

Monitoring Climate Changes by Geographical Information Systems: A Case Study of Izmir City

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Abstract

Climate is one of the most important factors that enable the existence of life on Earth. The climate has been studied by many scientists throughout the history for its influence on all living and non-living beings. Researchers have used climatological parameters (temperature, humidity, rainfall, sunshine duration, evapotranspiration etc.) with different approaches and created a variety of methods. When putting these classifications into consideration, they have taken different criteria into account and have produced different classification. Some of these formulas are short and simple, some are very long and complex. Using these formulas, researchers have determined different climatic types suited to different regions. In this study, two separate climate classification methods were used (Erinç and De Martonne). Meteorological data ranging from 1980 to 2011 were examined periodically and arranged according to determined classification methods. The data were processed in accordance with De Martonne and Erinç classification formulas by GIS and the climate change of Izmir province has been revealed between 1980-1989 and 2006-2011 time periods.

Keywords

GIS, Climate Change, Climate Modeling, De Martonne Climate Classification, Erinç Climate Classification

Coğrafi Bilgi Sistemleri ile İklim Değişikliklerinin İzlenmesi: İzmir İli Örneği

Özet

İklim dünya üzerinde yaşamın var olmasını sağlayan en önemli etkenlerden biridir. İklim, canlı ve cansız bütün varlıklar üzerindeki etkisinden dolayı tarih boyunca birçok bilim insanı tarafından incelenmiştir. Araştırmacılar iklimi oluşturan parametreleri (sıcaklık, yağış, nem güneşlenme süresi, rüzgâr, evapotranspirasyon vb.) farklı yöntemlerle birlikte kullanarak birçok iklim sınıflandırma yöntemleri ortaya koymuştur. Bu sınıflandırmaları ortaya koyarken farklı ölçütleri dikkate almışlar ve bu ölçütlere göre farklı sınıflandırma indisleri ortaya çıkarmışlardır. Sınıflandırmalarla alakalı birçok eşitlik mevcuttur. Bu eşitliklerin bir kısmı kısa ve basit, bir kısmı ise çok uzun ve karmaşıktır. Araştırmacılar bu eşitlikleri kullanarak farklı bölgelerde farklı iklim tipleri ortaya koymuşlardır. Bu çalışmada, Türkiye Meteoroloji Genel Müdürlüğü'nden elde edilen 1980-2011 arasındaki meteorolojik veriler dönemler halinde incelenmiş ve iki ayrı iklim sınıflandırma yöntemi kullanılarak belirlenen sınıflandırma yöntemlerine göre düzenlenmiştir. Düzenlenen veriler CBS ile De Martonne ve Erinç sınıflandırma eşitliklerine uygun şekilde işleme konulmuş ve çalışma alanı olarak seçilmiş olan İzmir ilinin 1980-1989 ve 2006-2011 yılları arasındaki iklim değişiklikleri tespit edilmiştir.

Anahtar Sözcükler

CBS, İklim Değişikliği, İklim Modellemesi, De Martonne İklim Sınıflandırması, Erinç İklim Sınıflandırması

1. Introduction

Climate is the average of weather events (temperature, precipitation, humidity, pressure, wind) observed over a long period of time in large areas, whereas, weather conditions are defined as short-lived weather events in smaller areas. As it can be understood from these definitions, there are differences between climate and weather conditions such as wide range of areas (Turkey climate, Mediterranean Region Climate, Marmara Region climate etc.) and observation times (this period is defined as 30 years if sufficient data is available). There are various parameters that create the climate like temperature, precipitation, humidity, pressure, wind, etc. These parameters are called climate elements and they affect each other. Also they affect the atmosphere, alone or all together combined. If this affection lasts a short time, they create short-term weather effect, but if they last a long time, they create the climate.

Climate of an area depends on the latitude, ascension, ground shape of the area, and also its distance from the seas. Because it is directly affected from the angle of the sunlight, latitude is the most important factor affecting climate. Generally, lower latitudes are warmer and upper latitudes are colder. The altitude is also influential on the climate.

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The lapse rate is generally understood to be the decrease of temperature with height (or depth in oceanography). The average lapse rate is the mean in situ lapse rate for many observations, usually given as 0.5°C/100 m or 3°F/1000 ft. These rates are the changes of temperature depending on the altitude. The sea is an intense moisture source and humidity which makes it an influential effect on temperature and precipitation. Additional information about climatology can be found in Encyclopedia of World Climatology (Oliver 2008).

From past to present, climate has affected people's lives, settlements, livelihoods and similar living environments. Knowing the climate of a region has a very important effect on anticipating and taking precautions against possible weather events. "For many years, many scientists have worked on the climate. These studies have produced so many climatic types that might be countless. However, as in every scientific discipline, climatologists have uncovered large climates by bringing together the scattered types, the more or less common ones." (Dönmez 1984). Various climate classifications have been made by many scientists. Still these scientists couldn't come up with the perfect equation to work in all areas. There are some differences between the formulas regarding their attributes or time variables. This situation can be interpreted as the difference between the views of various researchers, as well as the lack of a perfect formula working in every area. Some of the formulas used in classification are very simple, and some are very complex. But this cannot be interpreted as the longest formula would give the most accurate result. The criteria that researchers take into account in climate analysis are different. Some of these criteria can be defined as precipitation - temperature ratio, precipitation - evaporation rate, precipitation regime and vegetation cover (URL-1 2017). The common point of all the classification studies is that income (rainfall) is equal to the amount of equations they produce and expenditure (transpiration, evapotranspiration) is written to the stake and a classification is made according to the income-expenditure balance.

There are many definitions of climate change. One of them is an agreed definition by the United Nations Framework Convention on Climate Change (UNFCCC): "In addition to the natural climate change observed in a comparable time period, a change in the climate as a result of human activities directly or indirectly distorting the composition of the global atmosphere" (Gönençgil 2014). Climate change occurs with many factors. Some of these factors are natural, some of them originate from human effects. These factors can be listed as follows:

Natural Causes:

- The change in solar energy;
 - Sunspots
 - Movements of the earth
 - Duration of sunshine
- Changes in atmospheric components: Atmosphere contains 78% nitrogen, 21% oxygen and 1% noble gases. The changes in these rates, especially carbon dioxide change, strengthen greenhouse effect and global warming.
- Change in the physical geography conditions of the earth: This is presumed to be a change in climates as the orogenic (mountain formation movements, volcanic eruption) and epirogenic (continental formation movements) movements on the surface change the surface character, slope, aspect and elevation.

Human Causes:

- Surface Change: The surface change can be defined as the change on the surface of the earth made by human activities. With increasing population growth; destruction of forests and agricultural lands, intensive urbanization and concretization, change in albedo ratios (solar reflectance ratio) have been caused to meet human needs.
- Urbanization process: Since the 19th century, there has been an intense urbanization with increasing population. The intense urbanization has caused the cities to become irregular and complex, and the worst damage has been done to the areas where the city was founded. Natural characteristics of the cities from when the cities are first built have been lost and the cities have become almost anthropogenic islands. With the intense urbanization, air pollution in the cities has increased. With it, the effect of the greenhouse was felt more intensely in cities and the concept of "city heat island" was born.
- Greenhouse Gas Emissions: Increasing of the greenhouse gases that cause global warming are formed by the burning of fossil fuels. Carbon dioxide is the most notable greenhouse gas in the atmosphere. The amount of Carbon dioxide in the atmosphere can change for natural reasons like volcanic explosions, breathing of living things, or for human reasons like intensive use of fossil fuels (Gönençgil 2014).

The TEMA Foundation has provided the following important findings in its report that it was prepared in 2015. According to this report, the main negative impact is defined as the change in crop yields due to climate change and the decrease in crop yield. The reduction of underground and surface water levels and negatively affecting agricultural land are also held in the foreground. The warmer and drier summers are due to the formation of indefinite seasons, and the

colder days are beginning to occur in winters. With the increase in sea water temperature, the diversity of living creatures in the sea has begun to decrease. With the increase in temperature, the use of air conditioners has been increased for cooling and it is emphasized that there are also increases in respiratory diseases. It has been determined that erosion disasters have been accelerated and increased due to the heavy rainfall of soils, and agricultural lands and settlement areas have been found to be under water due to these rains. Extreme wind and tornado events have caused havoc in living spaces. Establishment of wind power plants for healthy energy production without feasibility studies creates social, economic and ecological problems. It is emphasized that wind energy plants that are produced without consideration of their environmental effects will cause problems and negative on areas like Bayındır and Tire, which are highly dependent on their livestock. It is stated that the same situation applies within Karaburun region. With the more efficient use of rain water, cleaning and water consumption can be reduced in house necessities. It is necessary to increase the amount of recycled paper. Importance and training of individuals involved in combating climate change should be emphasized (TEMA 2015).

Many studies have been conducted in our country to create awareness towards climate change and its consequences. Okkan and Karakan (2016) modelled the climate change effects on dam currents, projecting from 2015 to 2030. Berberoğlu et al. (2016), used biogeochemical approach to model regional climate change in Turkey with Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images. Sabancı (2016) studied climate classification with specific methods like Köppen, De Martonne etc. in Alanya and Manavgat of Turkey. Yılmaz (2016), in her thesis, studied to estimate climate extremes for Turkey to understand the high socio-economic impacts towards our country.

In this study, a climate classification is obtained by interpreting the raster of the study area which is created by interpolating climate criteria such as temperature, precipitation etc., gathered from meteorological stations. These raster data consist of the sub-data which can be found in the oldest date and the data which is presently available. Thus, climate change in the study area can be questioned between two dates. Using precipitation, temperature, humidity, sunshine period, evapotranspiration etc. data, which are taken from Turkish State Meteorological Service within a period of 1980-2011 (divided to 1980-89 and 2006-11), De Martonne and Erinc classification methods' raster, of İzmir province were created in the defined time period and various information about climate change has been gathered.

2. Study Area and Materials

İzmir province was chosen as the study area (Figure 1). İzmir is the third largest city of Turkey. İzmir province is surrounded by The Madra Mountains to the north, the Kuşadası Gulf to the south, the Tekne Cape of the Çeşme Peninsula to the west. It is also surrounded by the borders of Manisa and Aydın provinces in the east, and the İzmir Gulf in the west. The Gediz River is one of the most important rivers of the Aegean Region in İzmir province. The coastal region is recessed due to the stretch of the mountains.

İzmir province has a climatic character according to the tectonic feature of the coastal Aegean strike with the gulf structure which is open to the sea effects and has an internal marine character in the middle latitude. The Mediterranean climate is dominating the region by the fact that it is located on the middle latitude and also for being a coastal city. The summers are warm and dry, the winters are warm and rainy, and the spring months are transitional. The sunshine potential is considered high. The wind situation creates an important potential for coastal shoreline to have a combination of different topographical structures. Depending on the amount of precipitation and the duration of sunshine, the soil structure has an appropriate climate characteristic in terms of agriculture (Atalay 1994).

The data used in the study (URL-2 2017) were provided by Turkish State Meteorological Service within a time period of 1980 and 2011. This data includes monthly temperature, precipitation, relative humidity and so on. Some data such as sunshine duration, evapotranspiration, water shortage and surplus are required in several classification formulas, but not all of those data were found in all stations of İzmir province which have common data in the period of 1980 and 2011. Therefore, only Erinc and De Martonne methods were used in the study. Also, there were some lack of data in meteorological stations. According to this, we tried to create the best time periods in order to obtain better results. Between 1980 and 1989 years and also 2006 and 2011 years, we found complete data whereas in other periods some values of different months were not recorded. This causes problems when it comes climate classification but the lack of data pushed us to use shorter time periods. Interested readers can explore the same data we used from the link given in the references section.

In climate studies, it is very important to understand the estimation of climate parameters and the complex structure of non-data points because meteorological stations cannot be found at every characteristic point of the study area. For this reason, it has been necessary to use interpolation methods so that station data can be spread over the entire working area within the İzmir provincial boundary. 8 stations' data in İzmir province and 7 stations' data which are very close to the boundary of İzmir were used in the study (Figure 2). Inverse Distance Weighting (IDW) interpolation method is used on the geographical points, which is obtained from meteorological stations. They were used to create the raster data which later to be used in determining the climate change.

IDW is an advanced nearest neighbor approach that appoints a new point based on the observation distance from a known point. The value of the new point is obtained from linear combinations of known points. IDW method is widely used in climatology studies. Usually, this method is used to calculate the anomalies of climate changes in a monthly basis.

A good comparison between all the interpolation methods used in climate research can be found in Sluiter's review paper (Sluiter 2008). IDW is a method that gives the best results through cross validation. It includes no extrapolation, so that all interpolated values stay in the range of data points used in the study (De Smith et al. 2007).

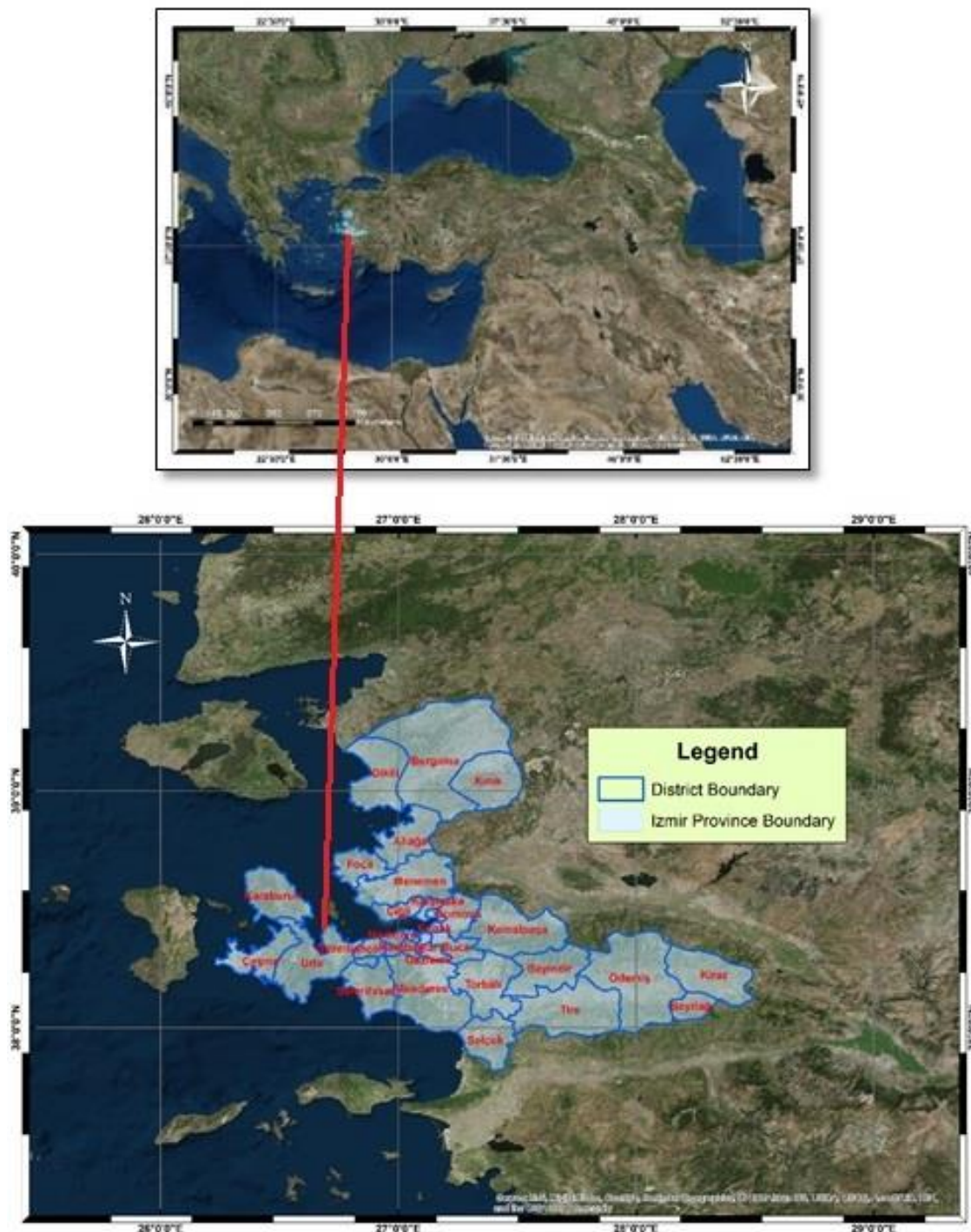


Figure 1: Study area

There are many studies using IDW methods to calculate climate parameters and create rasters related to them. Chen and Liu (2012) used IDW method to estimate rainfall distribution in Taiwan from 1981 to 2010. Crespi et al. (2017), used IDW to calculate the anomalies in climate change and gave a great evaluation of IDW methods used in related studies. Switanek et al. (2017), tried to observe seasonal effects of temperature and precipitation on honey bee life-cycle. Ramos et al. (2016), compared IDW and Kriging interpolation methods in an air pollution related study.

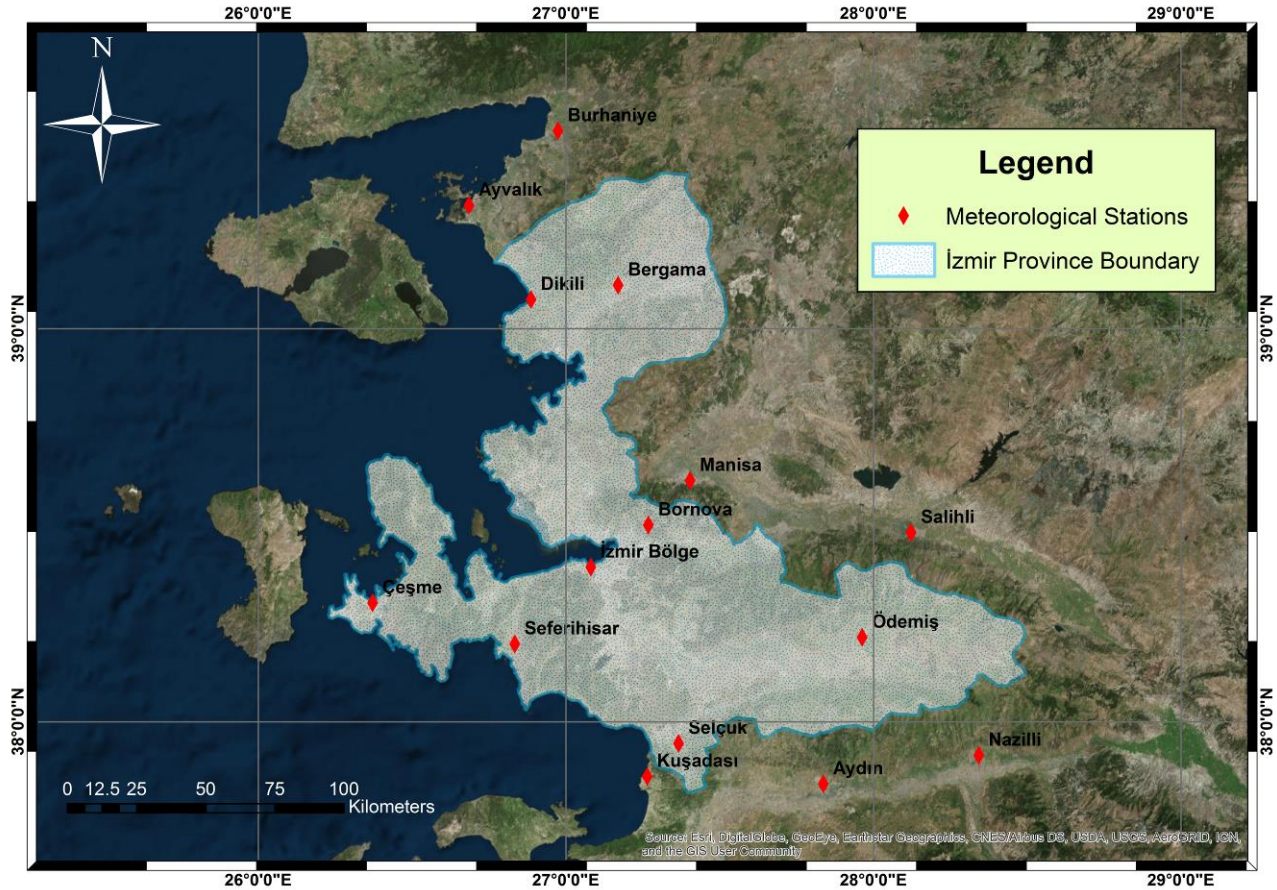


Figure 2: Meteorological stations

3. Methods

There are many climate classifications using different methods. In our work we have used De Martonne, which is defined as the first classification work used all over the world and named by inventor's name, and the Erinç classifications which is the most used in our country.

3.1. De Martonne Climate Classification

De Martonne climate classification is based on temperature and precipitation. Unlike other classifications, this classification method is considered as calculating the average temperature and precipitation of July and January, along with the annual mean precipitation and temperature. With annual rainfall data, arid and humid climates can be found as results. In the determination of arid climates, precipitation accounts with monthly evaporation too. According to De Martonne and Gottman, classification formula they developed is given below (URL-1 2017):

$$I_a = \frac{\left(\frac{P}{T+10}\right) + \left(\frac{12 \times p}{t+10}\right)}{2} \quad (1)$$

To explain the formula elements:

(Reason for the addition of 10) = Fixed number for making t positive in places where the temperature is below 0°C

P = Total precipitation for a long term (mm),

T = Average air temperature ($^\circ\text{C}$) for a long term,

p = Precipitation of the driest month (mm),

t = Average temperature of the driest month ($^\circ\text{C}$)

I_a = Climate Index Value

Table 1 contains the classification indices of the final products.

Table 1: Indices of De Martonne classification formula

Climate Type	Index Value (I _a)
Desert	0 - 5
Step (Semi-arid)	5 - 10
Step – Humid	10 - 20
Semi-humid	20 - 28
Humid	28 - 35
Very humid	35 - 55
Wet	>55
Polar	<0 (T < -5 C)

3.2. Erinç Climate Classification

In this classification, the amount of precipitation is directly proportional to the average temperatures and the classification indices are formed in this way. However, this created indices make the terrestrial climate appear to be more humid than normal. To prevent this, Erinç used average maximum temperature instead of average temperature. According to this method, months, in which temperatures drop below 0°C, are not considered in case of no evapotranspiration.

Erinç's formula is as follows (Şensoy 2012; Erinç 1984):

$$I_m = \frac{P}{T_{om}} \quad (2)$$

To explain the formula elements:

I_m = Rainfall activity element,

P = total annual precipitation (mm),

T_{om} = Annual average maximum temperature (°C).

Table 2: Indices of Erinç classification formula

Climate Class	Index Value (I _m)	Climate/Vegetation Cover
Full Arid	< 8	Desert (Full Arid)
Semi-arid	8 - 15	Desert – Step (Arid)
Semi-arid	15 - 23	Step (Semi-arid)
Semi-humid	23 - 40	Dry Forest (Semi-humid)
Humid	40 - 55	Humid Forest (Humid)
Very Humid	>55	Very Humid Forest (Very Humid)

4. Results

4.1. De Martonne Method

According to the climate classification prepared using meteorological data between 1980 and 1989, İzmir has only "Semi-humid" and "Humid" indices, but according to the climate classification between 2006 and 2011, it has begun to have "Very humid" indices especially on the sides of Bergama. Bergama region has changed from "Semi-humid" class to "Very humid" class. The transition from the "Humid" class to the "Semi-humid" class has been the subject of Ödemiş region. On the sides of Konak-Balçova-Bornova there are transitions from "Humid" class to "Semi-humid" class (Figure 3 and Figure 4).

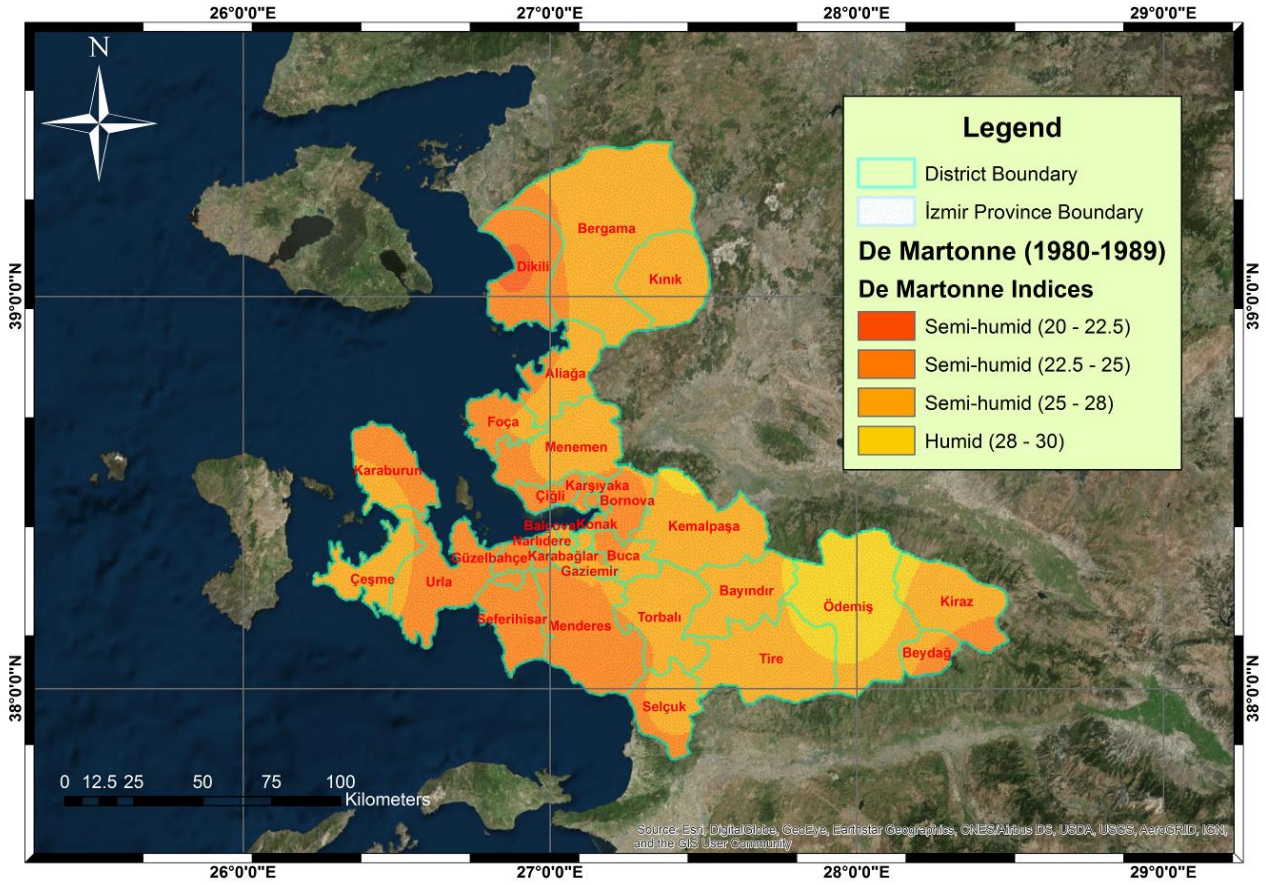


Figure 3: De Martonne (1980-1989)

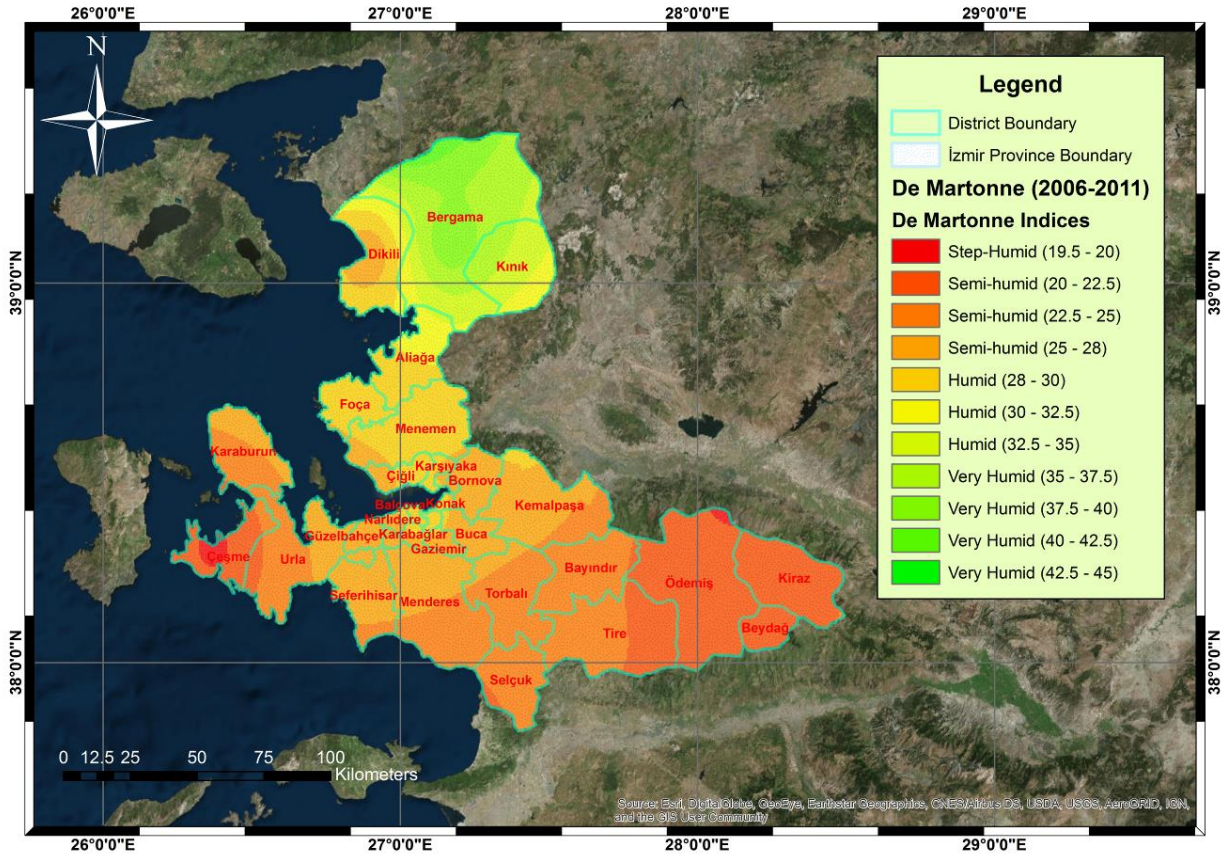


Figure 4: De Martonne (2006-2011)

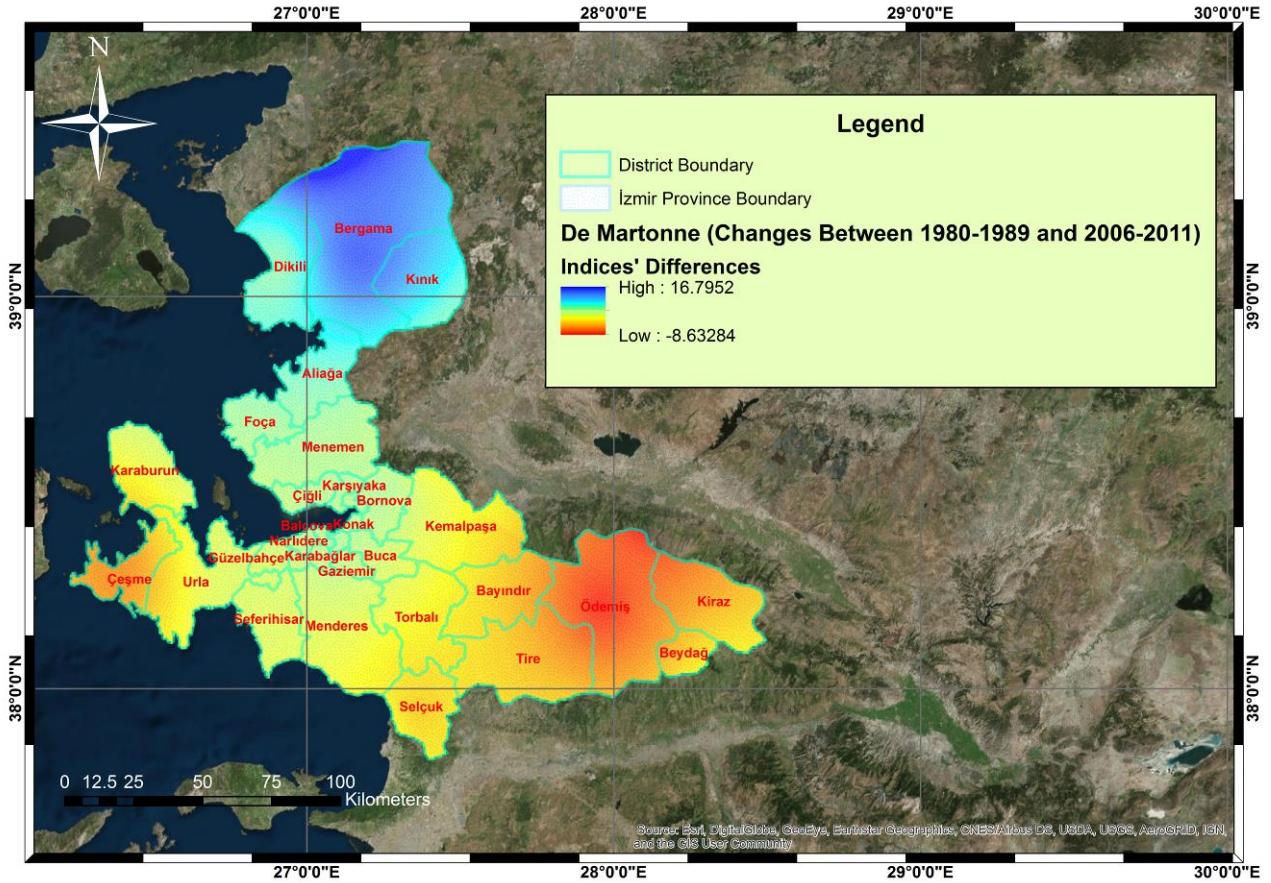


Figure 5: De Martonne (Changes between 1980-1989 and 2006-2011)

According to De Martonne, positive differences between the two-time series represent the movement towards humid class, whereas reductions represent the movement toward arid class. When the difference map is examined, biggest difference is located in Bergama region (Figure 5).

4.2. Erinç Method

When examining the classifications prepared using 1980/1989 data and 2006/2011 data, there is a change towards humidity in Urla area, also there is a tendency towards drought in the areas of Dikili, Ödemiş and Tire (Figure 6 and 7).

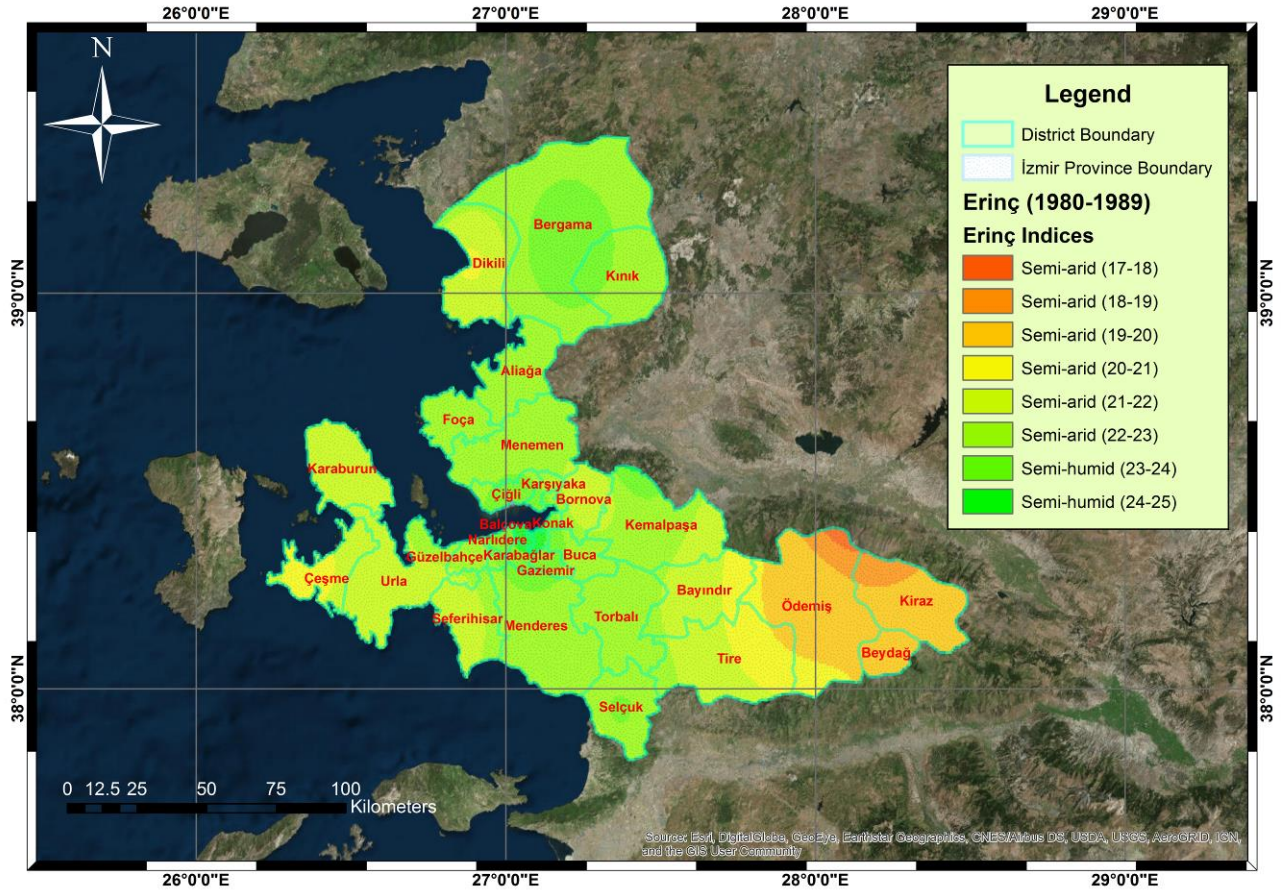


Figure 6: Eriç (1980-1989)

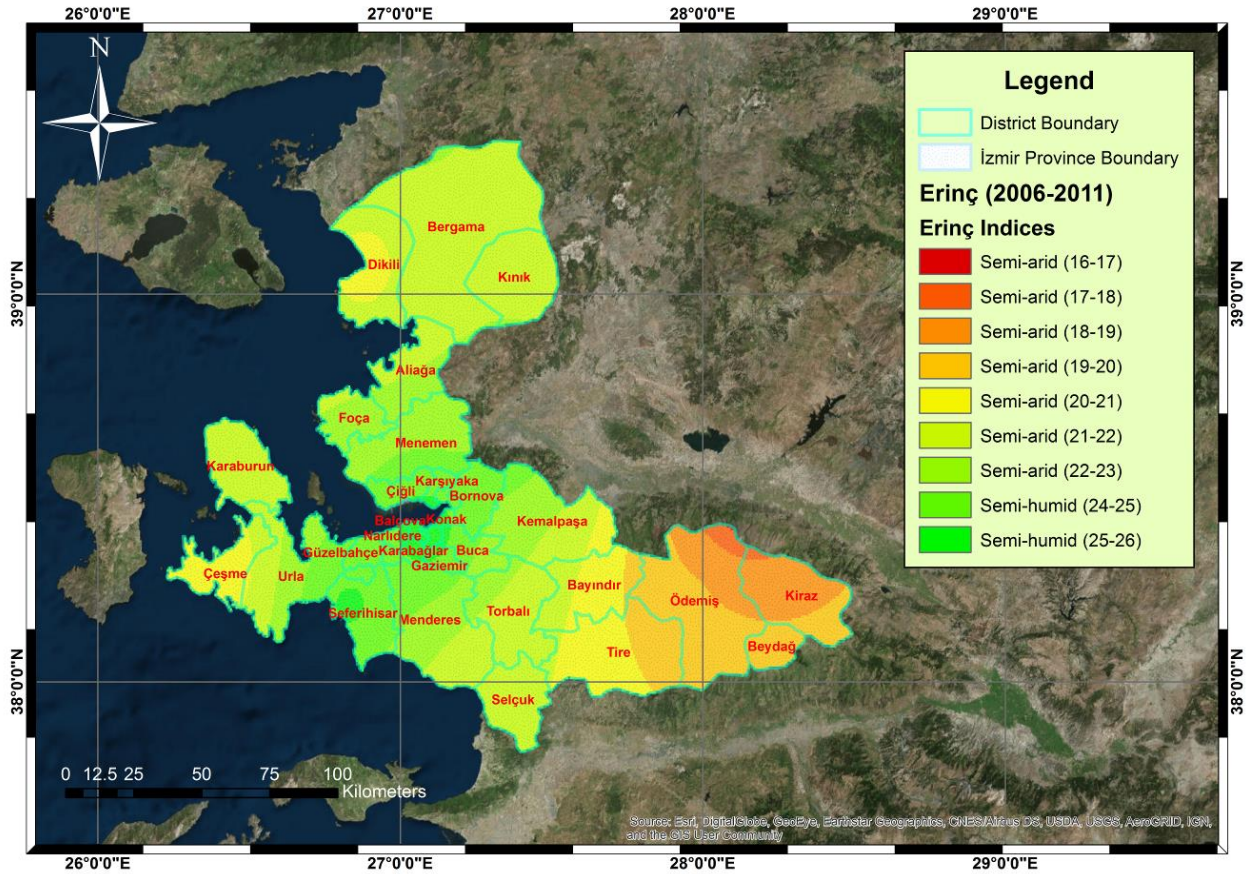


Figure 7: Eriç (2006-2011)

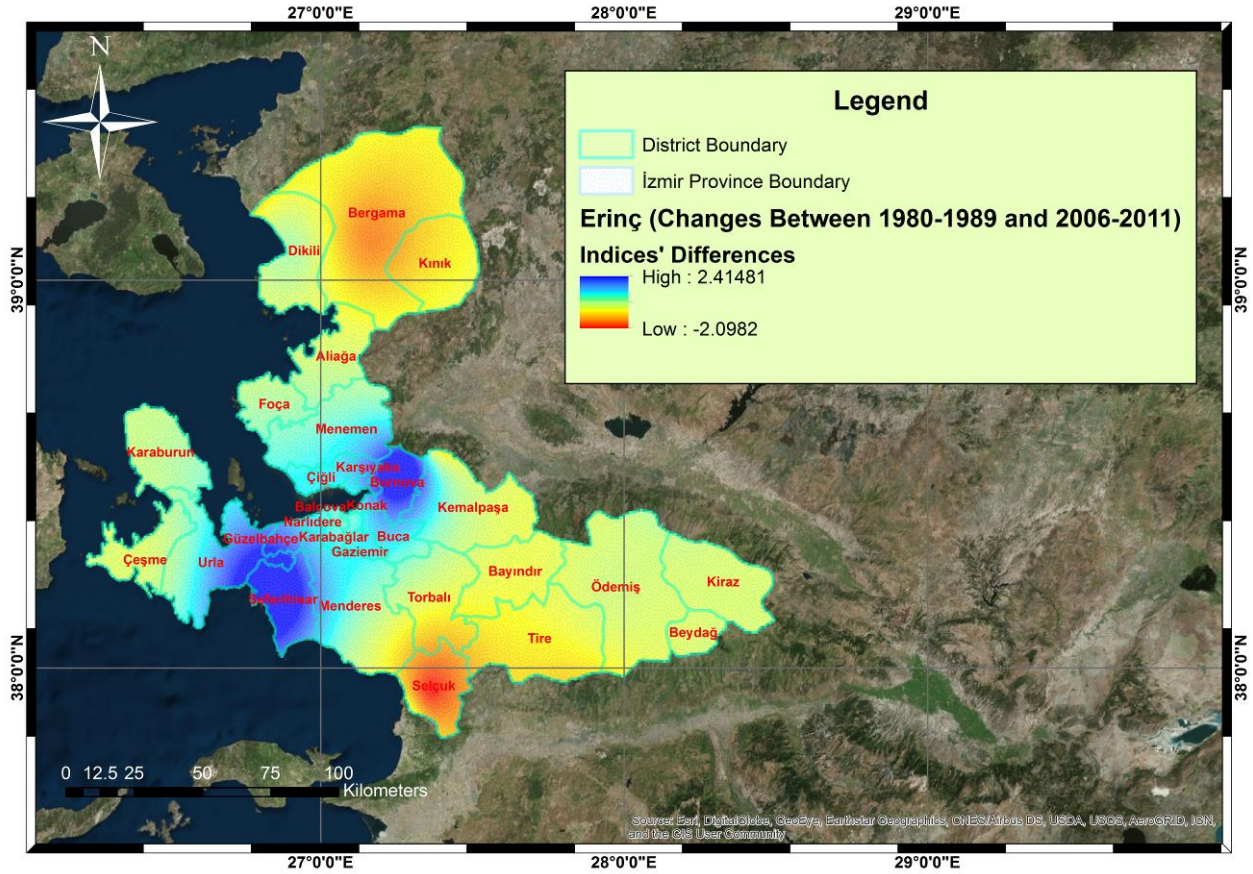


Figure 8: *Erinç* (Changes between 1980-1989 and 2006-2011)

When Figure 8 is examined, it can be understood that there are some increases in indices in Seferihisar, Karşıyaka, Bornova, Konak areas. According to the *Erinç* method, these increases indicate that they move towards humidity from drought. Unlike De Martonne climate classification, the Bergama region is still in the "Semi-humid" class, although its indices value goes from "Semi-humid" class to "Semi-arid" class. In the Selekuk region, indices are decreasing like Bergama region. According to the *Erinç* method, large scale class changes did not occur on the basis of the districts.

5. Discussions and Conclusions

When the climatic types represented by indices' raster are examined, it is found out that some changes are detected with both methods, and these changes seem to be different from each other. In the De Martonne classification, the northern parts of İzmir are advancing from semi-humid to humid class, and the southeast parts are moving towards less humid from semi-humid. In the method of *Erinç*, it is seen that there are not major changes on the basis of the districts but some transition to drought in the northern part. There are some differences between De Martonne and *Erinç* methods and also in their results. The reason for this can be defined the classification properties of both methods vary from each other. In addition, *Erinç* defined the equality he proposed by considering the climate of Turkey. For example, *Erinç*'s indices with values less than 8 are regarded as deserts, while in De Martonne this value is 5 and below. According to the *Erinç* method, a very humid climate is defined as 55 and above, whereas in De Martonne this value is defined as between 35 and 55.

In our study, lack of meteorological data prevented us from using longer time periods. To obtain more accurate results, we tried to create solid time periods. Because of this reason, second time period we used is shorter than expected (2006/2011). The number of meteorological stations are not enough to get more accurate results, also they are not distributed well throughout the province. In future work, different time periods and interpolation methods can be used to obtain better climate classification results to understand their effects on socio-economic standards. Also in future work, reasons of climate changes should be investigated further. Sufficient information about what could change the climate is given in the manuscript. This should be explored more in regard of İzmir province. There is a definite rise in urbanization process through this study's time period. This reason can directly change carbon dioxide amount in the atmosphere, resulting in strengthening greenhouse effect and global warming. Urbanization process requires more residential areas, which means the destruction of forests, agricultural lands etc. Also this could lead to a rise in fossil fuel use to meet human needs, which could change the amount of carbon dioxide in atmosphere.

As a result of this study, classification of the data obtained for a long term shows that İzmir province is one of the risky areas in which climate change can be experienced in Turkey. In particular, our country's southern and western regions, where the Mediterranean climate is dominating, show that we are very sensitive to climate change. According to this situation, the climate region where the effects of drought will be felt the most in our country will be in the Mediterranean climate area. However, especially at this point, floods and overflowing events as well as landslide events are more likely to occur due to sudden and extreme rainfall.

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