these trees are prohibited from being transplanted or re-planted, meaning their current location is static (Fitchett and Raik, 2021). Although Jacaranda trees alone cannot be monitored for any potential spread in distribution, other tree or pest species can be analyzed for influence towards the decline of Jacaranda trees or for future expansion of native species closer to risk zones where Jacaranda trees are currently known the occupy. The demand for Jacaranda trees as a 'natural capital' must be protected, not only for the tourism revenue it provides to the CoJ, but also for the aesthetic value which flowering street trees contribute to urban landscapes (Hall 2010).

Many cities move towards 'green statuses' with urban greening at the forefront of rapid urbanization (Berland and Lange, 2017). Urban greening has evolved into an aesthetic feature of the landscape which also attracts many enthusiasts to sustainable cities (Fernandes *et al.* 2019). Though focus is made towards citizens and tourists, sustainable cities attract new possibilities for scientific gain. Opportunity for scientists and researchers who specialize in the workings of urban forests are attracted to the CoJ for the diverse urban forest (Schäffler and Swilling, 2013). Attraction to the CoJ for the beauty, excitement and research possibilities around Jacaranda tree flowering contributes to a circular economy whereby revenue attracted from tourism can be directed at Jacaranda tree conservation, monitoring, and management efforts (Hall 2010). The harmony between conservation and tourism offers developing countries the opportunities to fund conservation programs on a large-scale (Catibog-Sinha 2010).

6.3 Future Applications

Spatial distribution maps contribute to possible study sites or sample areas for future research relating to biometeorology, climate change and phenology to be recorded (Ives *et al.* 2017). The accuracy of Google Street View highlights the numerous possibilities for early warning detection systems to be applied within Southern Africa for invasive species mapping (Barnard *et al.* 2017). Since invasive species mapping requires constant monitoring and management, policymakers and Government officials may rule out the need for costly expert research as Google Street View has proven to supply data across a vast spatial landscape whilst still being cost-effective and accurate (Crall *et al.* 2015; Buldrini *et al.* 2015).

Combining geospatial data from both ground-based geolocated points and Google Street View with citizen science can assist these monitoring and management networks by providing critical quick updates of real-time occurrences which citizens provide using digital surveys (O'Donoghue *et al.* 2010). Examples of these live updates which digital surveys assist with include the identification of affected areas and potentially affected areas, as well as detailed information on aspects such as resource availability (Tran *et al.* 2009; Joy *et al.* 2019; Yang *et al.* 2019). To counteract weaknesses relating to device GPS accuracy in cases where exact location is required, digital surveys may be created with a restriction rather than a warning message (*Section 4.2.3*). An accuracy restriction will prohibit the user from submitting a geotag if the device GPS accuracy is lower than the required threshold.

This combined approach was widely accepted when the Jacaranda Mapper survey was shared as an initiative together with Jacaranda season events and competitions. A large part of the success of this research study is owed to the power of social media and smart devices. The competitiveness and enjoyment of the "Jacaranda in your pocket" photography competition added a new layer to the response from the citizen science approach as participants in the survey were also Jacaranda season enthusiasts (*Section 5.4.1*). Goodchild (2007) and Newman *et al.* (2012) both reflect on the future of citizen science with mention of enjoyment and competitiveness as two common success factors within large-scale volunteer projects. Though Jacaranda trees are easily identifiable by their dominant winter season green and spring season purple appearances, many citizen science studies displayed high accuracy of identification of species which were not as distinct as Jacaranda trees. Bois *et al.* (2011) and Hawthorne *et al.* (2015) utilized citizen science to map invasive species in urban environments with both studies producing high accuracy from citizens to correctly geotag several different invasive species within a single geocoded survey.

Many successful citizen science projects offer incentives which have proven to increase voluntary participation (Goodchild 2007; Wright *et al.* 2015; Zhang *et al.* 2015). The future of citizen science and data collection resides in captivating audiences and maintaining attention for continuous participation (Newman *et al.* 2012; Wright *et al.* 2015). Digital gaming for conservation may offer some opportunities for users to physically capture plant species as the game would use device GPS to navigate the user to nearby locations which require exploration. Users may then capture photographs of the plant species using their smartphones or input data from a list of multiple choices to describe the plants appearance and abundance. A successful citizen science project, named *Project budburst*, has built-in digital games and incentives which are rewarded to users upon participation in data collection. Citizens readily collected data on the mobile application which aimed at tracking seasonal plant changes (Newman *et al.* 2012). The mobile application has automated functions around collecting the user's location whilst providing standardized plant list options and definitions to choose from (Newman *et al.* 2012).

6.4 Limitations

This research study involved the use of various data collection platforms such as a GIS, Google Street View, and citizen science. Hence, limitations occur due to software capability and human interpretation.

In cases where Jacaranda trees lined many streets in high numbers within suburbs, navigation during field campaigns were disorientating in identifying streets which were completed and those yet to be completed. Some streets were repeated during fieldwork with others completely left out. Efforts to manually log street names which were visited within a single suburb did assist with saving time and not repeating streets. However, this manual logging system was highly ineffective in larger suburbs where manual logging became an added time-consuming task and halted ground coverage when stops had to made to validate if the street was covered or not. A solution was not discovered during the first fieldwork campaign in July 2022. However, in October 2022 fieldwork, the use of Google Maps assisted with pre-planned routes whereby multiple streets could be added to a single travel journey route. Google Maps further assisted with creating clear administrative boundaries around suburbs, which ensured entire suburbs were visited and adjacent suburbs where streets were shared, were not repeated. Another solution to address missed streets from July campaigns, was the use of Google Street View to validate Jacaranda tree presence. Google Street View ensured every street was covered per suburb.

Although Google Street View was beneficial for solving ground-truthing limitations, issues with the temporal variability of Google Street View images for features on the landscape were evident. Some Google Street View captures were distorted, blurred, or captured Jacaranda trees that are bare, green, or flowering (*Section 6.2*). This limitation was partly solved since Google Street View imagery comprises a mosaic of images which are 'stitched' together to form one complete view. Hence, some captures were corrected by analyzing alternate views of the same area. In cases where alternate views were still obscured, Google Street View captures could not be corrected, and possible Jacaranda tree presence was not captured. In cases where Google Street View data was unavailable for some streets, the use of Google composite imagery was used for an aerial validation of Jacaranda tree presence. However, Google composite imagery could not provide spatial resolution as high as Google Street View, so individual Jacaranda trees were harder to identify compared to clusters of Jacaranda trees in one area.

Citizen science limitations arose with identifying geotags which were linked to a single user. Although individual users could be isolated, along with geotags collected, time-constraints inhibited individual analyses of average accuracy per user. The process of identifying users per suburb by cumulative collected geotags, and secondary data linked to demographic information, was far easier and time-effective to extract compared to analyzing geotags of a single user to validated Jacaranda tree presence.

Jacaranda season is limited to peak flowering months of spring which change each year as a result of climate change and increasing air surface temperature (Fitchett and Raik, 2021). These time-constraints and uncertainty around peak flowering dates of Jacaranda trees were counteracted by the citizen science data collection approach whereby digital surveys were launched early on

26 August 2022 and closed on 7 November 2022 when Jacaranda flowering came to an end. The limited 75-day survey collection period may have hindered the potential response count. Additionally, the survey was only available to residents of the CoJ. This targeted audience may have limited the number of responses received. Moreover, the digital survey was automatically closed at 08h30 on 7 November 2022, however, responses were still being received during the final hours of the survey being open. An extension of the survey open date may have contributed to more responses.

Further research on smart device availability concludes for low to mid-level range Samsung devices with average GPS accuracy fluctuating between 20-50 m to be the common smart device sold to South African citizens (Szot *et al.* 2019; Statista 2022). This may contribute to the majority of geotags falling into the 25-100 m accuracy range. These inaccuracies may not all be device-related problems as user-problems such as misidentification of Jacaranda tree presence or misinterpretation of the 'exact location' geotagging instructions on the digital survey are also possible. In the case of misinterpretation, users may not have physically stood beneath or next to a Jacaranda tree but instead geotagged this question in-line with the 'my street' and 'other street' specifications. This would in turn lead to greater inaccuracies especially if the user completed the 'exact location' question from their homes, in which case device GPS accuracy is degraded in indoor environments (Chen *et al.* 2016).

The final limitation to this study is tied to the safety factor. The Jacaranda Mapper survey had a question which required the user to physically stand beneath or adjacent to a Jacaranda tree and geotag its exact location. Citizens may have felt vulnerable walking around public streets with their devices in hand, and this safety concern may have hindered participation for the exact geotagging section.

6.5 Synthesis

Jacaranda trees are a category 3 alien-invasive species and therefore require strict monitoring and management practices. The first spatial distribution maps of Jacaranda presence in the CoJ created in this study, are imperative for locating suburbs with large numbers of Jacaranda trees, to high-risk areas. These high-risk streets and suburbs of the CoJ can receive conservation attention for effective monitoring and water model management of these invasive species. Additional risk factors linked to the attack of urban street trees by PSHB and the degradation of native urban species in the CoJ can be modelled for future risk.

Predictive modelling is essential for rapidly developing cities such the CoJ, where land use management and land change is at the forefront of future development. Now, land models can be framed and weighed against factors such as invasive species infiltration. The spatial distribution of Jacaranda trees contributes to economic and tourism revenue as flowering events attract many citizens and tourists' attention. The identification of streets and suburbs with large numbers of Jacaranda trees contributes to knowledge on potential locations for Jacaranda season events and competitions to take place. The integration of citizens within Jacaranda season and spatial distribution mapping, contributes to overall 'green consciousness' as citizens become increasingly aware of the spatial presence of Jacaranda trees as a prominent feature of the urban fabric in the CoJ.

CHAPTER 7: CONCLUSIONS

Own photograph taken in the suburb of Houghton Estate, on 14 October 2022.

7.1 Introduction

Spatial distribution mapping and suburb awareness of alien invasive Jacaranda tree presence in the CoJ did not exist, until this study. Moreover, a combined data collection approach which utilizes citizen science, Google Street View and ground-truthing techniques did not exist in South African literature, until this study. This combined data collection approach assists not only with alien invasive mapping (as discussed in this study) but also assists with addressing data resourcing and accurate data collection where data is needed over a large scale, at low-cost – which is particularly useful for third world or developing countries such as South Africa – where resource availabilities are limited.

Invasive species which occupy urban environments are a growing problem for rapidly developing cities where land availability is at the forefront of effective land use management and planning (Wakie *et al.* 2016; Woodward *et al.* 2021). Spatial distribution mapping of invasive species presence and abundance is imperative not only for effective land use management but also for conservation efforts and biodiversity modelling (Buldrini *et al.* 2015). Biodiversity modelling together with land use management assists not only with current planning, but also with future planning and predictive trend analysis (Tang and Liu, 2016).

Numerous studies support the need for up-to-date and relevant spatial information for effective monitoring and management (*Chapter 2*; Buldrini *et al.* 2015; Delgado-Aguilar *et al.* 2019; Azzurro and Cerri, 2021; Dujardin *et al.* 2022). Though Jacaranda trees are prohibited from being replanted, transplanted, or sold, their presence as high water-consumers will continue as a serious risk factor so long as these trees occupy the urban landscape. Currently, the Jacaranda trees which exist on the landscape, are all that will remain for the future unless the invasive species regulations change. Hence, monitoring and management of all vegetation types is vital for all-round decision making and future planning (Pedrotti 2012; Seiferling *et al.* 2017). The collection of data in city spaces can be achieved with citizen science as a tool for the identification of various vegetation species.

In this context, the primary aim of this study was to produce the first spatial distribution map of validated Jacaranda tree presence in the CoJ. Second to this, the study aimed to measure the level of accuracy of citizen science data to correctly identify and geotag the location of invasive Jacaranda tree species.

This chapter summarizes the key findings of the study by highlighting the extent to which the aims have been achieved along with unexpected results and the possibilities of citizen science, ground-truthing using a GIS and Google Street View combinations for future mapping applications.

7.2 Accomplishment of Study Aim, Objectives, and Research Questions

The primary aim of this study was to produce the first map of Jacaranda tree distribution in the CoJ through a combination of ground-truthing using a GIS, Google Street View, and citizen science techniques. This aim was achieved through the 14-day field campaign in July and October 2022, from which a total of 8,931 geopoints were collected through ground-based approaches. These were supplemented with the logging of trees remotely using Google Street View in a virtual campaign from August through to October 2022. This was further supplemented by geolocated points submitted by citizen scientists from an online geocoded survey, each of which was checked for accuracy from the two aforementioned approaches. The first research question was answered as a total of 54 suburbs were confirmed as having a large number of Jacaranda trees with a spatial distribution map indicating Jacaranda tree presence as a single geopoint on the map representing confirmed Jacaranda tree presence in reality.

Notable data gaps of the absence of geopoints in the spatial distribution map was observed. Data gaps either represent areas where ground-truthing and Google Street View campaigns were not completed or represent very scarce Jacaranda tree distribution. Therefore, the spatial distribution maps created are not comprehensive maps, but rather maps which represent validated suburbs for actual Jacaranda tree presence and abundance.

Aside from a spatial distribution map for confirmed Jacaranda tree presence in the CoJ, additional maps were created to display the distribution of citizen science collected geotags for apparent Jacaranda tree distribution. Although citizen science geotagging had a low spatial distribution of geotag placement around the CoJ, geotags displayed concentrated patterns with many citizens geotagging Jacaranda trees in the northern and central suburbs of the CoJ. Interestingly, these suburbs were among those confirmed suburbs with large numbers of Jacaranda trees following analysis of ground-truthing and Google Street View spatial distribution maps.

The secondary aim of this research study was to explore the accuracy of citizen science in mapping distinct tree species. A total of 66% of citizen science placed geotags were in the 'very high', 'high' and 'moderate' accuracy ranges of between <7-24 m, confirming Jacaranda tree presence. Although the spatial distribution of citizen science geotagging was low, accuracy was considered high in overall geotagging. Since citizen science accuracy is based on citizen familiarity with the landscape, geotags which were placed on the citizens street of residence had the highest accuracy compared to geotags which were placed on other streets. Accuracy of citizen science geotagging was also dependent on the suburb in which the citizen resided, with higher accuracy of geotagging from citizens who live in suburbs with large numbers of Jacaranda trees. Although Jacaranda trees are a distinct tree species to identify, with purple flowering in spring and lush green leaves with a distinct appearance in winter, other citizen science studies which map invasive species without distinct appearance also gave rise to high accuracy. Therefore, the distinct appearance of Jacaranda trees did not influence accurate geotagging but was rather influenced by citizen's length of stay in the CoJ and their suburb of residency.

The second research question is answered here since citizen science as a tool was highly effective from an accuracy perspective. However, the distribution of online survey links for citizen science data collection required high effort. Since this study also focuses on measuring the accuracy of citizen science, it can be concluded that citizen science was accurate. Notably, the total 488 collected geotags from citizen science was camouflaged by the extensive high-resolution ground-truthing of a total of 8,961 geotags and Google Street View campaigns identifying 54 suburbs as high for Jacaranda tree prevalence. Ground-truthing data collection methods are both accurate and highly effective, as vigorous field campaigns resulted in many validated suburbs for known Jacaranda tree presence. It is however more time and resource intensive. Google Street View was less accurate than ground-truthing in cases where captures were distorted and blurred but were effective since imagery of Jacaranda trees could be used to validate Jacaranda tree presence in both winter and spring seasons where neither citizen science nor ground-truthing could be done. In cases where image clarity was jeopardized, ground-truthing was conducted.

Though a framework comparison highlights different strengths and weaknesses, it must be noted that a combined approach of all three methods is most effective. This is seen in cases where citizen science identified areas where either ground-truthing, or Google Street View was not used. Areas which lacked both citizen science and ground-truthing data, presented gaps where Google Street View should then be used. Unclear imagery captured by Google Street View presented an opportunity for ground-truthing to be carried out. A combined approach accounts for any weakness which one data collection method may have, to be strengthened by the remaining two data collection approaches. It further presents opportunities to cross-check any data collection across all three methods.

7.3 Implications of Jacaranda Tree Distribution in the CoJ

The results of this study confirm that the northern and central suburbs have large numbers of Jacaranda trees. The maps produced indicate Jacaranda tree presence in fewer numbers in eastern, southern, and western suburbs of the CoJ. Though 54 suburbs were identified as having large numbers of Jacaranda trees, the true spatial distribution of Jacaranda tree presence is yet to be discovered. Although Jacaranda trees are prohibited from being re-planted or transplanted due to their category 3 invasive status, laws are not strictly implemented. During ground-truthing campaigns, many Jacaranda trees were identified in young stages, which implies illegal replanting and transplanting in some suburbs of the CoJ.

Although the primary aim of this study was to map the spatial distribution of Jacaranda trees in the CoJ, the findings in this study have potential for the combination of ground-truthing, Google

Street View and citizen science combined efforts for invasive species mapping in a wider context (Fonji *et al.* 2014; Ferreira-Rodriguez *et al.* 2021). The total count of suburbs with confirmed Jacaranda tree presence contributes extensively to the scarce existing literature on Jacaranda trees (Newete *et al.* 2022). Inherently, a larger risk factor has been discovered since these high water-consuming invasive species occupy greater land use than previously expected. Consequently, land use monitoring and management plans are non-existent for the current environmental impact of Jacaranda trees. Street-level knowledge of Jacaranda tree presence is especially useful for the identification of streets with high Jacaranda presence. This high spatial resolution facilitates the identification of the proximity to nearby water sources which may be at risk from the high-water consumption of Jacaranda trees.

7.4 Future Research Avenues

Studies with a combined ground-truthing, Google Street View and citizen science approach for invasive species mapping are scarce in Southern Africa, with existing invasive mapping studies focusing on remote sensing as a tool (Dubovyk *et al.* 2015; Jombo *et al.* 2020; Masemola *et al.* 2020; Newete *et al.* 2022). The resulting accuracy of citizen science data found in this study, together with ground-truthing using a GIS and Google Street View capabilities, offer a gap for future research to build on this triangulated data collection approach.

In this study, spatial distribution maps display suburbs where Jacaranda tree presence was extensively and accurately validated, however, many suburbs were not visited due to time-restrictions within the research completion. Hence, future mapping applications of remaining suburbs of the CoJ to create a comprehensive map for Jacaranda tree presence is yet to be explored. The exploration of remaining suburbs is imperative for effective invasive species management to identify high risk suburbs in the CoJ in need of management. Moreover, the presence of Jacaranda trees to nearby native species must be mapped for potential risk to native species sprawling into high-risk Jacaranda tree areas.

The presence of PSHB in the CoJ poses a significant threat to street trees. While the direct threat to Jacaranda trees remains unclear, trend analysis may only be conducted once all Jacaranda tree presence is known. Trends of Jacaranda trees decline due to PSHB attack, or converse trends of Jacaranda tree increase from illegal replanting or transplanting, can then be modelled into land use management plans. Since citizen science data can be validated using Google Street View for street vegetation or by ground-truthing efforts for existing data gaps, the inclusion of citizen science as a tool for data collection of street trees must be explored.

The use of geocoded digital surveys as a platform for data collection must also be explored further. The ease of digital geotagging grants seamless data transfer from users to digital platforms for data storage, management, and analysis to occur in real-time (Dickinson *et al.* 2012; Wright *et al.* 2015). Citizen science must be explored not only for vegetation mapping but for multi-disciplinary fields which require accurate, real-time data. This is applicable to emergency dispatch services, infrastructure reporting and crime reporting, among others (Newman *et al.* 2012; Joy *et al.* 2019). Since services and reporting are not as time restricted as Jacaranda flowering, geocoded surveys can be shared for longer periods of time, without being closed. The extension of data collection periods permits increased engagement of citizens with research needs and may contribute to greater spatial distribution of participants.

In this study, residents from outside the CoJ were keen to participate in Jacaranda mapping. The restriction of citizens who were not residents of the CoJ may have contributed to lower number of responses and a low spatial coverage of citizen science geotags. Expanding citizen science participation to include citizens at provincial and national level may contribute to increased response count and higher spatial resolution of geotags collected, but the accuracy would need to be carefully evaluated or compared to further ground-truthing or Google Street View efforts.

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Appendix A: Ethics Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Reddy

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H22/07/35**
PROJECT TITLE	Mapping the spatial distribution of Jacaranda trees in Johannesburg, South Africa: A citizen science and GIS approach
INVESTIGATOR(S)	Ms R Reddy
SCHOOL/DEPARTMENT	Geography, Archaeology and Environmental Studies/
DATE CONSIDERED	22 July 2022
DECISION OF THE COMMITTEE	Approved Risk Level: Minimal
EXPIRY DATE	22 August 2025

DATE 23 August 2022 **CHAIRPERSON** ________________ (Professor J Watermeyer)

cc: Supervisor : Professor J Fitchett

Appendix B: Survey Questionnaire

Participation Information Sheet

Introduction

Dear Sir/Madam

My name is Rohini Chelsea Reddy. I am currently registered for a Masters in Geography in the Faculty of Science at the University of the Witwatersrand, Johannesburg. My supervisor is Prof. Fitchett. For my Masters, I am conducting a study on the spatial distribution of Jacaranda trees in Johannesburg. The study title is **Mapping Jacaranda Tree Distribution in Johannesburg, South Africa: A Citizen Science and GIS Approach**. I am inviting you to take part in a short survey, as a resident of Johannesburg.
If you decide to take part, the survey consists of 11 possible questions and will last for approximately 15 minutes. In these survey questions you will be invited to list regions, streets and exact locations where you know Jacaranda trees to be located in Johannesburg city. This survey will require you to use your personal mobile device and will access the GPS location of your mobile device only for location-based questions. Some location-based questions ask you to physically stand beneath a Jacaranda tree(s) to geotag the tree(s) exact location. Instructions to geotag are included in the survey. Physical geotagging of a Jacaranda tree(s) should be done at your own risk, so please do not take your mobile device into unsafe public areas to do so.

Survey Information

Completion and submission of the survey is an indication that you consent to participate in this research study. You will not be paid for participating in this research study. All your answers in this survey are anonymous. You are not required to share any personal information which could be used for your identification, and you can choose not to do any geotagging if you feel uncomfortable doing so. Spatial data from these surveys will be stored in a secure online database for my analysis and reporting.
If you decide to take part in this research study, it should be because you want to volunteer. You can stop the survey at any point in time. You do not get any direct benefits for submitting responses for this research study.

Contact Details

If you have any questions about this research study, feel free to contact me or my supervisor on the details listed below. If you have any concerns or complaints about the ethical procedures of this research study, you are welcome to contact the University Human Research Ethics Committee (Non-medical), telephone +27 (0)11 717 1408, email hrecnon-medical@wits.ac.za

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Powered by ArcGIS Survey123

Mapping Jacaranda Trees in the CoJ

Consent

I have read and accept the participation information sheet*

- [ ] Yes

I agree to participate in this online survey.*

- [ ] Yes

Back | Submit

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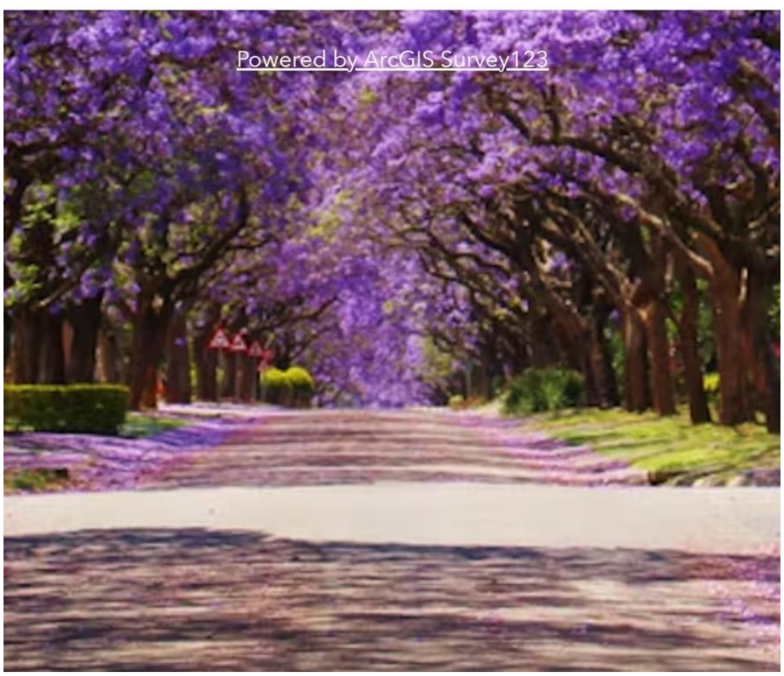

Mapping Jacaranda Trees in the CoJ

Consent

I have read and accept the participation information sheet*

Yes

I agree to participate in this online survey.*

Yes

Back Next

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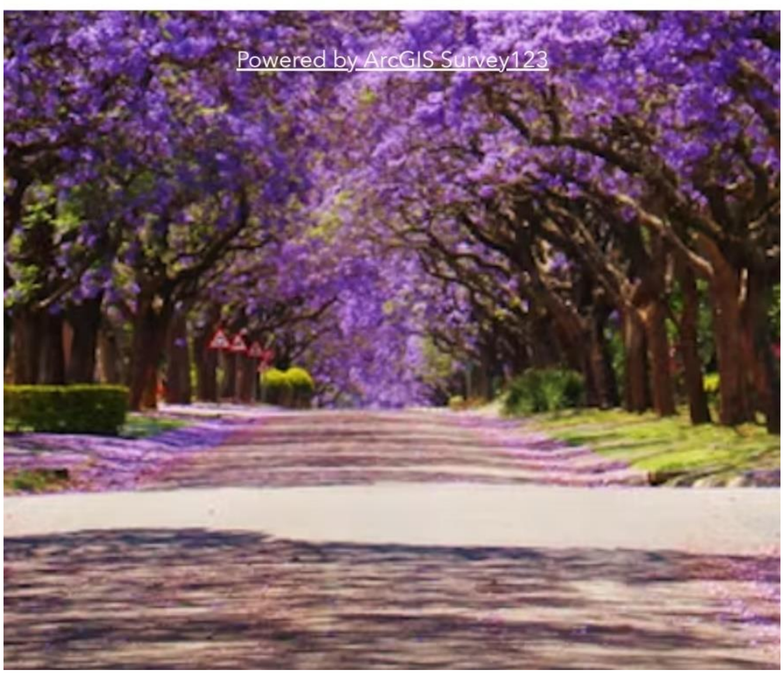

Mapping Jacaranda Trees in the CoJ

Citizen

Do you live in the city of Johannesburg?*

- Yes
- No

Back | Submit

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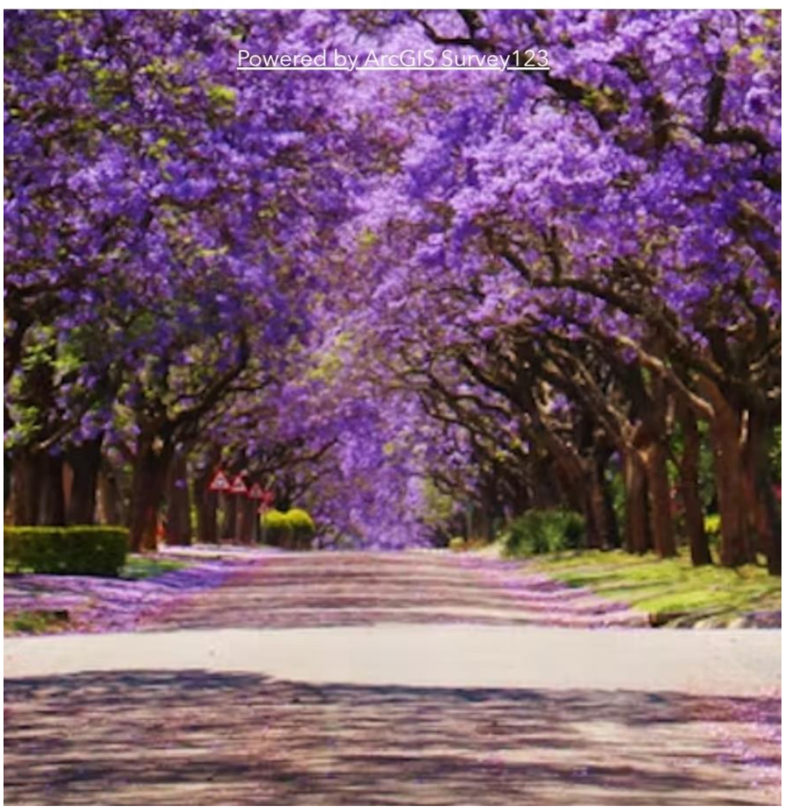

Mapping Jacaranda Trees in the CoJ

Length of stay in Johannesurg

How long have you lived in the city of Johannesburg?*

- 0 - 11 months
- 1 - 3 years
- 4 - 6 years
- 7 - 9 years
- More than 10 years

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Mapping Jacaranda Trees in the CoJ

Your Suburb

Please select your Suburb:*

Start by typing your suburb name. Select your suburb from the filtered options.

Are there Jacaranda trees in your Suburb?*

- Yes
- No

How certain are you of Jacaranda tree presence in your Suburb?*

- Very Uncertain
- Uncertain
- Neither Certain nor Uncertain
- Certain
- Very Certain

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Mapping Jacaranda Trees in the CoJ

Your Street

Are there Jacaranda trees in the street you live on?*

- ○ Yes
- ○ No

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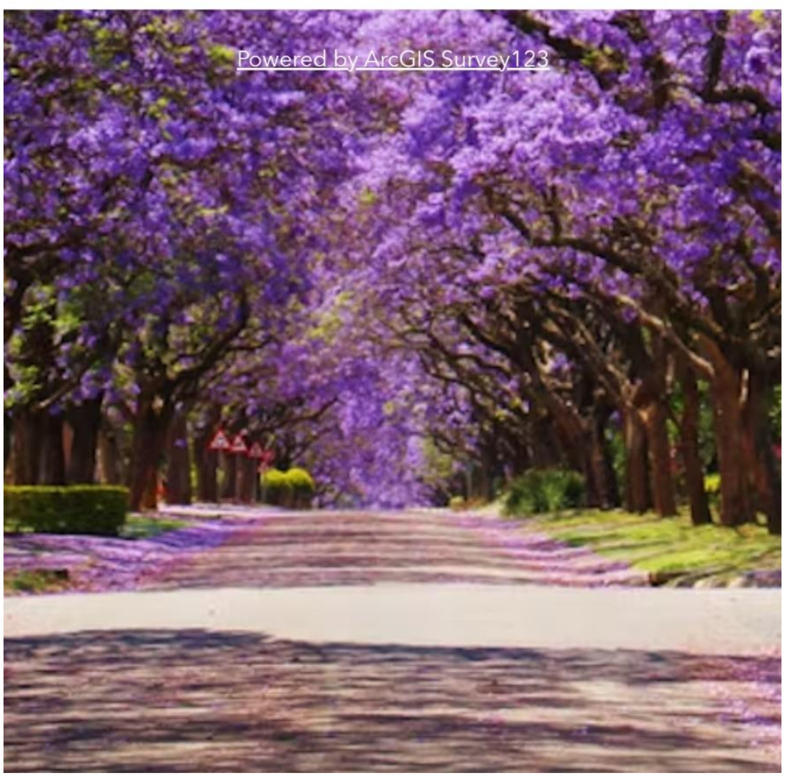


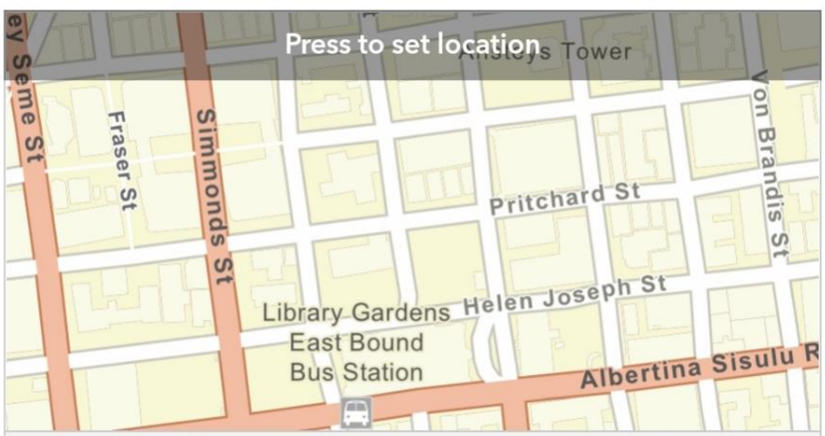
Jacaranda presence on your street

(1)

1

Please geotag the location of Jacaranda trees on your street*

Manueover to your street by pressing the square map tile icon below. Zoom in to your street using the "+" action. Zoom out of your street using the "-" action. Add one Jacaranda tree location at a time. Drop the location pin directly on your street where a Jacaranda tree is present. Press on the tick at the bottom-right corner when you are done with the first tree. Answer the "Certainty" question. To add another Jacaranda tree, press the "+" action within the white bubble labelled "1 of 1" and repeat the process. You can add up 20 Jacaranda trees on your street.



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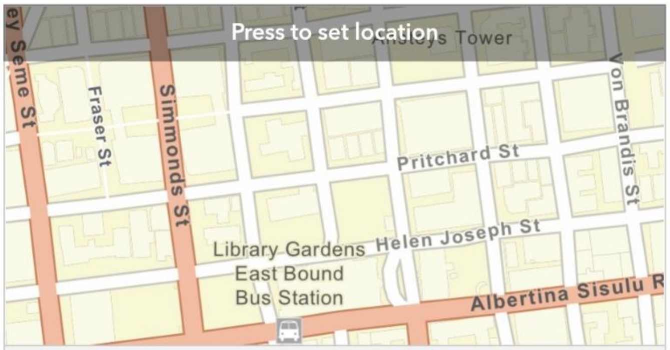
Jacaranda presence on your street (1)

1



No geometry captured yet.

How certain are you of these Jacaranda tree locations in your street?*

- Very Uncertain
- Uncertain
- Neither Certain nor Uncertain
- Certain
- Very Certain

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Reset Saved

Mapping Jacaranda Trees in the CoJ

Other Streets

Are there Jacaranda trees in other streets around you?*

- Yes
- No

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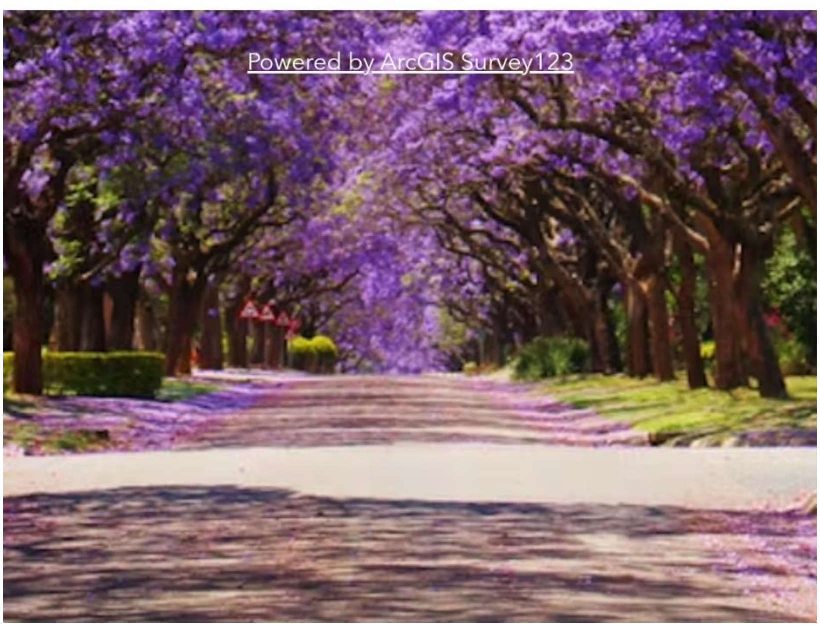


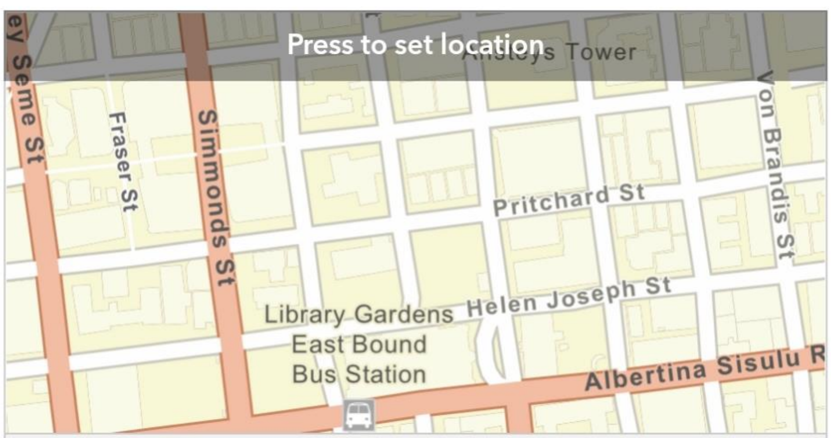
Jacaranda presence on other streets

(1)

1

Please geotag other streets where you know of Jacaranda tree presence*

Manueover to other streets by pressing the square map tile icon below. Zoom in to the street using the "+" action. Zoom out of the street using the "-" action. Add one Jacaranda tree location at a time. Drop the location pin directly on the street where a Jacaranda tree is present. Press on the tick at the bottom-right corner when you are done with the first tree. Answer the "Certainty" question. To add another Jacaranda tree to other streets, press the "+" action within the white bubble labelled "1 of 1" and repeat the process. You can add up 20 Jacaranda trees on other streets.



No geometry captured yet.

How certain are you of these Jacaranda tree locations in other streets?*

- Very Uncertain
- Uncertain
- Neither Certain nor Uncertain
- Certain
- Very Certain

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Reset Saved

Mapping Jacaranda Trees in the CoJ

Exact Locations

Can you geotag the exact location of a Jacaranda tree where it stands?*

If there is a Jacaranda tree in close proximity to you, it would be great if you could geotag it for us! You need to stand directly next to/beneath the Jacaranda tree, and tag this location. This will use your device's GPS location.

- Yes
- No

Back | Submit

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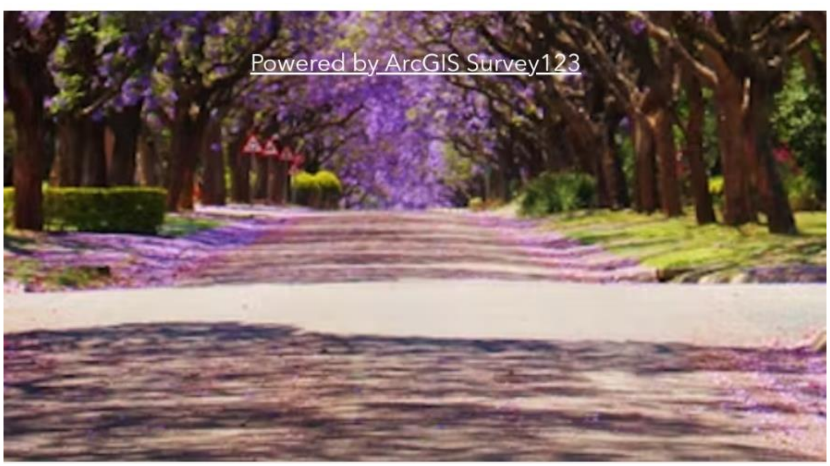
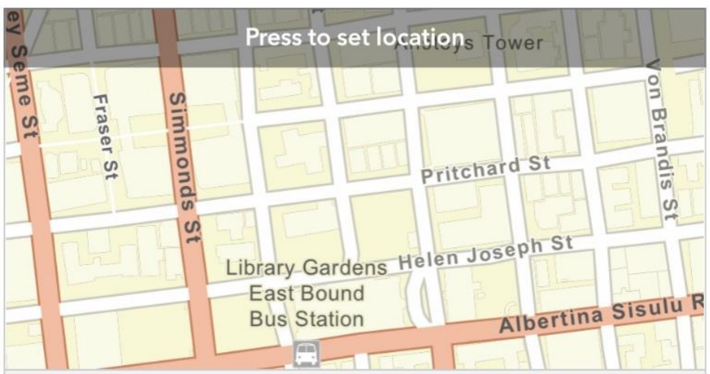


Exact Jacaranda tree locations (1)

1

Please geotag the exact location where Jacaranda trees are located

Add one exact Jacaranda tree location at a time. Press the circular icon below once you are standing next to/beneath the tree. To add another exact location of a Jacaranda tree, press the "+" action within the white bubble labelled "1 of 1" and repeat the process. Remember to move to the next Jacaranda tree location. You can add up 20 exact locations of Jacaranda trees.



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Back Submit

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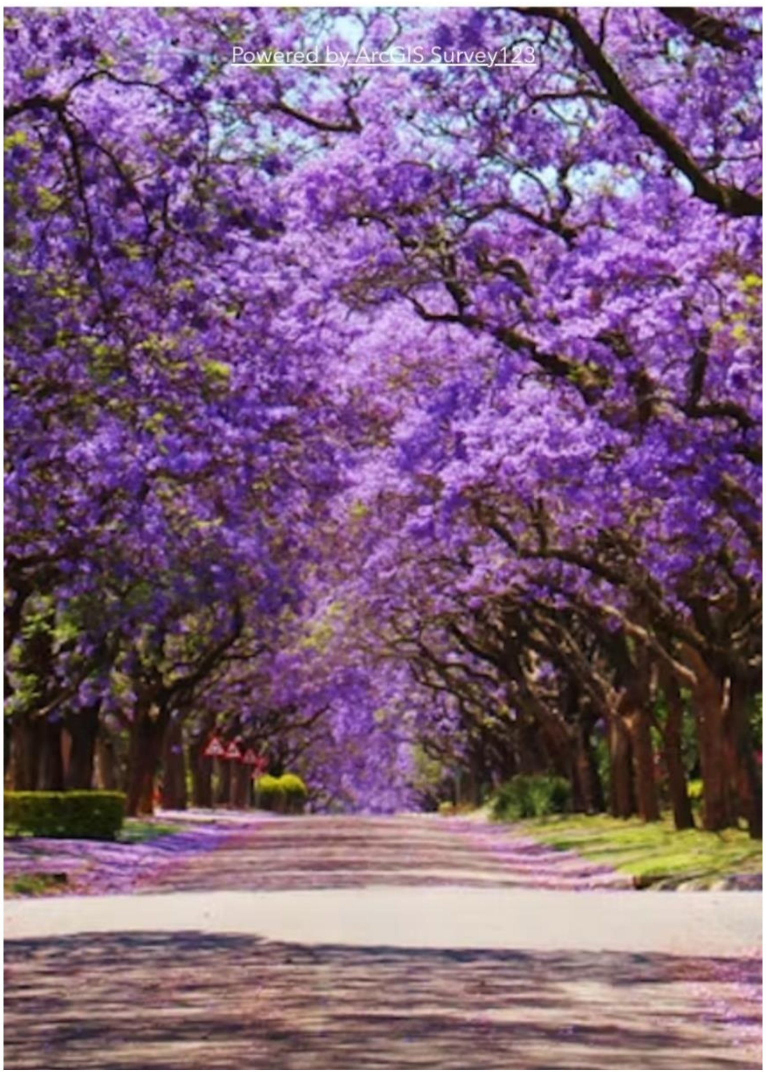
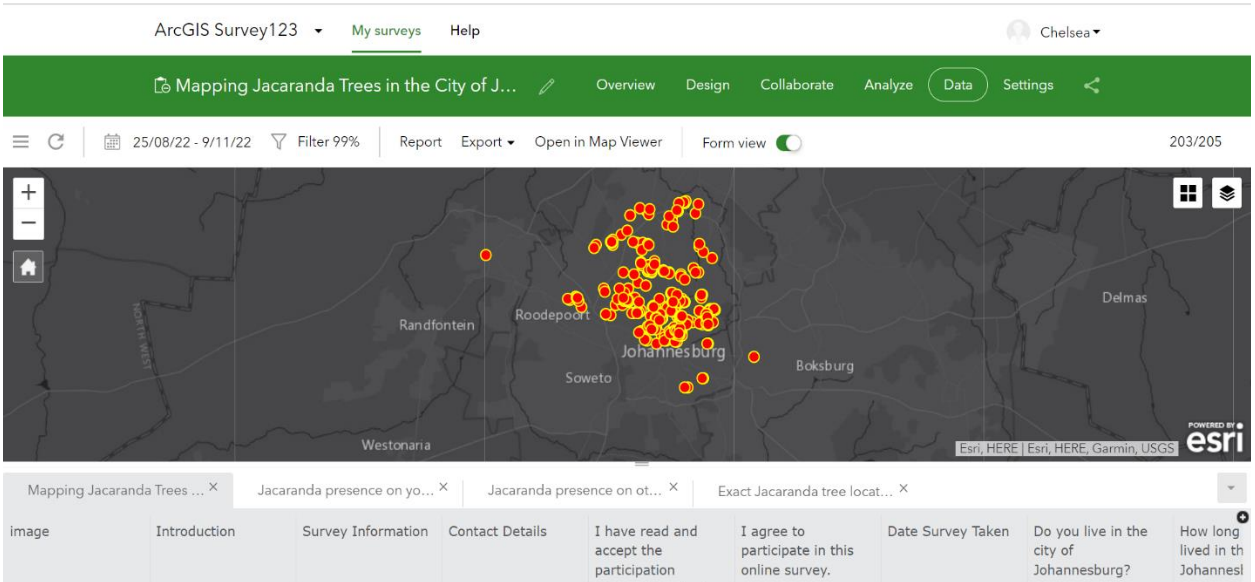
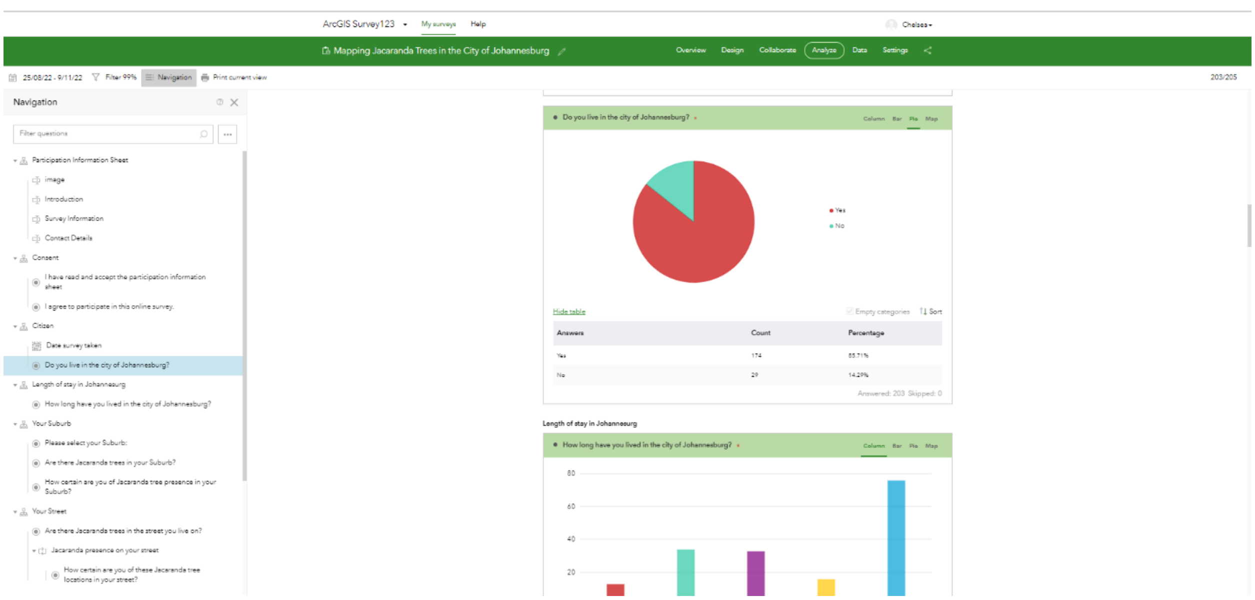
Mapping Jacaranda Trees in the CoJ

Thank you.
Your response was submitted successfully.

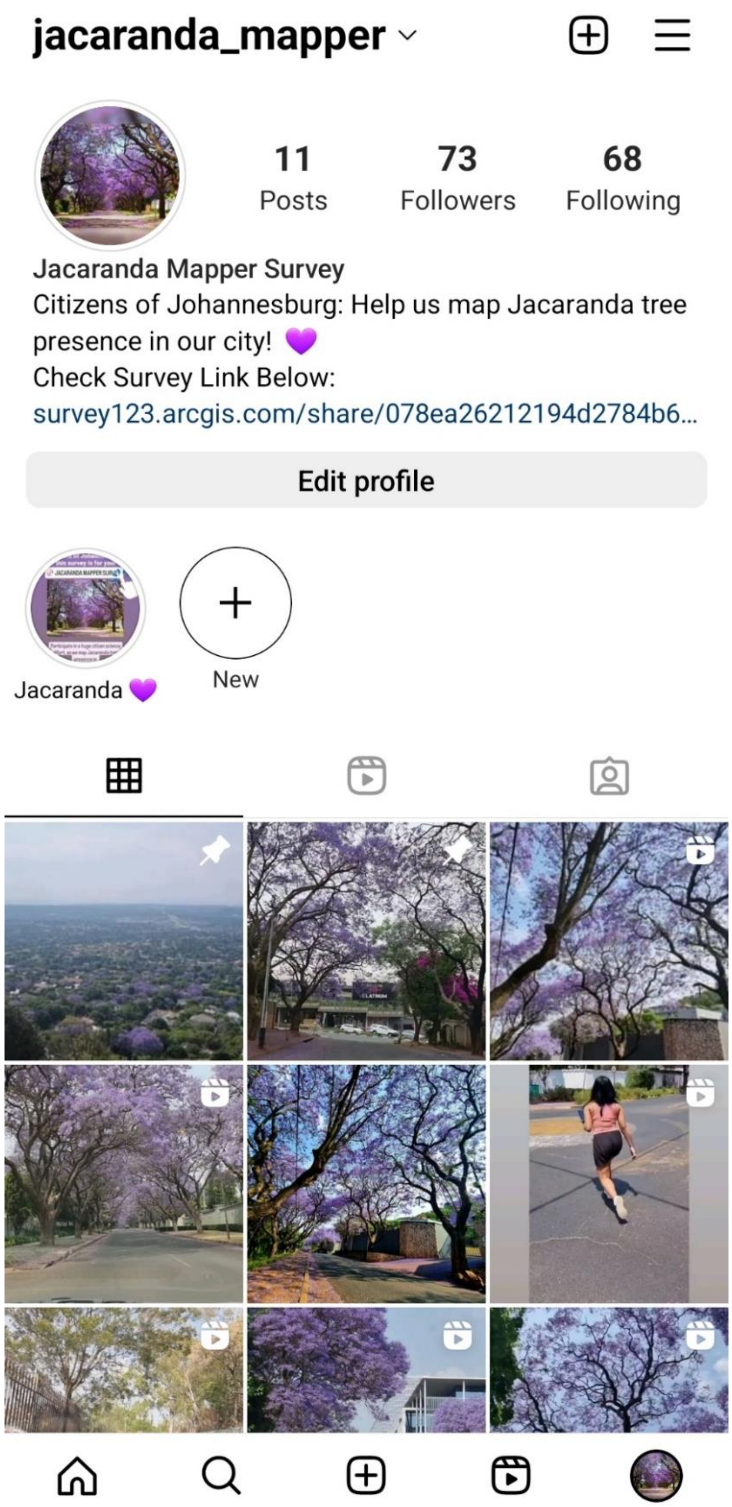


Survey Dashboard accessible through *ArcGIS Online*





Appendix C: Examples of Social Media Posts



inyour pocket
johannesburginyourpocket 1h
jacaranda_mapper
@JOHANNESBURGINYOURPOCKET
#yourjourneystartswithgautrain
#JACARANDAINYOURPOCKET2022

johannesburginyourpocket
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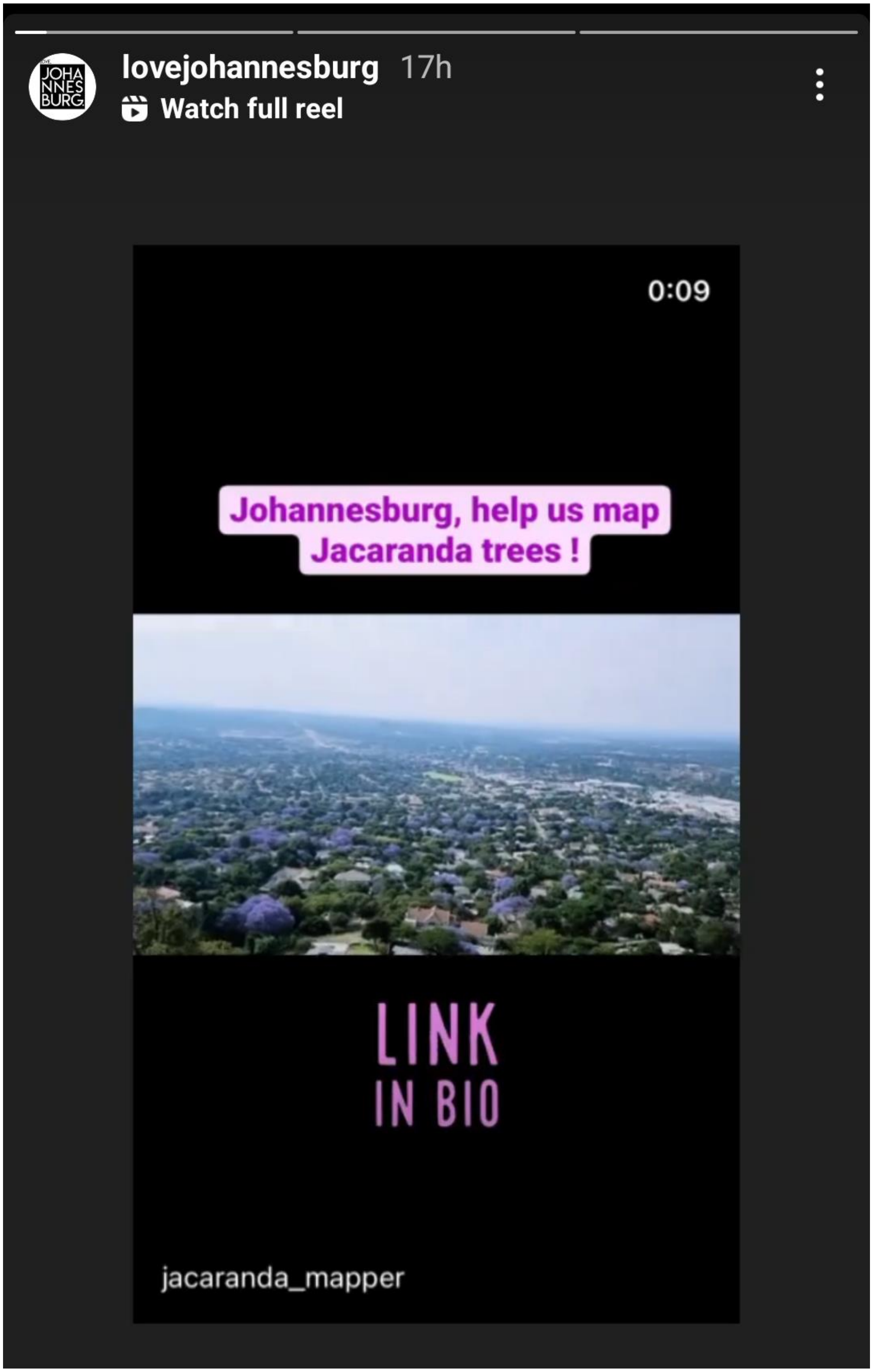
Jacaranda sites being mapped
@jacaranda_mapper
RANDPARK RIDGE
Thank you for the support !
@johannesburginyourpocket
JOHANNESBURG, TAP LINK BELOW:
JACARANDA MAPPER SURVEY


lovejohannesburg 17h
Watch full reel
0:09
Johannesburg, help us map Jacaranda trees !
LINK IN BIO
jacaranda_mapper


joburg.co.za 6h
jacaranda_mapper
@JOHANNESBURGINYOURPOCKET
@CITYOFJOBURG
@MAGICALFAIRYGODMOTHER
@2SUMMERS
@JOBURG.CO.ZA
jacaranda_mapper
Citizens of Johannesburg, this survey is for you!
JACARANDA MAPPER SURVEY
Participate in a huge citizen science effort, as we map Jacaranda tree presence in
JOHANNESBURG, SOUTH AFRICA
TODAY IS THE FINAL DAY TO SUBMIT YOUR RESPONSE !!!

Esri South Africa
7,512 followers
9m •

As we have recently welcomed Spring, from early October to early November you may notice the beginnings of purple petals from Jacaranda trees blooming around Johannesburg's streets.

Our geospatial intern Rohini Chelsea Reddy is mapping the Jacaranda trees in the city of Johannesburg. Help her map the spatial distribution of Jacaranda trees by completing the survey.

Rohini Chelsea Reddy • You
1h •

If you live in Johannesburg, South Africa, this survey is for you!

This survey aims at mapping the spatial distribution of Jacaranda trees in the City of Johannesburg.

To access the survey, click the link below:

https://lnkd.in/dUj8bpun

This survey was created using Esri's Survey123. This is just one of the many fantastic products I have worked with, whilst interning at Esri South Africa!

#EsriSouthAfrica #EsriProducts #EsriSurvey123 #esri #gis #CityOfJohannesburg #joburg #wits #wits100

Appendix D: Example of Poster with QR Code to Survey