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Assessment of the desertification vulnerability of the Cappadocian district (Central Anatolia, Turkey) based on aridity and climate-process system

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Abstract

The present study discusses climate of the Cappadocian district in Turkey on the basis of Thornthwaite's climate classification and water budget, Erinç's aridity index and United Nations Convention to Combat Desertification (UNCCD) aridity index, along with the spatial and inter-seasonal variations of precipitation and air temperatures. Vulnerability of the Cappadocia to desertification processes was also investigated with respect to the aridity, lithology dominated by tuffs and climate-process system and present land-use features of the district. The data analysis revealed that coefficients of variation (CV) of the mean and maximum temperatures are the greatest in summer and the smallest in winter. Nevşehir and Kayseri environs are the most continental parts of the Cappadocia with a high inter-annual variability and low temperatures. Cappadocia is characterized with a continental rainfall regime having a maximum precipitation in spring. Variability of summer precipitation totals is greater than that of other seasons, varying from 65.7% to 78%. The CVs of the annual precipitation totals are about 18% at north and about 20% at south. Semi-arid and dry sub-humid or semi-humid climate types prevail over Cappadocia according to Thornthwaite's moisture and Erinç's aridity indices. Steppe is the dominant vegetation formation with sparse dry trees. The Cappadocia is vulnerable to the desertification processes due to both natural factors (e.g. degree of aridity, climate-process system, weathering of tuffs, erosion, climate change, etc.) and human-involvement (e.g. land degradation and intensive tourism, etc.). In order to mitigate desertification and to preserve the historical and cultural heritages in Cappadocia, sustainable land-use management and tourism planning applications are urgently needed.

Key Words: Turkey; Cappadocia; climate variability; Thornthwaite's water budget; Erinç and the UNCCD aridity indices; climate-process system; desertification.

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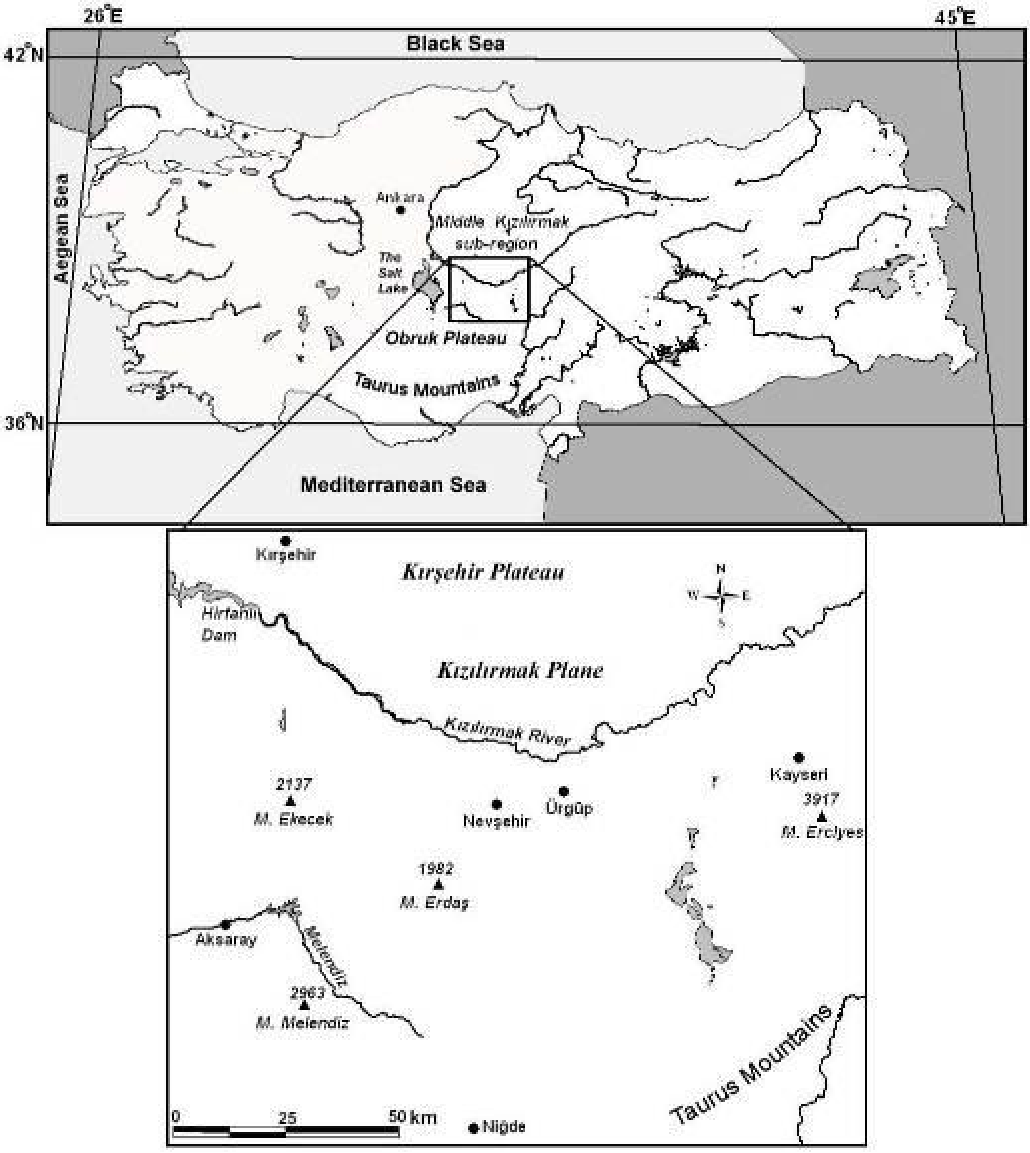

Figure 1: Location map of the Central Anatolia Region of Turkey including the Kızılırmak sub-region, and locations of six meteorological stations over the Cappadocian district used in the study.

1. Introduction

In addition to the agriculture, tourism is one of the important and increasing values of the Central Anatolia (CAN, here after) region of Turkey. Most of the touristic sites and activities are found around the administrative city provinces of the region, such as Ankara, Konya, Kayseri, Nevşehir, Aksaray and Niğde. Among these, Nevşehir-Aksaray-Niğde environs take part within the Middle Kızılırmak (Red River) sub-region of the CAN region. Today's Middle Kızılırmak sub-region, which is a definition used according to the classification of Turkey's geographical regions, mainly corresponds to southern part of the 'old Cappadocia Region' with respect to the historical geography of the Anatolia.

Historically, borders of the 'Cappadocia Region' had been described as a very large region surrounded by the Taurus Mountains in the south, Aksaray in the west, Malatya in the east and all the area extending up to the Black Sea coast in the north of the Anatolian Peninsula. It should be underlined at this point that the name 'the Cappadocian district' used presently for the purpose of tourism is, in reality, the area that is covered by the city provinces of Kırşehir, Nevşehir, Aksaray, Niğde and Kayseri (Figure 1). Presently smaller Cappadocian district has so many natural, historical and cultural beauties including the most well known sites of Üçhisar, Göreme, Avanos, Ürgüp, Derinkuyu, Kaymaklı and Ihlara. In the present study, we used, from the historical geographical standpoint, 'Cappadocia' to describe an extensive area that occurs among the city provinces of Kırşehir, Nevşehir, Kayseri, Aksaray and Niğde located at the southern part of the Middle Kızılırmak sub-region of the CAN region of Turkey.

Historical and cultural tourism comes first among tourism resources of the region. Traces of the prehistoric cultures in Cappadocia are found around Köşkhöyük (Niğde), Asıklıhöyük (Aksaray) and Civelek cave (Nevşehir). Scientific excavations in these sites are still implemented. Cappadocia had been influenced by many migrations and attacks from the east during the Roman Empire period. Today, there are many ancient churches characterized with colored wall pictures and religious motives. Churches were built up by carving out the volcanic tuff formations. Underground settlements at the Derinkuyu and Kaymaklı sites that had been built up by the first Christians who had escaped from the serious confusions are found very attractive by the tourists interested in the human civilizations and the history of fine arts of the region. Cappadocia is also suitable for development of the nature tourism with its fascinating natural beauties. The most famous one of the natural beauties could be most easily visited in the vicinity of Üçhisar-Ürgüp-Avanos triangle. This area is most known with its very attractive earth pillars (fairy chimneys) or so-called Peri Bacaları in Turkish and the under-ground cities. Ihlara valley that is located within the valley of the Melendiz River is another natural and historical beauty of Cappadocia.

Desertification is defined in the UNCCD as "land degradation in *arid, semi-arid, and dry sub-humid areas* resulting from various factors, including climatic variations and human activities" (UNCCD 1995). Furthermore, the UNCCD defines the land degradation as a reduction or loss in *arid, semi-arid, and dry sub-humid areas* of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including those arising from human activities and habitation patterns, such as: (i) Soil erosion caused by wind and/or water; (ii) Deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) Long-term loss of natural vegetation.

With parallel to these definitions, desertification vulnerability is of the degree to which a system (e.g. an arid or a semi-arid ecosystem or land) is susceptible to, or unable to cope with, adverse effects of desertification intensified by climate changes including increased climate variability and extremes. Vulnerability is also a function of the nature, magnitude, and rate of desertification to which a system is exposed, its sensitivity, and its adaptive capacity. In this frame, desertification vulnerability of the land mostly appears because of the miss land-use practices such as over-grazing, woodcutting, over-cultivation practices. On the other hand, wrong and/or irrational water management plans and applications leading to soil salinization is the main cause of the degradation of irrigated lands. Desertification process would also cause serious loss of soil fertility, soil compaction and crusting, in addition to vegetation degradation, soil erosion and salinization.

Although understanding vulnerability of a region or a district to the desertification in the arid, semi-arid and dry sub-humid or even in semi-humid environment are of great importance, vulnerability studies for these climatologically dry climate regions with an evident water deficient through the year or it's only one season or it's few seasons are limited with respect to both the content and numbers. There are some different approaches in studying the desertification process and vulnerability of a geographical area to desertification.

For instance, Reynolds et al. (2007) suggested a new synthetic framework so called "the Drylans Development Paradigm (DDP) by considering the recent lessons includes functioning of dryland ecosystems and the livelihood systems of their human residents. The DDP is supposed to help guiding the inherent complexity of desertification and dryland development, identifying and synthesizing those factors important to research, management, and policy makers. Some researchers investigated efficient and applicable ways of monitoring of the desertification processes and desertification vulnerability by making use of the climatic series of observations and climate-related variables, various climatic and/or aridity and drought severity indices, and remotely-sensed data and indices (Türkeş and Tatlı, 2010). For instance, these kind of studies were performed by Feoli et al. (2003) for the coastal area of Turkey, Karnieli and Dall'Olmo (2003) for the Negev (Israel) and Sinai (Egypt) regions of the Middle East, Michetti et al. (2007) for the Southern Italy, Sonmez et al. (2005), Türkeş (1999), Türkeş and Tatlı (2009), and Türkeş et al. (2009) for Turkey.

In further detailed studies, for example, Frattaruolo et al. (2008) produced a desertification vulnerability map at a scale of 1:25,000 for the Northern Apulia (Tavoliere) sub-region of the Southern Italy by combining two different approaches proposed by the Sardinian Regional Agrometeorological Service and by Pimenta et al. (1999). This methodology is mainly based on the combination of aridity, drought and soil loss indices. Each of these indices is related to one significant precipitation and water related aspects of the desertification process. On the other hand, Reich et al. (2001) investigated the desertification vulnerability of Africa by assessing the information on soils, climate and previously evaluated land resource stresses. The GIS-based desertification vulnerability map was coupled to the interpolated population density map to estimate the number of persons affected by the desertification. Eswaran et al. (2001) also studied the global desertification tension zones of the Earth's land surfaces and developed derivative maps of major land resource stresses, land quality, vulnerability to desertification, and susceptibility to wind and water erosion based on spatial data bases of the global soils, climates and published information on land resource constraints. Being similar with Reich et al. (2001), they superimposed the map of vulnerability to desertification on an interpolated population density map in order to evaluate the number of people affected. Their analysis revealed that there are about 7.1 million km^2 of land under low risk of human-induced desertification, 8.6 million km^2 at moderate risk, 15.6 million km^2 at high risk, and 11.9 million km^2 under very high risk due to the desertification processes. They also pointed out that the major critical tension zone that requires immediate attention via policies and measures is the very high-risk class characterized with an 11.9 million km^2 of land with about 1.4 billion inhabitants.

It is generally known that the Cappadocian district is characterized with a continental climate and arid environmental conditions. However, the Cappadocian climate was not studied so far in detail except those performed by Kutiel and Türkeş (2006), Türkeş (2007) and Atalay (2010), although some important spatial differences are evident with respect to the climate types particularly due to the precipitation and temperature climatology of the sub-region. On the other hand, the Cappadocian district has been under the heavy pressure of human-induced activities such as agriculture, tourism and several geo-environmental factors including the desertification processes mainly arising from geology, dry environmental conditions and climate-process system.

Consequently, the aims of the study are determined as follows:

(i) To reveal spatial and inter-seasonal patterns of precipitation and temperatures; (ii) to synthesis associations of variability in the Cappadocian climate with synoptic-scale atmospheric circulation and large-scale atmospheric oscillation patterns based on previous studies performed for Turkey as a whole or directly for the district; (iii) to examine the hydroclimatological characteristics of the district in detail according to the Thornthwaite's climatic water budget approach; (iv) to determine arid land types of the district according to various climate classifications and make a comparison among them; and (v) to assess vulnerability of the Cappadocian district to desertification mainly with respect to the climatic and some other geologic, geomorphologic and anthropogenic factors.

2. Environmental Settings

According to the regional geographical classification of Turkey, boundaries of the southern portion of the Middle Kızılırmak sub-region of the CAN region covering Cappadocian district is delimited by the Kırşehir plateau and the Kızılırmak plain in the north, Erciyes volcano and Sultan Sazlığı (the Sultan Marsh) in the northeast and the Tuz Gölü (the Salt Lake) closed basin and the Obruk plateau in the west (Figure 1). The eastern and southern boundaries of the sub-region pass through western and northern slopes of the segments of the Aladağlar and Bolkar mountains of the Taurus Mountains, respectively. The sub-region has an appearance of large plateaus, plains and individual volcano mountains and other types of volcanic landforms.

The Mesozoic and Paleozoic metamorphic and plutonic rocks and Pleistocene–Neocene aged terrestrial and lacustrine sediments are found in and southern and south-eastern environs of the Kırşehir plateau (Atalay, 1997; İlhan, 1976). According to Sür (1972), a large area in the CAN was affected by volcanic activities during the early Pliocene-Miocene. Thus, the CAN volcanic area is characterized with several eruptive centers represented with the presence of various volcanoclastic lithologies. In and around the CAN volcanic area, there are several tectonically induced Quaternary basins of various shapes and size (Kuzucuoglu et al., 1998), such as Salt Lake (Tuz Gölü) and Konya Plain to the west, Derinkuyu and Niğde basins to the south, and the Sultansazlığı depression to the east. Kuzucuoglu et al. (1998) studied the Quaternary environmental evolution history in the CAN. They considered tephra layers as chronostratigraphical markers between lacustrine sequences studied in cores or in sections surrounding eruptive centers of the CAN volcanic area. They identified, characterized and linked tephra samples from different locations in the Konya Plain and the Cappadocia, to eruptions of the nearby volcanoes. In addition, their study on the sediment fill of the so-called Eski Acıgöl (or Nar Gölü) maar near Nevşehir has allowed the recognition of several eruptions during the Late Glacial and the Holocene in the vicinity of this lake.

The most interesting erosion landforms cut in ignimbrites are situated around the volcanic fields. The Quaternary and the late Pliocene aged volcanic formations are most pronounced for the Nevşehir and Ürgüp environs (Sür, 1972). Earth pillars that constitute very spectacular landforms in Cappadocia area are found typically in the Nevşehir and Ürgüp environs. Today, these forms have a considerable tourism value and, in practice, they are used for several purposes, such as residents, fruit and vegetable store places. To conclude in terms of the geomorphologic perspective, the most obvious characteristic of the Cappadocian district is that the landforms do not show great complexity due particularly to geologic and tectonic features.

The climate of Turkey, which is characterized mainly by the Mediterranean macroclimate, results from seasonal alternation of the mid-latitude frontal lows, with the polar air masses, and the subtropical high pressures, with the subsiding maritime tropical and continental tropical air masses. Continental tropical air-streams from the Northern African and the Middle East/Arabian regions generally dominate particularly throughout summer by causing long-lasting warm and dry conditions over Turkey, except in the Black Sea region and the continental northeastern part of the Anatolian Peninsula (Türkeş, 1996, 1998, 1999, 2003a). In winter, a well-known combination of the North-eastern Atlantic originated mid-latitude and the Mediterranean cyclones and subtropical anticyclones from the Azores control the weather and climate in Turkey. Turkish precipitation is generally associated with the location, variation and activity of the atmospheric centers of action throughout the year

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except summer over most of Turkey (e.g., Atalay, 2010; Kutiel et al., 2001; Tatli et al., 2004; Türkeş, 1998, 2010a; Türkeş et al., 2002a; Türkeş et al., 2009).

In a recent study, Jones et al. (2006) produced a high-resolution proxy record, which is a proxy of precipitation and evaporation variability through the past 1700 years, from oxygen isotope analysis of a varved lake sequence from the Cappadocian district of the continental CAN region, and analyzed its links to the North Atlantic and the monsoon climate. They concluded that changes in their proxy data were consistent with changes in instrumental and proxy records of Indian monsoon, dry summer in the Eastern Mediterranean being related with periods of enhanced monsoon precipitation. In addition, major shifts in the record were coherent with changes in North Atlantic winter climate with cold, wet periods in the Alps occurring at times of dry Turkish climate (Jones et al., 2006).

Table 1: Basic information on six meteorology stations of the Cappadocian district chosen for the study.

Station	Station ID Number	Longitude (E)	Latitude (N)	Station Height (m)	Record period Precipitation	Temperature
Kırşehir	17160	34°09'	39°10'	1007	1930-2002	1930-2002
Kayseri	17196	35°29'	38°45'	1093	1938-2002	1938-2002
Ürgüp	17835	34°55'	38°38'	1060	1963-2002	1970-2002
Nevşehir	17193	34°42'	38°37'	1260	1955-2002	1960-2002
Aksaray	17192	34°03'	38°23'	961	1938-2002	1964-2002
Niğde	17250	34°41'	37°58'	1211	1935-2002	1935-2002

3. Data

Precipitation and temperature data sets used in the study were originally developed by Türkeş (1996, 1998) for the 99 stations in the period 1929-1993 and Türkeş et al. (2002b) for the 70 stations in the period 1929-1999 in Turkey, respectively. The precipitation data set was updated for the years 1994 to 2002 and temperature set 2000 to 2002 with two short-period stations such as Ürgüp and Nevşehir for the present study. Precipitation and temperature data sets consisted of monthly precipitation totals (mm) and monthly mean, maximum and minimum temperatures (°C) recorded at six stations of the Turkish State Meteorological Service (Table 1). Detailed information for meta-data and homogeneity analyses applied to long-term precipitation and temperature series of Turkey can be found in

Türkeş (1996, 1999) and Türkeş et al. (2009), and Türkeş et al. (2002b), respectively. Spatial distribution of six stations over Cappadocia is shown in Figure 1.

Table 2: Thornthwaite's climate types corresponding to the Moisture Index (L_m). Rearranged based on Essenwanger (2001), according to Carter and Mather's expansion (1966).

Moisture index (L_m)	Climate type	
100 and above	*A*	Perhumid
80 – 100	B_4	Humid
60 – 80	B_3	Humid
40 – 60	B_2	Humid
20 – 40	B_1	Humid
0 – 20	C_2	Moist humid
-20 to 0	C_1	Dry sub-humid
-40 to -20	*D*	Semi-arid
-60 to -40	*E*	Arid

4. Methodology

4.1 Thornthwaite's Climate Classification

Thornthwaite's climate classification and water budget were calculated by taking into consideration of the approach used in the WATBUG program, which was developed by Willmott (1977) for climatic water budgets.

Table 3: Thornthwaite's classification for seasonal variation of the effective moisture. Rearranged based on Essenwanger (2001), according to Carter and Mather's expansion (1966).

Dry climates (C_1, *D*, *E*)	I_h	Moist climates (*A*, *B*, C_2)	I_a
d Little or no water surplus	0 – 16.7	*d* Little or no water deficiency	0 – 10
s Moderate winter water surplus	16.7 –33.3	*s* Moderate summer water deficiency	10 – 20
w Moderate summer water surplus	16.7 – 33.3	*w* Moderate winter water deficiency	10 – 20
s_2 Large winter water surplus	> 33.3	s_2 Large summer water deficiency	> 20
w_2 Large summer water surplus	> 33.3	w_2 Large winter water deficiency	> 20

Thornthwaite's ***Moisture Index*** (1948) is calculated as follows:

$$L_m = (100S - 60D)/PE \quad (1)$$

where, *S* is annual water surplus and *D*, water deficit in mm; *PE* is annual adjusted potential evapotranspiration (*APE*) in mm. Negative values of the moisture index are found in dry climates, while positive values are found in moist climates (Table 2).

Thornthwaite's ***Aridity Index*** (I_a) and ***Humidity Index*** (I_h) are used to determine Seasonal Variation of the Effective Moisture (Table 3). The humidity index is used for dry

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climates; and the aridity index is used for moist climates (Mather, 1974). These indices are defined as follows:

$$I_h = (S/PE)\cdot 100 \quad (2)$$

and

$$I_a = (D/PE)\cdot 100 \quad (3)$$

where, *S*, *D* and *PE* equal annual water surplus, deficit, and potential evapotranspiration, respectively.

Table 4: Index of the Thermal Efficiency and classification for summer concentration of the Thermal Efficiency. Rearranged based on Mather (1974).

Thermal efficiency *PE* (cm)	Climate type	Summer concentration %	Type
114.0	A' Megathermal	< 48.0	a'
114.0 – 99.7	B'_4 Fourth Mesothermal	48.0 – 51.9	b'_4
99.7 – 85.5	B'_3 Third Mesothermal	51.9 – 56.3	b'_3
85.5 – 71.2	B'_2 Second Mesothermal	56.3 – 61.6	b'_2
71.2 – 57.0	B'_1 First Mesothermal	61.6 – 68.0	b'_1
57.0 – 42.7	C'_2 Second Microthermal	68.0 – 76.3	c'_2
42.7 – 28.5	C'_1 First Microthermal	76.3 – 88.0	c'_1
28.5 – 14.2	D' Tundra	88.0 – 100	d'
–	E' Frost	–	

Thornthwaite's ***Index of Thermal Efficiency*** is used to get a thermal classification of the climate types. Thornthwaite used *PE* as an index of thermal efficiency (Mather 1974). Since it expresses the amount of energy available in climate at a particular place in terms of the water that could be evaporated by this energy if water was readily available, *PE* combines both thermal and moisture aspects of the climate. A *PE* value of 114 cm was selected, which would result at a station having a mean temperature every month of 23°C and there is no variation in day length, to separate megathermal from mesothermal climates (Table 4).

Thornthwaite's ***Summer Concentration of Thermal Efficiency*** is used as an index for expressing how much of the thermal energy is received during three summer months (Table 4). Three-month period varies depending on the climate types. In Turkey, the warmest three summer months are widely used (Erinç, 1969). It is defined as the total PE amount of three summer months as percentage of annual PE.

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4.2 Erinç's Aridity Index

Erinç's ***Aridity (Precipitation Efficiency) Index*** (I_m) (1965) is based on precipitation and maximum temperature, which is supposed to cause water deficiency due to evaporation. The basic equation of I_m is defined as follows:

$$I_m = (\overline{P}/\overline{T}_{\max}) \quad (4)$$

where, $\overline{P}$ and $\overline{T}_{\max}$ equal to long-term averages of annual precipitation total (mm) and annual maximum temperature (°C), respectively.

Table 5: Erinç's climate types corresponding to the Aridity Index (I_m) and vegetation types (from Kutiel and Türkeş (2005) based on Erinç (1965).

Aridity Index (I_m)	Climate type	Vegetation type
< 8	Severe arid	Desert
8 – 15	Arid	Desert-like steppe
15 – 23	Semi-arid	Steppe
23 – 40	Semi-humid	Dry forest
40 – 55	Humid	Humid forest
> 55	Perhumid	Perhumid forest

Erinç (1965) divided his index into six major classes by comparing results of the index with spatial distribution of vegetation formations over Turkey as in Table 5.

Table 6: Dry land (arid climate) types in Turkey according to the Aridity Index (AI) and their vulnerability to desertification (Türkeş, 1999).

Aridity criteria	Dry land type	Assessment
$0.05 \le AI < 0.20$	Arid areas	Vulnerable to desertification (no in Turkey)
$0.20 \le AI < 0.50$	Semi-arid areas	Vulnerable to desertification
$0.50 \le AI < 0.65$	Dry sub-humid areas	Vulnerable to desertification
$0.65 \le AI < 0.80$	Sub-humid areas	Vulnerable to desertification

4.3 The UNCCD Aridity Index

For the purposes of the United Nations Convention to Combat Desertification (UNCCD), arid, semi-arid and dry sub-humid climates were defined as "areas, other than polar and sub-polar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65" (UNCCD 1995). In the present study, *UNCCD Aridity Index (AI)* is used as one of the base methods for determining dry land types in the study area and assessing their vulnerability to the desertification processes. Following the UNEP (1993), *AI* is written as:

$$AI = (P/PE) \qquad (5)$$

where, P and PE are annual precipitation (mm) and potential evapotranspiration (mm) totals, respectively. The AI values below 1.0 show an annual moisture deficit in mean climatic conditions. The criterions in Table 6 were used to characterize the dry lands of Turkey (Türkeş, 1999).

5. Results

5.1 General Climatology

Temperature Conditions

The coldest month of monthly *minimum temperatures* (monthly averages of daily minimum (night-time) temperatures) is January and the warmest month is July at all stations. If all monthly average minimum temperatures are compared, it is seen that monthly minimum temperatures in Cappadocia vary between -7.3 °C at Kayseri station in January and 15.7 °C at Aksaray station in July (monthly tables and figures of minimum, maximum and mean temperatures are not given). Annual (Figure 2a) and seasonal average minimum temperatures are generally characterized by a meridional pattern increasing from west to east.

The coldest month of monthly average *maximum temperatures* (monthly averages of daily maximum (day time) temperatures) is January at all stations with a minimum of 3.4 °C at Nevşehir, whereas the warmest month is July at stations of Kayseri, Aksaray, Nevşehir and Ürgüp with a maximum of 30.5 °C at Kayseri. However, August is the warmest month at Kırşehir and Niğde. Annual (Figure 2b) and seasonal average maximum temperatures display a geographical relationship over the sub-region with a centre of minimum just over Nevşehir.

Regarding all monthly *mean temperatures* (monthly averages of daily mean temperatures), the coldest month of the year is January with a minimum value of about -2.0 °C at Kayseri, while the warmest month of the year is July with a maximum value of 23.4 °C at Aksaray. Mean January temperatures are below zero at all stations, except a positive value at Aksaray. Annual (Figure 2c) and seasonal averages of mean temperatures generally show a different spatial pattern when compared with each other. The mean annual temperatures vary from 10 °C at Ürgüp to 11.8 °C at Aksaray). Below zero mean winter temperatures are

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observed at Kayseri and Ürgüp, which are more continental type stations in the east of the sub-region.

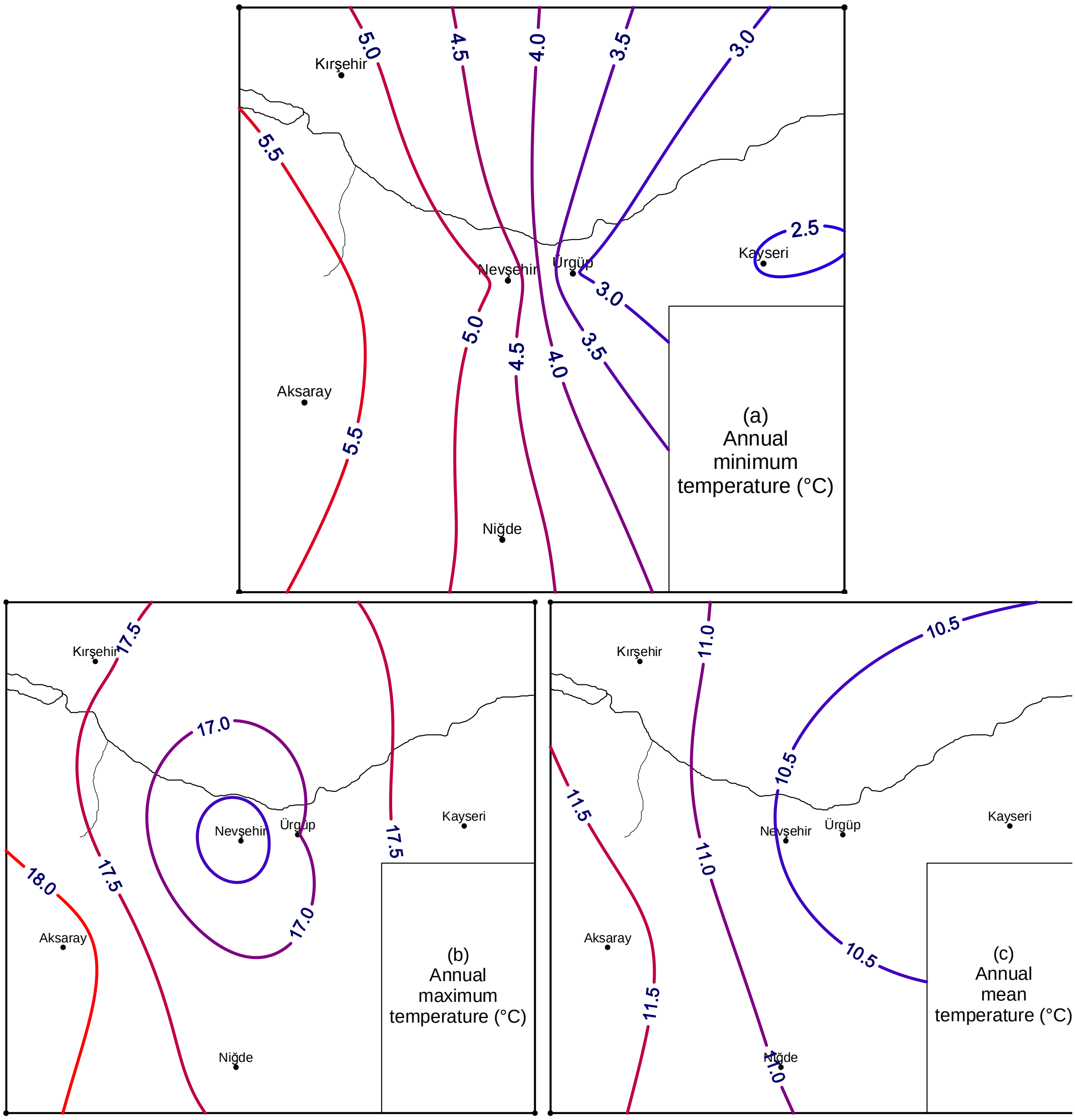

Figure 2: Spatial distributions of long-term averages of annual minimum, maximum and mean temperatures (°C) for six stations in the Cappadocian district.

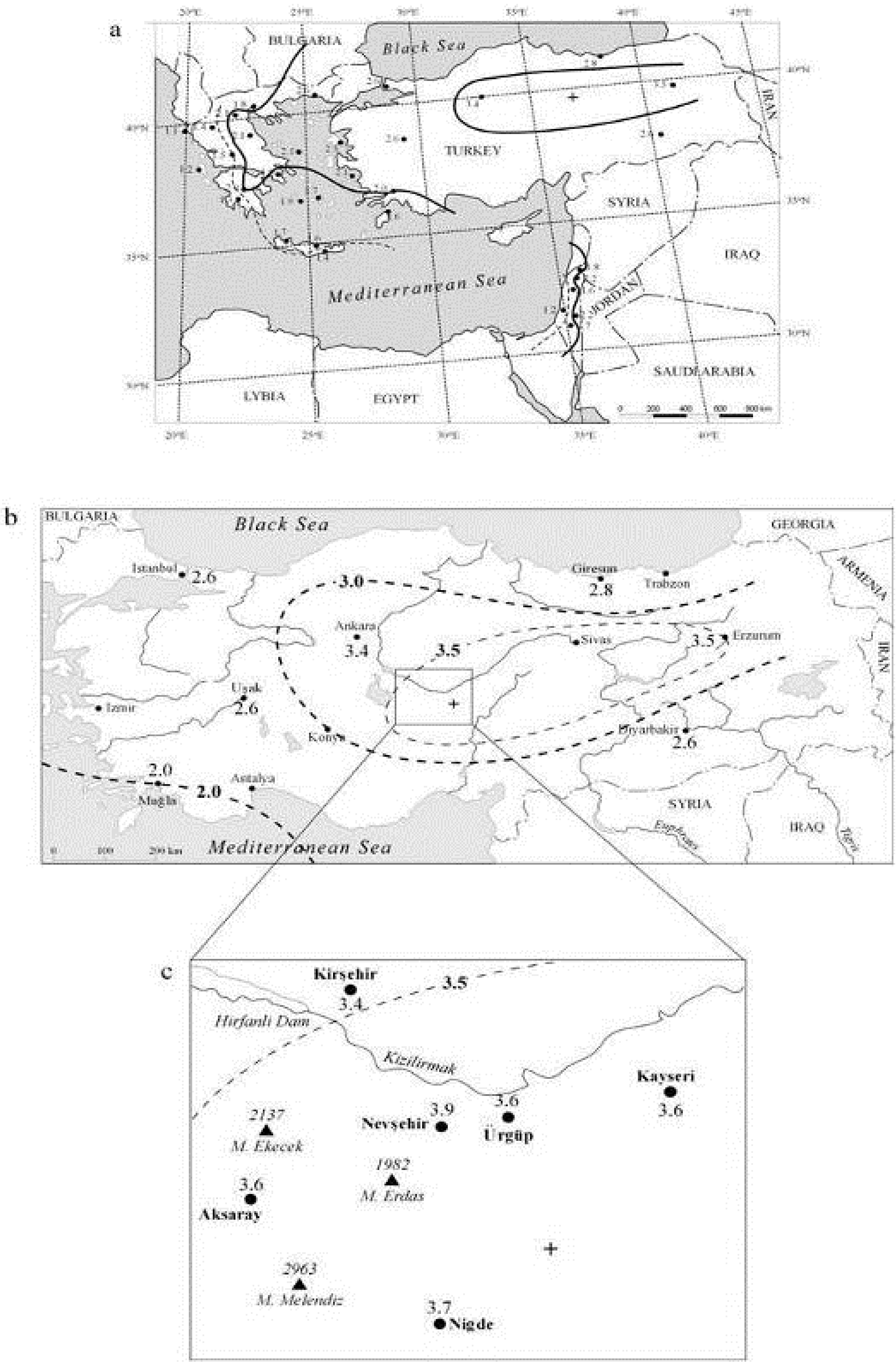

Figure 3: The spatial distribution of the temperature differences between NCP(–) and NCP(+). Values indicate the mean difference between NCP(–) and NCP(+) (in °C) for the period October to April: (a) in the region; (b) in Turkey; (c) in the Cappadocia (from Kutiel and Türkeş, 2005).

Kutiel et al. (2002) showed that temperatures in the continental CAN region, as in other regions of Turkey and the Middle East, are highly influenced by large-scale circulation at the 500 hPa upper-air level. The two phases of the North Sea–Caspian Pattern (*NCP*-an upper level teleconnection with two poles located at the North-Sea and at the Caspian) differentiate better than any other teleconnection between below or above normal temperatures. During the negative phase – *NCP*(-), there is an enhancement of south-westerly to southerly circulation resulting in above average temperatures, whereas during the positive phase – *NCP*(+), there is an enhancement of opposite circulation, resulting in a significant temperature reduction. The greatest influence on mean temperatures was detected in Turkey, especially over Cappadocia district, mainly from October to April (Kutiel et al., 2002; Kutiel and Türkeş, 2005) (Figure 3).

Inter-annual variability in temperature and precipitation series was examined by the coefficient of variation (CV) in order to make an objective comparison among stations with respect to variability. The CV is calculated by expressing standard deviation as percentage of long-term average of the series. The CVs for winter minimum and mean temperatures could not be used due to below zero values in these series, even though CVs of all temperature series were calculated for each season. Consequently, a comparison of variability among the stations was made only for seasonal average maximum temperatures along with annual average minimum, maximum and mean temperatures.

The CV rates of maximum temperatures are found to be the greatest in winter and the smallest in summer. The CVs of winter maximum temperatures range from about 37% at Aksaray to about 48% at Nevşehir. Summer maximum temperatures are characterized by small CV rates, and CVs are found between about 3.4% at Aksaray and 4.4% at Nevşehir. Maximum centre of CVs of summer maximum temperatures shows a clear consistency with the spatial pattern of summer maximum and mean temperatures.

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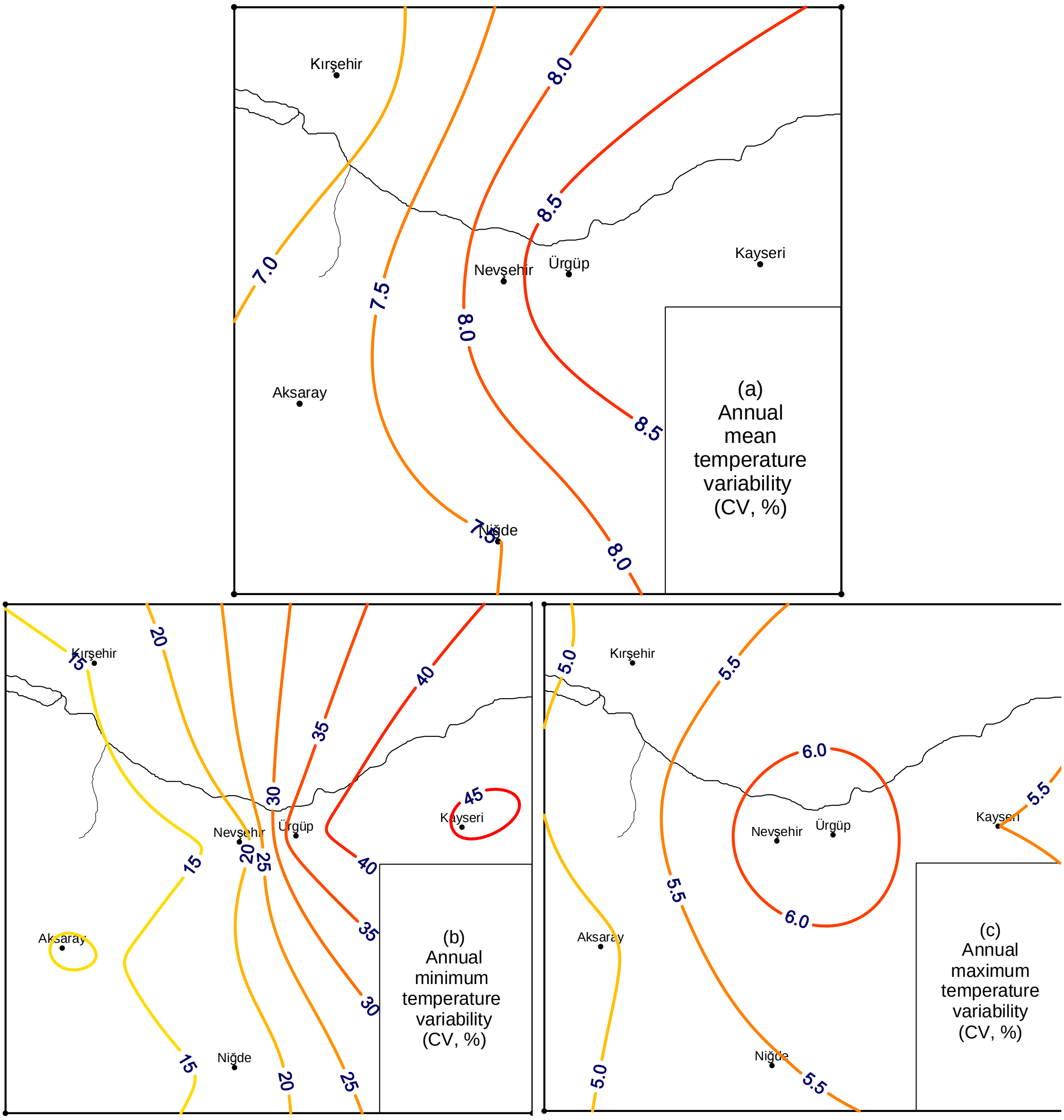

Figure 4. Spatial distributions of inter-annual variability (CV in percentage) in annual averages of mean, minimum and maximum temperatures of six stations in the Cappadocian district.

The CVs of annual minimum, maximum and mean temperatures increase from western stations towards eastern stations (Figure 4). The centres of maximum CV rates of minimum, maximum and mean temperatures mostly locate over Kayseri and Nevşehir-Ürgüp provinces. The mid-eastern portion of Cappadocia between Nevşehir and Kayseri, therefore, could be considered as most continental part of the Cappadocia with a higher year-to-year variability and the lower temperatures compared with rest of the sub-region.

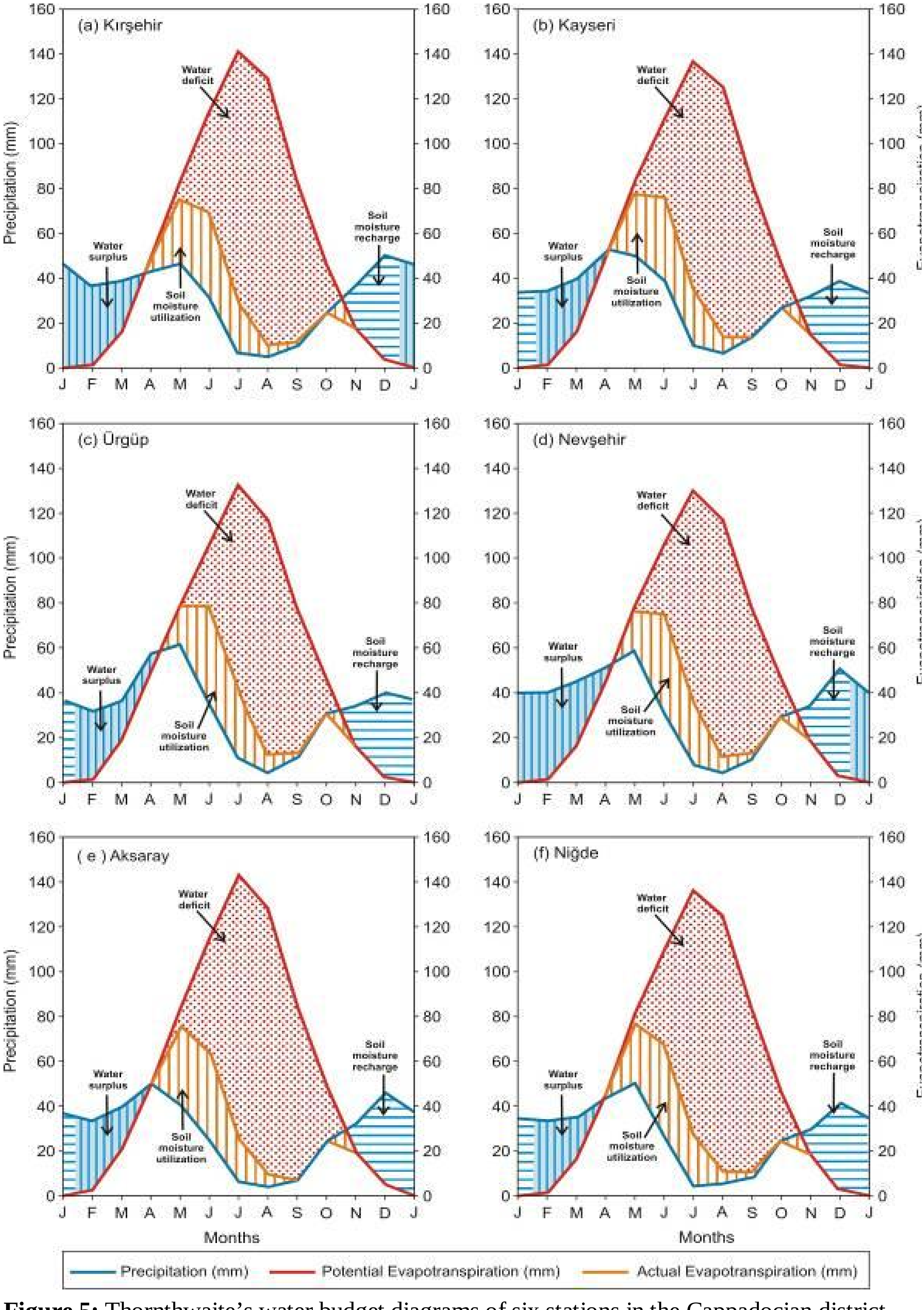

Figure 5: Thornthwaite's water budget diagrams of six stations in the Cappadocian district.

Hydroclimatology

Temporal variations of monthly *average precipitation amounts* show a somewhat uniform distribution in course of the year, except the period of July-August-September (Table 7). The period from July to September is characterized with insufficient precipitation and great evapotranspiration compared with other months. According to the Thornthwaite's water budget calculated for the six stations, a market water (i.e. soil moisture) deficit also occurs in this hot and dry period of the year (Figure 5).

Maximum precipitation amounts show up in spring months (April or May) at all stations except at Kırşehir that is in December, whereas minimum precipitation amounts are recorded in August at all stations except at Niğde that is in July (Table 7). Maximum precipitation amounts in May or April are explained by additional contribution of the local convective instability showers and thunderstorm activities, which are so called "Kırkikindi yağmurları" (forty-afternoon rains) in Turkish, to the frontal mid-latitude cyclone activities in spring.

Dry (rainy) conditions in the sub-region are closely related with the anticyclonic (cyclonic) circulation types or pressure centers over just Turkey and/or its near surroundings. Regarding dry and wet conditions in the continental CAN region (including Cappadocia) represented by Ankara station, it is very likely that dry conditions in the region are associated with the anticyclonic anomaly circulation over Turkey, whereas wet conditions are linked to the cyclonic anomaly circulation just over Turkey or over the Aegean Sea and the Balkans, and the Black Sea basin from November to April (Kutiel et al., 2001).

Annual and seasonal average precipitation amounts in Cappadocia tend to decrease spatially from north or northeast to southwest (Figure 6). Annual precipitation amounts vary from a maximum of 412.4 mm at Nevşehir to a minimum of 336.4 mm at Niğde (Figure 6a). Maximum precipitation is generally concentrated over Nevşehir and Ürgüp environs, except in winter with a maximum at Kırşehir. Spring is the rainiest season in the sub-region except at Kırşehir, whereas the driest season is summer at all stations (Figure 6). Spring precipitation varies between a maximum of 156.6 mm at Nevşehir and a minimum of 126 mm at Aksaray, whereas winter precipitation range from a maximum of 134.6 mm at Kırşehir to a minimum of 106.4 mm at Kayseri. In autumn, precipitation amounts are found between 75.2 mm at Ürgüp and 61.9 mm at Niğde.

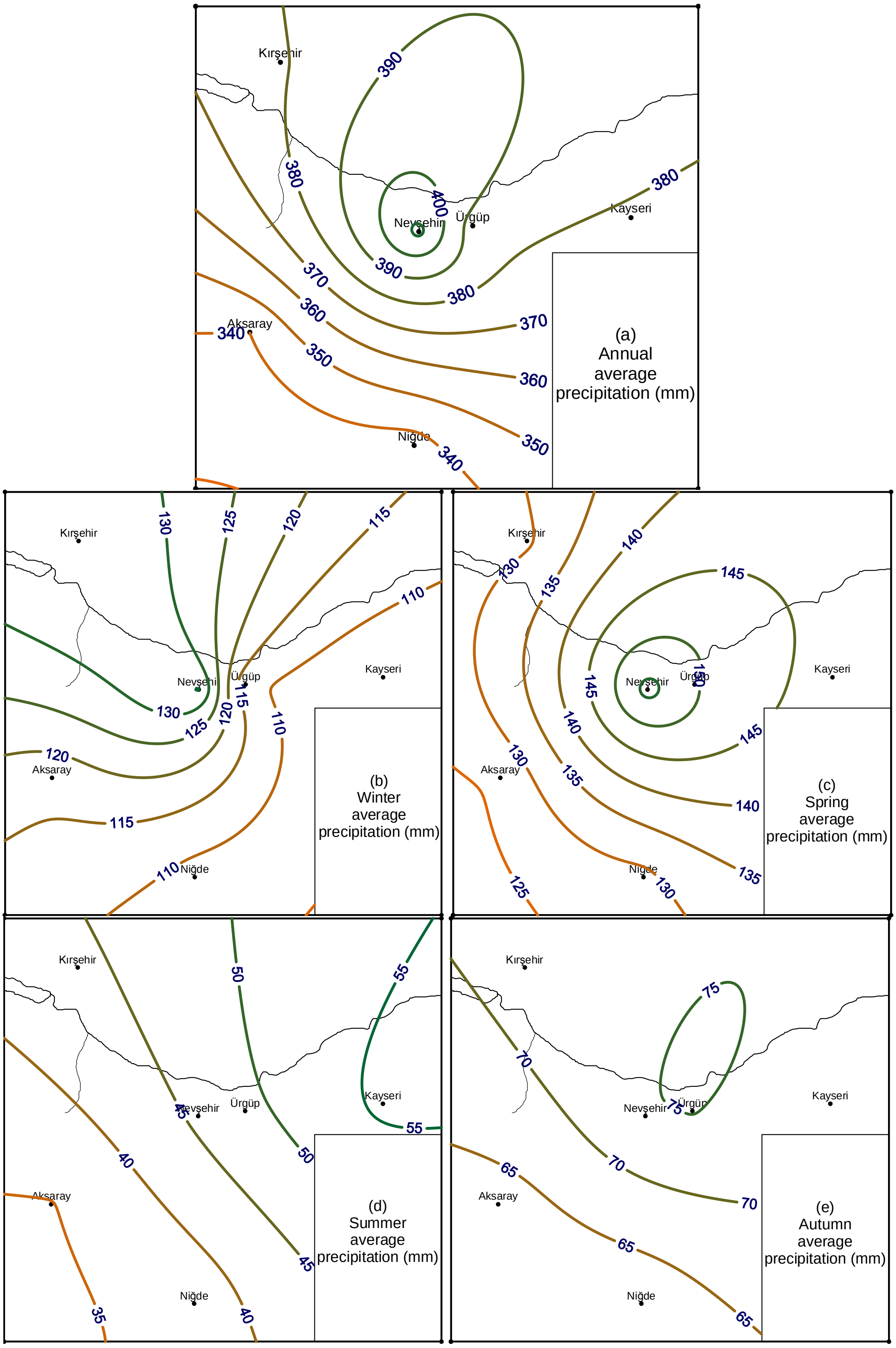

Figure 6: Spatial distributions of annual and seasonal average precipitation amounts (mm).

Precipitation variability of the study area is most sensitive to influence of the North Atlantic Oscillation (NAO). Türkeş and Erlat (2003, 2005) found a negative relationship between year-to-year variability of most of annual and seasonal precipitation series of Turkey, except in summer, and variability of the NAO indices (NAOIs). Negative correlation coefficients, which are particularly strong in winter and partly in autumn over western and central Turkey including the Cappadocia, become weaker in spring and almost non-existent in summer. Türkeş and Erlat (2003) showed that precipitation regime in Turkey is mostly characterized by wetter than long-term average conditions during the negative (i.e. weak) NAOI phase, whereas the positive (i.e. strong) NAOI responses mostly exhibit drier than long-term average conditions throughout the year, except in summer.

As for the *seasonality of precipitation*, percentage contribution of spring average precipitation amount to annual average precipitation total, which is varying between about 34% and 39.0%, is greater than in winter at all stations except at Kırşehir. Contribution of winter precipitation is found between 28.1% and 35.5%. Summer precipitation contributes to about 10% to 15% of annual total, whereas autumn precipitation contributes about 18% to 20% of annual total, which are the most homogeneous inter-stations distribution compared with other seasons. According to Türkeş's (1996, 1998) classification, the Cappadocian district belongs to the continental CAN rainfall regime. The CAN rainfall region is mainly situated between the uniform rainy Black Sea rainfall regime at north and the winter-rainy Mediterranean rainfall regime at south. Consequently, seasonality characteristics of the Cappadocian precipitation are influenced somehow by both two rainfall regimes in addition to influence of the continentality effect from the continental Eastern Anatolia region. Therefore, the Cappadocian rainfall regime is neither wholly uniform as in the Black Sea regime nor apparently seasonal as in the Mediterranean regime.

Inter-annual variability of monthly precipitation totals is considerably high in the Cappadocian district (Table 7). CV rates are well above 45% at all stations except at Nevşehir in February with a rate of 43.6%. Minimum CVs are found in winter or spring months. Maximum CVs correspond to August ranging from 177.2% at Nevşehir to 251.4% at Niğde (Table 7). These rates indicate very likely that the higher the inter-annual variability, the higher probability of occurrence of the drought events in summer in Cappadocia.

Table 7: Long-term averages, standard deviations (STD) and coefficients of variation (CV) of monthly and annual precipitation totals (mm) at six meteorology stations of the Cappadocian district, along with the confidence intervals (CI) of long-term averages at the 5 percent level of significance.

Descriptive Statistics	Months I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
	KIRŞEHİR (1930-2002)												
Average (mm)	46.6	36.8	39.5	43.1	46.7	32.3	6.5	5.1	10.4	24.9	36.2	50.7	378.8
CI (mm)	6.8	4.6	5.3	5.5	6.5	5.4	2.0	2.1	2.5	4.6	6.2	5.7	15.5
STD (mm)	29.8	20.0	22.9	24.0	28.2	23.6	8.9	9.0	11.0	20.0	26.8	24.8	67.8
CV (%)	63.8	54.3	58.1	55.6	60.5	73.2	137.7	177.3	106.1	80.0	74.0	49.0	17.9
	KAYSERİ (1938-2002)												
Average (mm)	33.6	34.4	39.1	53.0	50.9	39.2	10.0	6.8	13.4	26.8	32.7	38.7	378.6
CI (mm)	4.8	4.2	4.3	6.0	5.9	7.4	3.2	3.4	3.5	5.5	5.4	4.6	18.3
STD (mm)	19.8	17.3	17.6	24.8	24.5	30.4	13.0	13.9	14.5	22.5	22.1	19.0	75.4
CV (%)	58.9	50.2	45.0	46.8	48.0	77.6	130.1	203.8	108.5	83.8	67.7	49.0	19.9
	ÜRGÜP (1963-2002)												
Average (mm)	37.2	32.5	37.5	53.9	59.0	35.6	9.5	3.7	11.5	29.3	34.4	41.9	385.8
CI (mm)	6.2	5.4	5.6	9.1	9.3	7.8	4.5	2.2	4.1	7.8	6.5	6.0	21.2
STD (mm)	19.8	17.2	17.9	28.9	29.5	24.9	14.3	7.1	13.2	24.9	20.6	19.2	67.6
CV (%)	53.3	53.1	47.6	53.6	50.0	69.9	150.5	191.5	115.0	85.0	59.9	45.9	17.5
	NEVŞEHİR (1955-2002)												
Average (mm)	42.9	41.0	44.1	51.9	60.0	33.5	8.0	4.3	11.4	28.1	34.1	49.9	409.2
CI (mm)	6.7	5.1	5.9	7.3	8.9	7.0	3.1	2.1	3.1	7.4	6.3	6.8	22.3
STD (mm)	23.6	17.9	20.9	25.9	31.6	24.6	11.0	7.5	11.1	26.3	22.2	24.1	78.7
CV (%)	55.1	43.6	47.5	49.9	52.6	73.5	138.0	177.2	97.4	93.4	65.1	48.2	19.2
	AKSARAY (1938-2002)												
Average (mm)	39.3	34.3	39.1	45.3	41.4	25.5	4.7	4.2	8.4	24.6	30.0	42.9	339.7
CI (mm)	5.3	4.1	4.8	6.3	5.6	5.4	2.3	2.2	2.3	5.1	5.2	5.5	16.1
STD (mm)	21.7	16.9	19.7	25.8	23.1	22.4	9.3	9.2	9.5	21.0	21.3	22.4	66.2
CV (%)	55.3	49.1	50.3	56.9	55.7	87.6	199.1	217.2	112.5	85.5	71.1	52.3	19.5
	NİĞDE (1935-2002)												
Average (mm)	34.7	33.3	34.9	43.0	50.5	27.3	4.4	5.0	8.6	25.2	29.1	41.4	337.3
CI (mm)	4.9	4.6	4.7	5.4	7.0	4.8	1.4	3.0	2.4	4.6	4.7	5.3	16.0
STD (mm)	20.8	19.2	19.6	22.6	29.3	20.3	6.0	12.5	10.1	19.4	19.8	22.3	67.5
CV (%)	59.9	57.8	56.1	52.5	57.9	74.3	136.9	251.4	117.6	77.1	68.3	53.9	20.0

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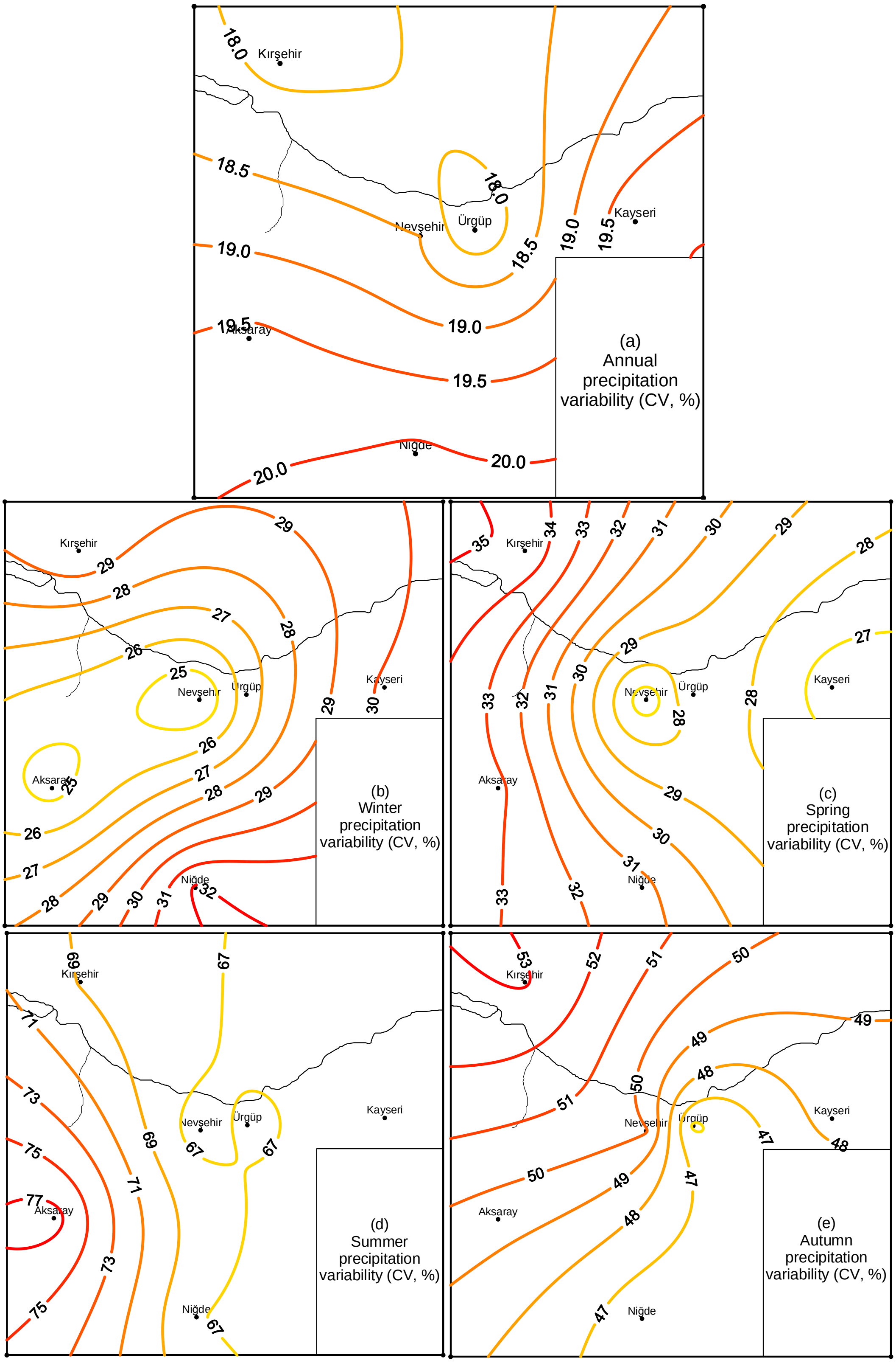

Figure 7: Spatial distributions of inter-annual variability (CV in percentage) in annual and seasonal precipitation totals.

Spatial pattern of inter-annual variability in annual precipitation totals (Figure 7a) reflects the common pattern of annual precipitation variability over Turkey, which decreases from southern part of the country mainly characterized by the Mediterranean type rainfall regimes to the Black Sea coast mainly with a uniform-rainy rainfall regime (Türkeş, 1996, 1999). The CVs are found between about 18% at north and about 20% at south, with a minimum centre of 17.5% at Ürgüp. On the other hand, variability in seasonal precipitation totals exhibit a differentiated spatial pattern among seasons with different maximum and minimum centers (Figure 7b-e).

Table 8: Climate types of the Cappadocian district in terms of various climate classifications.

Station	Erinç's Aridity Index (I_m)	Climate type	Thornthwaite's Moisture Index (L_m)	Climate Type	UNCCD Aridity Index (*AI*)	Climate type
Kırşehir	21.55	Semi-arid	-22.6	Semi-arid	0.55	Dry sub-humid
Kayseri	21.15	Semi-arid	-22.4	Semi-arid	0.57	Dry sub-humid
Ürgüp	22.71	Semi-arid	-20.0	Dry sub-humid	0.60	Dry sub-humid
Nevşehir	25.73	Semi-humid	-17.8	Dry sub-humid	0.63	Dry sub-humid
Aksaray	18.54	Semi-arid	-27.9	Semi-arid	0.49	Semi-arid
Niğde	19.46	Semi-arid	-26.2	Semi-arid	0.50	Dry sub-humid

5.2 Climate Types

Climate types of Cappadocia were determined by three climate classifications, and climate types of the stations were summarized in Table 8. Spatial distributions of these various classifications of Cappadocia climate are also shown in Figure 8 together in order to make a comparison among them.

Table 9: Detailed climate types of the Cappadocian district according to Thornthwaite's climate classification.

Station	Moisture index (L_m)	Thermal efficiency	Humidity index (I_h)	Summer concentration (%)	Climate type with symbols
Kırşehir	-22.6	68.4	10.2	55.9	$D\ B'_1\ d\ b'_3$
Kayseri	-22.4	65.9	8.4	56.4	$D\ B'_1\ d\ b'_3$
Ürgüp	-20.0	63.6	8.5	55.6	$C_1\ B'_1\ d\ b'_3$
Nevşehir	-17.8	64.8	11.7	54.6	$C_1\ B'_1\ d\ b'_3$
Aksaray	-27.9	70.0	5.8	55.1	$D\ B'_1\ d\ b'_3$
Niğde	-26.2	66.7	6.7	55.4	$D\ B'_1\ d\ b'_3$

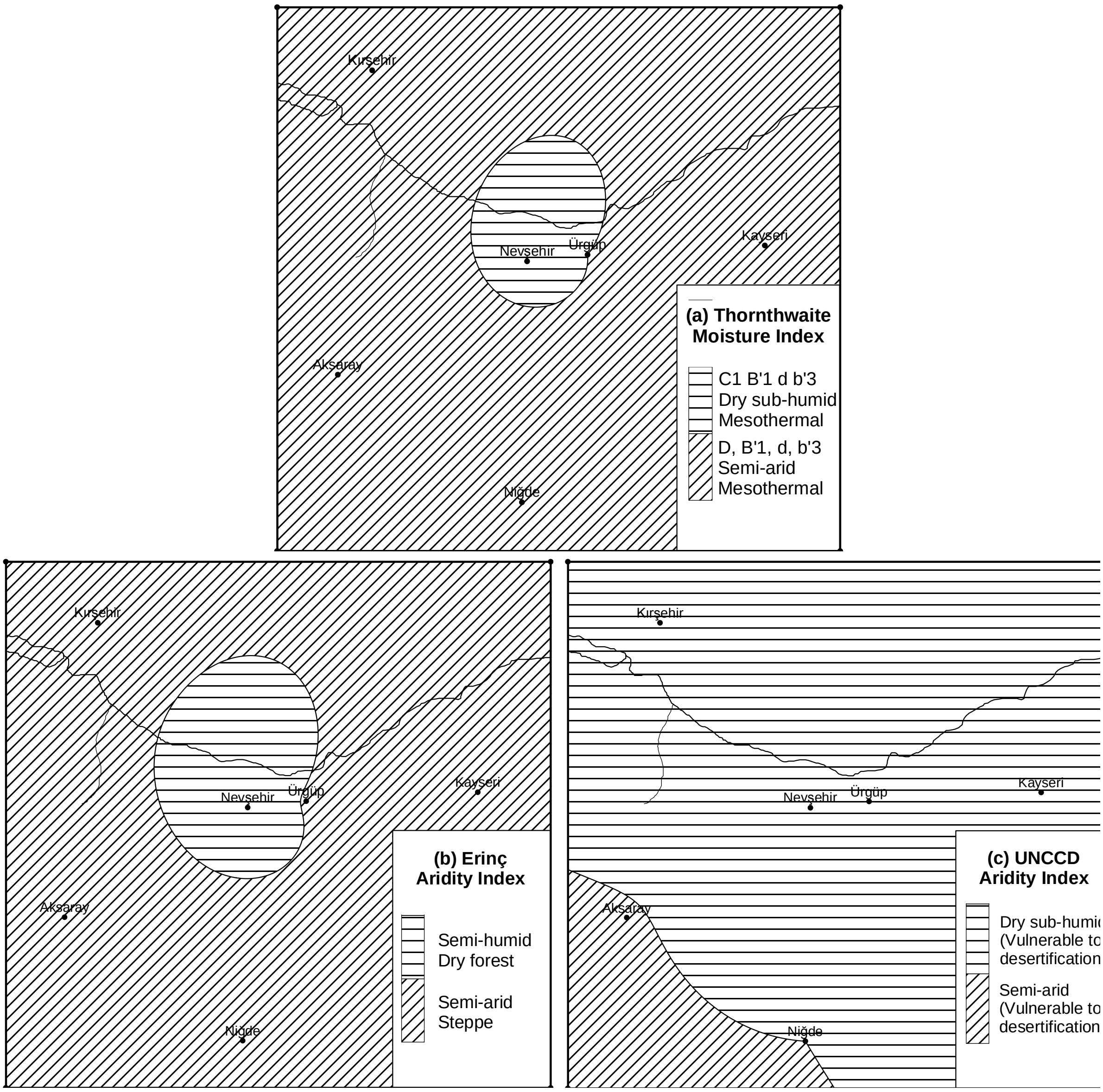

Figure 8: Geographical patterns of the climate types in the Cappadocian district according to the values of (a) Thornthwaite Moisture Index, (b) Erinç Aridity Index, and (c) the UNCCD Aridity Index, all of which were computed by using the climate data of six meteorology stations.

Thornthwaite's Moisture Index

According to the Thornthwaite's Moisture Index (*L*m), semi-arid and dry sub-humid climate types are dominant over the sub-region (Table 9; Figure 8a). Dry sub-humid climatic conditions concentrate only over the Nevşehir and Ürgüp (Figure 8a).

By referring the Thornthwaite's symbols in Table 9, climatic description of the stations could also be written in detail as follows by grouping the stations having the same climate symbols:

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(1) Kırşehir, Kayseri, Aksaray and Niğde are **semi-arid**, first mesothermal, little or no water surplus throughout the year, with a summer concentration of thermal efficiency equal to a third mesothermal climate.

(2) Ürgüp and Nevşehir are in a **dry sub-humid** climatic region, first mesothermal, little or no water surplus throughout the year, with a summer concentration of thermal efficiency equal to a third mesothermal climate.

Erinç's Aridity Index

Erinç's Aridity Index (I_m) perfectly depicts similar climatic conditions with the Thornthwaite's Moisture Index: semi-arid and semi-humid climate types prevail over the sub-region (Table 8 and Figure 8b). Semi-humid climate concentrates only over Nevşehir and Ürgüp environs, which is very similar spatial pattern with dry sub-humid climate of Thornthwaite's L_m over the same area (Figure 8b).

The *UNCCD Aridity Index*

According to the *UNCCD Aridity Index* (*AI*), dry sub-humid climate dominates at all stations except at Aksaray (Table 8). Dry sub-humid climate conditions exhibit a large spatial coherence over the sub-region, except the semi-arid area that covers southwestern portion of Aksaray and Niğde environs (Figure 8c). Although the AI generally produces more humid climate conditions for Cappadocia than those of other two climate indices, the Cappadocian district takes part in the semi-arid lands of the Earth having vulnerability to the impacts of the desertification processes with respect to the present (contemporary) climate.

5.3 Climate and Morphogenesis

Climatic geomorphology is one of the major philosophic approaches in the science of geomorphology. Wilson (1968) suggested the relationship between climate and process that is called a climate-process system, and the relationship between climate-process and landforms that is called a morphogenetic system. Based on the diagram (Ritter et al., 2002) consisting of the six major climate process systems that had been originally suggested by Wilson (1968), the Cappadocian district takes place within a semi-arid (sub-humid) climate process system. This assessment was made based on the data of Kırşehir, Niğde, Kayseri, Aksaray, Nevşehir and Ürgüp meteorology stations, by using their long-term averages of annual mean temperatures with 11.3, 11.0, 10.5, 11.8, 10.4 and 10.0 °C and of annual precipitation amounts of 378.8, 336.4, 378.6, 340.0, 412.4 and 385.8 mm, respectively. Consequently, dominant geomorphic processes in the research area are of running water and weathering (especially mechanical), which is the most common process seen in the research area, and associated landscape characteristics include pediment and fans, angular slopes with coarse debris and badlands.

5.4 Ecosystems and Land-use

Under the present semi-arid and dry sub-humid climate conditions, steppe is the dominant vegetation type in Cappadocia with some dry forests. According to Atalay (2002), who classified the ecological regions of Turkey, Cappadocia is located in the "dry forest-anthropogenic steppe sub-region" of the CAN region. Oaks (*Quercus* sp.) and black pine (*Pinus nigra*) are main natural tree species of the region. However, major parts of these forests were mostly cleared; only some little forested areas dominated on the slopes facing north and of the mountainously areas of the Cappadocian district. Steppe formation is widespread on the destroyed dry forest areas. Mountain grass formation (Alpine meadows) is only found on the mountainous areas rising over 2000 m such as on the mountains of Erciyes, Melendiz and Hasan Dağı. In general, the central Anatolia plateau of Turkey has historically been an important meeting place and corridor for animals moving between the Europe and the Asia, and between the Eastern Europe and the Africa. This terrestrial ecoregion characterized with step ecosystem and important inland wetlands (e.g. Tuz Gölü and Sultan Sazlığı, etc.) is also classified as an "Important Bird Area" by the Birdlife International, because it provides critical habitat for many threatened and restricted-range species.

With respect to the land-use, volcanic sand and tuff that are widespread in Cappadocia create suitable conditions for the agriculture of potato and particularly quality grape that well grows on these volcanic originated sandy soils under the dry-farming. Yellowish and white sandy soils are seen on the volcanic formations in the vicinities of Nevşehir, Ürgüp and Niğde (Atalay, 2002).

6. Discussion on the Vulnerability of Cappadocia to Desertification

As mentioned previously, the unique erosion morphologies i.e. so-called fairy chimneys, in Cappadocian were cut in ignimbrites. The fairy chimneys with historically and culturally valuable wall paintings, which had been used as dwellings in the past, have been under the process of chemical and physical weathering due to the atmospheric effect [erosion because of the rainfall events (splash and rill erosion), wind erosion, corrosion effect and thermoclastic effects, etc.] in addition to the various human-induced adverse effects. For conservation and sustainability studies in the Cappadocian area, understanding of the properties of the tuff is of utmost significance. This account has been previously connoted by several authors focusing on the engineering and geological properties, durability and weathering assessments of the Cappadocian volcanic formations (Topal and Doyuran, 1997, 1998). On the other hand, our results of analysis towards understanding of the aridity and climate-process system in the study area seem to be in good agreement with these geologic findings. Indeed, desertification vulnerability of the Cappadocian district is firmly associated with the dominant *semi-arid* and *dry sub-humid* climate characterized by the unique temperature and precipitation regime and variability in addition to the erosion-prone lithology dominated by tuff and ignimbrite. The maximum precipitations caused by cyclonic anomaly circulation just over Turkey in spring (April or May) that range between 156.6 mm and 126 mm, is of primary importance in terms of gully erosion, sheet flood effect and precipitation of iron-oxide and formation of smectite-type clay mineral by chemical weathering on rock surfaces (Topal and Doyuran, 1998). The effects of running water and rock weathering are also increased by the occurrence of the intensive rainfall events so called "Kırkikindi yağmurları" in that period.

However, winter precipitations varying between 134.6 mm and 106.4 mm are of secondary importance. Dry and hot summer climate in Turkey is mainly associated with the increased anticyclonic circulation types from west and surface circulation-based effect of the Asian monsoon over the eastern Mediterranean basin including Turkey and its region. In summer, overall precipitation is just of minor importance with insufficient precipitation percentages of about 10% to 15%. During this dry and hot period, mechanical disintegration occur at a maximum rate based on approach on major climate process systems (Wilson, 1968; Ritter et al., 2002) during the period from July to September under very low precipitation and very high evapotranspiration conditions. Having considered salt occurrence within the tuffs, the possible negative effects of soluble salts was indicated by Topal and Doyuran (1998). Climate and water budget analyses also support this view, because increased evapotranspiration is of great potential for crystallization of salt during the dry season.

Based on petrographic and geochemical analyses of volcanics collected from Hasan Dağı and Karacadağ volcanic mountains, Ercan et al. (1990) investigated characteristic features of the volcanism of the CAN for the period from the Middle Miocene to the recent. They identified 15 different lithologic units mainly characterized with subalkaline (tholeiitic + calcalkaline) and alkaline rocks. In a recent study by Ertek and Öner (2008), mineralogy, geochemistry and uses of altered tuff from Cappadocia were suggested as a potential raw material for manufacturing of white cement. Their analyses indicated that the altered tuffs are mainly composed of quarts and kaolinite. The alteration of tuff and formation of kaolinite and quartz took place through thermal water, which was found to circulate along the NW-SE trending fault system. Alkali and other major oxides (Fe_2O_3, MgO, CaO, MnO, P_2O_5 and Na_2O) were found to have been leached out from parent rock by the hydrothermal process. Topal and Doyuran (1997, 1998) indicated that the Cappadocian tuff is mostly fresh, with local discoloration and moderately weak to very weak, and has low unit weight, very high porosity and high deformability. The presence of smectite-type clay mineral was fount to be associated with chemical alteration of tuffs (Topal and Doyuran 1998), which is a common occurrence in tuff as previously evidenced from various parts of the world (Franks et al., 1999; Duzgoren-Aydin et al., 2002; Dobson and Nakagava, 2005; Tazaki, 2006).

With respect to the durability of the tuff, they found dominance of poor to very poor durability, and the adverse effects of joints on the structural stability of the fairy chimneys. Topal and Doyuran (1998) further indicated that chemical weathering on the tuff may be traced to a depth of 2 cm below lichen-covered surfaces and 20 cm adjacent to discolored joint walls.

On the other hand, Burri and Petitta (2005) investigated some aspects of runoff drainage, groundwater exploitation and irrigation with underground channels in Meskender Valley adjacent to the Göreme Valley. In terms of the future development and possible conservation measures, Burri and Petitta (2005) indicated for the study area, terracing, groundwater drainage tunnels and drainage channels are emblematic of the integrated management of the area, albeit in a poorly defined historical period. They made some recommendations for conservation of natural and architectural patrimony at rock churches in Cappadocia, tunnel topography and other historical values in order to prevent present serious risks of irreversible degradation already faced in many cites of the district. Burri and Petitta (2005) summarized the causes of degradation as lack of maintenance due to the low interest in their function, in turn due to the abandonment of this particular agricultural practice, which survives only episodically, and excessive tourist pressure since the course of the historical tunnels is included in tour routes. Burri and Petitta (2005) also proposed that promoting the resumption of the traditional agricultural practice with restoration of the channels, and regulation of the tourist flows by limiting to a few emblematic structures and providing further information in the form of illustrative panels or museum-type micro-installations are of specific conservation measures.

Although wind erosion is considered as an important degradation process of soils in the arid and semi-arid lands of the Earth's surface in addition to the adverse impacts of climate change, little is known in Turkey about the nature and magnitude of this process and its effect on soil nutrient transport.

When the dominant geologic formations, which are of mainly tuff -characterized with the high deformability, poor to very poor durability- and ignimbrites, and characteristics of soils that developed over these formations are considered, it is assessed that summer water deficit and strong evaporation (Figure 5) causing soil drying in Cappadocia also make the district more vulnerable to wind erosion risk particularly during summer. Even though detailed studies based on specific surface meteorological observations and soil analyses were not performed for the district, theoretically wind erosion, which is significantly effective during the dry season, in addition to other adverse factors such as intense showers, is very likely supposed to sweep away the productive upper soil and make the soils poor in terms of nutrient matters. For instance, Somuncu (1988) found that wind-driven sand and dust transportation and accumulation cause sand and dust movements, and dune formations in some smaller areas in the Develi Plain, which is located in south-eastern margin of the study area, and provided some suggestions to prevent wind erosion in that plain.

On conclusion, both dry sub-humid (semi-humid for Erinç's index) and semi-arid areas, which entirely dominate over Cappadocia (Figure 8), are vulnerable to the desertification processes in the region whether natural including climatic change or human-induced. Those processes include a large number of factors: such as; high year-to-year climatic variability, summer dryness, drought events and mid- and high-level drought occurrence probabilities in various time-scales (Türkeş, 1996, 1998, 1999, 2010b; Türkeş and Tatlı, 2008, 2009, 2010; Türkeş et al., 2009 etc.), increased surface air temperatures (Türkeş et al., 2002b) and heat waves (Kuglitsch et al., 2010), geology (lithology and structure) and geomorphology, soil and vegetation features, erosive effects due to rainfall and wind, land degradation arising from miss-land use activities, and over-use of the historical sites and natural beauties of the sub-region by all kind of intense and unplanned tourism activities.

7. Conclusions

(1) The mid-eastern portion of the Cappadocia district could be considered as the most continental part of with a higher year-to-year variability and the lower temperatures. Cappadocia is characterized by a continental rainfall regime with a maximum precipitation in spring. Contribution of spring precipitation to the annual total is found between about 34% and 39%, whereas summer precipitation accounts for about 10% to 15% of the annual total. Inter-annual variability of monthly precipitation totals is considerably high in all months. The CVs of annual precipitation totals are about 18% in the north and about 20% in the south. Variability of summer precipitation totals is greater than that of other seasons, and ranges from about 65.7% to 78%.

(2) According to Thornthwaite's Moisture Index and Erinç's Aridity Index, semi-arid and dry sub-humid or semi-humid climate types prevail in the Cappadocia district. Dry sub-humid or semi-humid climatic conditions concentrate only over the Nevşehir and Ürgüp environs. On the other hand, the UNCCD aridity index indicates relatively more humid conditions than those of other two climate indices. Dry sub-humid climate dominates at all stations except at Aksaray. Steppe is the dominant vegetation formation and terrestrial ecosystem in Cappadocia with sparse dry forests.

(3) The stable and mobile processes of landform development such as chemical weathering, physical disintegration, and intensive gully erosion and sheet floods are greatly climatically controlled in Cappadocia. Climate, especially high evapotranspiration and low precipitation conditions in dry and hot period and maximum precipitation amounts in spring season, are of importance for both desertification vulnerability and engineering geological

properties. Our aridity and climate-process system-focused approach could be of potential for accurate definition geological characteristics of tuff and ignimbrite.

(4) By taking the contemporary desertification and vulnerability definitions and concepts into account (Türkeş, 1999, 2010b; Türkeş and Tatlı, 2010; UNCCD, 1995; UNEP, 1993), it should be recognized that the Cappadocian district of Turkey, which is characterized entirely with semi-arid and dry sub-humid climatic conditions, is vulnerable to adverse effects of the desertification processes. It should be also expected that these influences will be stronger in a warmer and drier Turkey in the future (Türkeş, 1999, 2010b; Türkeş and Tatlı, 2009; Türkeş et al., 2002b), associated with the projected human-induced global climate change mainly due to increased green-house effect of the Earth's atmosphere (IPCC, 2001, 2007; Demir et al., 2008; Önol and Semazzi, 2009; Türkeş, 2003b, 2008, 2010c, etc.). Therefore, in order to protect and sustain its historical, cultural and natural heritages, all human activities and applications in Cappadocia should be planned in particular by considering environmentally sound socio-economic development principles.

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References

Atalay, İ. (2002). Ecoregions of Turkey, Orman Bakanlığı Yayınları No. 163, 266 p, İzmir.

Atalay, İ. (2010). Applied Climatology, Meta Basım, İzmir. (In Turkish)

Burri, E., Petitta, M. (2005). Runoff drainage, groundwater exploitation and irrigation with underground channels in Cappadocia: Meskendir Valley case-study. *Journal of Cultural Heritage* 6, 191-197.

Carter, D.B., Mather, J. R. (1966). Climatic classification for environmental biology, in: Climatology, XIX, 4: 305-395, Laboratory of Climatology, Elmer.

Demir, İ., Kılıç, G., Coşkun, M. (2008). Climate predictions for Turkey using PRECIS Regional Climate Model: Scenario HaDAMP3 SRES A2. In Proceedings of the International Fourth Symposium on Atmospheric Sciences, 25–28 March 2008, İstanbul, Turkey.

Dobson, P. F., Nakagawa, S. (2005). Summary of rock-property measurements for Hong Kong tuff samples. Lawrence Berkeley National Laboratory. Paper LBNL-58878. http://repositories.cdlib.org/lbnl/LBNL-58878.

Düzgören-Aydın, N. S., Aydın, A., Malpas, J., (2002). Distribution of clay minerals along a weathered pyroclastic profile. *Catena* 50, 17-51.

Ercan, T. et al. (1990). The origin and evolution of the Cenozoic volcanism of Hasandağı – Karacadağ area (Central Anatolia), *Bulletin of Geomorphology* 18, 39-54. (In Turkish)

Erinç, S. (1965). An Attempt on Precipitation Efficiency and A New Index, İstanbul Üniversitesi Coğrafya Enstitüsü Yayınları No. 41, İstanbul, 51 p. (In Turkish)

Erinç, S. (1969). Climatology and Methods, İstanbul Üniversitesi Coğrafya Enstitüsü Yayınları No. 35, İstanbul, 538 p. (In Turkish)

Ertek, N., Öner, F. (2008). Mineralogy, geochemistry of altered tuff from Cappadocia (Central Anatolia) and its use as potential raw material for the manufacturing of white cement. *Applied Clay Science* doi:10.1016/j.clay.2008.01.020.

Essenwanger, O.M. (2001). Classification of Climates, in World Survey of Climatology Volume 1C (General Climatology 1C), Epilogue by Landsberg H E, Elsevier, Amsterdam, 112 p.

Eswaran, H., Reich, P., Beinroth, F. (2001). Global Desertification Tension Zones. In Sustaining the Global Farm, D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory, pp.24-28.

Feoli, E., Giacomıch, P., Mignozzi, K., Öztürk, M., Scimone, M. (2003). Monitoring desertification risk with an index integrating climatic and remotely-sensed data: An example from the coastal area of Turkey. *Management of Environmental Quality: An International Journal* 14, 10-21.

Franks, C.A.M., Campbell, S.D.G., Shum, W.W.L. (1999). Assessment of geological features related to recent landslides in volcanic rocks of Hong Kong. Phase B-Aberdeen study area. GEO Report No. 67, Geotechnical Engineering Office, Civil Engineering Department, The Government of Hong Kong.

Frattaruolo, F., Pennetta, L., Piccarreta, M. (2008). Desertification vulnerability map of Tavoliere, Apulia (Southern Italy). *Journal of Maps*, 117-125.

IPCC. 2001. Climate Change (2001): The Scientific Basic - Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), *Eds*.: J. T. Houghton *et al.*, Cambridge University Press, Cambridge.

IPCC. 2007. Climate Change (2007): The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), *Eds*.: S. Solomon *et al.*, Cambridge University Press, Cambridge.

İlhan, E. (1976). Geology of Turkey, ODTÜ Mühendislik Fakültesi Yayın No. 51, Ankara, 239 pp. (In Turkish)

Jones, M.D., Roberts, C.N., Leng, M.J., Türkeş, M. (2006). A high-resolution late Holocene lake isotope record from Turkey and links to North Atlantic and monsoon climate. *Geology* 34, 361-364.

Karnieli A., Dall'Olmo G. (2003). Remote-sensing monitoring of desertification, phenology, and droughts. *Management of Environmental Quality: An International Journal* 14, 22-38.

Michetti, L., Del Moro, M.A., Testa, O., Teodonıo, L. (2007). Climate change and desertification vulnerability in Southern Italy. *Phytocoenologia* 37, 495-521.

Kuglitsch, F. G., Toreti, A., Xoplaki, E., Della-Marta, P.M., Zerefos, C. S., Türkeş, M., Luterbacher, J. (2010). Heat wave changes in the eastern Mediterranean since 1960. *Geophysical Research Letters* 37, L04802, DOI:10.1029/2009GL041841.

Kutiel, H., Hirsch-Eshkol, T.R., Türkeş, M. (2001). Sea level pressure patterns associated with dry or wet monthly rainfall conditions in Turkey. *Theoretical and Applied Climatology* 69, 39-67.

Kutiel, H., Maheras, P., Türkeş, M., Paz, S. (2002). North Sea – Caspian Pattern (NCP) – an upper level atmospheric teleconnection affecting the eastern Mediterranean – implications on the regional climate. *Theoretical and Applied Climatology* 72, 173-192.

Kutiel, H., Türkeş, M. (2005). New evidence about the role of the North Sea – Caspian Pattern (NCP) on the temperature and precipitation regimes in continental central Turkey. *Geografiska Annaler: Series A, Physical Geography* 87, 501-513.

Kuzucuoğlu, C., Pastre, J.-F, Black, S., Ercan, T., Fontugne, M., Guillou, H., Hatté, C., Karabiyikoğlu, M., Orth, P., Türkecan, A. (1998). Identification and dating of tephra layers from Quaternary sedimentary sequences of Inner Anatolia, Turkey. *Journal of Volcanology and Geothermal Research* 85, 153-172.

MatheR, J.R. (1974). Climatology: Fundamentals and Applications, McGraw-Hill Book Company, New York, 412 p.

Önol, B., Semazzi, F.H.M. (2009). Regionalization of climate change simulations over the Eastern Mediterranean. *Journal of Climate* 22, 1944-1960.

Pimenta, M.T., Santos, M.J., Rodrigues, R. (1999). A proposal of indices to identify desertification prone areas. In CCD Portugal - Instituto de Agua, Murcia, 22-23 May 1999, p.11.

Reich, P.F., Numbem, S.T., Almaraz, R.A., Eswaran, H. (2001). Land resource stresses and desertification in Africa. *Agro-Science* 2, 1-10.

Reynolds, J.F. et al. (2007). Global Desertification: Building a Science for Dryland Development. *Science* 316, 847 – 851.

Ritter, D.F., Kochel, R.C., Miller, J.R. (2002). Process Geomorphology. Fourth Edition. Mc Graw Hill, New York.

Somuncu, M. (1988). Some problems of wind-erosion and its precautions: a case study of northern and western part of the Develi Plain, Central Anatolia, *Bulletin of Geomorphology* 16, 37-45. (In Turkish)

Sönmez, F.K., Kömüşçü, A.U., Erkan, A., Turgu, E. (2005). An analysis of spatial and temporal dimension of drought vulnerability in Turkey using the standardized precipitation index. *Natural Hazards* 35, 243-264.

Sür, Ö. (1972). Geomorphological Research in the Volcanic Area of Turkey, especially in Central Anatolia, Ankara Üniversitesi DTCF Yayınları No. 223, Ankara, 119 p.

Tatli, H., Dalfes, H.N., Menteş, Ş.S. (2004). A statistical downscaling method for monthly total precipitation over Turkey. *International Journal of Climatology* 24, 161-180

Tazaki, K. (2006). Green-tuff landslide areas are beneficial for rice nutrition in Japan. *Anais da Academia Brasileira Ciências* 78, 749-763.

Thornthwaite, C.W. (1948). An Approach toward a rational classification of climate. *Geography Review* 38, 55-94.

Topal, T., Doyuran, V. (1997). Engineering geological properties and durability assessment of the Cappadocian tuff. *Engineering Geology* 47, 175-187.

Topal, T., Doyuran, V. (1998). Analyses of deterioration of the Cappadocian tuff, Turkey. *Environmental Geology* 34, 5-20.

Türkeş, M. (1996). Spatial and temporal analysis of annual rainfall variations in Turkey. *International Journal of Climatology* 16, 1057-1076.

Türkeş, M. (1998). Influence of geopotential heights, cyclone frequency and Southern Oscillation on rainfall variations in Turkey. *International Journal of Climatology* 18, 649-680.

Türkeş, M. (1999). Vulnerability of Turkey to desertification with respect to precipitation and aridity conditions. *Turkish Journal of Engineering and Environmental Science* 23, 363-380.

Türkeş, M. (2003a). Spatial and temporal variations in precipitation and aridity index series of Turkey, in: Bolle, H.J. (Ed), Mediterranean Climate – Variability and Trends, Regional Climate Studies, Springer Verlag, Heidelberg, pp. 181-213.

Türkeş, M. (2003b). Global climate change and our future climate. In Türkeş, M. (*Ed*), 23 Mart Dünya Meteoroloji Günü Kutlaması Gelecekteki İklimimiz Paneli Bildiriler Kitabı, Devlet Meteoroloji İşleri Genel Müdürlüğü, Ankara, pp. 12-37. (In Turkish)

Türkeş, M. (2007). Orta Kızılırmak Bölümü güney kesiminin (Kapadokya Yöresi) iklimi ve çölleşmeden etkilenebilirliği. *Ege Coğrafya Dergisi* 14, 75-99.

Türkeş, M. (2008). What is climate change? Basic definition, causes, observed and predicted results of climate change. *İklim Değişikliği ve Çevre* 1, 45-64.

Türkeş, M. (2010a). Climatology and Meteorology. First Edition, Kriter Publisher - Publication No. 63, Physical Geography Series No. 1, ISBN: 978-605-5863-39-6, 650 + XXII pp., İstanbul (in Turkish).

Türkeş, M. (2010b). Analysis of the UN Convention to Combat Desertification with respect to the climate, climate change and drought, and applications in Turkey, *Invited Panel Paper*. In Proceeding of Symposium on Combating Desertification. Çorum: Turkey, pp.601-616. (In Turkish)

Türkeş, M. (2010c). Global climate change: Principal causes, observed and predicted changes and their impacts, *Invited Paper.* In Uluslararası Katılımlı 1. Meteoroloji Sempozyumu Bildiri Kitabı, pp.9-38, Ankara. (In Turkish)

Türkeş, M., Erlat, E. (2003). Precipitation changes and variability in Turkey linked to the North Atlantic Oscillation during the period 1930-2000. *International Journal of Climatology* 23, 1771-1796.

Türkeş, M., Erlat, E. (2005). Climatological responses of winter precipitation in Turkey to variability of the North Atlantic Oscillation during the period 1930-2001. *Theoretical and Applied Climatology* 81, 45-69.

Türkeş, M., Koç, T., Sarış, F. (2009). Spatiotemporal variability of precipitation total series over Turkey. *International Journal of Climatology* 29, 1056-1074.

Türkeş, M., Sümer, U.M., Kılıç, G. (2002a). Persistence and periodicity in the precipitation series of Turkey and associations with 500 hPa geopotential heights. *Climate Research* 21, 59-81.

Türkeş, M., Sümer, U.M., Demir, İ. (2002b). Re-evaluation of trends and changes in mean, maximum and minimum temperatures of Turkey for the period 1929-1999. *International Journal of Climatology* 22, 947-977.

Türkeş, M., Akgündüz, A.S., Demirörs, Z. (2009). Drought periods and severity over the Konya Sub-region of the Central Anatolia Region according to the Palmer Drought Index. *Turkish Journal of Geographical Sciences* 7, 129-144. (In Turkish).

Tatlı, H., Türkeş, M. (2008). Drought events of 2006/2007 in Turkey and determination of its association with large-scale atmospheric variables by logistic regression. In IV. Atmosfer Bilimleri Sempozyumu Bildiri Kitabı, pp.516-527, İstanbul. (In Turkish)

Türkeş, M., Tatlı, H. (2009). Use of the standardized precipitation index (SPI) and modified SPI for shaping the drought probabilities over Turkey. *International Journal of Climatology* 29, 2270–2282.

Türkeş, M., Tatlı, H. (2010). The Role of drought and precipitation severity indices for determination, characterization and monitoring of the desertification. In the Proceeding of Symposium on Combating Desertification. Çorum: Turkey, pp.245-263 (In Turkish).

UNCCD, (1995). The United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa, United Nations Environment Programme (UNEP), Geneva, 71p.

UNEP, (1993). World Atlas of Desertification, United Nations Environment Programme (UNEP), London.

Willmott, C.J. (1977). WATBUG: A FORTRAN IV Algorithm for Calculating the Climatic Water Budget, University of Delaware, Delaware.

Wilson, L. (1968). Morphogenetic classification in Encyclopedia of Geomorphology, Ed.: Fairbridge, R. W., Dowden, Hutchinson and Ross, Inc.