

Investigation of Climate Relations of Metropolitan Cities in Türkiye

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Abstract

This study aims to analyze and classify the climatic relationships among metropolitan cities in Türkiye based on temperature and precipitation data. The study aims to contribute to a better understanding of the current climatic characteristics of metropolitan cities in Türkiye by revealing their climatic similarities and differences. In this context, the climate profile of each metropolitan city was prepared using the monthly average temperature and precipitation data obtained from the General Directorate of Meteorology between 1927 and 2023. The correlation function was used to identify climatic relationships. Climatic similarities and differences among metropolitan areas were analyzed using hierarchical classification methods. Hierarchical tree (dendrogram) and minimum spanning tree techniques were used to group metropolitan areas according to similar climatic data. In addition to providing a better understanding of climatic relationships, this analysis aims to provide scientific data suitable for use in areas such as agriculture, environmental regulation, water resource management, and urban planning by facilitating visualization analysis. By identifying climatic differences among metropolitan cities in Türkiye, the study will enable the development of more accurate strategies in the face of climate change and environmental risks. In addition, the data obtained will help to predict the effects of future climate changes in cities by modeling their impacts.

Keywords: *Climate, Türkiye metropolitan cities, data analysis, hierarchical classification*

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1. Introduction

Climate is a factor that directly affects human life. It is of great importance in areas such as the selection of settlements, agricultural activities, and tourism. Determining the climatic relations between provinces is important in terms of identifying provinces with similar climates in different regions. Throughout history, the world climate has undergone numerous changes, largely attributable to natural causes and forcings. In addition to these natural fluctuations, anthropogenic factors have emerged as a primary driver of climate change, particularly in the aftermath of the Industrial Revolution. In the contemporary era, marked by the Industrial Revolution, human activities have emerged as a pivotal factor in modulating climate patterns, alongside natural variability (Wan, 2024) (Rahmani, 2024). Consequently, contemporary climate changes can be characterized by the repercussions of human activities, which have led to an augmentation of greenhouse gases in the atmosphere, a phenomenon referred to as global warming. As a result, global surface temperatures are expected to rise, followed by a change in the hydrological cycle, a shift in climate zones, more frequent and severe heat waves, excessive rainfall in some regions and an increase in severe drought. These are significant changes that directly affect human life and ecological systems. Identifying a country's climate zones is very important because climate information has a wide range of uses. Strategies or policies on solar and wind energy can be developed on regional water management planning; areas suitable for agriculture and the type of animals that

live in that area can be identified. Furthermore, understanding current climate zones can provide valuable information about climate change over time (Iyigun, 2013).

Hierarchical classification methods are generally a collection of graphical methods that aim to reveal the relationships between financial assets (currency, stocks, stock market index, etc.) in economic systems and the clustering structures of the assets that make up the systems based on these relationships (Bivona, 2008) (Buda, 2013) (Kantar, 2011) (Wang, 2009) (Yang, 2008). Today, much numerical data is recorded and presented statistically on the internet. In light of this data, many analyses can be made. Hierarchical structure methods based on theoretical physics and applied mathematics have been developed to understand the relationship between systems and to provide solutions to these systems. The most important hierarchical structure methods used in understanding and analyzing complex systems are minimum spanning tree (MST) and dendograms. By using these methods, the relationships between entities in various systems are elucidated (Mantegna, 2000).

Climate is one of the factors that significantly affect people's lives. It affects many areas such as human settlement, agriculture, and animal husbandry. Therefore, it is important to determine the changing climate conditions. Nowadays, climate change is an important problem because climate conditions are changing faster than before. The aim of the study is to analyze the climate relations of metropolitan cities in Türkiye based on temperature and precipitation data, to identify metropolitan cities with similar climate characteristics, and to facilitate analysis by visualizing the results. For this purpose, correlation functions will be calculated, and data will be analyzed using hierarchical classification methods such as dendograms and MST graphs, and a grouping will be made among metropolitan areas. This study aims to analyze the average temperature and average monthly precipitation data of metropolitan areas in Türkiye, classify these areas into groups, and visualize the findings for clearer interpretation. These analyses contribute to various fields, including agriculture, environmental regulations, and understanding the impacts of climate change.

2. Materials and Methods

Using the average temperature and average monthly total precipitation data obtained from the General Directorate of Meteorology (MGM, 2025), the annual average temperature and total precipitation amounts of each province were obtained.

Correlation Analysis: The relationships between temperature and precipitation data of metropolitan cities were calculated using Pearson correlation coefficient. For the system to be analyzed, R_i is the monthly average temperature or monthly average total precipitation for the i -th related metropolitan city. Using this data of metropolitan cities, the correlation coefficient between metropolitan cities is calculated. The correlation coefficient provides information about the direction of variables and how they interact. It can be observed whether there is an interaction between the variables, if there is, whether the interaction is very high or strong, and whether the observation values of one of the observation groups increase while the other decreases or whether the values change in the same direction. When there is more than one independent variable, it is called multiple correlation. In scientific research, simple correlation analysis is most commonly used. Different correlation coefficients have been developed for different situations. The best known of these is the Pearson's correlation coefficient between two cities i and j denoted as C_{ij} which is calculated as

$$C_{ij} = \frac{\langle R_i R_j \rangle - \langle R_i \rangle \langle R_j \rangle}{\sigma_i \sigma_j}. \quad (3.1)$$

Here, $\sigma_i = \sqrt{\langle R_i^2 \rangle - \langle R_i \rangle^2}$ is the standard deviation, $\langle R_i \rangle$, $\langle R_j \rangle$, and $\langle R_i R_j \rangle$ denote the statistical average over time. The correlation coefficient C_{ij} has values between $-1 \leq C_{ij} \leq 1$ where $C_{ij} = -1$ means that the assets are completely opposite-correlated and $C_{ij} = 1$ means that the assets are completely correlated. It is important to note that while a correlation coefficient of $+1$ or -1 implies perfect linear relationships, non-zero values generally indicate varying degrees of linear association. A coefficient close to zero indicates weak correlation. It should also be noted that the Pearson correlation coefficient only captures linear dependencies and may not adequately represent non-linear relationships that could exist in the data. Therefore, while our

analysis provides understanding of linear associations among climate variables across metropolitan cities, future work may consider using non-linear correlation measures (e.g., Spearman, Kendall etc.) to uncover more complex dependencies.

Correlation analysis will be used to mathematically determine the relationships between temperature and precipitation data of the provinces. This analysis aims to visualize climatic similarities and differences between provinces. The data obtained as a result of correlation analysis will be clustered using dendrogram and MST method. In this way, complex relationships between provinces will be simplified and provinces with similar climatic variations will be easily identified. The data obtained from the correlation matrix between metropolitan cities, metropolitan cities with similar climate characteristics were identified by using the program related to hierarchical classification in MATLAB program. The following table (Table 1) presents an inventory of metropolitan cities in Türkiye, along with their respective abbreviations.

Table 1. Metropolitan cities and their abbreviations

Metropolitan cities	Abbreviation
VAN	VAN
TRABZON	TRB
TEKİRDAĞ	TEK
ŞANLIURFA	SAN
SAMSUN	SAM
SAKARYA	SAK
ORDU	ORD
MUĞLA	MUG
MERSİN	MER
MARDİN	MAR
MANİSA	MAN
MALATYA	MAL
KONYA	KON
KOCAELİ	KOC
KAYSERİ	KAY
KAHRAMANMARAŞ	KAH
İZMİR	IZM
İSTANBUL	IST
HATAY	HAT
GAZİANTEP	GAZ
ESKİŞEHİR	ESK
ERZURUM	ERZ
DİYARBAKIR	DIY
DENİZLİ	DEN
BURSA	BUR
BALIKESİR	BAL
AYDIN	AYD
ANTALYA	ANT
ANKARA	ANK

3. Results and Discussion

Various algorithms have been developed to detect the minimum spanning tree. Kruskal Algorithm is used in this study (Munier, 2017). Kruskal Algorithm creates the shortest tree by connecting the entities so that the edge weights are minimum. The temperature and precipitation data of the provinces were collected in Excel program and transferred to MATLAB program. The program used Pearson correlation coefficient to determine the climate relations between the provinces. The results of the analysis showed that the metropolitan cities of Türkiye are divided into certain groups according to temperature and precipitation data. Based on the correlation analysis, the relationships between metropolitan cities with similar climatic characteristics were determined and visualized with the MST method and dendograms. These results are presented in the figures below.

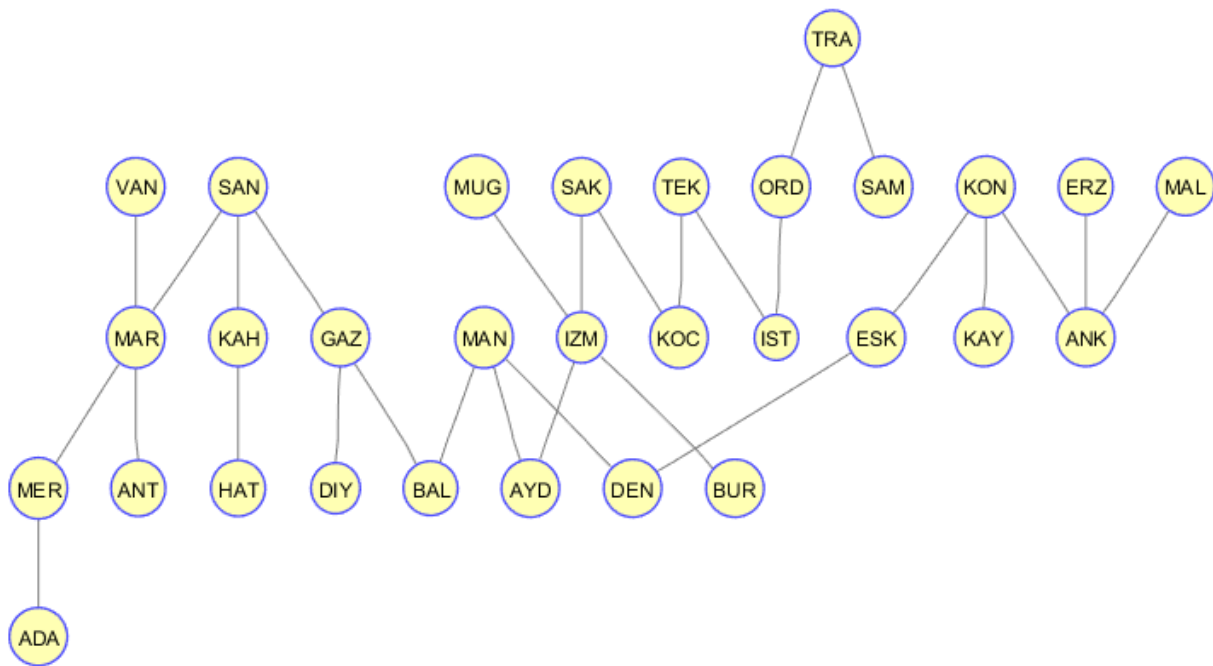


Figure 1. Minimum Spanning Tree of 30 Metropolitan Cities' Average Temperature Relationships

In Figure 1, the nodes on the tree represent the cities and the links (edges) represent the temperature similarities between the cities. The MST structure is organized as a tree that provides the shortest total distance between the temperature relationships of the cities. Metropolitan cities such as Ankara (ANK), Erzurum (ERZ), Konya (KON), Kayseri (KAY) and Malatya (MAL) are associated with low temperature values and are closely connected to each other on the network. The southern coastal cities of Antalya (ANT), Hatay (HAT) and Mersin (MER) are located close to each other as they have Mediterranean climate temperature characteristics. Metropolitan cities in the Black Sea region, such as Trabzon (TRA), Samsun (SAM), and Ordu (ORD) on the Black Sea coast are directly connected as they have similar temperature patterns. In Central Anatolia and Aegean regions, Central Anatolian cities such as Eskişehir (ESK), Ankara (ANK), and Konya (KON) are located in their own cluster, while Aegean cities such as İzmir (IZM), Manisa (MAN), and Aydın (AYD) are connected together. Some cities act as a bridge between different regions. For example: Gaziantep (GAZ) appears as a node connecting eastern and southern cities. Izmir (IZM) connects the Aegean and Marmara regions. The MST shows that geographical and climatic relationships exhibit a highly significant distribution in terms of temperature. This network, based on the temperatures of the cities, is based on climate similarities, although it does not correspond exactly to geographical distances.

Figure 2 is useful for drawing inferences for grouping provinces based on similarities in rainfall. Among provinces, those with closer ties are those that are more similar to each other in terms of rainfall. For example, metropolitan cities located in the same geographical region are more frequently connected. (e.g. Aegean, Central Anatolia, Eastern Anatolia groups). Southeastern Anatolian provinces (Gaziantep (GAZ), Kahramanmaraş (KAH), Diyarbakır (DIY)) are connected to each other. Aegean Region provinces (Aydın (AYD), İzmir (IZM), Denizli (DEN)) are in the same group. Central Anatolian provinces (Konya (KON), Ankara (ANK), Kayseri (KAY)) are connected. Istanbul (IST) is located at a central connection point, connected to both the cities of the Marmara Region and the Black Sea Region. Gaziantep (GAZ) and Diyarbakır (DIY) are also seen as transit points to other provinces.

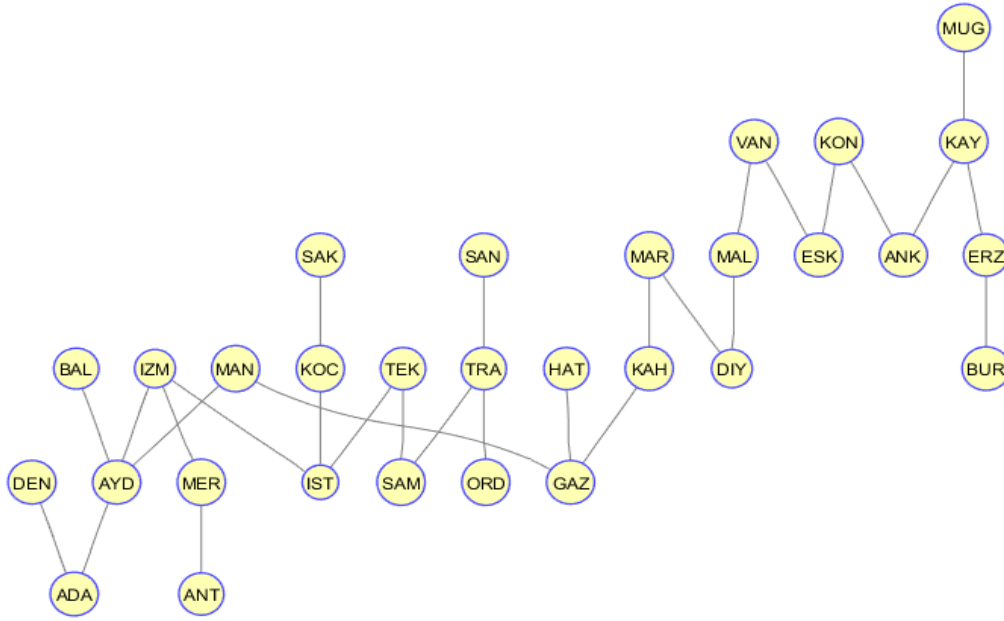


Figure 2. Minimum Spanning Tree of 30 Metropolitan Cities in terms of Average Monthly Total Precipitation (mm)

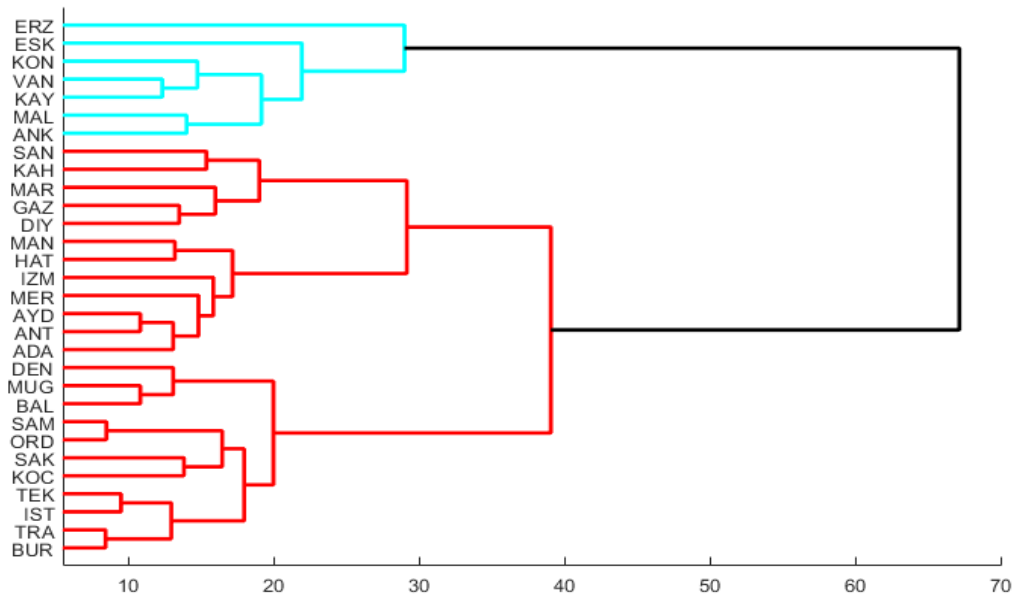


Figure 3. Dendrogram of 30 Metropolitan Cities Average Temperature Relations

Figure 3 shows a dendrogram based on the monthly average temperatures of 30 major cities in Türkiye, showing that the cities are clustered according to their climatic similarities. Cluster 1 (Cold Cities), Erzurum (ERZ), Van (VAN), Kayseri (KAY), Malatya (MAL), Ankara (ANK), Konya (KON) and Eskişehir (ESK) are in the same cluster. These cities are located in inland regions with continental climates, cold winters and high annual temperature fluctuations. Another cluster (Coastal and Warm Cities), Antalya (ANT), Muğla (MUG), İzmir (IZM) and Hatay (HAT), form a different cluster. These cities are located on the southern and western coasts where the Mediterranean climate prevails, with mild winters and hot summers. The geographical and climatic differences between Türkiye's cities are clear, with coastal regions clearly separated from inland regions. Cities with high altitudes (e.g. Erzurum and Van), although geographically distant, are in the same group due to their cold climates.

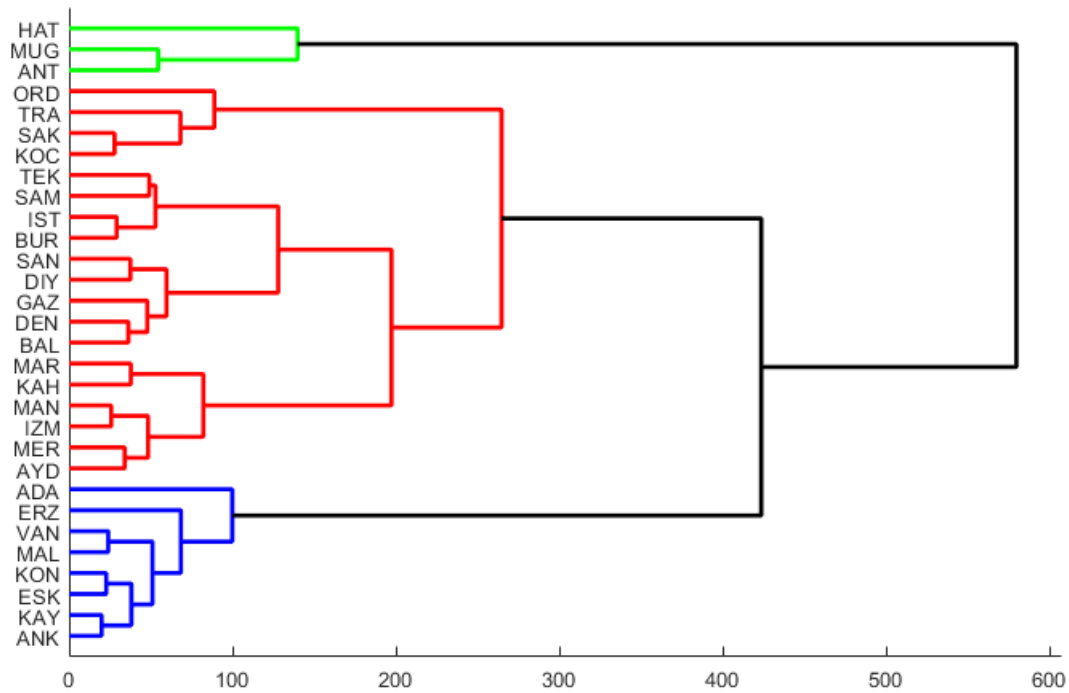


Figure 4. Dendrogram of 30 Metropolitan Cities in terms of Average Monthly Total Precipitation (mm)

Figure 4 shows a dendrogram based on total precipitation data, with clusters emphasizing differences in precipitation. High Precipitation Cities, Hatay (HAT), Muğla (MUG) and Antalya (ANT) are in the same group. These cities are located on the southern coasts with a Mediterranean climate that receives heavy rainfall during the winter months. Moderately Rainy Cities, Trabzon (TRA), Samsun (SAM) and Istanbul (IST) are in the same group in the red cluster. These cities are located along the Black Sea and receive regular rainfall throughout the year. Cities with low rainfall, such as Erzurum (ERZ), Van (VAN) and Konya (KON), form a separate cluster and are drawn in blue. These inland cities have lower rainfall due to their distance from rainfall sources and the mountains blocking rainfall.

Although this study focuses on climatic similarities among metropolitan areas using temperature and precipitation, it is worth noting that anthropogenic factors - particularly population density and industrial activity - can affect local climates. For example, the urban heat island effect can lead to elevated temperatures in densely populated and industrialized areas. While our correlation-based analysis does not directly account for these variables, future work could explore the integration of demographic and industrial metrics to assess their impact on regional climate behavior. In addition, air pollution from industrial activities and transportation may also play a significant role in altering local climate patterns. Concentrations of greenhouse gases in urban areas, such as carbon dioxide and methane, can contribute to heat trapping and exacerbate temperature increases. Therefore, a more comprehensive analysis that includes these anthropogenic factors could provide a more accurate understanding of how human activities affect urban climates. By incorporating demographic and industrial data into future studies, researchers can better assess the complex interplay between natural and anthropogenic factors in shaping regional climate trends.

4. Conclusion

The results reveal a clear distinction between coastal cities, particularly those situated in the Mediterranean and Black Sea regions, and other geographical locations. Inland cities, on the other hand, exhibit distinct rainfall patterns due to their lower precipitation levels. This observation underscores the impact of Türkiye's varied topography on precipitation levels. The temperature and precipitation dendograms reveals that coastal cities tend to cluster together, a phenomenon that is evident in the examples of Muğla, Antalya, and Hatay.

Inland cities with cold climates, such as Erzurum and Van, are distinctly separated in both analyses. The temperature analysis is predominantly influenced by seasonal and altitudinal effects, while in the precipitation analysis, geographical location and proximity to moisture sources are found to be significant factors. A notable distinction emerges in the analysis of precipitation, where cities along the Black Sea coast, such as Samsun and Trabzon, demonstrate a more pronounced differentiation compared to their temperature-based classification. The integration of both analyses unveils the intricate and diverse climate structure of Türkiye. This comprehensive understanding can serve as a crucial foundation for agricultural planning, infrastructure development, and the formulation of climate adaptation strategies.

The findings of studies of this nature can facilitate the formulation of strategic decisions in a myriad of domains, including regional water management, renewable energy policies, agricultural planning, and climate change analysis. Concurrently, it will furnish pertinent information in diverse domains, offering a more nuanced delineation of Türkiye's climate zones. Interdisciplinary research enhances the rigor and relevance of scientific inquiry by incorporating diverse perspectives into existing knowledge. Utilizing monthly mean temperature and precipitation data from metropolitan cities in Türkiye spanning from 1927 to 2021, this study aims to identify the prevailing climatological patterns within these urban regions. The identification of these clusters will facilitate scientific analysis and decision-making processes by providing a visual representation of Türkiye's diverse climate zones. Moreover, the findings of this study can contribute to global climate change research. The scope of this study encompasses the potential for extension to encompass all provinces and, ultimately, all countries.

Article Information

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