Visualization of Urban Development in Plovdiv and Analysis of Its Causes

Matej Sembera **15.7.2025**

Goal of the paper 3
Geo data description 3
Accuracy of the data 4
Processing of the data 6
1. Data extraction and structuring 6
2. Conversion to geospatial format 6
3. Aggregation and derived metrics 6
5. Export and output 7
Visualization principles 7
Created visualizations 9
1. Dashboard 9
2. Dashboard 13
Using the visualization in historical context 16
1. Forced relocation (sürgün) of Muslims to the west in the 1520s 16
2. The rise of the christian population in late 16th and early 17th century 19
3. Tataran 21
Paper summary 24
Sources 25

Goal of the paper

The historical development of Plovdiv, along with a detailed analysis of its demographic and urban development, has already been examined by Grigor Boykov in his book *Ottoman Plovdiv: Space, Architecture, and Population (14th–17th Centuries)* [1]. In this work, Boykov explores the transformations of the city's urban landscape and population dynamics over several centuries.

In addition to the book, an interactive visualization of the underlying data is available on the website ottomanplovdiv.org. This platform utilizes ArcGIS software to allow users to explore historical layers. Users can select specific map layers corresponding to demographic indicators such as population densities and total populations for the years 1472, 1489, 1516, 1525, 1530, 1570, 1596, and 1614.

The platform additionally enables the visualization of spatial features such as *mahalles* (neighborhoods/districts), as well as landmarks. These include Muslim and Christian cemeteries, orchards, fields, forests, and individual buildings.

The primary aim of this paper is to build upon the existing foundation by proposing alternative methods for visualizing the same dataset, with the goal of further enhancing historical interpretations.

In this paper, we created two dashboards in Tableau and used them to explain three historical events, demonstrating how the use of dashboards can contribute to a deeper understanding of historical interpretations. The three historical events are: the forced relocation (*sürgün*) of Muslims to the west in the 1520s, the rise of the Christian population in the late 16th and early 17th centuries, and Tataran.

Geo data description

The dataset is provided in ESRI JSON format, a specialized variant of JSON commonly used in geographic information systems (GIS). It can be transformed into standardized JSON for broader compatibility and processing. JSON (JavaScript Object Notation) is a hierarchical data format that organizes information through nested structures using curly braces {}.

In this dataset, polygon vertices are defined as coordinate pairs in the format [x_coordinate, y_coordinate]. The spatial reference system used is UTM Zone 35N, corresponding to EPSG:32635. In this coordinate system, the X coordinate (Easting) indicates the distance in meters east of the zone's central meridian, while the Y coordinate (Northing) measures the distance in meters north from the equator. The dataset covers multiple historical years: 1472, 1489, 1516, 1525, 1530, 1570, 1596, and 1614.

JSON Schema

```
├── displayFieldName
├── fieldAliases{}
├── geometryType: "esriGeometryPolygon"
├── spatialReference
├── fields[]
└── features[]
    ├── attributes{}
    │   ├── OBJECTID: 1
    │   ├── Name: "Debbağ hisarı"
    │   ├── Area_ha: 0.1386
    │   ├── Mus_hane: 26
    │   ├── Chr_hane: null
    │   ├── Total_pop: 130
    │   ├── Density_ha: 67
    │   ├── ...
    └── geometry
        └── rings[][]
            ├── [ [x1, y1], [x2, y2], ..., [x1, y1] ]
```

Accuracy of the Data

The data used in this study originates from the website ottomanplovdiv.org. The detailed methodology for drawing the polygons and the historical sources referenced are outlined in [1], under the subsection *Population Sources* within the section *Documentary Archaeology: Recreating Ottoman Plovdiv*.

The primary source for the demographic data comes from the *tahrir* tax revenue registers, which span the years 1472 to 1614. These registers include nine *mufassal* (detailed) and one *icmal* (summary) register. The *tahrir* registers were used in the Ottoman Empire to record expected tax revenues and provide only approximate population figures, rather than exact demographic statistics, due to two main limitations.

First, the registers use a metric called *hane*, which refers to a household typically consisting of a married couple and their underage children. The exact size of each household is not recorded and must be estimated using an average household size. In this dataset, the total population is calculated by multiplying the number of *hane* by a factor of five—representing two adults and three children. While this coefficient is a reasonable estimate, other scholars have proposed different multipliers. For example, in a landmark study, Heath Lowry suggested a coefficient of 4.6 [2], though his research primarily focused on 15th-century Macedonia.

Second, the *tahrir* registers tend to undercount the total population because they include only tax-paying households, excluding groups such as military personnel. As a result, the demographic data should be understood as an approximation of the minimum total population, derived by multiplying the recorded households by the coefficient. Estimates of military personnel are not included in the data, as no reliable method was found to consistently estimate their numbers across the entire time period.

The primary spatial units used in the *tahrir* registers were the districts, or *mahalle*. These districts were approximated using multiple polygons. The polygon construction process occurred in several stages. Initially, polygon boundaries were extracted and drawn using historical maps of Plovdiv created by Ilinskij (1878) and Schnitter (1891). ArcGIS software was employed to define key features and infer polygon boundaries rather than drawing them directly. While these maps do not explicitly contain polygons, both include street layouts that allow the approximate shapes of residential and commercial areas to be reconstructed.

The accuracy of the derived polygons depends not only on the method of extraction but also on the accuracy of the historical maps themselves. Upon closer inspection, notable differences can be seen between the two maps. Although drawn only 13 years apart, the Schnitter map includes a significantly greater number of streets than the Ilinskij map. One possible explanation is that Ilinskij may have only drawn the main streets, while Schnitter included smaller ones as well.

Although the methods used in [1] for approximating both the district boundaries and the demographic data are inherently estimates, I believe they represent the most reliable approach currently available for reconstructing these aspects of Ottoman Plovdiv.

It should also be noted that the physical boundaries of the districts likely evolved over time. However, such changes are not reflected in the data, which is based solely on the 19th-century maps by Schnitter and Ilinskij. Importantly, the names of the districts remained consistent throughout the period. The stability of these names is supported by the work of Vidin Sukarev [3], who studied the evolution of Plovdiv's quarters. While it was common in the Ottoman Empire for district names to change frequently—often named after local religious figures—this issue does not affect our dataset, as the district names remained stable [3].

Processing of the Data

The data preprocessing workflow involved transforming a series of historical population density GeoJSON files into structured geospatial datasets suitable for Tableau. The dataset comprises multiple JSON files (e.g., 1472PopDensity.json, 1489PopDensity.json, etc.), each representing demographic and spatial information for Ottoman districts across different years.

1. Data Extraction and Structuring

Each GeoJSON file was parsed to extract key attributes from the features dictionary, including OBJECTID, district Name, area (Area_ha), population attributes (Mus_hane, Chr_hane, Total_pop), and geometric information (rings). This data was written into a consolidated CSV file (Districts.csv) with a consistent schema. The year of each record was derived from the filename.

2. Conversion to Geospatial Format

The geometric data, originally represented as ring coordinates in ArcGIS format, was converted into shapely.Polygon objects, which are compatible with a wide range of geospatial software. The CSV was then read into a pandas DataFrame, which was transformed into a GeoDataFrame using GeoPandas, with polygons as geometry. The Coordinate Reference System (CRS) was first set to EPSG:32635 (UTM Zone 35N) for accurate area-based calculations and later converted to EPSG:4326 for interoperability with web mapping tools.

3. Aggregation and Derived Metrics

Population and household data were aggregated at the district level by grouping records based on district Name and Year. This enabled the computation of:

- Total Muslim and Christian households per district
- District-level total population and area
- District population density

Boolean columns were added to classify whether Muslims were the majority within each polygon and district.

To assess demographic change over time, the percentage change from previous year in Muslim and Christian households was calculated at the polygon level using the .pct_change() method, grouped by PolygonID. Initially, we considered calculating the percentage change relative to a baseline year—specifically, 1472. However, this approach was ultimately abandoned for two main reasons: first, some districts did not exist in 1472; and second, in certain districts, either the Muslim or Christian population was absent in that year but appeared in later periods. This would have resulted in numerous null values across many districts, thereby producing visualizations with significant gaps, which could lead to user confusion.

5. Export and Output

The processed datasets were exported as GeoJSON files for further analysis and visualization:

- districts.geojson: contains enriched demographic and spatial data for each polygon across all years.

- pct_change.geojson: contains polygon-level percentage changes in Muslim and Christian households, filtered to essential attributes.

All missing or infinite values were handled appropriately to ensure data integrity.

The districts.geojson is available at link:

https://drive.google.com/file/d/1zHVRbg6iy7YrTH8oqx26i2ZQmvNzyYZI/view?usp=drive_link

The pct_change.geojson is available at link:

https://drive.google.com/file/d/1gGekYKjoKAwjsMgcPM4nr6TiPeykI8vo/view?usp=drive_link

Visualization Principles

One may ask why it is important to visualize data in the first place. Data visualization plays a critical role in helping users understand, interpret, and interact with complex data. It makes patterns, relationships, and trends more understandable and interpretable by user. The main advantages of data visualization in the context of urban development in Plovdiv are outlined below:

1. Enhances Understanding:
Visual maps enhance the understanding of the evolution of urban areas such as Plovdiv. By presenting geographic data visually, users can more easily grasp how the city has grown, changed, and developed over time. These visualizations allow for intuitive understanding of shifting population densities, which are often too complex to fully comprehend through text.

2. Connects History and Geography:
Visualization serves as a bridge between historical narratives and geographical contexts. By mapping historical events onto spatial representations, viewers are able to view when and where key urban developments occurred.

3. Highlights Patterns and Trends:
Patterns such as population growth, religious segregation across districts, and shifting urban dynamics become more apparent when visualized. These trends, which might remain hidden in textual or numerical data, are easier to grasp through visual representation. For example, changes in population density over time can be clearly illustrated using an interactive, time-based map.

4. Engages the Audience:
Interactive visual content is more engaging than raw data or dense blocks of text. Users can interact with the map to discover patterns and explore details on demand.

Data visualization is defined by Tamara Munzner as "computer-based visualization systems that provide visual representations of datasets intended to help people carry out some task more effectively" [4]. According to Munzner, effective visualization should not only present data, but also encourage users to discover patterns and insights that might not have been visible previously. Visualization aims to reveal new, previously unseen relationships.

In our project, when creating visualization we followed Ben Shneiderman's information-seeking mantra: "Overview first, zoom and filter, then details-on-demand" [4]. This design philosophy promotes a layered approach. Initially, users should be presented with a high-level overview, giving them a general sense of the dataset. Subsequently, through interactivity, they should be able to zoom in on areas of interest, apply filters to refine the view, and access detailed data points as needed.

We also incorporated Edward Tufte's principles of data visualization. Tufte outlines several steps when creating vizualizations [4]:

- Above all else, show the data
- Maximize the data-ink ratio
- Erase non-data ink
- Eliminate redundant data ink
- Revise and edit relentlessly

Following these principles, we designed our visualizations to be as clear and as possible. Unnecessary graphical elements—such as decorative backgrounds or any chart junk were removed. Our aim was to present the data without distractions or noise.

To further align with Tufte's approach, we selected the most effective visual encodings for our data. In data visualization theory, marks refer to basic graphical elements (such as points, lines, and areas), and channels refer to the visual properties used to represent data (such as position, color, size, and shape). Among these, position on a common scale is considered the most accurate channel for encoding quantitative data. Accordingly, our visualizations primarily used bar charts, line charts, and maps.

We chose to include maps because we were working with spatial data, such as polygons representing each district. Maps provide spatial context and help users better understand where changes and events took place.

When creating the maps, one version includes a background of Plovdiv with street names to help users identify the locations of districts within the city. In contrast, the other maps use a simplified white background to reduce visual noise.

All the maps display the same data; the first one primarily helps users orient themselves, while the others focus on presenting the data as clearly as possible.

Furthermore we removed unnecessary gridlines. We also enhanced the readability of our charts by adding data labels—placing numerical values directly above bars in bar charts and above points in line charts. These additions help users interpret the data quickly.

Created visualizations

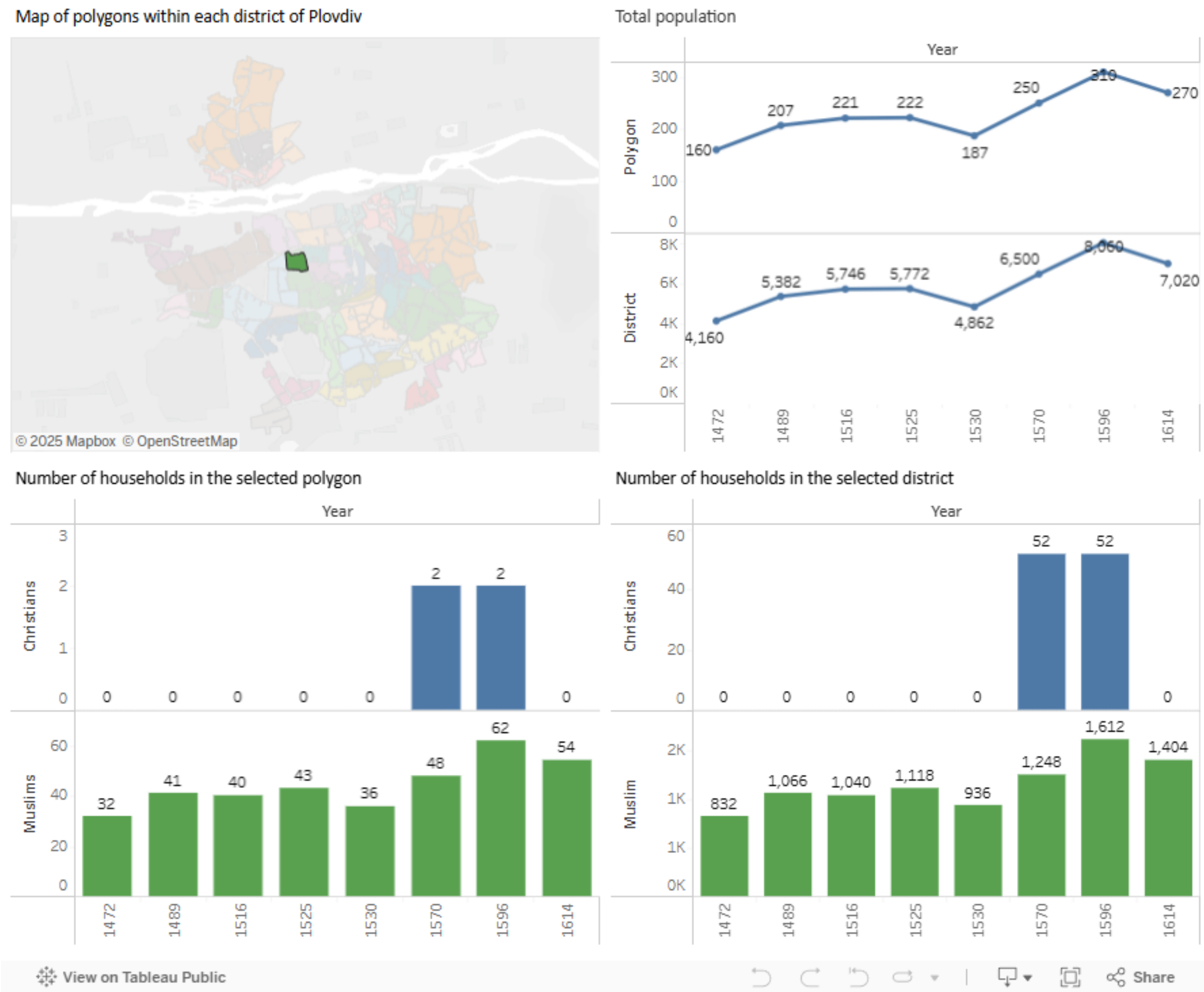
For creating the visualizations, we used Tableau software. We chose Tableau because it allowed us to build interactive visualizations that can be accessed via a direct link, eliminating the need to create a separate website.

We developed two dashboards to tell different data stories. A dashboard is a visual interface that presents data in multiple views in a clear, organized, and interactive format.

It should be noted that Tableau may change the way views are displayed depending on the screen or monitor. For example, a dashboard might appear in a single column with four rows, each containing one view. To address this, we provide a screenshot of each dashboard showing the intended layout.

1. dashboard:

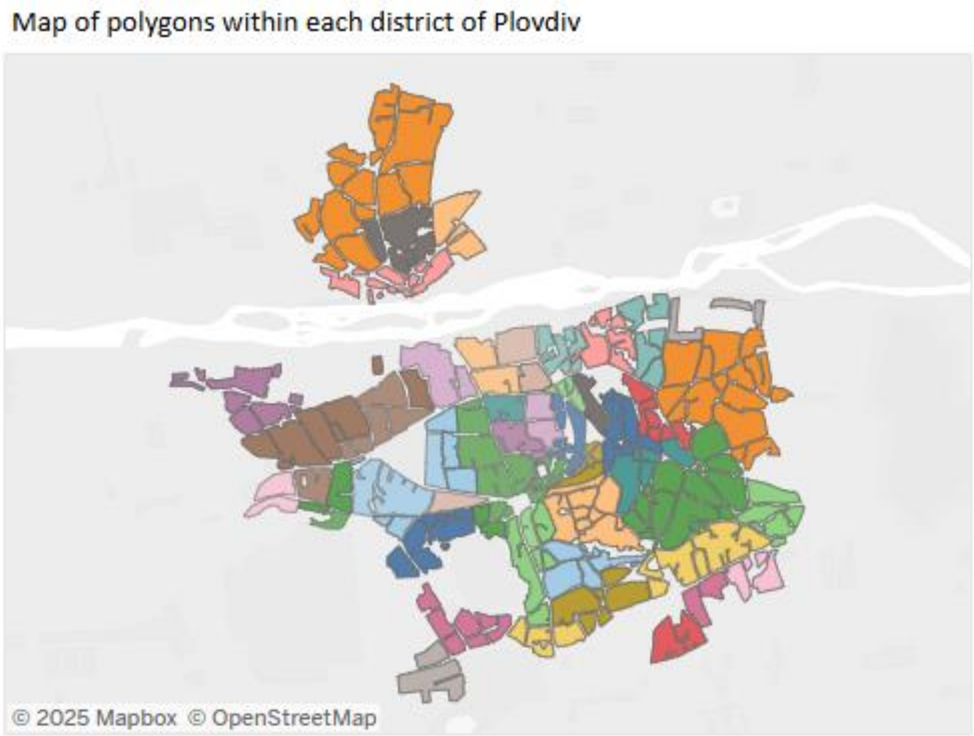
https://public.tableau.com/views/Plovdiv_polygons/Polygons?:language=en-US&:sid=&:redirect=auth&:display_count=n&:origin=viz_share_link



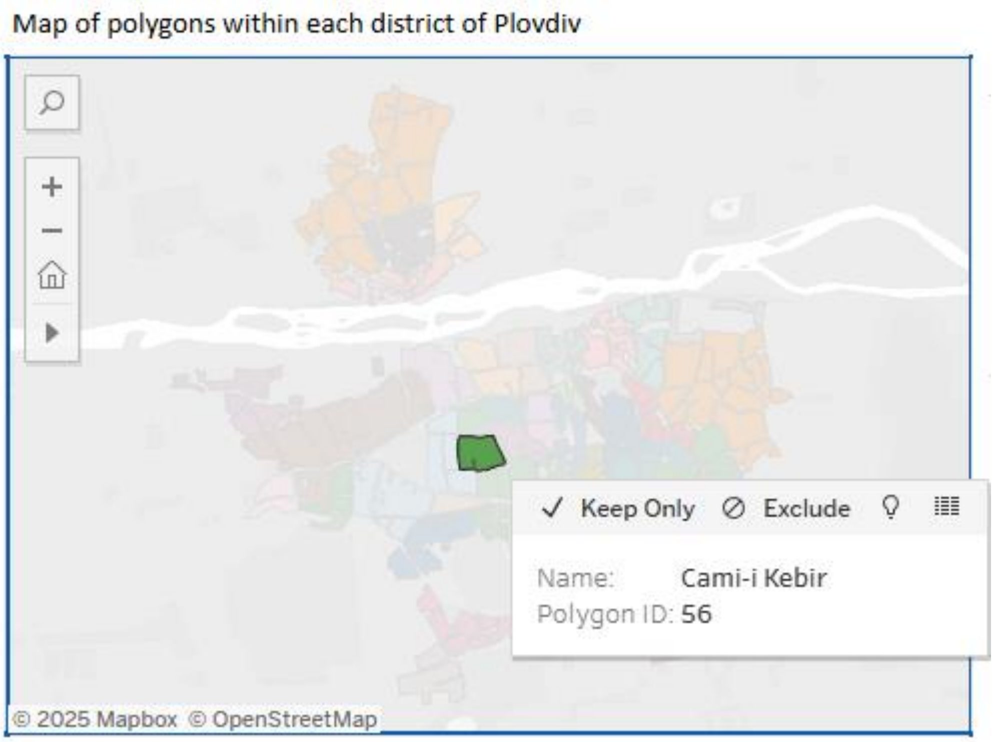
The main goal of this dashboard is to provide a demographic overview of each individual district, with a focus on religious composition and total population. It consists of four views.

The first view is a map designed to show each district as a separate polygon. Each district is represented by a unique color. Due to the large number of districts, some may share similar colors; however, these similarly colored districts are typically far apart, minimizing the risk of user confusion. Reducing the number of categories was not an option, as it would compromise historical accuracy.

The map is interactive. The following image shows the map with none of the polygons selected.

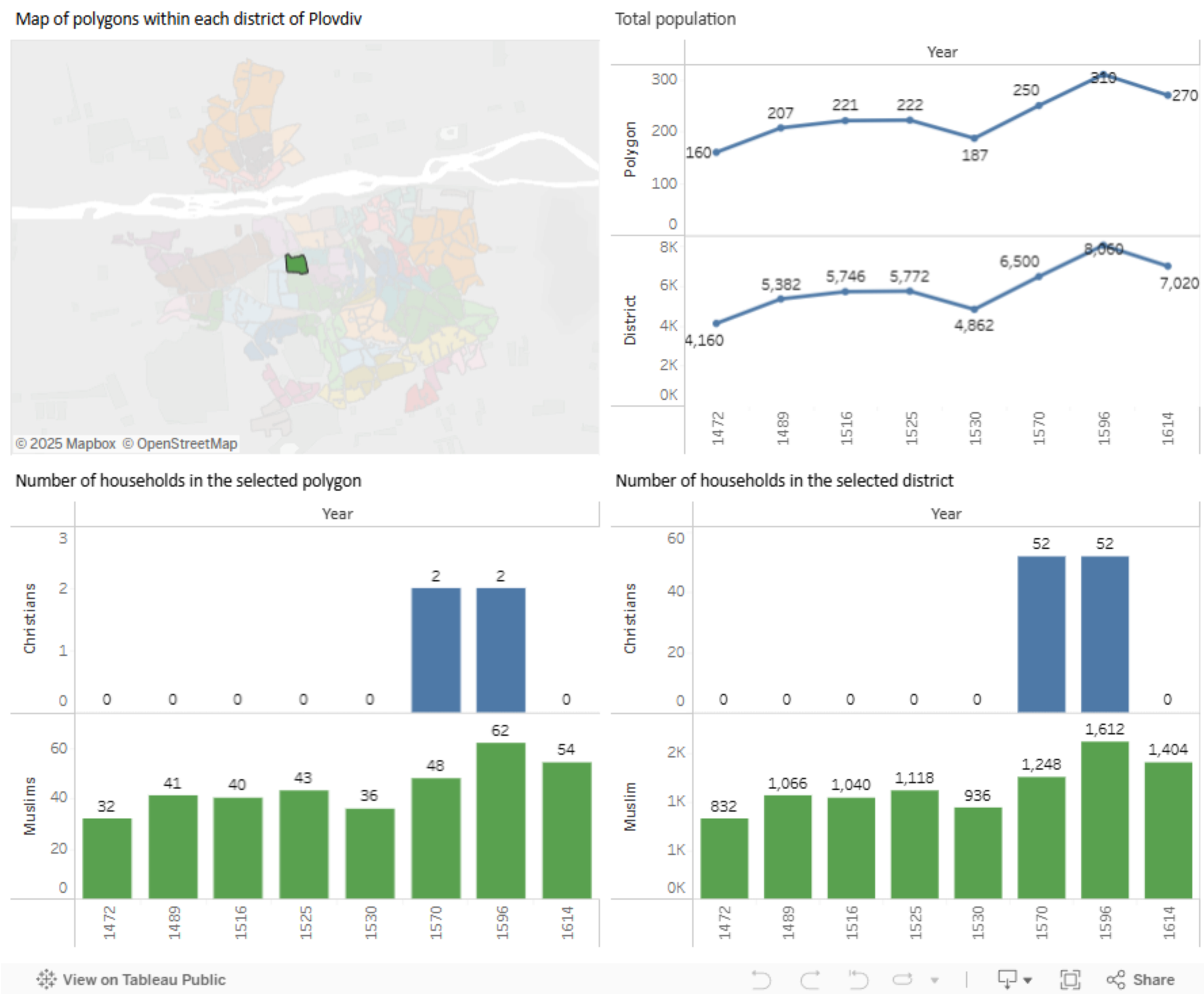


The subsequent image demonstrates how the map changes upon selecting a specific polygon.



When a specific polygon is selected, the user can see the polygon ID and the district in which it is located. Subsequently, the other views on the dashboard update accordingly.

The second and third views are bar charts located below the map.



The first bar chart, located in the lower left corner, displays the number of Christian and Muslim households in the selected polygon for the chosen year. The second bar chart shows the number of Muslim and Christian households in the district where the selected polygon is located.

In this visualization, we used green to represent Muslims, as Islam is commonly associated with that color. Blue was chosen to represent Christians.

We treated the year as a discrete variable rather than a continuous one, because the data was collected in specific, distinct years. Displaying the year as a continuous variable would result in bar charts appearing in some years, while null values would appear in others. This could confuse users and lead them to believe that the polygon or district was populated only during certain years.

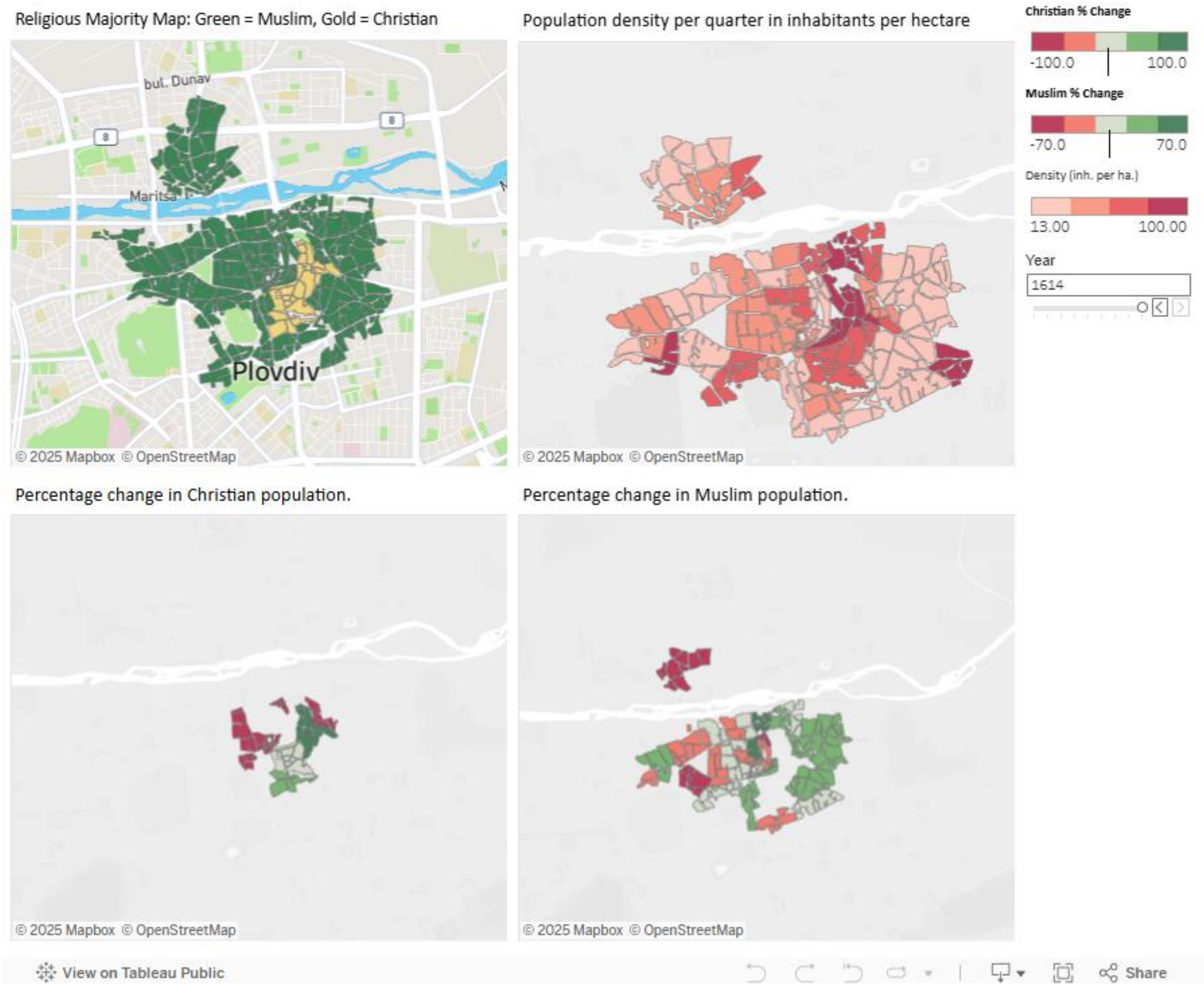
In our example, we can see that no Christian households were recorded until the year 1530. By 1570, two Christian households were recorded in the selected polygon. Throughout the years, this polygon remained a Muslim-majority area.

The final view, located in the upper right corner, shows the total population recorded in each year within both the district and the polygon. Total population is estimated by multiplying the number of households by a coefficient of five. We added dots to the line chart to indicate exactly which years data was recorded, making it easier for users to interpret the timeline.

Overall, the interactive map offers an overview of individual districts in Plovdiv and allows users to explore them in greater detail by interacting directly with the map.

2. dashboard:

https://public.tableau.com/views/Plovdiv_maps/Maps?:language=en-US&:sid=&:redirect=auth&:display_count=n&:origin=viz_share_link



The second dashboard provides an overview of demographic changes over time, presented through four interactive maps. Users can change the year using the slider on the right side of the dashboard.

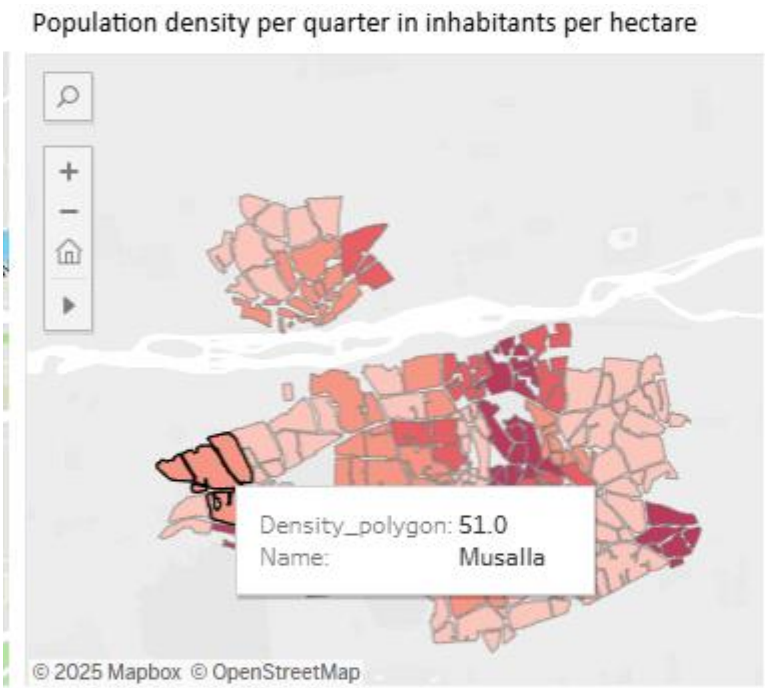
The first map, located in the upper left corner, serves as an overview. It displays the districts on a map with street names, helping users understand where each polygon is located in present-day Plovdiv. The remaining three maps are shown on a plain background to reduce visual noise and avoid unnecessary distractions. This first map also displays the religious composition of the city, though it remains static, as the layout of Plovdiv's districts did not change over time. The map is interactive, but the district shapes stay the same throughout the years.

The second and third views—located in the lower section of the dashboard—show the yearly percentages of Muslim and Christian populations. Initially, we considered showing percentage changes relative to a baseline year (1472). However, this approach proved problematic: some districts had no population in 1472, and others only had a single religious group at that time. As a result, calculating percentage change often involved dividing by zero, which created infinite values. These infinite values were converted to nulls, resulting in maps with many missing data points. To avoid this, we opted to calculate only the percentage change to previous year. If a polygon had no prior population to compare to (i.e., a zero denominator), we marked the change as null. While representing population growth as a null value is not ideal, we could not find a better alternative.

We also considered displaying the absolute change in the number of households instead of percentage change. However, this posed another challenge: different districts vary greatly in size. An increase of 7 households has a very different impact in a district with 5 households than in one with 75. Thus, absolute values would not accurately represent the scale of change across districts.

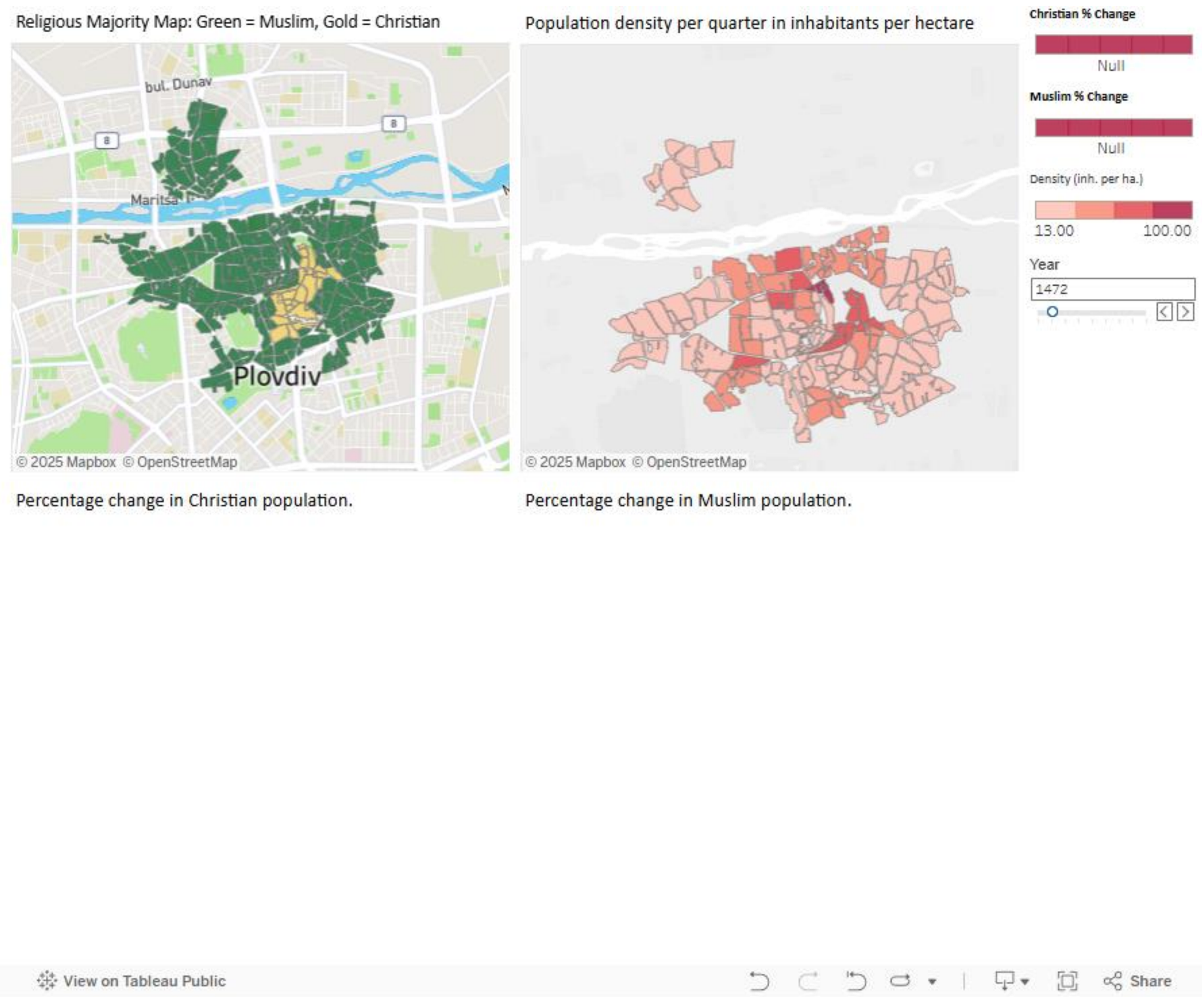
To further reduce noise, we chose not to display districts with null values—these are districts where no measurable change occurred in the selected year.

The final view shows the population density of individual districts in Plovdiv. Users can hover over a district to see its specific density value for the selected year.



As in the previous example, we only show districts with non-null values. For instance, in the following image, we can see that some districts are missing in the year 1472, even though they appear in the previous image. This is because they have null values for that year.

We can also observe that in the second and third views for the year 1472, no districts are shown, as all percentage changes are null.



Using the visualization in historical context

The main purpose of this visualization was to enhance the historical understanding of certain events. For this purpose we will use the created visualizations for exploring and explaining historical events.

1. **Forced relocation (sürgün) of Muslims to the west in the 1520s**

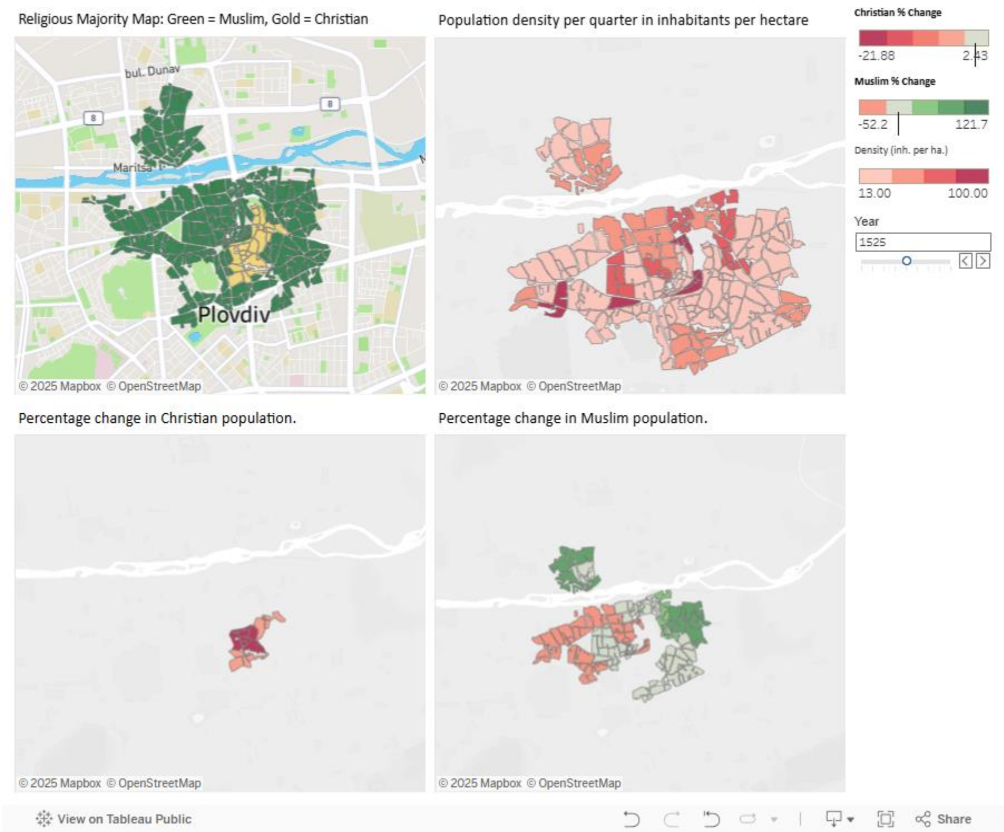
In the late 1520s, when the city experienced a sudden and dramatic drop in its Muslim population. This decline was not the result of natural causes such as disease or famine, but rather the consequence of a deliberate state policy known as *sürgün*, or forced population relocation.

The *sürgün* was implemented during the reign of Sultan Süleyman I and was part of a broader strategy to consolidate Ottoman rule in newly conquered western territories, particularly in the Balkans and Central Europe [1, page 196]. As the Ottoman Empire expanded into areas such as Belgrade, Buda, and Bosnia, the central government required experienced Muslim populations to populate and stabilize these frontier cities.

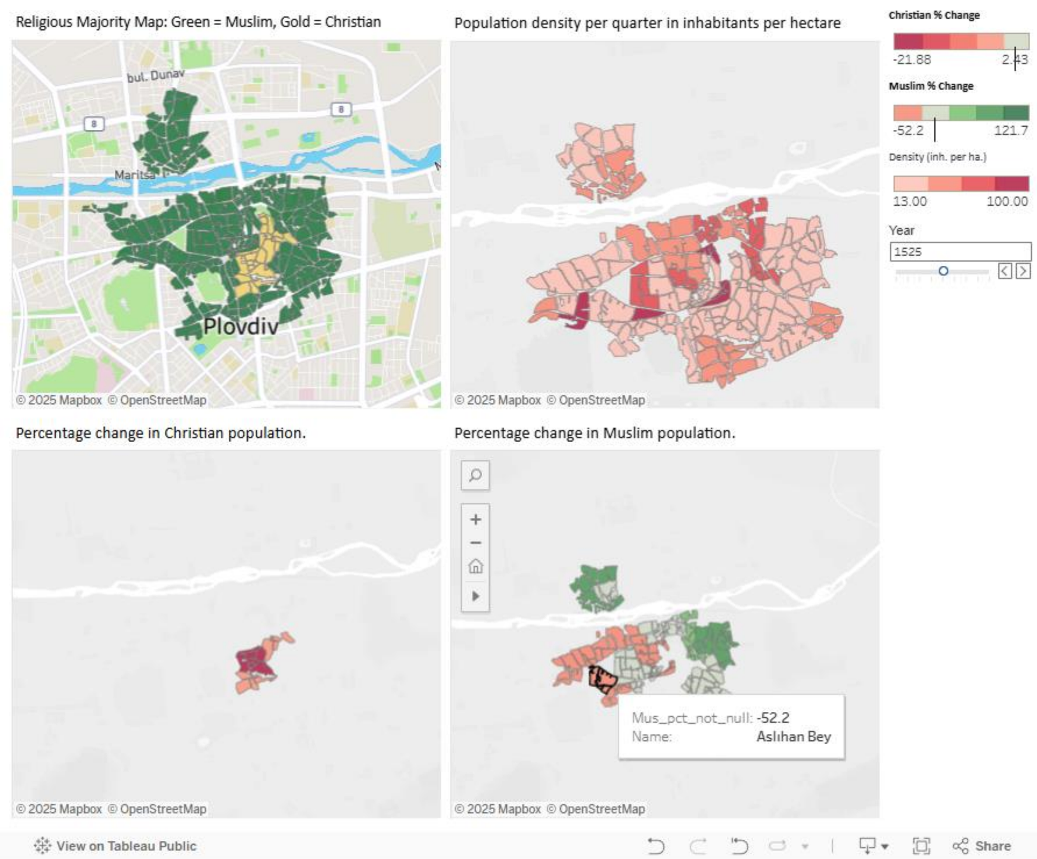
The impact of the *sürgün* on Plovdiv's urban fabric was immediate and severe. The tahrir register of 1525 documents a Muslim community supported by thirty-three imams serving the city's neighborhoods [1, page 194]. However, just five years later, the 1530 register records only three imams still active in the city—a stark indicator of the scale of depopulation. Moreover, several central and western Muslim quarters—including Musalla, Aslıhan Bey, and Hacı Ömer—experienced sharp declines in household numbers.

This exodus had spatial as well as demographic consequences. One notable example is the suburb of Tataran, which temporarily saw a rise in population in 1525, likely serving as a staging ground for Muslim households awaiting relocation. By 1530, however, Tataran had been almost completely depopulated, reinforcing the interpretation that it had played a transitional role in the *sürgün* process.

All of these events can be explored through the two dashboards that were created. The image below shows the second dashboard for the year 1525.

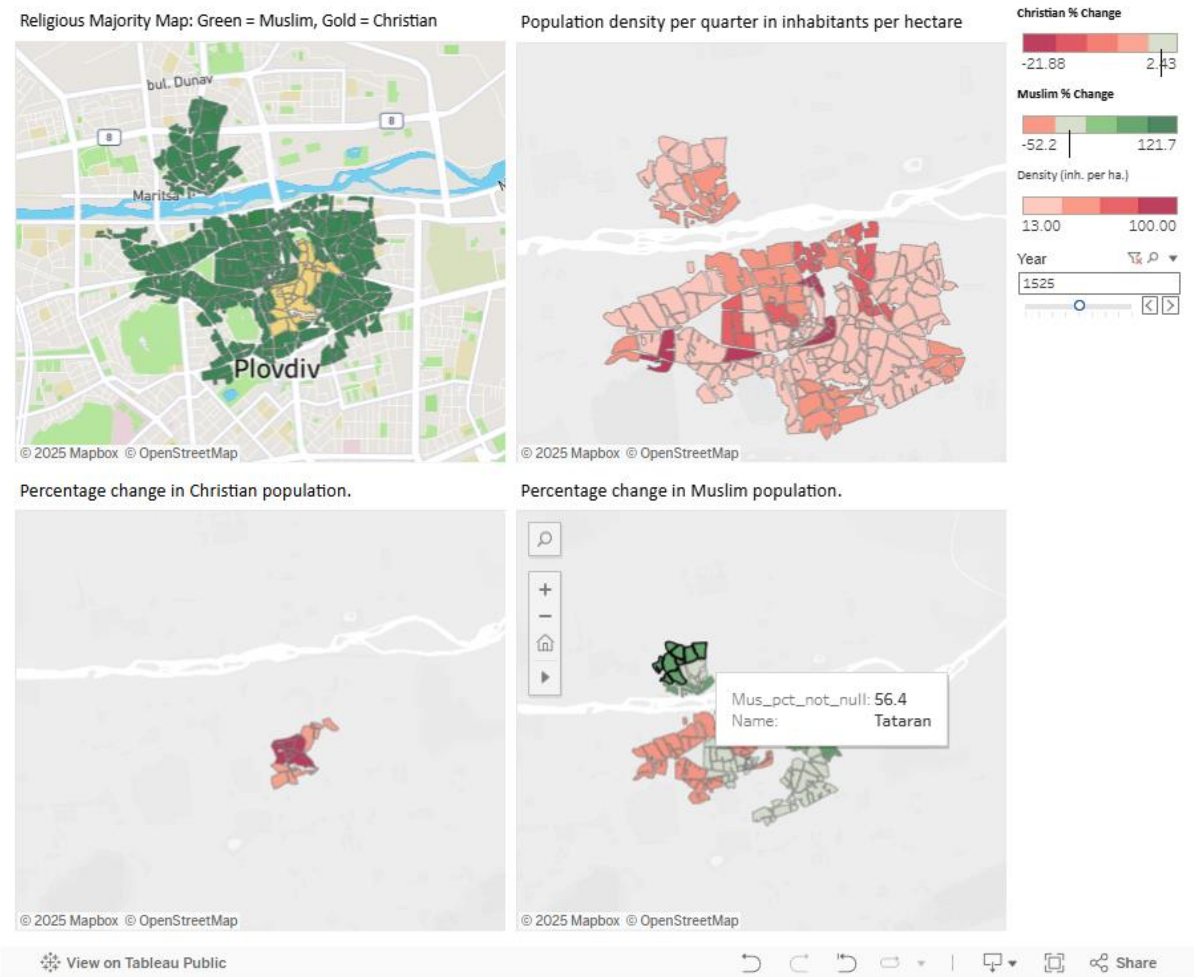


We can observe a sharp decline in the Muslim population in the western districts. By hovering the mouse over these areas, we can identify which districts were affected.

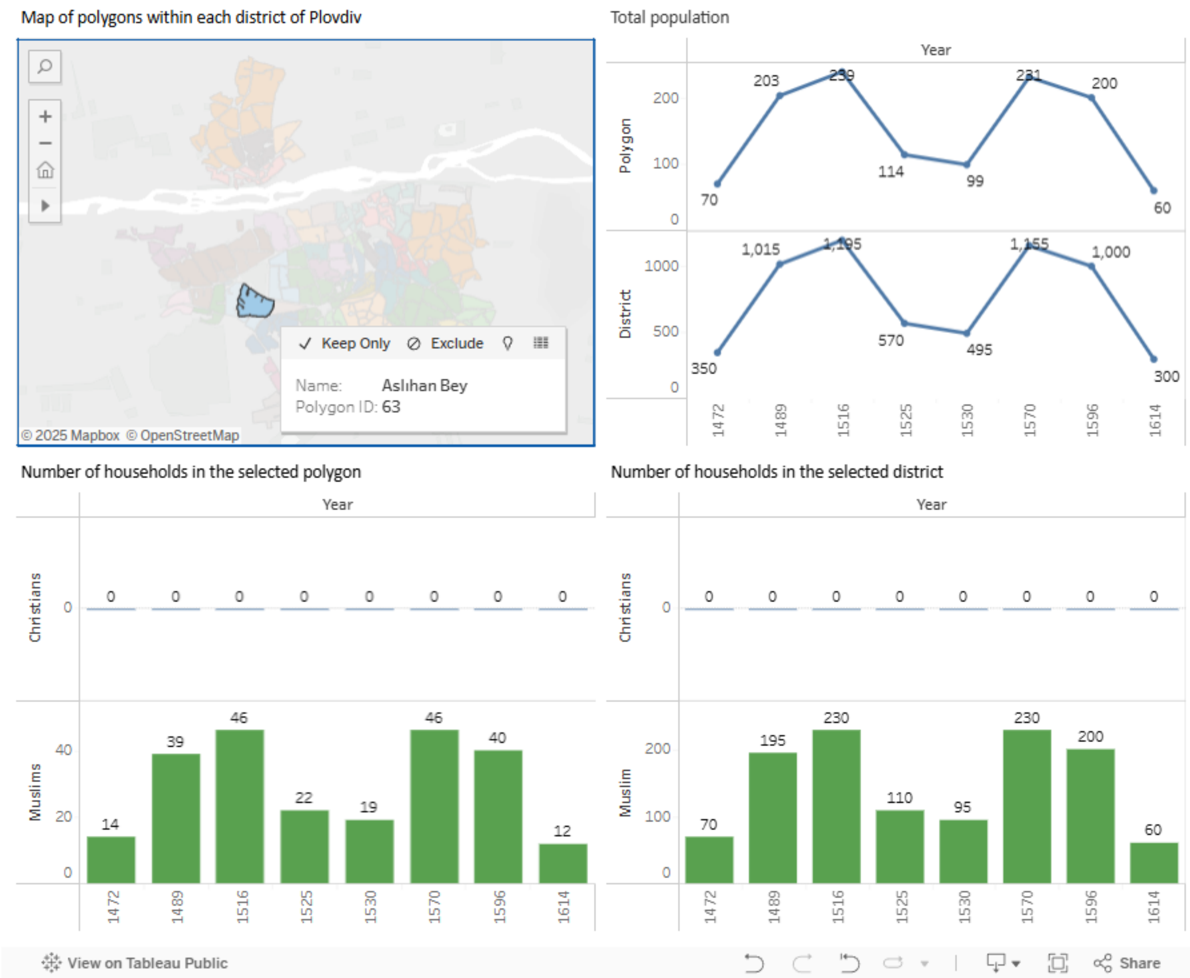


In our example, we can see that the district named Aslıhan Bey experienced a decrease of 52.2 percent.

We can also observe a sharp increase in the district called Tataran, with a rise of 56.4 percent.



Additionally, we can explore the individual districts on the first dashboard. In the subsequent view, we can observe the demographic change in the district called Aslıhan Bey.

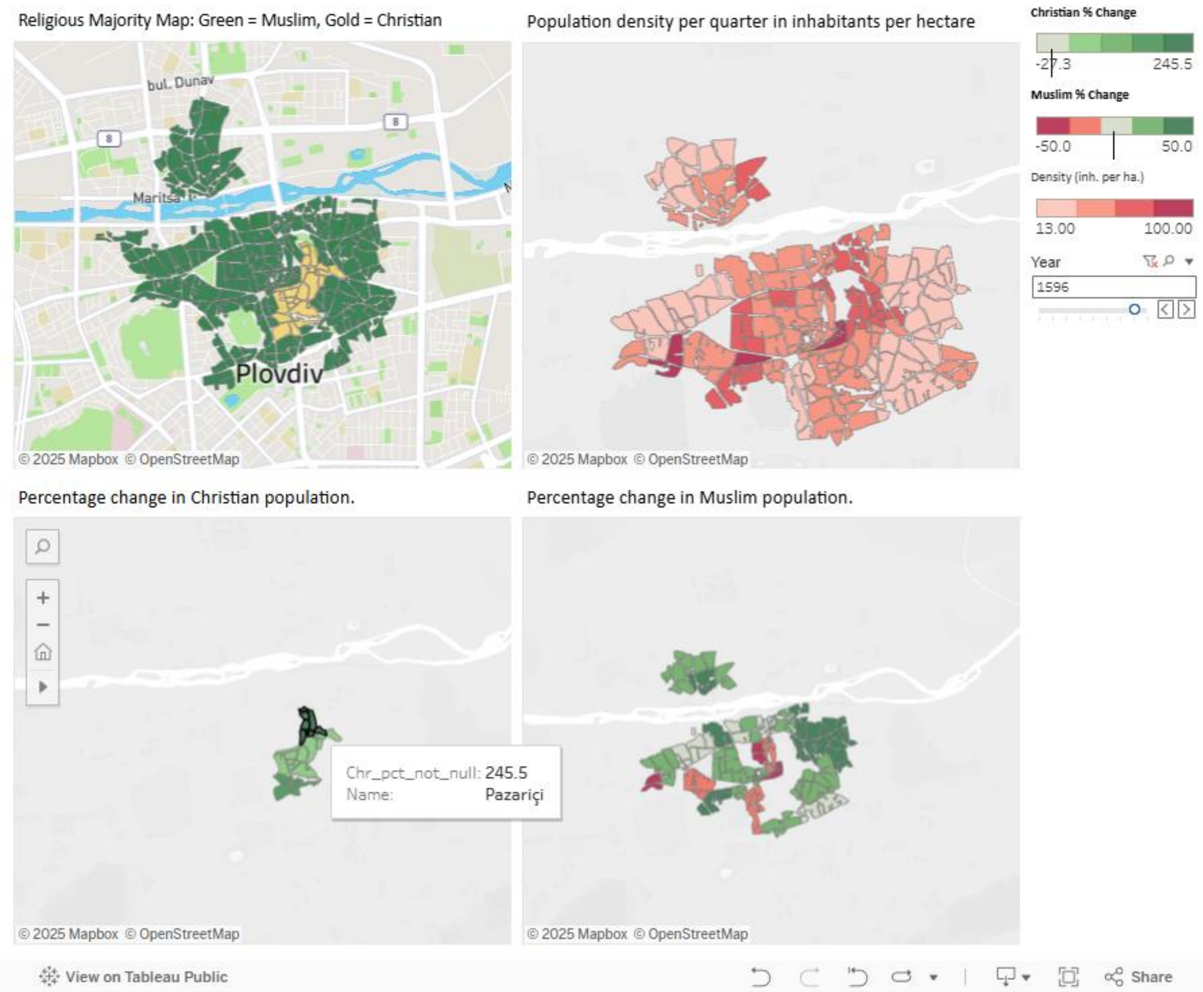


We can see that the polygon with ID 63 experienced a decrease in Muslim households, from 46 in 1516 to just 19 in 1530. The total population in this polygon also declined significantly, dropping from 299 to just 99 over the same period. A similar demographic change occurred across the entire district, where the number of Muslim households fell from 230 to just 95, and the total population decreased from 1,195 to only 495.

2. The Rise of the Christian Population in Late 16th and Early 17th Century

While much of the early Ottoman period in Plovdiv was characterized by the establishment and expansion of a dominant Muslim urban core, the demographic trajectory of the city shifted notably in the second half of the 16th century. During this period, Christian communities, especially Bulgarian Orthodox Christians, began to grow, marking a significant transformation in the city's social and religious landscape.

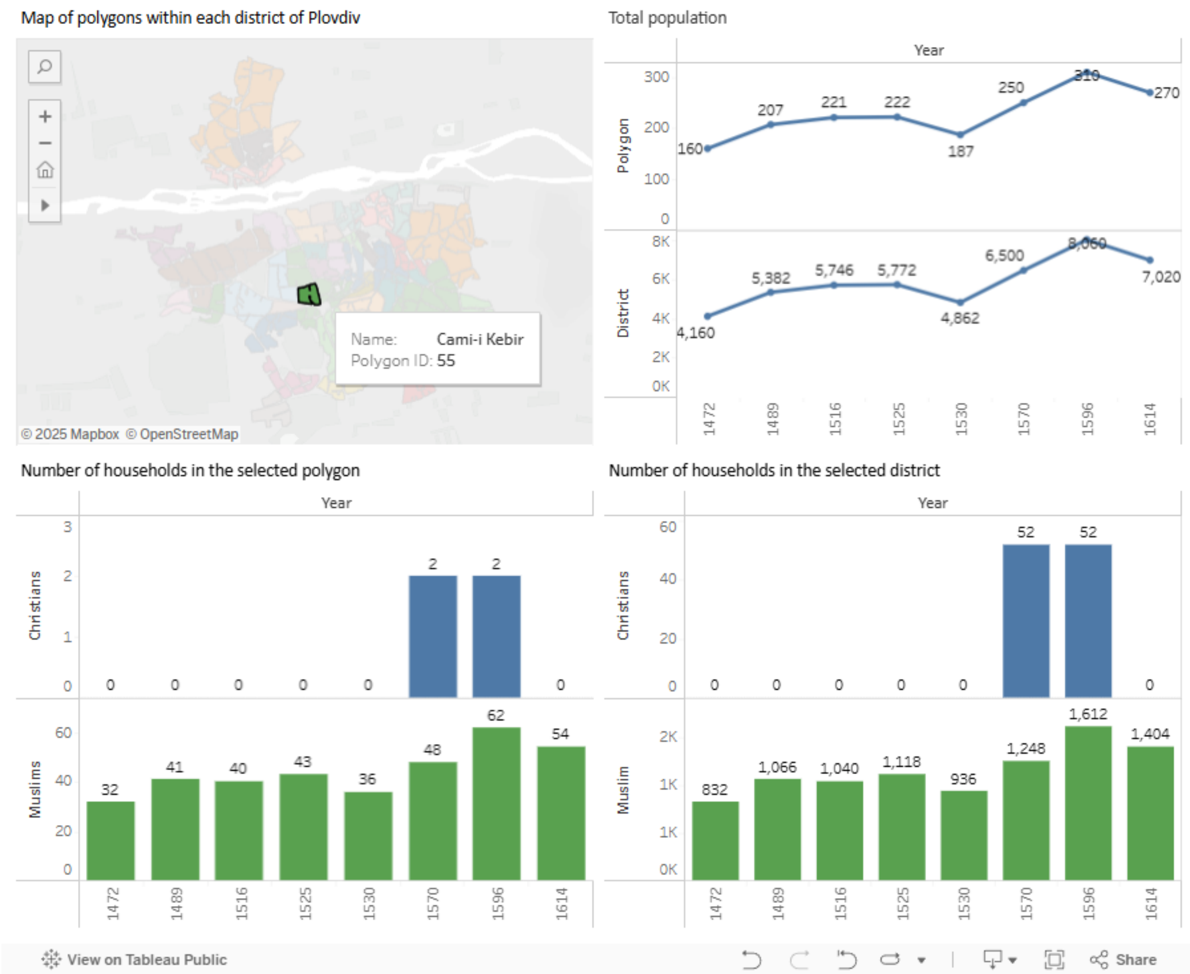
The tahrir registers and spatial analyses presented in the study provide clear evidence of this demographic trend. Between 1570 and 1596, the Christian population in Plovdiv nearly doubled, rising from 798 to 1,521 taxable households [1]. In contrast, the Muslim population during the same period showed only modest growth—from 1,519 to 1,650 households. Those changes can be viewed on the second dashboard [1].



We can see that all Christian districts are marked in green. The district of Pazarici shows an increase of 245.5 percent. It should also be noted that the scales in the upper right corner reveal an interesting trend. On the Christian percentage change scale, only green areas are visible, indicating that all polygons experienced growth up to the maximum value of 245.5 percent.

In contrast, the Muslim percentage change scale extends in both directions, with a maximum value of 50 percent on either side—significantly lower than the maximum on the Christian scale.

In some cases, Christians began to settle in previously Muslim-dominated areas, such as the Cami-i-Kebir district, which started showing signs of a Christian presence by the end of the century. In the subsequent image, we can see the Cami-i-Kebir district.



The polygon with ID 55 had only Muslim households until the year 1570, when two Christian households were recorded. We can also see that in Cami-i-Kebir, only Muslim households were recorded initially, but in 1570, 52 Christian families moved in.

The area experienced a notable rise in its Christian population, driven in part by broader climatic and economic pressures. A period of harsh winters and food shortages pushed many Christian peasants from the surrounding mountains into the city. As a result, Christian quarters expanded significantly in both size and population.

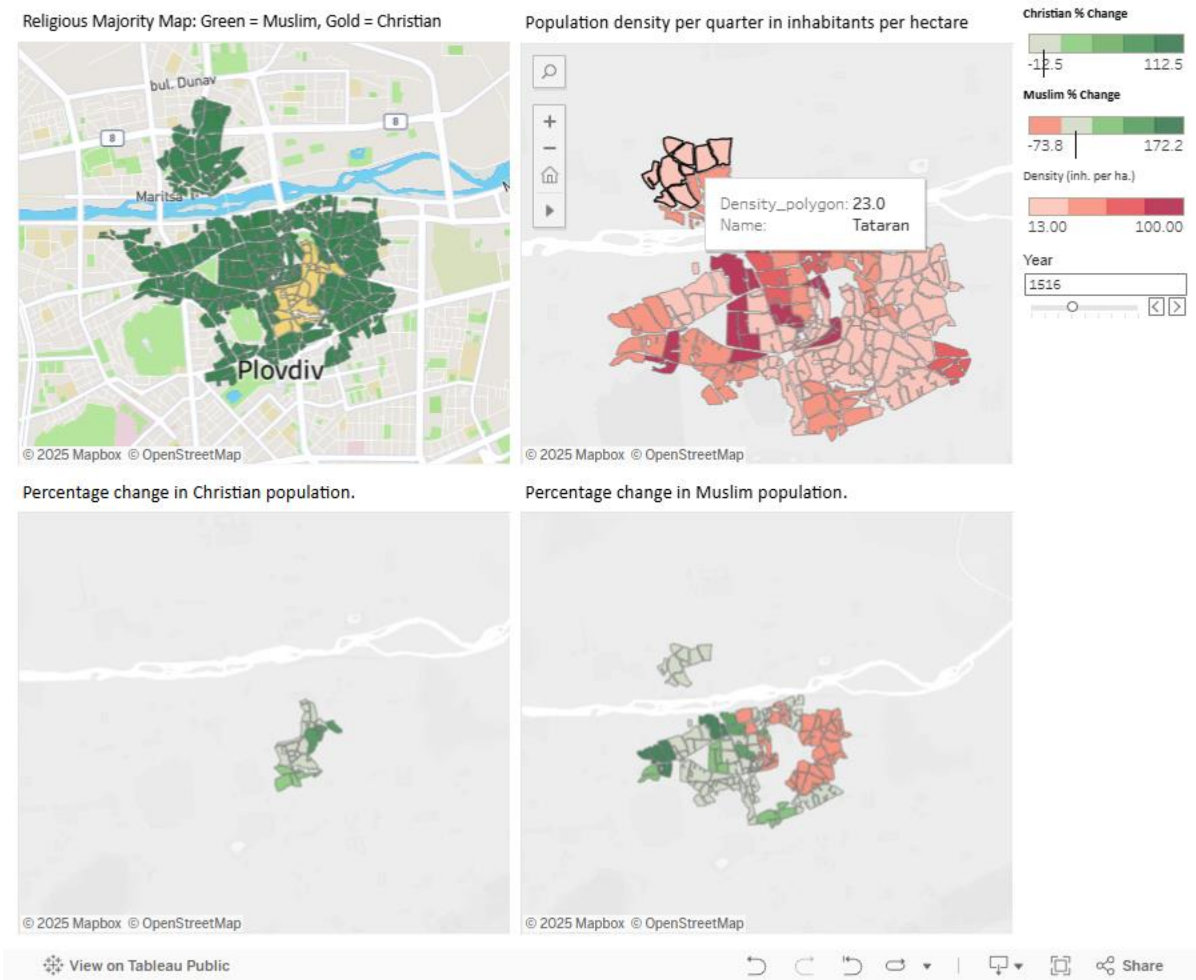
By the early 17th century, Plovdiv was evolving from a predominantly Muslim town into a more religiously mixed and socially diverse city—a transformation rooted in gradual migration and the enduring presence of its Christian communities.

3. Tataran

Between 1525 and 1530, the northern suburb of Tataran in Plovdiv experienced a short-lived population increase, followed by a rapid decline. This brief demographic fluctuation, clearly visible in the tahrir records, suggests that Tataran served as a temporary staging area for households being prepared for forced relocation (sürgün) to newly conquered Ottoman territories in the west.

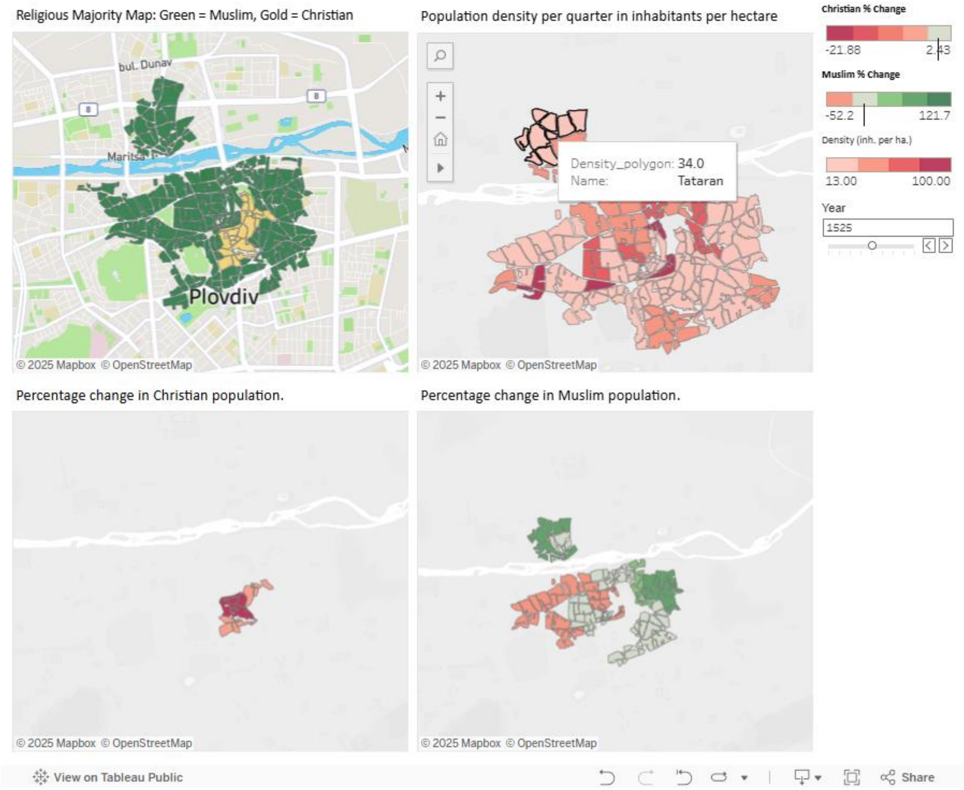
Tataran's sudden demographic spike in 1525 was followed by near abandonment by 1530. Its peripheral location made it an ideal logistical hub where selected households could be housed temporarily before their transfer.

We explore this transition using the second dashboard through the years. We can start in the year 1516.



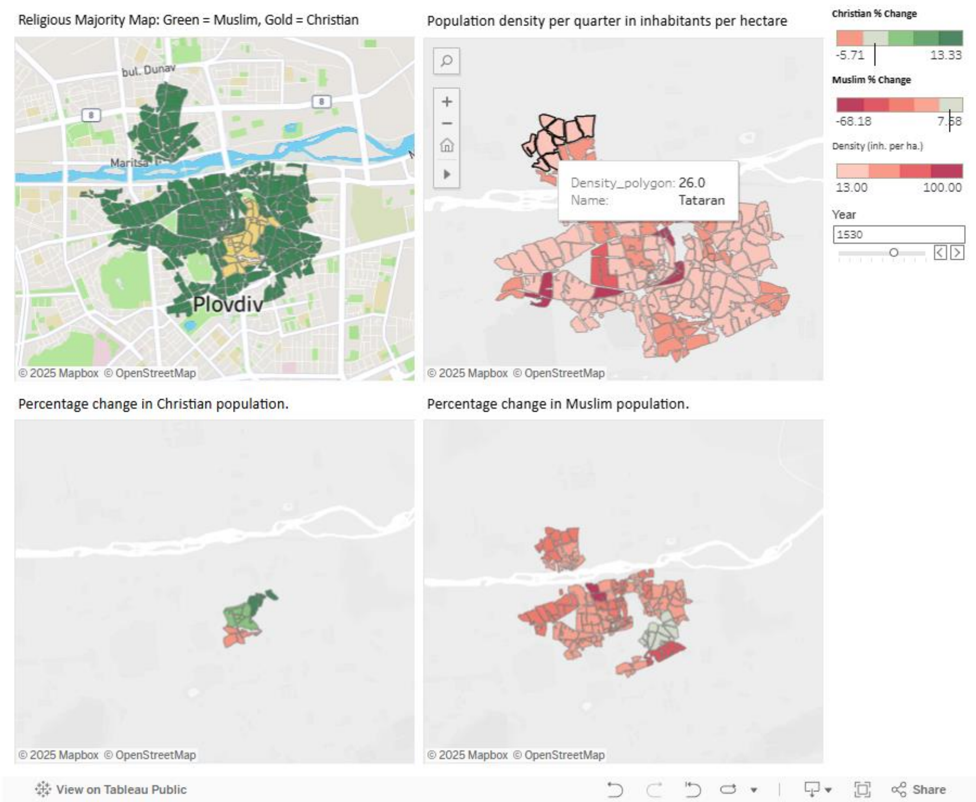
We can see that the density is just 23, and on the map in the lower right corner, we can observe that there was no significant change in the Muslim percentage.

We can progress to the year 1525.



The density increased to 34. We can also see a significant percentage increase of Muslims in this district, rising by 56.4 percent.

Now, we can progress to the year 1530.



We can see that the density decreased to just 26. We can also observe a decrease of 22.95 percent in the Muslim population percentage.

Using the second dashboard, we can see how the population evolved during the sürgün, with a significant rise in population in 1525 followed by a subsequent decrease in 1530, depicting the forced relocation.

Paper summary

In this paper, we introduce a new way of visualizing data. We provide a detailed outline of the data used and the process applied to transform it. Next, we present two new dashboards created in Tableau. The first dashboard allows exploration of demographic statistics for each polygon. The second dashboard features maps depicting the density and percentage change in the Muslim and Christian populations. We then use these visualizations to provide explanations of historical events. Specifically, we discuss the forced relocation (sürgün) of Muslims to the west in the 1520s, the rise of the Christian population in the late 16th and early 17th centuries, and the Tatar population. This paper also serves as an example of how historical data can be visualized interactively to enhance historical explanations.

Sources

[1] Boykov, Grigor. *Ottoman Plovdiv: Space, Architecture, and Population (14th–17th Century)*. Vienna: Austrian Academy of Sciences Press, 2024.

[2] Lowry, Heath W. “Changes in Fifteenth-Century Ottoman Peasant Taxation: The Case Study of Radilofo.” In *Continuity and Change in Late Byzantine and Early Ottoman Society: Papers Given at a Symposium at Dumbarton Oaks in May 1982*, edited by Anthony Bryer and Heath W. Lowry, 23–37. Washington, D.C.: Dumbarton Oaks Research Library and Collection, 1986.

[3] Sukarev, Vidin. “Plovdivskite mahali prez vtorata polovina na XIX vek.” *Plovdivski istoričeski forum* 4, no. 1 (2020): 49–78.

[4] Visual and Exploratory Data Analysis Course (2025S), University of Vienna