Urban Green Space Analysis

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GIS322 Programming Principles GIS II

Introduction

Parks and green open spaces are basic environmental means that should be used in protection of the environmental quality and improvement of the health status of urban residents. In principle, green open space provides a variety of ecosystem services, including carbon sequestration, stormwater management, and temperature control. Besides all the other reasons, green open spaces are community meeting places, enabling the residents to socialize and exercise more outdoors. But in too many cities, green open spaces exist only as inequitably distributed resources. For instance, green areas are absent in low-income or disadvantaged regions, which contributes to a low quality of life among its residents. In light of these issues, this project focuses on **Tempe, Arizona**, with the goal of analyzing the city's green space distribution and urban tree biodiversity.

The central research questions addressed in this study are:

- How are green spaces distributed across Tempe?
- Are there significant gaps in access to green spaces for certain neighborhoods?
- What is the composition of tree species in Tempe, and how does it reflect the city's environmental conditions?

By addressing these questions, the project aims to provide actionable insights for urban planners, policymakers, and conservationists to improve green space accessibility and biodiversity in Tempe.

Data Description

OpenStreetMap (OSM) Data for Green Spaces

- **Source**: OpenStreetMap (OSM) is a collaborative mapping platform that offers free geographic data, including roads, buildings, land use, and green spaces. For this project, the OSMnx Python library was utilized to extract green space data for Tempe.
- **Format**: The data was retrieved in GeoJSON format, a widely adopted format for geographic features in JSON (JavaScript Object Notation).
- **Resolution**: The OSM data for green spaces provides high-resolution polygons representing individual parks, gardens, and playgrounds.
- **Projection**: The original data uses the WGS84 coordinate system (EPSG:4326). For more accurate area calculations, the data was reprojected to UTM Zone 12N (EPSG:32612).

Green space data had to be used for mapping and further analysis of the spatial distribution of parks, gardens, or other areas used for recreational purposes. By calculating the total area covered by these spaces, we could assess if the green space allocation in Tempe is adequate for the population.

Tree Inventory Data

- **Source**: The City of Tempe provides a Tree Inventory, documenting the city's urban forest, including tree species, size, and location. The dataset was obtained in both GeoJSON and CSV formats.
- **Attributes**: The inventory includes fields such as Species_Name, DBH (Diameter at Breast Height), and carbon storage per tree. These attributes are crucial for understanding the ecosystem services provided by trees, including carbon sequestration and energy savings.
- **Resolution**: Each tree is geolocated with precise latitude and longitude coordinates, enabling detailed spatial analysis.

- **Projection**: Like the OSM data, the tree inventory was reprojected to UTM Zone 12N to ensure consistency during spatial analysis.

The tree inventory provides insight into the biodiversity present within Tempe's urban forest. Variety and distribution of tree species provide further evidence of how green infrastructure in the city can adapt to environmental changes, like drought or pest infestations.

Methodology

This project followed a multi-stage process, from data collection to spatial analysis and visualization. The subsequent sections of this report will provide a comprehensive explanation of each step in the process, including the specific code used to carry out the analysis.

Data Collection

The green space data was retrieved using the OSMnx Python library, which allows users to download OSM data based on geographic queries. In this case, the query focused on green spaces in Tempe, using the following tags: `{'leisure': ['park', 'garden', 'playground']}`.

Code Snippet for Downloading OSM Data:

```
import osmnx as ox
place_name = "Tempe, Arizona, USA"
tags = {'leisure': ['park', 'garden', 'playground']}
tempe_osm_data = ox.features_from_place(place_name, tags)
```

The tree inventory data was loaded as a GeoJSON file using the `geopandas` library, which is designed for geospatial data analysis.

Code Snippet for Loading Tree Data:

```
import geopandas as gpd
tree_inventory_file = '/content/Tree_Inventory.geojson'
tree_data = gpd.read_file(tree_inventory_file)
```

Data Preprocessing

Once the data was collected, it was necessary to reproject both the green space and tree inventory datasets into UTM Zone 12N to ensure accurate area calculations. Additional cleaning on the tree inventory dataset was performed by filtering out unnecessary columns related to tree species and geographic locations.

Code Snippet for Reprojection:

```
green_spaces_cleaned = tempe_osm_data.to_crs(epsg=32612)
green_spaces_cleaned['area_m2'] = green_spaces_cleaned['geometry'].area
```

Spatial Analysis

The spatial analysis was conducted in three key components: **green space coverage**, **tree species diversity**, and **environmental benefits**.

1. **Green Space Coverage**: The total number of green spaces in Tempe and their combined area were calculated using the area function provided by **geopandas**. This analysis assessed whether green space allocation in the city is sufficient for the population.
2. **Tree Species Diversity**: The tree species distribution was analyzed by counting the occurrences of each species in the inventory. A **bar chart** was created to visualize the top 10 most common species.

Code Snippet for Tree Species Analysis:

```
tree_cleaned = tree_data[['Species_Name', 'geometry']].dropna()
tree_summary = tree_cleaned['Species_Name'].value_counts()
```

3. **Environmental Benefits**: The **carbon storage**, **carbon sequestration**, and **pollution removal** capabilities of the trees were analyzed by species. A **GIS map** was created to show the spatial distribution of these benefits, focusing on carbon storage.

Visualization

The results of the spatial analysis were visualized using matplotlib and folium, Python libraries for creating static, interactive, and animated visualizations. Four key visualizations were produced:

1. **Bar Chart for Top 10 Most Common Tree Species**: Below is a chart of the most common tree species in Tempe, Arizona. A snapshot of which tree species dominate the urban forest-a reflection of ecological choices and environmental conditions within the city.

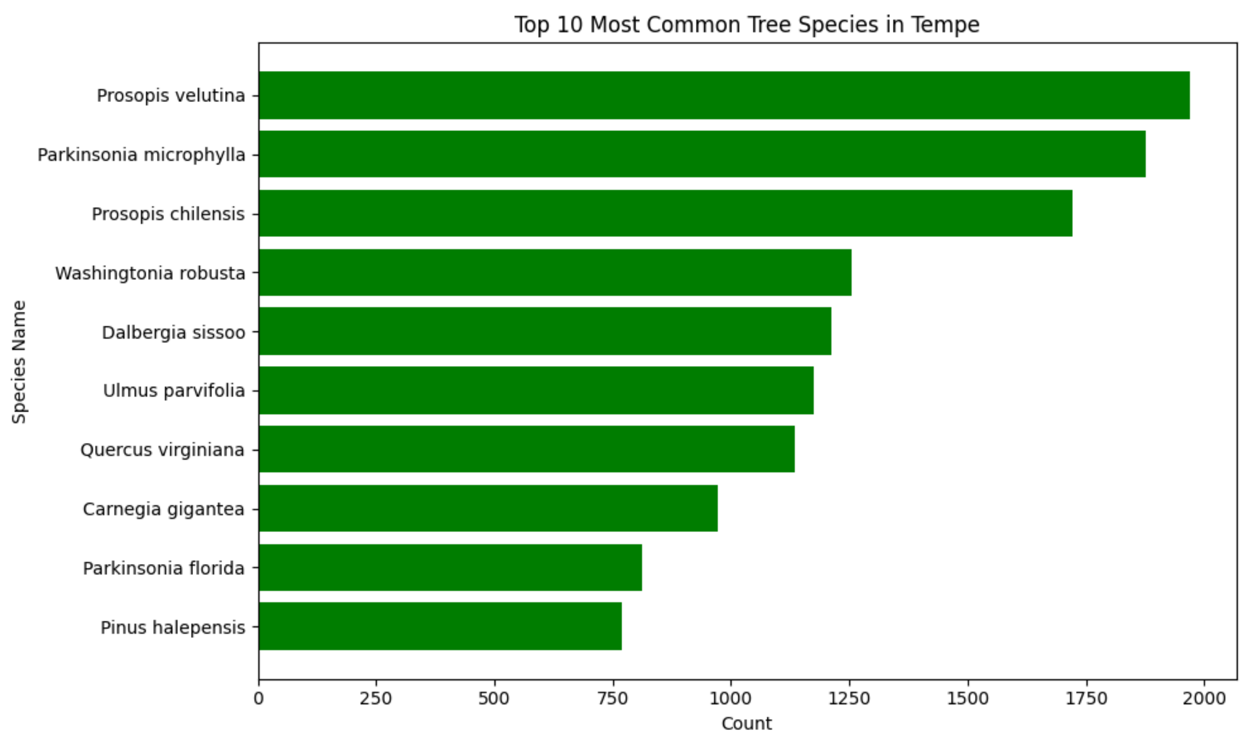

Figure 1: *Top 10 Most Common Tree Species in Tempe, Arizona*

2. **Tree Species Density Map**: The following map shows density and distribution of the top 10 tree species throughout Tempe. What becomes clear is which species dominate which regions within the city.

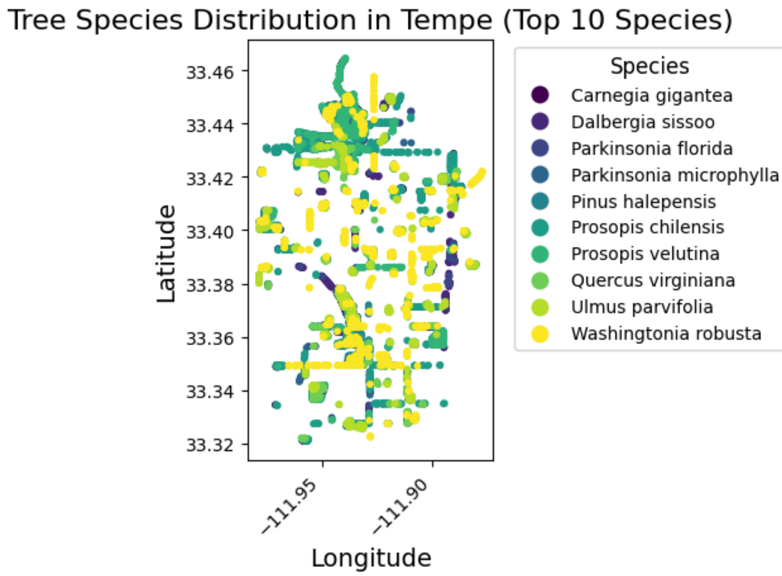

Figure 2*: Tree Species Distribution in Tempe (Top 10 Species)*

3. **Combined Tree and Green Space Map**: The Combined Tree and Green Space Map combines tree location information with green spaces to provide a more integrated picture of the urban forestry and green infrastructure of Tempe.

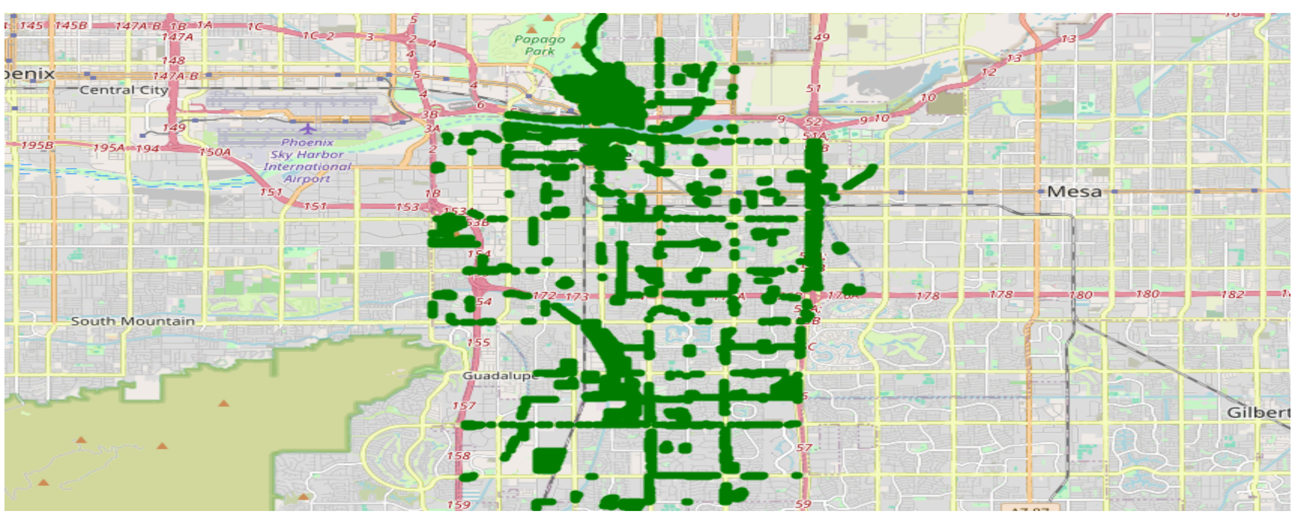

Figure 3*: Combined Map of Trees and Green Spaces in Tempe*

4. **Tree Environmental Benefits Analysis**: The top 10 tree species featured in the Tree Environmental Benefits Analysis chart play a critical role in environmental services like carbon storage, carbon sequestration, and pollution removal. This analysis has become crucial in order to understand how different tree species tackle the issues of climate change mitigation and air quality improvement.

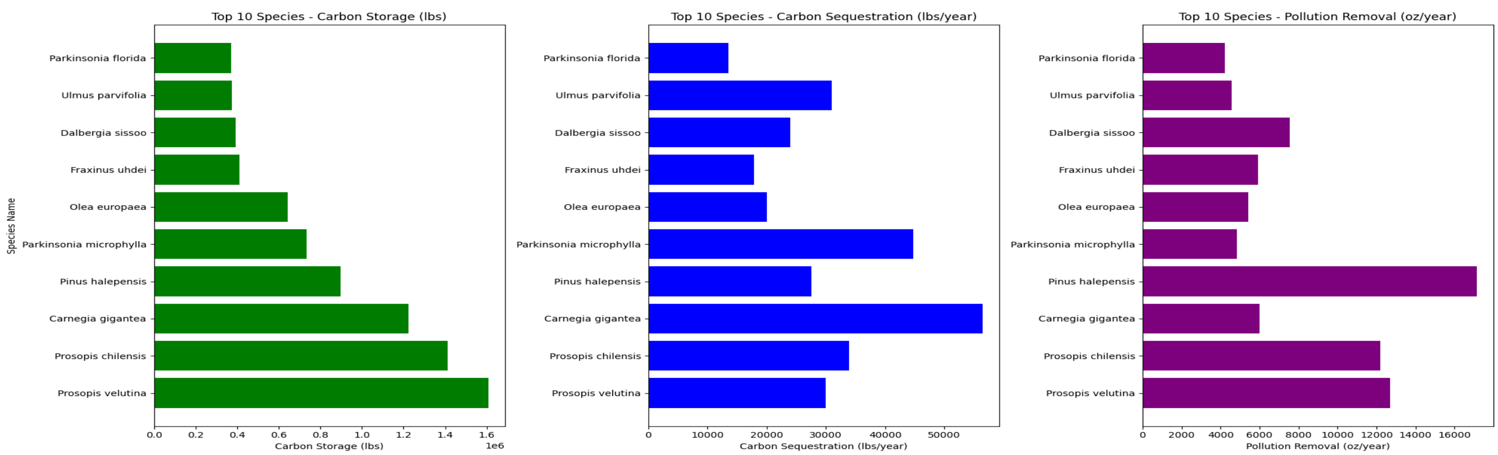

Figure 4*: Environmental Benefits of the Top 10 Tree Species in Tempe*

5. **The Environmental Benefits Map:** This maps the distribution of trees in Tempe, color-coded by their species. It seeks to figure out which parts of the city are most responsible for capturing carbon.

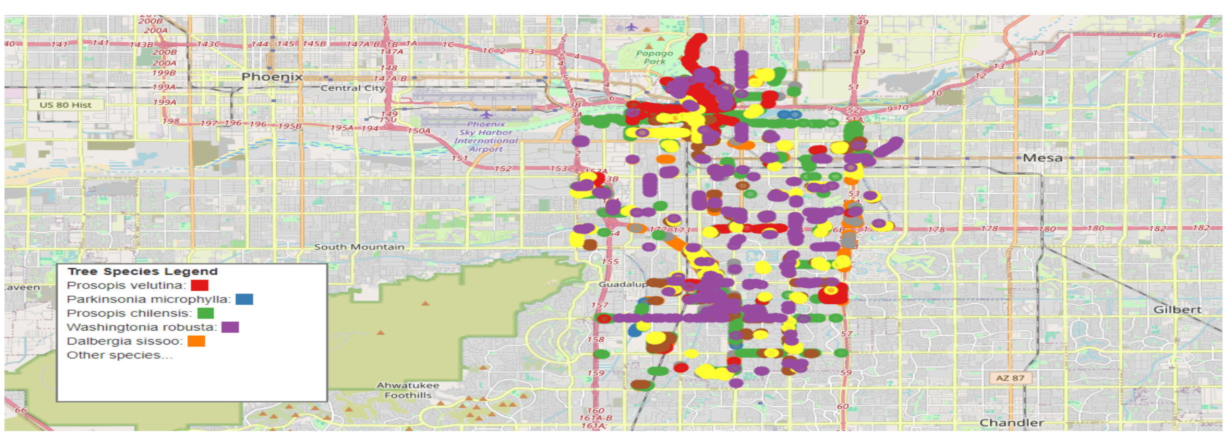

Figure 5: Spatial Distribution of Carbon Storage by Trees in Tempe

Findings

The analyses and subsequent visualizations of Tempe's tree inventory and green space data provide critical insights into the urban biodiversity, distribution of green space throughout the city, and environmental benefits of trees within the urban framework.

1. **Bar Chart for Top 10 Most Common Tree Species**: The **bar chart** highlights the most common tree species in Tempe. **Prosopis velutina**, **Parkinsonia microphylla**, and **Prosopis chilensis** are the most dominant species, which is indicative of Tempe's climate, as these species are well-suited for arid environments. Dominance of drought resistance trees therefore reflects the means by which this city manages water in its urban forestry management.
2. **Tree Species Density Map**: The **tree species density map** reveals that the distribution of tree species is not uniform across the city. Certain regions, especially near urban parks and green spaces, exhibit higher concentrations of tree species. Even the number of useful species such as Prosopis velutina is higher in areas having large parks and recreation spaces. This type of uneven distribution suggests that the city has deliberately planted the most useful species in certain locations.
3. **Combined Tree and Green Space Map**: The combined tree and green space map provides a spatial visualization of the overlap in urban green spaces and tree biodiversity. While green spaces are somewhat well distributed within the city, some neighborhoods contain fewer trees within their green spaces. This might indicate which areas could be targeted for tree planting with the purpose of enhancing biodiversity and ecological balance in areas which are currently underserved.
4. **GIS-Themed Carbon Storage Map**: The carbon storage map with a GIS theme shows the spatial distribution according to the contribution by trees. High-value tree species, such as Dalbergia sissoo and Prosopis velutina, are kept within key areas to ensure their climate benefits are only localized. The mapped critical function of these species in mitigating urban heat and improving air quality absorbs carbon.

Limitations and Future Work

Limitations:

1. **Data Completeness**: One of the main limitations of this study is that the dataset on tree inventory may be incomplete. The data appears to be fairly all-encompassing for public spaces, but it may not account for trees on private property or those areas that could potentially fall outside of the city's urban forestry.
2. **Temporal Dynamics**: This analysis is based on static data and does not represent seasonal fluctuations or the latest tree plantings and removals. Long-term urban growth, climate change, and a shift in policies regarding nature conservation could, over time, result in changes in tree species distribution and greener space area.
3. **Tree Health**: While the analysis focuses on the pivotal role played by tree species and environmental contributions, it does not account for the health status of the trees contributing to the model. For instance, damaged or sickly trees could not contribute as highly to carbon storage or the removal of air pollution as a healthy one would.

Future Work:

1. **Dynamic Monitoring**: The time-series data or periodic update on the tree inventory can provide insights into the changes in the populations of trees and green spaces that have been experienced overtime, particularly in response to urban development or environmental policies.
2. **Incorporating Climate Data**: Additional studies can be done using local climate variables such as temperature and rainfall to model variations in the environmental conditions for each tree species, thus allowing projections of which tree species will do well under the different projected climate variations.
3. **Public and Private Tree Integration**: Increasing the dataset to include trees on private property would give a more holistic view of the urban forest, allowing better analysis in terms of biodiversity and environmental contribution.

Conclusion

This project provides a detailed analysis of Tempe’s urban forest and green space distribution. The findings reveal that certain species, such as **Prosopis velutina** and **Dalbergia sissoo**, dominate the urban landscape, likely due to their drought tolerance and environmental benefits. The GIS-themed visualizations, particularly the **combined tree and green space map** and the **carbon storage map**, offer insights into how biodiversity and environmental services are distributed across the city.

Despite some limitations in the dataset and its temporal scope, the analysis demonstrates the importance of thoughtful urban forestry management. The maps indicate areas where biodiversity could be increased, particularly in neighborhoods with fewer trees, and highlight the importance of key species in contributing to carbon storage and air pollution removal.

Appendix

Appendix A: Code for Data Analysis and Visualization

```
# Required libraries
import osmnx as ox
import geopandas as gpd
import matplotlib.pyplot as plt
import folium
import pandas as pd

# Step 1: Load OpenStreetMap data for parks, gardens, playgrounds
place_name = "Tempe, Arizona, USA"
tags = {'leisure': ['park', 'garden', 'playground']}  # Green spaces tags
tempe_osm_data = ox.geometries_from_place(place_name, tags)

# Step 2: Load Tree Inventory data (GeoJSON)
tree_inventory_file = '/content/Tree_Inventory.geojson'
tree_data = gpd.read_file(tree_inventory_file).dropna(subset=['geometry'])  # Remove missing
geometries

# Step 3: Display basic info of loaded data
print("Green spaces from OSM:", tempe_osm_data.head())
print("Tree Inventory Data:", tree_data.head())

# Step 4: Static map with matplotlib
fig, ax = plt.subplots(figsize=(10, 10))
tempe_osm_data.plot(ax=ax, color="green", label="Green Spaces")  # Plot green spaces
tree_data.plot(ax=ax, color="blue", marker="o", markersize=5, label="Trees")  # Plot trees
plt.title("Urban Green Spaces and Tree Inventory in Tempe, Arizona")
plt.legend()
plt.show()

# Step 5: Interactive map with folium
tempe_map = folium.Map(location=[33.4255, -111.9400], zoom_start=13)

# Add green spaces to folium map
for idx, row in tempe_osm_data.iterrows():
    if row.geometry.type == 'Polygon':
        folium.GeoJson(row.geometry).add_to(tempe_map)

# Add trees to folium map
for idx, row in tree_data.iterrows():
    folium.Marker(
        location=[row.geometry.y, row.geometry.x],
        popup=row.get('Tree_Type', 'Tree')
    ).add_to(tempe_map)
```

```
tempe_map  # Display interactive map

# Step 6: Analyze Tree_Inventory.csv
csv_file = '/content/Tree_Inventory.csv'
tree_csv_data = pd.read_csv(csv_file)

# Display basic info and descriptive statistics
print("Tree Inventory CSV Data:", tree_csv_data.head())
print("Descriptive statistics:", tree_csv_data.describe())
```

Appendix B: Code for Data Cleaning and Summary Statistics

```
# Required libraries
import osmnx as ox
import geopandas as gpd
import pandas as pd

# Step 1: Load Tree Inventory data (GeoJSON)
tree_inventory_file = '/content/Tree_Inventory.geojson'
tree_data = gpd.read_file(tree_inventory_file)

# Step 2: Load OSM green spaces data (parks, gardens, playgrounds)
place_name = "Tempe, Arizona, USA"
tags = {'leisure': ['park', 'garden', 'playground']}
tempe_osm_data = ox.features_from_place(place_name, tags)

# Clean Tree Inventory data (keep 'Species_Name' and 'geometry')
tree_cleaned = tree_data[['Species_Name', 'geometry']].dropna()

# Tree species summary
tree_summary = tree_cleaned['Species_Name'].value_counts()

# Clean and reproject OSM green spaces data to UTM Zone 12N
green_spaces_cleaned = tempe_osm_data[['geometry']].dropna()
green_spaces_cleaned = green_spaces_cleaned.to_crs(epsg=32612)
green_spaces_cleaned['area_m2'] = green_spaces_cleaned['geometry'].area

# Calculate number of green spaces and total area
num_green_spaces = green_spaces_cleaned.shape[0]
total_green_space_area = green_spaces_cleaned['area_m2'].sum()

# Prepare summary tables
tree_summary_df = pd.DataFrame(tree_summary).reset_index()
tree_summary_df.columns = ['Species_Name', 'Count']

green_space_summary_df = pd.DataFrame({
    'Number of Green Spaces': [num_green_spaces],
    'Total Green Space Area (m²)': [total_green_space_area]
```

```
})

# Display summary tables
print("Tree Species Summary:")
print(tree_summary_df)

print("\nGreen Space Summary:")
print(green_space_summary_df)
```

Appendix C: Code for Data Summary and Visualization

```
# Required libraries
import osmnx as ox
import geopandas as gpd
import pandas as pd
import matplotlib.pyplot as plt

# Step 1: Load Tree Inventory data (GeoJSON)
tree_inventory_file = '/content/Tree_Inventory.geojson'
tree_data = gpd.read_file(tree_inventory_file)

# Step 2: Load OSM green spaces data (parks, gardens, playgrounds)
place_name = "Tempe, Arizona, USA"
tags = {'leisure': ['park', 'garden', 'playground']}
tempe_osm_data = ox.features_from_place(place_name, tags)

# Clean Tree Inventory data (retain 'Species_Name' and 'geometry')
tree_cleaned = tree_data[['Species_Name', 'geometry']].dropna()

# Tree species summary
tree_summary = tree_cleaned['Species_Name'].value_counts()

# Clean and reproject OSM green spaces data to UTM Zone 12N
green_spaces_cleaned = tempe_osm_data[['geometry']].dropna()
green_spaces_cleaned = green_spaces_cleaned.to_crs(epsg=32612)
green_spaces_cleaned['area_m2'] = green_spaces_cleaned['geometry'].area

# Calculate number of green spaces and total area
num_green_spaces = green_spaces_cleaned.shape[0]
total_green_space_area = green_spaces_cleaned['area_m2'].sum()

# Prepare tree summary table
```

```
tree_summary_df = pd.DataFrame(tree_summary).reset_index()
tree_summary_df.columns = ['Species_Name', 'Count']

# Visualization: Bar chart for top 10 most common tree species
top_10_species = tree_summary_df.head(10)

plt.figure(figsize=(10, 6))
plt.barh(top_10_species['Species_Name'], top_10_species['Count'], color='green')
plt.xlabel('Count')
plt.ylabel('Species Name')
plt.title('Top 10 Most Common Tree Species in Tempe')
plt.gca().invert_yaxis()  # Display largest count on top
plt.tight_layout()
plt.show()
```

Appendix D: Code for Visualization and Analysis

```
# Required libraries
import osmnx as ox
import geopandas as gpd
import pandas as pd
import matplotlib.pyplot as plt
import folium
import numpy as np

# Step 1: Load Tree Inventory and OSM Green Spaces data
tree_inventory_file = '/content/Tree_Inventory.geojson'
tree_data = gpd.read_file(tree_inventory_file)

place_name = "Tempe, Arizona, USA"
tags = {'leisure': ['park', 'garden', 'playground']}
tempe_osm_data = ox.features_from_place(place_name, tags)

# Clean Tree Inventory and OSM Data
tree_cleaned = tree_data[['Species_Name', 'geometry']].dropna()
green_spaces_cleaned = tempe_osm_data[['geometry']].dropna().to_crs(epsg=32612)
green_spaces_cleaned['area_m2'] = green_spaces_cleaned['geometry'].area

# Visualization: Tree Species Distribution Plot (Wider x-axis)
plt.figure(figsize=(30, 10))
ax = tree_cleaned.plot(column='Species_Name', legend=True, markersize=10,
cmap='viridis')
```

```
plt.xticks(rotation=45, ha='right')
legend = ax.get_legend()
legend.set_bbox_to_anchor((1.05, 1))
legend.set_title("Species", prop={'size': 12})
plt.title('Tree Species Distribution in Tempe (Top 10 Species)', fontsize=16)
plt.xlabel('Longitude', fontsize=14)
plt.ylabel('Latitude', fontsize=14)
plt.tight_layout()
plt.show()

# Combined Map of Green Spaces and Trees (folium)
combined_map = folium.Map(location=[33.4255, -111.9400], zoom_start=13)
for idx, row in green_spaces_cleaned.iterrows():
    folium.GeoJson(row.geometry, style_function=lambda x: {'color':
'green'}).add_to(combined_map)
for idx, row in tree_cleaned.iterrows():
    folium.CircleMarker(location=[row.geometry.y, row.geometry.x], radius=2,
color='green', fill=True, fill_opacity=0.6).add_to(combined_map)
combined_map

# Environmental Benefits Analysis (Carbon Storage, Sequestration, Pollution Removal)
tree_benefits = tree_data.groupby('Species_Name').agg({
    'Carbon_Storage__lb_': 'sum',
    'Gross_Carbon_Sequestration__lb_': 'sum',
    'Pollution_Removal__oz_yr_': 'sum'
}).reset_index()

top_10_benefits = tree_benefits.nlargest(10, 'Carbon_Storage__lb_')

# Subplots for Tree Benefits
fig, axes = plt.subplots(nrows=1, ncols=3, figsize=(20, 8))

# Carbon Storage
axes[0].barh(top_10_benefits['Species_Name'], top_10_benefits['Carbon_Storage__lb_'],
color='green')
axes[0].set_title('Top 10 Species - Carbon Storage (lbs)')
axes[0].set_xlabel('Carbon Storage (lbs)')
axes[0].set_ylabel('Species Name')

# Carbon Sequestration
axes[1].barh(top_10_benefits['Species_Name'],
top_10_benefits['Gross_Carbon_Sequestration__lb_'], color='blue')
```

```
axes[1].set_title('Top 10 Species - Carbon Sequestration (lbs/year)')
axes[1].set_xlabel('Carbon Sequestration (lbs/year)')

# Pollution Removal
axes[2].barh(top_10_benefits['Species_Name'],
top_10_benefits['Pollution_Removal__oz_yr_'], color='purple')
axes[2].set_title('Top 10 Species - Pollution Removal (oz/year)')
axes[2].set_xlabel('Pollution Removal (oz/year)')

plt.tight_layout()
plt.show()

# Color-Coded Species Map (folium)
top_10_species = tree_data['Species_Name'].value_counts().head(10).index.tolist()
top_10_tree_data = tree_data[tree_data['Species_Name'].isin(top_10_species)]

colors = plt.cm.get_cmap('Set1', len(top_10_species))
species_color_map = {species: colors(i) for i, species in enumerate(top_10_species)}

def rgb_to_hex(rgb):
    return '#%02x%02x%02x' % (int(rgb[0]*255), int(rgb[1]*255), int(rgb[2]*255))

top_10_species_map = folium.Map(location=[33.4255, -111.9400], zoom_start=13)

# Add trees with color-coded markers
for idx, row in top_10_tree_data.iterrows():
    if row.geometry is not None:
        color = rgb_to_hex(species_color_map[row['Species_Name']])
        folium.CircleMarker(
            location=[row.geometry.y, row.geometry.x],
            radius=5,
            color=color,
            fill=True,
            fill_opacity=0.7,
            popup=f"Species: {row['Species_Name']}"
        ).add_to(top_10_species_map)

# Add custom legend to the map
legend_html = '''
<div style="position: fixed;
     bottom: 50px; left: 50px; width: 250px; height: 200px;
     background-color: white; border:2px solid grey; z-index:9999; font-size:14px;">
```

```
     <b>  Tree Species Legend</b><br>
       Prosopis velutina: <i
style="background:{}">    </i><br>
       Parkinsonia microphylla: <i
style="background:{}">    </i><br>
       Prosopis chilensis: <i
style="background:{}">    </i><br>
       Washingtonia robusta: <i
style="background:{}">    </i><br>
       Dalbergia sissoo: <i
style="background:{}">    </i><br>
       Other species...<br>
</div>
'''.format(rgb_to_hex(species_color_map['Prosopis velutina']),
           rgb_to_hex(species_color_map['Parkinsonia microphylla']),
           rgb_to_hex(species_color_map['Prosopis chilensis']),
           rgb_to_hex(species_color_map['Washingtonia robusta']),
           rgb_to_hex(species_color_map['Dalbergia sissoo']))

top_10_species_map.get_root().html.add_child(folium.Element(legend_html))
top_10_species_map
```

References

OpenStreetMap Contributors (2023). OpenStreetMap. Available at: https://www.openstreetmap.org

- OpenStreetMap (OSM) was used to retrieve geographic data on green spaces in Tempe, Arizona, via the OSMnx Python library.

City of Tempe (2023). Tree Inventory Data. Available at: https://www.tempe.gov

- The tree inventory dataset, which includes information on tree species, carbon storage, and pollution removal, was provided by the City of Tempe.

Boeing, G. (2023). OSMnx: A Python package to work with OpenStreetMap's data. Available at: https://github.com/gboeing/osmnx

- The OSMnx Python library was used to retrieve green space data from OpenStreetMap, enabling spatial analysis of Tempe's parks and recreational areas.

Jordahl, K. (2023). Geopandas: Python tools for geographic data. Available at: https://geopandas.org

- Geopandas was used for geospatial data manipulation, particularly for reading the tree inventory data and performing spatial operations.

U.S. Census Bureau (2023). American Community Survey. Available at: https://www.census.gov/programs-surveys/acs

- The U.S. Census Bureau's data provided context for demographic analysis related to green space accessibility and tree distribution in urban areas.