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Türkiye'nin Doğu Anadolu Bölgesindeki Sıcaklık Eğilimlerinin Yenilikçi Trend Analizi ve Mann-Kendall ile Belirlenmesi

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Öz

Küresel ısınma dünya atmosferinin kademeli olarak ısınmasına neden olurken, su kaynaklarını da önemli oranda etkilemektedir. İklim değişiminin en önemli parametrelerinin başında da sıcaklık gelmektedir. Bu parametrenin trendinin araştırılması gelecekte yapılacak çalışmalar açısından oldukça önemlidir. Bu araştırmada, Türkiye'nin doğusunda Doğu Anadolu Bölgesi'nde bulunan 14 ile ait sıcaklıklara ilişkin analiz yapılmıştır. Çalışmada, Mann-Kendall testi, Yenilikçi Trend Analizi (ITA) ve ITA'yı baz alan istatistiksel analiz kullanılmıştır. Yapılan analizlerin bulguları, 12 noktada pozitif bir trend görülmüştür. Bu bölgede sadece Erzurum ilinde bir düşüş eğilimi tespit edilmiştir. Ayrıca %95 güven aralığında Bitlis'de herhangi bir trend oluşmadığı da bulgular arasındadır. Çalışmada kullanılan üç yöntemin, sadece bir analiz dışında, %95 güven aralığında birbirini destekledikleri görülmüştür.

Anahtar kelimeler: *Mann-Kendall, Yenilikçi trend analizi, Sıcaklık, Türkiye, Doğu Anadolu Bölgesi*

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Determination of Temperature Trends in The Eastern Anatolia Region of Turkey Using Innovative Trend Analysis and Mann-Kendall

Abstract

While global warming causes the world's atmosphere to gradually warm up, it also significantly affects water resources. Temperature is one of the most important parameters of climate change. Investigation of the trend of this parameter is very important for future studies. In this research, an analysis of the temperatures of 14 provinces in the Eastern Anatolia Region of eastern Turkey was conducted. Mann-Kendall test, Innovative Trend Analysis (ITA) and statistical analysis based on ITA were used in the study. The findings of the analyzes performed showed a positive trend at 12 points. In this region, a decreasing trend was detected only in Erzurum province. In addition, it is among the findings that there is no trend in Bitlis 95% confidence interval. It was seen that the three methods used in the study supported each other at the 95% confidence interval, except for only one analysis.

Keywords: *Mann-Kendall, Innovative trend analysis, Temperature, Turkey, Eastern Anatolia Region*

1. Giriş

Dünyanın tatlı su kaynakları, gezegendeki toplam suyun yaklaşık yüzde üçünü oluşturmaktadır. Sanayileşme ve nüfus artışı ise hâlihazırda mevcut olan tatlı su kaynaklarını olumsuz yönde etkilemektedir. Bu etkiye, özellikle sıcaklıktaki dalgalanmalar sebep olmaktadır. Bu durum, önümüzdeki yıllarda suyla ilgili çok önemli sorunların olabileceğine dair bir uyarının işareti olarak karşımıza çıkmaktadır. Sonuç olarak, mevcut su kaynaklarının hem bugünü hem de geleceği için mümkün olan en iyi planlamaya sahip olması gerekir. Bu planlamanın yapılabilmesi içinde akımların trendlerinin bilinmesi oldukça önemlidir. Son zamanlarda bu alanda çok sayıda çalışma yapılmıştır. Örneğin, Bangladeş'te (Baria, vd., 2016), Sicilya'da (Cannarozzo, vd., 2006), Türkiye'de (Partal & Butler, 2006), Suudi Arabistan'da (Alhathloul, vd., 2021), Japonya'da (Yue & Hashinoya, 2003), Türkiye'nin Güneydoğusunda (Bahadir, 2011), Çin'in Yangtze havzasında (Yue ve Hashinoya, 2003) yağış trendi verilerinin analizi yapılmıştır (Ayrıca göller üzerinde çeşitli araştırma projeleri yürütülmüştür (Saplıoğlu vd., 2017), nehirler (Saplıoğlu vd., 2014), sediment (Burgan, 2022) ve su kalitesi (Saplıoğlu, vd., 2014; Lampe ve Kundapura, 2021). Yapılan çalışmaları kategorilere ayırmak gerekirse çoğu teorik (Singh & Goyal, 2016), istatistiksel (Onyutha, 2016) ve grafik olarak (Cui vd., 2017; Şen, 2012) yapılmıştır.

İstatistiksel yöntemlerin en önemlilerinden biri Mann-Kendall eğilim testi olarak bilinir (Mann, 1945; Kendall, 1975). Bu test önemli sayıda araştırmaya konu olmuştur. Bangladeş (Baria, vd., 2016), Sicilya (Cannarozzo, vd., 2006), Arjantin Córdoba (Casaa & Nasello, 2010) ve Brezilya'nın üç farklı bölgesinde (Baria, vd., 2016) araştırmacılar tarafından analiz edilmiştir (Carvalhoa, vd., 2014) Malezya Yarımadası'ndaki saatlik yağıştaki değişiklikler (Syafrina, vd., 2015) ve güney bölgelerdeki yağış yoğunluklarının eğilimleri (Kamruzzamana, vd. al., 2016; Saplıoğlu ve Çoban, 2013), Sudan'daki yağış eğilimini (Goenstera, vd., 2015), Birleşik Devletler'deki yağış ve sıcaklık eğilimi Mann-Kendall ile yürütülen birçok çalışmadan sadece birkaçıdır.

Şen (2012) tarafından önerilen ve görsel olarak değerlendirilen ITA'dan önemli sayıda çalışan faydalanmaktadır (Esit, 2023). Araştırmaların bir kısmı, yağış (Güçlü, 2018; Sanikhani, vd., 2018), nehir akışı (Saplıoğlu ve Güçlü, 2022) ve sıcaklık (Dabanlı & Şen, 2018; Cui, vd., 2017) alanlarında yapılmıştır. Literatürde nispeten yeni olan bu yöntem, trend belirlemede ekstrem olayların önemini vurgulamaktadır (Saplıoğlu, vd., 2017). Bu test, veri setini ikiye bölerek birinci ve ikinci yarıları karşılaştırır (Şen, 2014).

Bu çalışmada, Türkiye'nin Doğu Anadolu Bölgesinde yer alan on dört farklı istasyondan alınan yıllık ortalama sıcaklık verilerinden yararlanılmıştır. Bu verilerin hem MK hem de ITA yöntemleri ile trendleri belirlenmiştir.

Ayrıca Saplıoğlu (2015) tarafından sunulan bir analiz yöntemi olan ITA'nın istatistiksel analizi kullanılarak analiz gerçekleştirilmiştir. Her üç analiz yönteminin sonuçları tablo ve şekiller ile karşılaştırılmıştır.

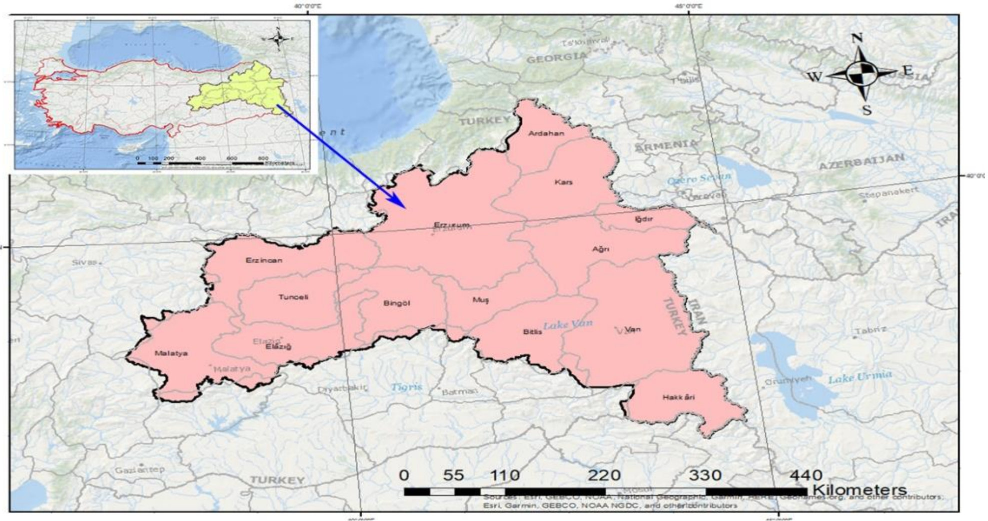
2. Materyal ve Yöntem

2.1. Materyal

Çalışmada, Türkiye'nin Doğu Anadolu bölgesinde bulunan toplanan 14 farklı ile ait istasyonlar incelenmiştir (Şekil 1). Ardahan, Erzincan, Erzurum, Kars, Ağrı, Iğdır, Tunceli, Van, Malatya, Elazığ, Bingöl, Muş, Bitlis ve Hakkari istasyonları için sıcaklık ve istatistik bilgileri Tablo 1'de verilmiştir. Bu tablodaki değerlere bakıldığında verilerin normal dağılıma uyduğu söylenebilir.

Tablo 1. Verilerin istatistiksel değerlendirmesi

İstasyonlar	Ortalama Sıcaklık (C^0)	Standard Sapma	Çarpıklık	Basıklık	Veri Periyodu (yıl)
Ardahan	3.82	1.12	0.57	0.48	1963-2016
Erzincan	11	1.10	0.16	0.13	
Erzurum	5.52	1.12	0.21	-0.08	
Kars	4.85	1.15	-0.11	0.23	
Ağrı	6.23	1.24	0.02	-0.17	
Iğdır	12.1	1.17	-0.47	-0.21	
Tunceli	12.8	0.93	0.58	-0.29	
Van	9.22	1.05	-0.61	-0.31	
Malatya	13.8	0.96	0.31	0.14	
Elazığ	13.1	0.97	1.35	-0.29	
Bingöl	12.1	1.05	0.48	-0.14	
Muş	9.79	1.33	0.24	-0.13	
Bitlis	8.66	0.77	0.40	-0.12	
Hakkari	10.3	1.16	-0.06	-0.13	



Şekil 1. Doğu Anadolu Bölgesi yer bulundu haritası

2.2. Metot

2.2.1. Mann-Kendall Trend Testi

Mann-Kendall trend testi, 1945 yılında Mann ve 1975 yılında Kendall tarafından geliştirilmiş parametrik olmayan bir testtir. Verilerin dağılımına bağlı değildir. Hipotezin sonucu olumsuz ise, trendin oluşumu hakkında bir açıklama yapmak mümkündür. Hipotez, zaman serileri içindeki herhangi bir eğilimin oluşumunu anlamak için kurulur. Çalışmada kullanılan zaman sondan başa ve baştan sona olmak üzere iki farklı kategoriye ayrılabilir. Bu çiftlerin her biri için eski veri sonraki veriden küçükse, P değeri +1 arttırılır; tam tersi durumdaki koşul için M değeri +1 arttırılır. Bundan sonra, S değeri P değerinden M değerinin çıkarılması ile elde edilir (Gociç ve Trajkoviç, 2013). Hipotez, test tarafından desteklenmediğinde ve S değeri pozitif bulunduğunda, yükseliş eğilimi olduğu sonucuna varılır. S'nin değeri negatif değerlerinde ise azalış trendi olduğu belirlenir.

MK'in Z değeri veri sayısı 30'dan fazla olduğu durumlarda aşağıdaki gibi hesaplanır.

$$\mu_s = 0 \; ve \; \sigma_s = \sqrt{n(n-1)(2n+5)/18} \qquad (1)$$

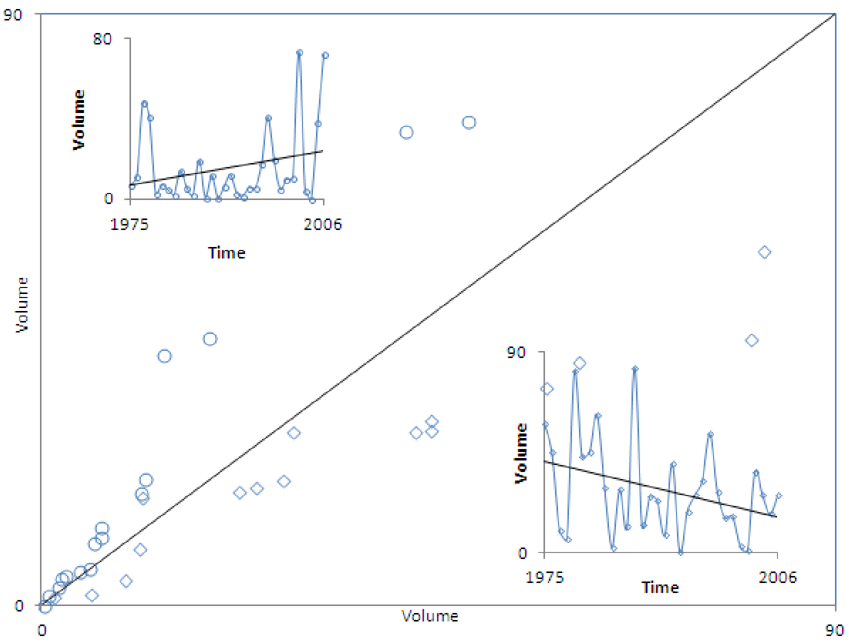
$$z = \begin{cases} \frac{s-1}{\sigma_s} & s > 0 \\ 0 & s = 0 \\ \frac{s+1}{\sigma_s} & s < 0 \end{cases} \qquad (2)$$

Elde edilen Z değeri normal dağılımdaki Z/2 değerine (% 95 güven aralığı için 1.96) karşılık gelen değerden küçük olduğu durumda hipotez kabul edilir. Böyle bir durumda trend oluşmaz. Bunun nedeni Z/2 değerinin trend olup olmadığını belirleyen değer olmasıdır. Bu değerin Z/2 değerine karşılık gelen değerden yüksek çıkması durumunda hipotez çürütülürken trendin geçerli olduğu kabul edilir. Verilerin dağılımla tutarlı olması gerekmediğinden bu oldukça pratik bir yöntemdir (Yue, vd., 2002).

2.2.2. Yenilikçi Trend Analizi (ITA)

Şen (2012), koordinat sisteminin 1:1 doğrusuna dayalı bir eğilim analizi yöntemi sunmuştur. Bu çizgiye görece yakın olan bölgelerde belirgin bir eğilim görülüp görülmeme ilkesine dayanır. 1:1 hattının her iki yanında üçgen bölümler yer almaktadır. Trend hakkında bilgi bu üçgen alanlarda bulunabilir (Şekil 2). Yöntem için ilk adımında, zaman serisindeki veriler eşit büyüklükte iki gruba ayrılır. Zaman serisinin başından ortalarına kadar olan veriler bu serilerin birincisini oluşturmaktadır. Verilerin ikinci kısmı, zaman serisinin orta noktasını belirleyen verilerden sonra meydana gelen verilerdir.

İki grup veride küçükten büyüğe doğru sıralanır. Birinci veri grubu x ekseni boyunca ve ikinci veri grubu y ekseni boyunca konumlandırılır. Son adımda, dağılım diyagramının ortasından geçen 1:1 oranında bir çizgi çizilir. Dağılım diyagramı sonuçları 1:1'den küçük olduğunda trend azalan eğilimdedir. Tam tersi durumda, trend yukarı yönlü hareket etmektedir. Ayrıca 1:1 çizgisine yakın değerlerin alındığı gözlenirse bu durumda trend olmadığını söylemek mümkündür. (Şen, 2012; Şen, 2014).



Şekil 2. ITA ile artan ve azalan trend gösterimi (Saplıoğlu, 2015)

2.2.3. İstatistiksel ITA

Saplıoğlu (2015), Şen tarafından geliştirilen grafik testten esinlenerek bu yöntemi geliştirmiştir. Aynı Şen testinde olduğu gibi veriler iki eşit parçaya bölünür ve en küçükten en büyüğe doğru sıralanır. Daha sonra, birinci veri setinin birinci değerinin ikinci veri setinin birinci değerinden çıkarılmasıyla ölçülen değer ilk değer olarak alınır. İkinci sırada, birinci veri setinin ikinci değeri ikinci veri setinin ikinci değerinden çıkarılır. Bu işlem daha sonra tüm veriler tamamlanana kadar tekrarlanır. Bir sonraki adımda ise, elde edilen tüm değerlerin ortalaması hesaplanır (Denklem 3).

$$MX = \sum_{i=1}^{n}(X_{2i} - X_{1i})/n \qquad (3)$$

Burada i indis X_1 birinci veri seti, X_2 ikinci veri seti, her veri setindeki n veri sayısı ve MX karşılaştırılan veriler arasındaki farkların ortalamasıdır. MK'da kullanılan Denklem 1 ve 2, Z'nin değerini bulmak için bu yöntemde de kullanılır. Sadece bu denklemdeki S değeri yerine MX değeri kullanılır.

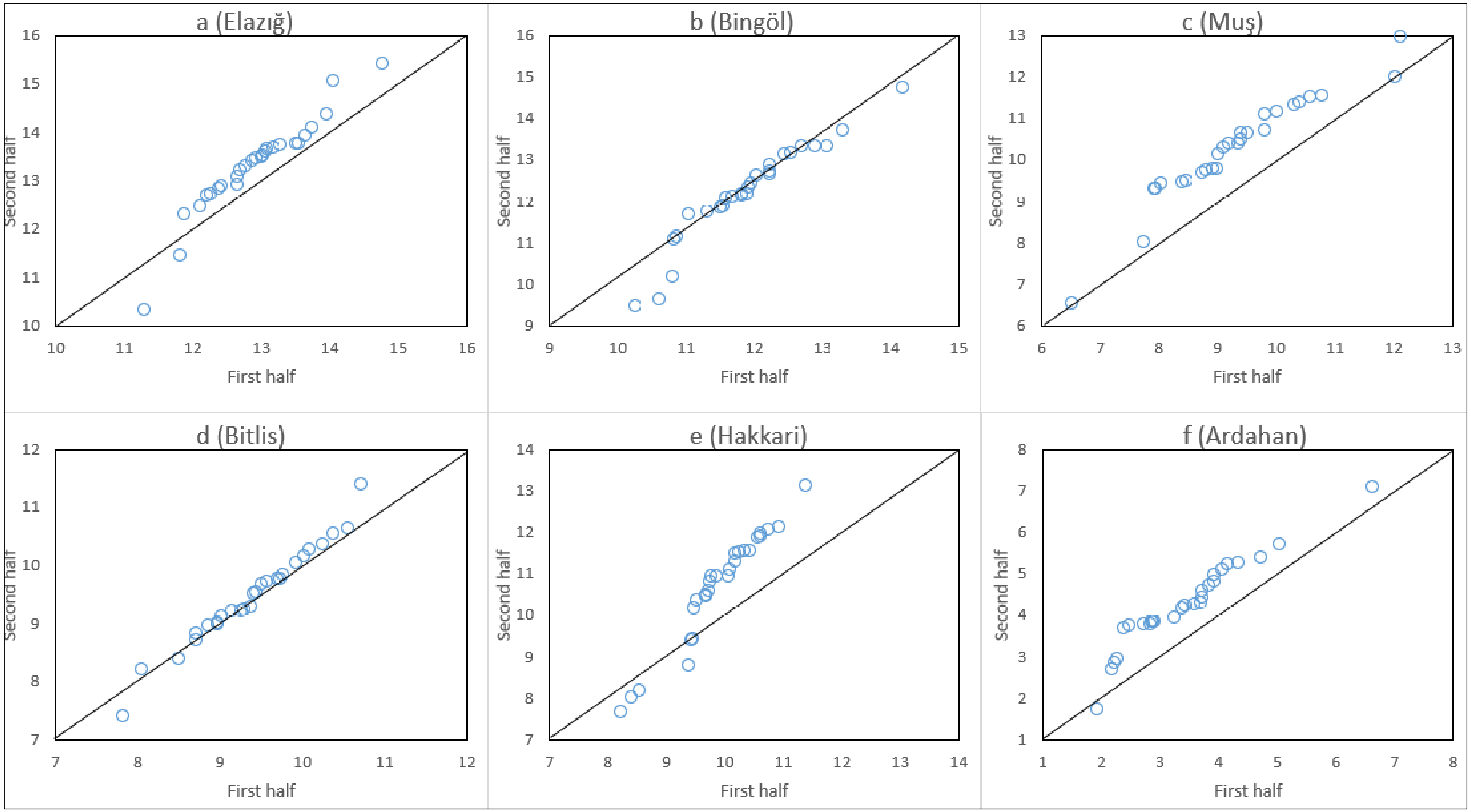
Burada da H_0 hipotezi kurulmuştur. Bu teoride herhangi bir değişiklik olmadığı kesin olarak kabul edilmektedir. Hipotezin bulguları 30'dan küçük olduğunda t testi kullanılır. Aksi takdirde bulgular z testine tabi tutulur. Bu tür araştırmalarda, hipotez çürütüldüğünde genel eğilimde değişiklik olduğu kabul edilir. Bulguların negatif çıkması durumunda, trendin negatif olduğu, pozitif çıkmasında durumunda ise trendin artış yönünde olduğu kabul edilir.

3. Bulgular

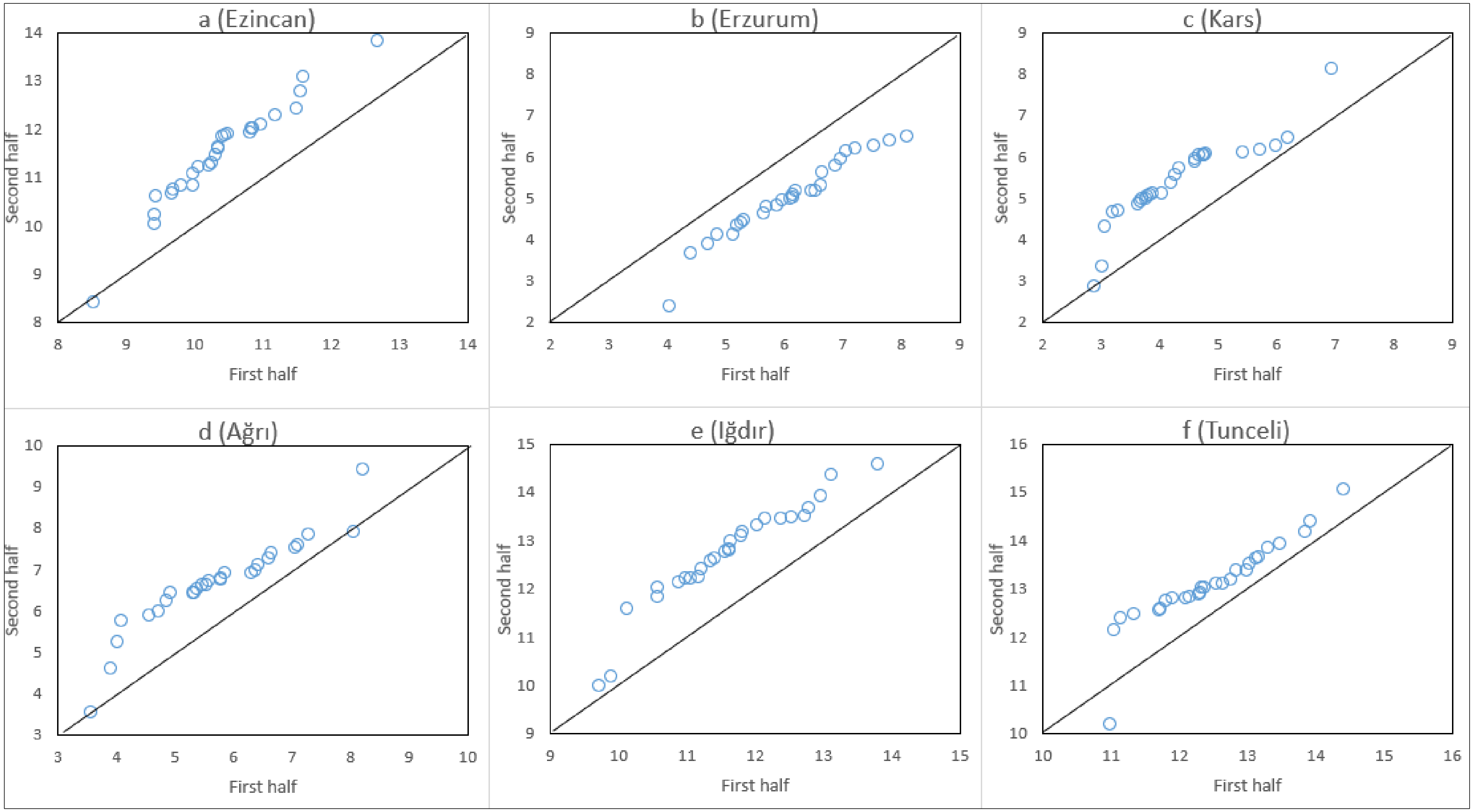
Türkiye'nin Doğu Anadolu bölgesini oluşturan iller arasında yer alan 14 sıcaklık ölçüm noktasından toplanan veriler üzerinde analiz yapmak için ITA, MK ve ITA'nın istatistiksel ifadesi kullanılmıştır. MK'nin Z değerleri ve ITA'nın istatistiksel ifadesi hesaplanmış Tablo 2'de gösterilmiştir. Z'nin bu değerleri sırasıyla Z_{mk} ve Z_{ITA} olarak yazılmıştır. Yüzde 95 güven aralığında kabul edilebilir sayılabilmesi için trendin ±1,96 aralığının dışında olması gerekmektedir. Bu çalışma, toplam elli dört yıla yayılan verileri incelemektedir. Veri seti ikiye bölündükten sonra analiz edilmesi gereken toplam 27 gözlem olacak ve bu 27 gözlemden Z_{ITA} değeri elde edilecektir. Bu nedenle, yüzde 95 için güven aralığı, 27 gözleme karşılık gelen t değeri (2,05) kullanılarak test edilmiştir. İki istatistiksel analiz karşılaştırıldığında, 13 analizin uyumlu olduğu görülmektedir. Bingöl'deki pozitif eğilim sadece MK testi ile bulunduğu için diğer yöntemle tespit edilememiştir. Bu analizlerin her ikisine göre 11 pozitif eğilim ve yalnızca bir negatif eğilim vardır. Bitlis'te ise ana yöntemlerden hiçbiri %95 güven aralığında trendi bulamamıştır. ITA yöntemi, istatistiksel yöntemi ile elde edilenlere benzer sonuçlar vermiştir. MK, Bingöl'de pozitif bir eğilim tespit edebilmiştir, ancak ITA ve ITA tarafından derlenen istatistikte aynı eğilimi göstermedi (Şekil 3b). Erzurum Z değeri negatif olan tek istasyondur (yüzde 95 güven aralığı) ve diğer tüm istasyonlarda Z değerleri pozitif olmasına rağmen bu negatif eğilim ITA tarafından desteklenmektedir (Şekil 4b). Bölgedeki tüm istasyonlarda sıcaklıklarda bir eğilim ya da pozitif bir eğilim olmamasına rağmen, Erzurum'da meydana gelen sıcaklık düşüşü dikkatle araştırılması gereken bir konudur. Elde edilen Z değerleri bölgesel çalışıldığı için idari harita üzerinde işlenmiştir (Şekil 6 ve Şekil 7), ve bu haritalar incelendiğinde MK ve ITA istatistiklerinin birbirine çok yakın olduğu görülmektedir. Tüm sonuçlar değerlendirildiğinde bölge genelinde sıcaklıklarda artış yaşandığını söylemek mümkündür. Ancak Erzurum'daki gerileme bu genellemenin yapılmasını engellemektedir. Çalışmada elde edilen sonuçlar, bölgede yapılacak su kaynakları projeleri ve yönetiminin optimum olarak çalışılabilmesi için önemli bir kaynak oluşturmuştur. Çünkü özellikle yağış ve buharlaşma üzerinde önemli etlisi olan sıcaklık verilerinin eğiliminin bilinmesi proje ve yönetiminin optimum şekilde değerlendirilmesini sağlayan parametrelerin başında gelmektedir.

Tablo 2. MK ve ITA'nın ilgili testlerinin sonuçları

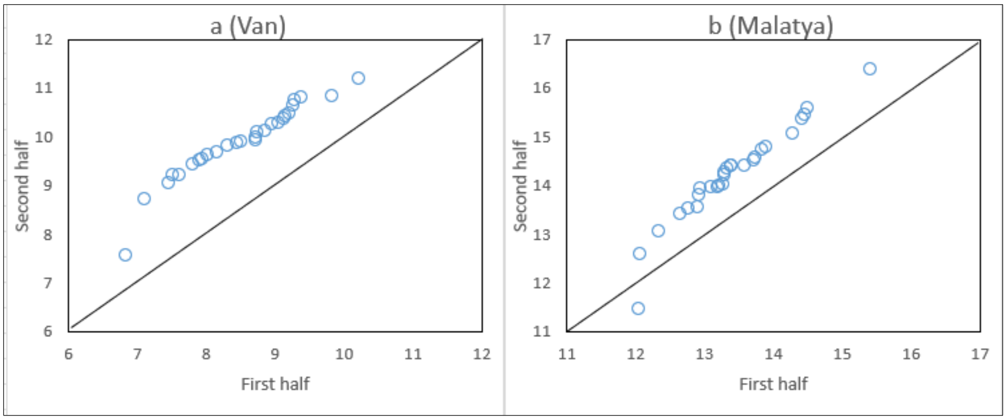
	Z_{MK} (%95) (Z testi 1.96)		Z_{ITA} (%95) (t testi 2.05)		ITA	Trend
Elazığ	3.62	↑	2.11	↑	↑	Artan
Bingöl	2.07	↑	0.75	→	→	Trend yok
Muş	3.55	↑	2.75	↑	↑	Artan
Bitlis	0.98	→	0.49	→	→	Trend yok
Hakkari	3.8	↑	2.28	↑	↑	Artan
Ardahan	4.25	↑	2.86	↑	↑	Artan
Erzincan	4.89	↑	2.33	↑	↑	Artan
Erzurum	-1.96	↓	-2.08	↓	↓	Azalan
Kars	4.36	↑	3.87	↑	↑	Artan
Ağrı	2.53	↑	2.06	↑	↑	Artan
Iğdır	5.13	↑	2.00	↑	↑	Artan
Tunceli	3.14	↑	2.01	↑	↑	Artan
Van	5.73	↑	4.22	↑	↑	Artan
Malatya	4.60	↑	3.50	↑	↑	Artan



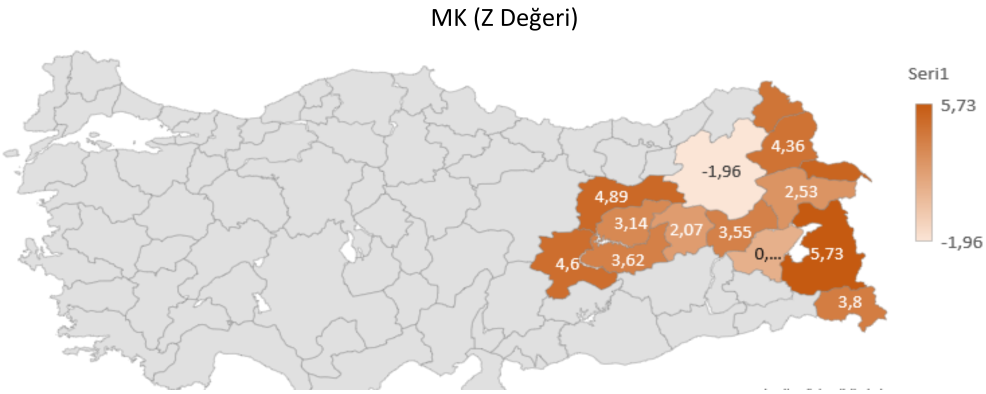
Şekil 3. ITA yöntemi sonuçları Elazığ (a), Bingöl (b), Muş (c), Bitlis (d), Hakkari (e), Ardahan (f)



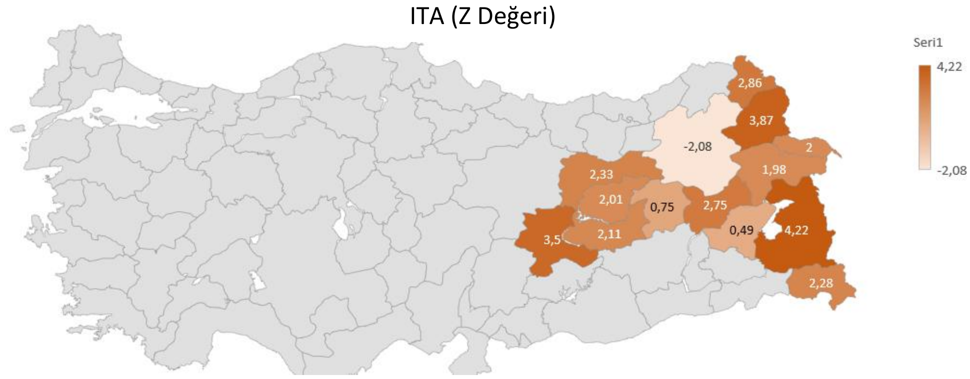
Şekil 4. ITA yöntemi sonuçları Erzincan(a), Erzurum (b), Kars (c), Ağrı (d), Iğdır (e), Tunceli (f)



Şekil 5. ITA yöntemi sonuçları Van(a), Malatya (b)



Şekil 6. Trendlerin gösterimi (MK)



Şekil 7. Trendlerin gösterimi (ITA)

4. Sonuçlar

Su kaynaklarının verimli kullanılması için sıcaklık gibi parametrelerin çok iyi analiz edilmesi gerekmektedir. Bu analizlerden biri de trend analizidir. Trendlerin analizi bu analizlerin en önemli kısmıdır. Bu tartışma kapsamında literatürde önemli miktarda çalışma yapılmıştır. Bu çalışma, Türkiye'de Doğu Anadolu bölgesinde analiz edilen 14 farklı veri istasyonunu içermektedir. Tüm analizler dikkate alındığında en çarpıcı sonuç Erzurum hariç tüm istasyonların yükseliş trendinde olmasıdır. MK ve ITA istatistikleri için yapılan 28 analizin 25'inde bu istatistik yüzde 95 güven aralığında desteklendi. Ayrıca 14 ITA testinden 12'si aynı artış oranını desteklediği görülmüştür. Araştırmadan çıkan bir diğer bulgu da bölgenin yukarı kesimlerinde yer alan Erzurum'da gözlenen düşüş eğilimidir. Bu eğilim, her üç analiz tarafından da doğrulanmıştır. Eğilim belirlemede kullanılan yöntemler incelendiğinde, ITA ve ITA için kullanılan istatistiksel yöntemlerin benzer olduğu görülmüştür. Ayrıca üç farklı yöntemin her biri kullanılarak elde edilen sonuçların birbiriyle %95 güven düzeyinde tutarlı olduğu görülmüştür. Bingöl'deki bulgularda ise MK analizi ile uyuşmadığı görülür. Çalışma Türkiye'nin Doğu Anadolu Bölgesinde bulunan tüm illere ait sıcaklık verilerinin trendlerinin belirlenmesi ve gelecekte yapılacak çalışmalar için alt yapı oluşturmuştur.

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Araştırma Makalesi / Research Article

The Effect of Temperature and Salty Water on the Capillary Water Absorption Capacity of Volcanic Rocks Used as Building Stones

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Abstract

One of the main deterioration factors of natural building stones is the presence of liquids entering the material. The most common mechanism of liquid ingress into building stones is capillary water absorption. It is necessary to know the capillary water absorption capacity, an important hygrothermal material feature for the deterioration of building stones. For this purpose, the effects of 5 different water temperatures (22, 30, 40, 50, and 60 °C) in both water and salty (NaCl) water in Ayazini tuff and İscehisar andesite were investigated. At the end of 2880 min, at 22 °C, Ayazini tuff absorbed 10.47% more capillary water in salty water than in water and 6.46% more capillary water at 30 °C. It was calculated that when the water temperature rises to 40 °C, it absorbs capillary water at 7.18%, 3.22% at 50 °C, and 3.86% at 60 °C. In the İscehisar andesite at the end of 2880 min, salty water absorbed 36.70% more capillary water at 22 °C and 57.21% more at 30 °C than water. It absorbed capillary water 27.42% at 40 °C, 20.84% at 50 °C, and 10.85% at 60 °C. In terms of salty water absorption rate, it has been determined that the water absorption amount decreases if the water temperature rises to 50 and 60 °C.

Keywords: *Capillary water absorption, Temperature, Andesite, Tuff, Building stones,*

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Yapı Taşı Olarak Kullanılan Volkanik Kayaçların Kılcal Su Emme Kapasitesine Sıcaklık ve Tuzlu Suyun Etkisi

Öz

Doğal yapı taşlarının ana bozulma faktörlerinden biri, malzemeye giren sıvıların varlığıdır. Yapı taşlarına sıvı girişinin en yaygın mekanizması kılcal su emilimidir. Yapı taşlarının bozulması için önemli bir higrotermal malzeme özelliği olan kılcal su emme kapasitesinin bilinmesi gerekmektedir. Bu amaçla Ayazini tüfü ve İscehisar andezitinde 5 farklı su sıcaklığının (22, 30, 40, 50 ve 60 °C) hem suda hem de tuzlu (NaCl) sudaki etkileri incelenmiştir. 2880 dakika sonunda 22 °C'de Ayazini tüfü tuzlu suda suya göre %10.47, 30 °C'de %6.46 daha fazla kılcal su emmiştir. Su sıcaklığı 40 °C'ye yükseldiğinde kılcal suyu %7,18, 50 °C'de %3,22 ve 60 °C'de %3,86 oranında emdiği hesaplanmıştır. İscehisar andezitinde 2880 dakika sonunda tuzlu su 22 °C'de %36,70, 30 °C'de ise %57,21 daha fazla kılcal su emmiştir. 40 °C'de %27,42, 50 °C'de %20,84 ve 60 °C'de %10,85 kapiler su emmiştir. Tuzlu su emme oranı açısından ise su sıcaklığının 50 ve 60 °C'ye çıkması halinde su emme miktarının azaldığı tespit edilmiştir.

Anahtar kelimeler: *Kılcal su emme, Sıcaklık, Andezit, Tüf, Yapı taşları,*

1. Introduction

It is seen that the structures within the scope of historical heritage belonging to many civilizations in Anatolia have survived until today. Stone-works buildings constitute an essential part of this cultural heritage. When critical historical buildings such as temples, amphitheaters, baths, bridges, mosques, and caravanserai are examined, it is seen that natural building stones are essential building materials. Many stone types such as marble, limestone, granite, travertine, andesite, basalt, and tuff were used depending on the importance and usage characteristics of the building. Natural building stones have always been an important building material due to their favorable properties, such as decorative appearance, high strength, and abundance. Some building stones have been used for hundreds of years, especially for the regions where they are located (Alves et al. 2020; Sousa et al. 2021; Çelik and Sert 2022).

In the Afyonkarahisar area, volcanic rocks such as tuff, andesite, and trachyte are used as construction stones. Building stones of volcanic origins, such as andesite and tuff, is preferred more in cultural heritage structures, as they are easy to cut and process. Most cultural heritage in Afyonkarahisar, such as caravanserais, fountains, bridges, and mosques, was built by the Seljuk and Ottomans using tuffs and andesite. The tuffs and andesites used were preferred due to their easy cutting or shaping, proximity to quarries, abundance, and easy transportation to the Afyonkarahisar region (Çelik and Sert 2020).

Ayazini tuffs have traditionally been used as building materials in many areas of local building construction in the region since prehistoric times. Most of the large tuff quarries today are located in the Ayazini region. In the village of Ayazini, many rock settlements and early Christian churches with rock basilicas and tombs from the Byzantine period were carved into tuffs (Figure 1a-i). Churches and structures made of tuff are well preserved despite all atmospheric influences. In addition to the natural rock formation and fairy chimneys, tuff formations contain numerous Phrygian cultural heritage (Figure 1j, k). The territory of Phrygia is the ancient geography name in central and NW Anatolia. Phrygians lived in this region between the 6th and 9th centuries BC, and they established a vital state. This mountainous region is composed of volcanic tuff rocks that are easy to carve. Therefore, Phrygian lands are characterized by rock-cut tombs, castles, cult monuments, and rock settlements carved into tuff rocks (Çelik and Sert 2021; Özdemir et al. 2023).

İscehisar andesite is one of the most common building stones in the Afyonkarahisar. İscehisar andesites are located 12 km northeast of the İscehisar district. This reddish-pink, light brown, and gray-black colored volcanic rocks, commercially known as "İscehisar andesite," have been utilized as construction stones since antiquity. The usage area of andesites, which are used without polishing, is increasing daily with different surface shaping techniques such as honing, sandblasting, and hammering (Çelik et al. 2019a).

Many historical buildings such as bridges, mosques, and fountains show that İscehisar andesites have been used since ancient times. Especially in Seljuk and Ottoman architecture, it is seen that andesites are extensively used in bridges, mosques, and fountains. A carved sarcophagus of andesite exhibited in an open-air environment in İscehisar is seen in Figure 1a. Another of these is a historical bridge belonging to the city of Dokimeion, which is estimated to be where İscehisar is located today. The ancient bridge called "Koca Bridge" in the region is located on Kurudere (Doureius), a branch of Akarçay that divides the city into two and passes through it. It belongs to the Hellenistic period and is still used (Figure 1). It was built with Gothic arches from andesite and marble blocks to connect the city's two sides. Kırkgöz Bridge, built by Byzantine Emperor Manuel Kommen on Akarçay in Bolvadin (Afyonkarahisar) and repaired by Mimar Sinan in 1550, was also made using andesite and marble (Figure 1) (Göncer 1971). The Altıgöz Bridge (1209) and the Yukarıpazar Mosque (1264), which have survived until today and were used in their construction, can be given as examples. It is seen that other stones and bricks were used together with these andesites in the construction of dozens of mosques and bridges belonging to the Ottoman period. Some of these are Kaaba Mescit Mosque (1397), Otpazarı Mosque (before 1590), Arapmescit Mosque (before 1800), and Kuyulu Mosque (1900) are given in Figure 1.

Water-soluble salts, the essential decomposition substance, act as transport vehicles of other substances, such as atmospheric pollutants, significantly increasing their role in degradation processes. Also, atmospheric pollution and gradual or sudden temperature changes cause deterioration and can provide a space for colonization by biological entities in the presence of water (Rodriguez-Navarro and Doehne 1999; Goudie and Viles 1997). If the moisture content of the material is more than a certain percentage, the degradation effect of moisture is activated, resulting in some physical, chemical, and biological effects. Soluble salts are one of the leading causes of the decay of materials used in buildings, deteriorating and reducing their strength. The formation of salt crystals, especially in the pores of porous building stones, can create significant stress when the stone exceeds its tensile strength and can split into more than one piece. Therefore, the decay of stones of much cultural heritage and contemporary structures made of tuff and andesite in the Afyonkarahisar area can be based on the water with soluble salts.

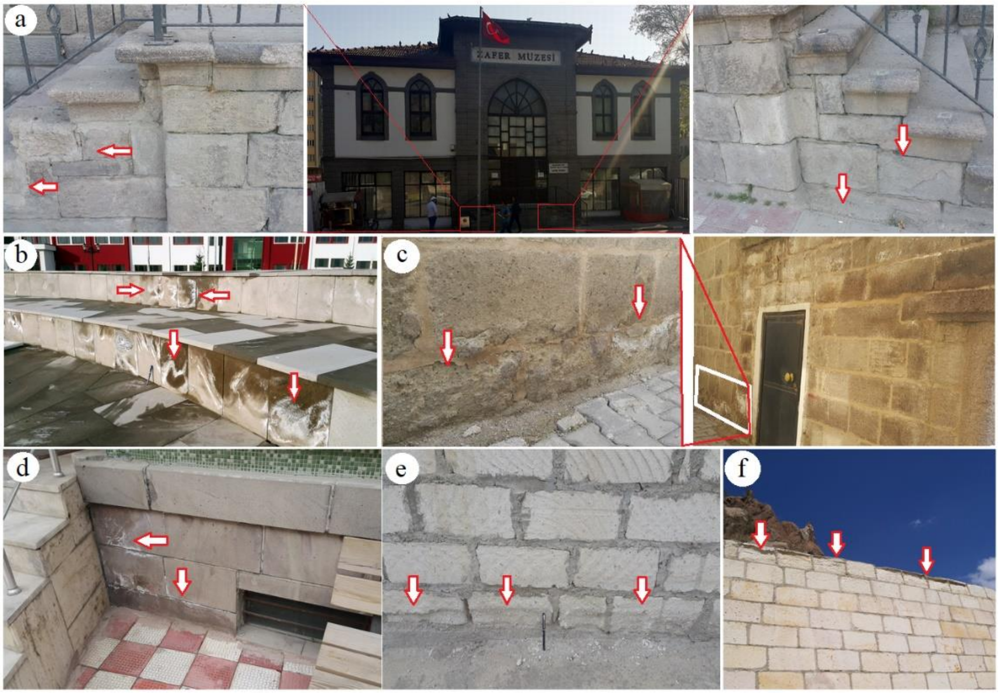

Figure 1. The view of andesites and tuffs in historical buildings and natural monuments in the Afyonkarahisar region a) a sarcophagus carved from andesite, b) İscehisar (Dokimeion) Roman Bridge (300 BC) (Göncer 1971), c) Bolvadin Kırkgöz Bridge (construction 1150, repair 1550) (Göncer 1971), d) Altıgöz Bridge (1209) (Göncer 1971), e) Yukarıpazar Mosque (1264) (Göncer 1971), f) Otpazarı Mosque (before 1590) (Göncer 1971), g) Kuyulu Mosque (1900) (Göncer 1971), h) Kaaba Mescit Mosque (1397) (Göncer 1971), i) Arapmescit Mosque (before 1800) (Göncer 1971), j) Phrygian valley fairy chimneys, k) Ayazini Carved church)

The disintegration due to capillary uptake and salt crystallization in historical and current structures made of Ayazini tuff and İscehisar andesite in the Afyonkarahisar is shown in Figure 2.

In addition to the historical heritage, the deterioration of any monument or building using building stones is a problem encountered since antiquity. The decay processes of building stones, on the one hand, are closely related to the textural and structural properties of the material (such as mineral composition, porosity, and particle size). Alternatively, it depends on external factors such as pollution conditions, climate, and building location (Winkler 1973). Building stones in contact with underground water sources tend to absorb this water through the pore system. The most common way for groundwater to rise in the pore structure of a building stone is capillary force (Siegesmund and Dürrast, 2011).

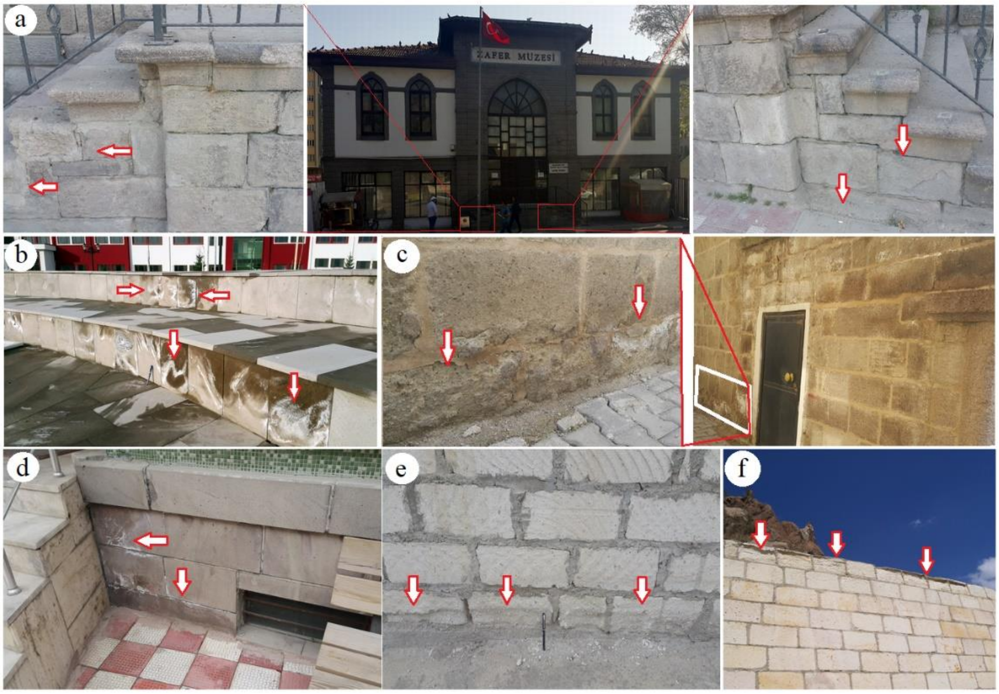

Figure 2. Deteriorations due to capillary uptake and salt crystallization in historical and modern buildings made of Ayazini tuff and İscehisar andesite in Afyonkarahisar (a: Zafer Museum, b: Afyon Kocatepe University, c: Gürcani Mosque, d: Green Mosque, e: tuff garden wall, f: Afyon Castle wall)

Capillary water absorption is the vertical upward movement of groundwater through a permeable wall structure. The moisture that rises due to this movement begins to move along the pores and micro-cracks in the building stone. Depending on the content of the moving water, different separations begin to occur in the building stones. Other decomposition events, such as salt crystallization, freezing-thawing, and wetting-drying, are controlled by water content and environmental factors (Vazquez et al. 2010; Siegesmund et al. 2002).

The frequent weathering of building stones in cultural heritage and the emergence of various types of damage have led to research and publications focusing on capillary water absorption. As a result, there is much research in the literature on the building stones' capillary moisture capability. Most of the research focuses on building stones' capillary moisture uptake capabilities and the impact of capillarity. Lubelli et al. (2013) studied the effect of chemical products on building materials with different degrees of water saturation. Wedekind et al. (2013) investigated the weathering of tuffs caused by capillary moisture-induced expansion. According to Török et al. (2005) investigated the weathering of the rhyolitic tuffs, which are the building stones of the Eger fortress (Hungary). They indicated that the tested stones are susceptible to deterioration due to their structural properties, and their strength declines significantly, especially when saturated with water. Dinçer and Bostancı (2019) studied the capillary uptake features of natural stones and the function of capillarity in their degradation. Some research has been conducted on the capillary uptake effect of natural building stones' structural features (texture, pore geometry). Martínez-Martínez et al. (2018) on the durability of the natural stones used in Morelia (México) architectural heritage, Çelik et al. (2019b) the effect of protective resin on the capillary uptake potential of volcanic rocks, Li et al. (2019) water uptake of argillitic rocks, Lu et al. (2020) conducted experimental studies on the capillary uptake of porous rocks. Germinario and Török (2020) investigated the microstructure, geochemical, and microporosity properties of the deterioration observed in the castle tuff walls.

Some researchers used laboratory testing to investigate the correlations between physical and mechanical factors and capillary water capacity. Vázquez et al. (2010) the velocity of P-waves in granites, the relationship between water capillary suction and crack network, Akın et al. (2016) The role of capillary water absorption in the degradation of Ahlat Seljuk ignimbrite tombstones, Çelik (2017) changes in water absorption and ultrasonic wave during the freeze-thaw process in travertine, Qiao et al. (2017) investigated the alteration of the mesoscopic properties and mechanical behavior of sandstone due to hydro-physical and hydro-chemical effects. Besides, some authors have also researched the influence of capillary uptake of building stones on environmental conditions, like dynamic influence, salinity, and temperature. Çelik and Kaçmaz (2016) investigated static and dynamic capillary water absorption in porous building stones under normal and salty water conditions, Karagiannis et al. (2016) the impact of temperature on the capillary coefficient of building stones, Çelik and Yılmaz (2018) the effect of different aqueous (acidic, salty, and static) ambiances on the capillary water absorption capability of porous building stones, Çelik et al. (2019c) The influence of temperature on time-dependent water absorption in Ayazini (Afyonkarahisar) tuffs, Karagiannis et al. (2019) investigated the effect of dynamic environmental conditions on capillary water uptake of building materials. Apart from these, there are also recent studies examining the capillary water absorption performance of building stones such as tuff (Germinario ve Török 2020; Çelik ve Sert 2021), andesite (İnce 2021), limestone (Sousa vd. 2021; Khodabandeh ve Rozgonyi-Boissinot 2022), sandstone (Zhang vd. 2022; Feng vd. 2022), and travertine (Korkanç 2018).

The purpose of this study was to investigate the effect of temperature on the capillary water absorption capacity. For this purpose, capillary water absorption experiments were conducted in the laboratory environment by the standards. The effects of 5 different water temperatures (22, 30, 40, 50, and 60 ^{o}C) on the capillary water absorption capacity in both water and salty water

(NaCl) were investigated in Ayazini tuff and İscehisar andesite. Previous studies have not extensively investigated the specific effects of temperature on the capillary water absorption capacity of Ayazini tuff and İscehisar andesite, which are commonly used as building materials. This study aims to fill this gap and can be considered original. By conducting capillary water absorption experiments in a laboratory environment, following the appropriate standards, it investigates the effects of five different water temperatures (22, 30, 40, 50, and 60°C) on the capillary water absorption capacity of both water and salty water (NaCl) in Ayazini tuff and İscehisar andesite.

2. Material and Methods

2.1. Materials

NaCl was used to prepare salty solutions and water in the experiments conducted to examine the capillary water absorption capacity. 14% NaCl solution at 22 °C was prepared by dissolving 140-g salt in 860-g water. Capillary water absorption experiments were conducted in a hot water bath device with a thermostatic heating feature that keeps the operating temperature at the desired level. Six Ayazini tuff and İscehisar andesite samples in a cube of 50×50×50 mm at each temperature (22, 30, 40, 50, and 60 °C) depending on water and salty water were used in the experiments. Andesite samples were obtained from andesite quarries located 12 km north of İscehisar, and tuff samples were obtained from tuff quarries in the Ayazini region around the Afyonkarahisar-Eskişehir highway. These quarries are active and produce tuff, and andesites are used as building stones in the region. Ayazini tuffs are light-colored and commonly consist of volcanic glass (pumice), phenocrysts, rock fragments, and cavities. Andesites can be found in grayish, pinkish, and red-purplish colors. The location map of the quarries from which the samples of Ayazini tuff and İscehisar andesite were taken and the view of the quarries is given in Figure 3.

2.2. Methods

Five different temperature values (22, 30, 40, 50, and 60 °C) were selected considering the temperatures to which the building stones can be exposed. Experimental studies to examine the effect of 5 different water temperatures (22, 30, 40, 50, and 60 °C) on the capillary water absorption capacity of Ayazini tuff and İscehisar andesite were conducted in 2 stages. First, a series of characterization studies were performed to determine the material properties of the building stones used in the experiments. For this purpose, chemical, mineralogical-petrographic (polarizing microscope, XRD, and SEM), pore size distribution, and physical and mechanical tests/analyzes were applied.

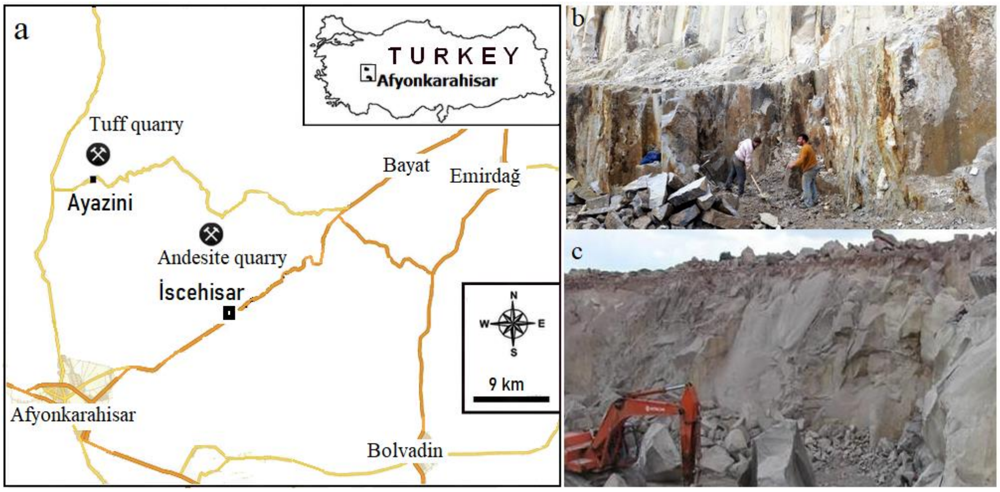

Figure 3. Location map of the building stones used in the experiments (a) and view of the quarries; Ayazini tuff (b), İscehisar andesite (c)

Chemical analyses were conducted with Rigaku/ZSX Primus II brand XRF device at Afyon Kocatepe University Mining Engineering Natural Stone Analysis Laboratory in 50 g test samples prepared with a grain size of 0.063 mm. For petrographic analysis, thin sections prepared in 2 pieces in both building stone samples were examined using a Leica DM 2500P microscope. One of the most critical components affecting capillary water absorption properties is pore size and distribution. For this purpose, the pore size distributions of the building stone samples were determined in the mercury porosimeter Micromeritics Auto Pore IV 9500 device at the Technology Application and Research Center of Afyon Kocatepe University (TUAM). Test conditions are a contact angle of 140 ^oC under a vacuum of 480,00 erg/cm^2.

Experiments were carried out in the Afyon Kocatepe University Mining Engineering Laboratory by TS EN standards to ascertain the physical and mechanical characteristics of Ayazini tuff and İscehisar andesite. Tests of total and open porosity (TS EN 1936), density (TS EN 1936), P-wave velocity (TS EN 14579), water absorption (TS EN 13755), uniaxial compressive strength (TS EN 1926), and capillary water absorption (TS EN 1925) were performed to determine the physical and mechanical properties. In each experiment, six samples of 50×50 ×50 mm in size were used for each stone.

Capillary water absorption (CWA) experiments were conducted in Ayazini tuff and İscehisar andesite in both water and salty (NaCl) water at five different water temperatures (22, 30, 40, 50, and 60 ^oC). The temperature deviation of ± 1 ^oC due to the thermostat of the water bath was accepted as normal in the experiments. In CWA experiments, the base of samples was immersed in water to a depth of 3 ± 1 mm. During the measurement of the amount of capillary water absorption, the time intervals were 1, 3, 5, 10, 15, 30, 60, 480 (8 h), 1440 (24 h), and 2880 min (48 h). The capillary water absorption test procedure performed according to TS EN 1925 is shown in Figure 4. The samples were removed from the water at each time interval, and the droplets were wiped with a dry cloth. Then, each sample was weighed with a sensitivity of 0.01 g, the amount of water absorbed depending on the time interval was determined, and the test samples were photographed to determine the water absorption levels. Capillary water absorption graphs were generated from the data obtained.

3. Result and Discussions

3.1. Chemical Analysis

According to the chemical analysis results of tuff and andesite samples, the main element oxide contents are given in Table 1. The most significant component of tuff and andesite is SiO_2, and it is 72.30% and 58.30%, respectively. Al_2O_3 constitutes the second major component with 13,60% and 15,8%. Na_2O and K_2O alkaline element compounds were determined as 3.02% and 7.00%, respectively. Other important ingredients are K_2O, CaO, Fe_2O_3, Na_2O, and MgO.

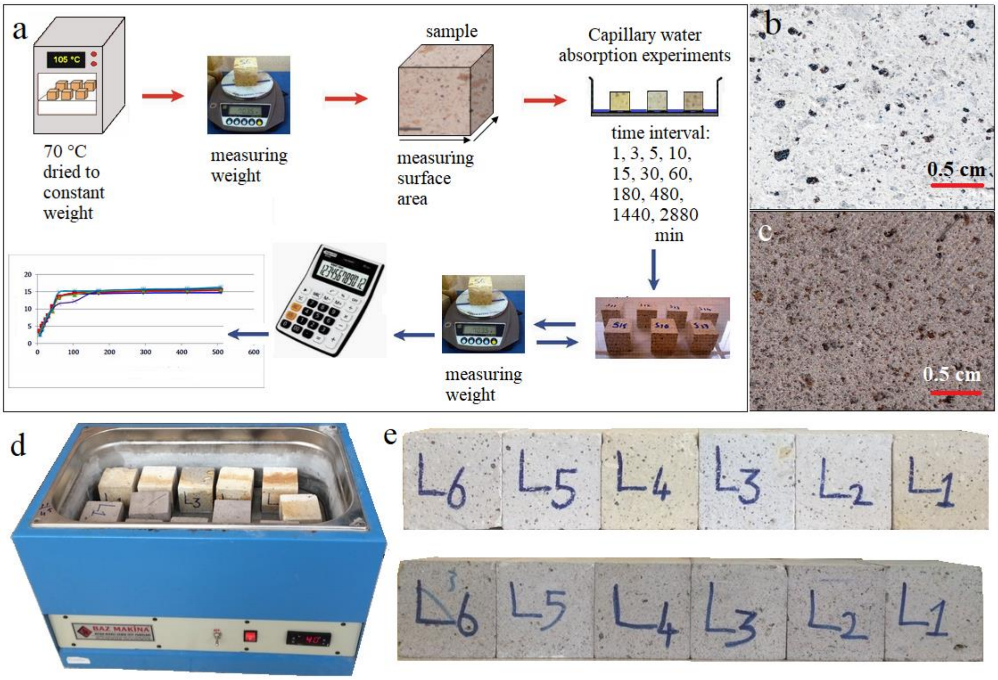

Figure 4. Capillary water absorption (CWA) test procedure (a) and surface view of the samples Ayazini tuff (b), İscehisar andesite (c), digital thermostatic temperature-constant water bath (d), and the appearance of cubic samples (e)

Table 1. Chemical composition of the Ayazini tuff and İscehisar andesite

Chemical composition (%)	Ayazini tuff	İscehisar andesite
SiO_2	72.30	58.3
Al_2O_3	13.60	15.8
Fe_2O_3	1.43	4.96
MgO	0.12	2.73
CaO	1.02	4.79
Na_2O	2.29	3.02
K_2O	6.24	7.00
TiO_2	0.11	1.12
LOI	2.84	0.93

3.2. Petrography and mineralogy

3.2.1. Polarizing optical microscope analysis

Standard thin sections prepared for the mineralogical and petrographic descriptions of the Ayazini tuff and İscehisar andesite were examined with the help of a polarizing microscope. Great phenocryst content was observed in the Ayazini tuffs. The Ayazini tuff contains crystals of quartz, feldspar (sanidine) and hornblende minerals (Figure 5). The various rocks and volcanic glass (pumice) pieces are also in the composition. Ayazini tuff matrix is glassy and composed of fine-grained plagioclase in microliths. The physical decomposition was observed in some feldspar and biotite crystals in the tuffs. Therefore, discoloration has occurred in some areas due to iron oxide released.

The main minerals of İscehisar andesite are quartz, plagioclase, and mafic minerals pyroxene and biotite. Biotite and pyroxene were observed as larger-sized phenocrysts. Plagioclase minerals form a matrix with distinct flow textures in microliths. Partly weathering traces are observed in randomly distributed mafic minerals. Fractures and cracks are particularly evident in pyroxene, hornblende, and biotite minerals. The composition includes volcanic glass fragments and 200–300 μm pores. It was determined that the optic-microscope data of tuffs and andesites examined petrographically were in accordance with the XRD data.

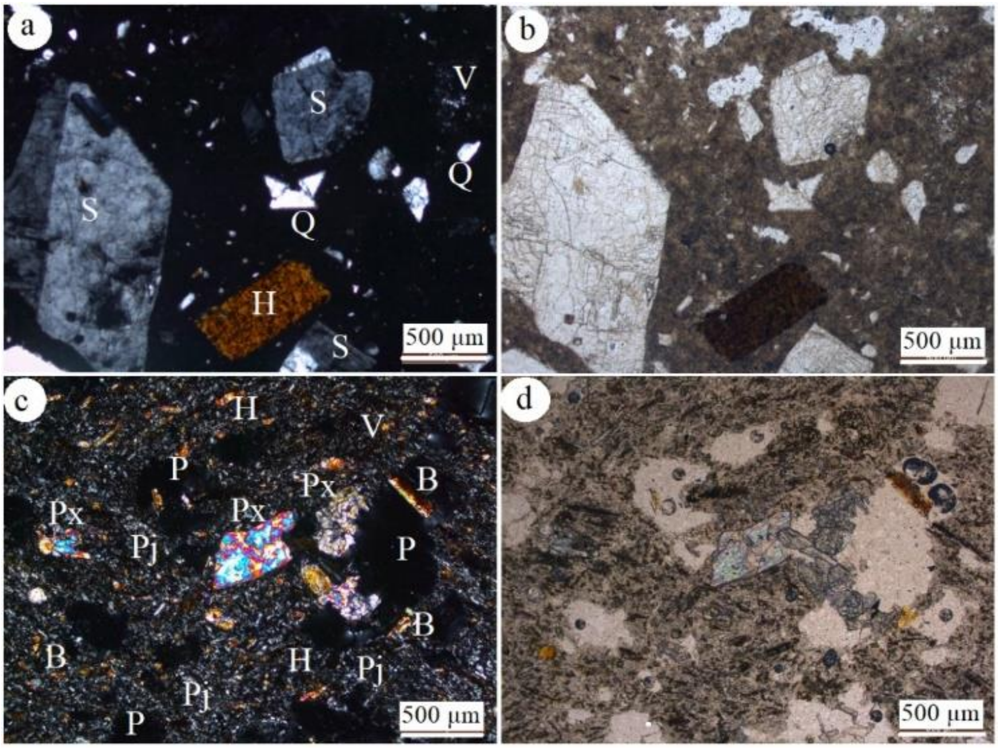

Figure 5. Thin section under crossed polarized light and plane-polarized light of the Ayazini tuff (a, b) and İscehisar andesite (c, d). Q: quartz, S: sanidine, Pj: plagioclase, Px: pyroxene, H: hornblende, B: biotite, P: pore, V: volcanic glass).

3.2.2. XRD analysis

The graph of the peaks obtained by XRD analysis of the Ayazini tuff and İscehisar andesite samples is given in Figure 6. XRD analysis of Ayazini tuff samples showed the presence of quartz, feldspar, cristobalite, and illite minerals. The XRD study of İscehisar andesites revealed the presence of feldspar (andesine, oligoclase, and sanidine), pyroxene, biotite, hornblende, and montmorillonite minerals. Clay minerals such as montmorillonite and illite were observed in both samples tested. The presence of clay minerals indicates that volcanic glass components and feldspars are weathered. Amorphous material (volcanic glass) was detected in tuff samples in thin section examines, and XRD analysis also confirmed this. In the XRD graph, the elevation of the ground starting from 2θ = 0° supports the presence of amorphous material (volcanic glass).

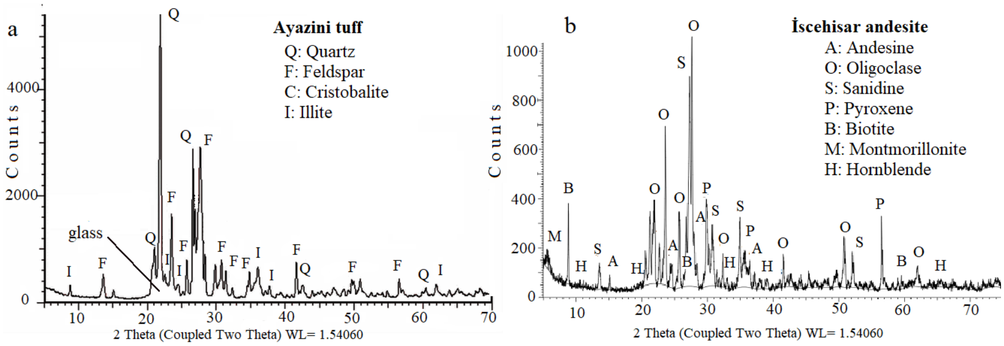

Figure 6. XRD analyses of the Ayazini tuff and İscehisar andesite

3.2.3. Pore-size distribution

Pore size distribution, which is directly related to weathering mechanisms, is an important physical parameter of natural building stones. Knowing the pore size distribution is crucial to comprehend capillary water uptake, salt crystallization, and freeze-thaw events, which are all directly related to the amount of water absorption. Therefore, mercury porosimetry was used to determine the pore size distribution of the Ayazini tuff and İscehisar andesite (Figure 7). Different pore size classifications, such as IUPAC (1976), Klopfer (1985), and DIN 66131 (1993), have been proposed for different purposes. For example, Klopfer (1985) divided the pore sizes into three categories and named those smaller than 0.1 µm as micropores, those between 0.1 µm and 1 mm as mesopores (capillary pores), and those larger than 0.1 µm as macropores. Capillary absorption is known to be related to pore diameters ranging between 1 µm and 1 mm, which are commonly referred to as capillary pores (Siegesmund and Dürrast 2011).

Ayazini tuffs have a unimodal pore size distribution. This pore size distribution is in an extensive range between 0.01 and 400 µm. However, most of these pores are concentrated around 1–9 µm. Pores between 0.1 µm–1 mm are of great importance in terms of capillary water absorption. Most of the pores of the Ayazini tuffs are of this size. Therefore, a high-water absorption rate of the Ayazini tuffs should be expected.

İscehisar andesite has a pore size distribution between 0.08 µm-300 µm. Most of the pores are in the range of 0.01–3 µm. The pore size distribution of andesite is between 0.01 and 10 µm and has a bimodal pore size distribution. While the first peak is around 0.01 µm, the second peak is around 3 µm. İscehisar andesite has a size distribution essential for capillary water absorption, just like the Ayazini tuff.

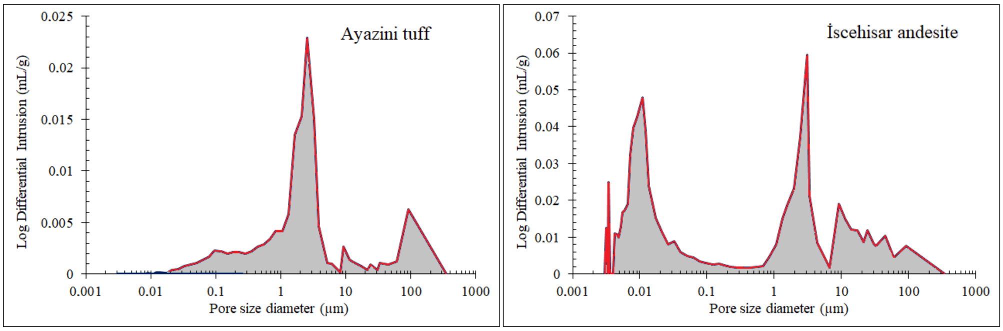

Figure 7. Pore size distribution of the Ayazini tuff and İscehisar andesite was measured by mercury intrusion porosimetry.

3.3. Physico-Mechanical Properties

Natural building stones used outdoors are constantly exposed to the weathering effect of atmospheric effects. Stones with high porosity are both less durable and absorb more water, and therefore they are more easily weathered. If there are dissolved salt solutions in the environment, the amount of separation increases even more (Siegesmund et al. 2002). In this respect, the physico-mechanical features of building stones are of great importance in defining the places of use. Therefore, laboratory tests were conducted to determine the physical and mechanical properties of Ayazini tuff and andesite samples, such as water absorption, density, ultrasonic velocity, uniaxial compressive strength, and porosity, the relevant standards. Table 2 contains the results from the experiments. In the Ayazini tuff, the total pore ratio was 36.64%. In the andesite, it was found to be 19.46%. It negatively affects properties such as high porosity, water absorption, and strength of natural building stones. While building stones with high porosity values have higher water absorption values, the compressive strength and ultrasound transmission rate data are low and inversely proportional to this situation.

Similarly, the average water absorption data by weight are 17.16% for tuffs and 4.25% for andesite. The average density of the Ayazini tuff was found to be 2573 kg/m³, while that of andesites was 2730 kg/m³. The average uniaxial compressive strength was determined as 17.31 MPa for tuffs and 40.25 MPa for andesite. According to these data, it can be said that Ayazini tuff has lower properties as building stones with very high porosities compared to andesite. There are differences in origin and formation with diagenesis in sedimentation conditions of tuffs and cooling of magma in andesites. For this reason, it is quite natural for the physico-mechanical properties to be different. Although the experimental conditions remained constant, the changes in the standard deviation were due to the structure of the samples. In these conditions, the structural differences in the examples also led to a high standard deviation in the uniaxial compressive strength test.

Table 2. Average physico-mechanical properties of the Ayazini tuff and İscehisar andesite

Tests	Ayazini tuff		İscehisar andesite	
	Mean	Standard deviation	Mean	Standard deviation
Density (kg/m^3)	2573	1.58	2730	2.51
Water absorption by weight (%)	17.16	1.63	4.25	2.34
Open porosity (%)	28.01	2.10	9.36	0.46
Total porosity (%)	36.64	1.15	19.46	2.38
Ultrasound pulse velocity (km/s)	2.40	0.19	3.39	0.20
Uniaxial compressive strength (MPa)	17.31	5.12	40.25	11.33

3.4 Capillary water absorption experiments

Capillary forces that occur spontaneously in the pores provide capillary water uptake in porous materials. Pore diameters between 0.1 μm–1 mm is responsible for capillary water uptake (Siegesmund and Dürrast 2011). Klopfer (1985) building stones are classified as follows according to their water absorption capacity: capillary absorption value of building stones with low capillary water absorption property <0.5 kg/m^2, medium capillary water absorption in the range of 0.5 to 3.0 kg/m^2, and strong capillary water absorption showing stones have a value of >3.0 kg/m^2. A capillary water absorption value greater than 3.0 kg/m^2 provides sufficient water intake to retain moisture in the pores for a long time and move existing salts (Snethlage 2005; Graue et al. 2011). According to the data obtained in the experiments, the capillary water uptake evaluation of the stones tested will be made according to this classification.

3.4.1. Capillary water absorption (CWA) experiments at 22 °C

In the CWA test of the tested stone, time-dependent water absorption values in 22 °C water and salty water are given in Table 3, and the water absorption graph is in Figure 8. At 22 °C, at the end of 2880 min, Ayazini tuffs have a capillary water absorption capacity of 20.47 and 22.61 kg/m^2, and İscehisar andesites 4.70 and 6.42 kg/m^2 in water and salty water. At the end of 2880 min at 22 °C, the Ayazini tuff absorbed 10.47% more water in salty water than water. İscehisar andesite absorbed 36.70% more water in salty water than water. This situation is due to the surface tension of salty water being higher than that of water. Ayazini tuffs, with total porosity of 36.64%, were found to have high capillary water absorption potential, as expected. According to these data, Ayazini tuffs and İscehisar andesite are in the class of stones with strong capillary water absorption since their capillary water absorption values are greater than 3.0 kg/m^2.

Table 3. In the CWA test of tested stone, time-dependent water absorption values in 22 °C water and salty water (kg/m^2) (AT: Ayazini tuff, İA: İscehisar andesite)

Time ($s^{0.5}$)	7.75	13.42	17.32	24.49	30.00	42.43	60.00	169.71	293.94	415.69
Water 22 °C (AT)	1.28	2.31	3.16	4.52	5.64	7.35	9.33	17.30	20.27	20.47
Salty water 22 °C (AT)	2.16	3.96	5.75	8.03	10.10	12.08	13.42	18.49	22.32	22.61
Water 22 °C (İA)	0.29	0.38	0.47	0.58	0.84	0.95	1.10	2.33	4.05	4.70
Salty water 22 °C (İA)	0.23	0.33	0.45	0.59	0.71	0.85	1.14	2.28	5.28	6.42

In the CWA test of the tested stone, the elevation views of time-dependent water absorption levels in 22 oC water and salty water are given in Figure 9. The capillary water absorption level of the Ayazini tuff increased more rapidly than that of the İscehisar andesite. In the first 60 min, the capillary water absorption height ratio of the Ayazini tuff is approximately 90%, while it is only 20% in andesite. Ayazini tuff samples reached full saturation in 480 min. This situation shows that the tuffs absorb capillary water quickly. Capillary water absorption height in water was only 30% in andesites even after 2880 min. In addition to the number of pores, clay minerals in the composition of tuffs determined in XRD analysis can contribute to the high capillary water absorption value.

In the salty water experiment, it was observed that the Ayazini tuff had a faster capillary water absorption regime. However, the Ayazini tuff reached full saturation after 480 min in salty water. Alternatively, Andesite samples showed a higher CWA height than water; at the end of 2880 min, the water height was close to 50%. The higher the liquid density used, the higher the surface tension. For example, salt mixed with water increases surface tension. For this reason, salty water is expected to absorb more capillary water than water. The penetration and crystallization of salt solutions into the pores by capillary water absorption gradually increase in the following process.

Salt crystals formed due to evaporation cause fluorescence on the surface of the building stones. Although these formations cause visual damage, they do not cause significant degradation (Veran-Tissoires et al. 2012). Since the salt crystallization in the Ayazini tuffs is generally in the pores and deep, very little fluorescence was observed on the surfaces only at 2880 min. In andesites, on the other hand, fluorescence started to appear on the surface of the samples after 1440 min, and it was more distinct than in tuffs. However, the fluorescence formations did not show any symptom of physical harm in tuff and andesite.

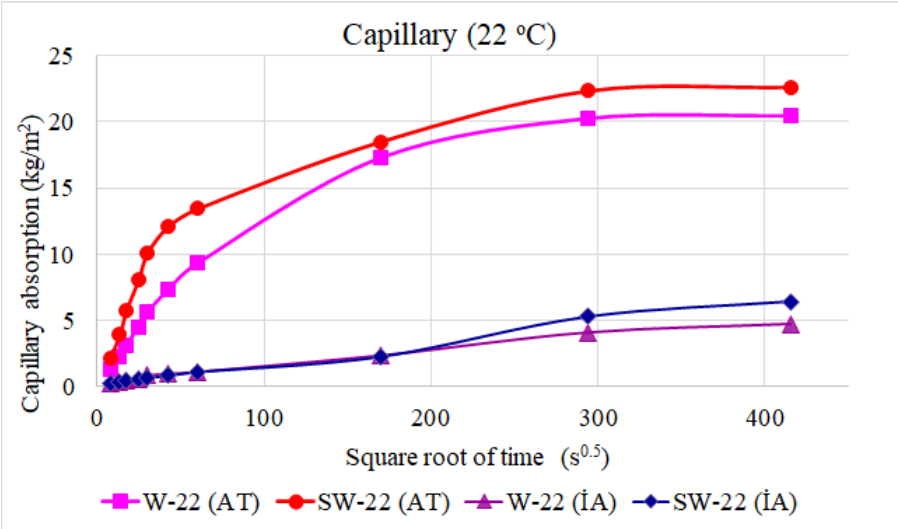

Figure 8. In the CWA test of tested stone, time-dependent water absorption graph in 22 °C water and salty water (W: water, SW: salty water, AT: Ayazini tuff, İA: İscehisar andesite)

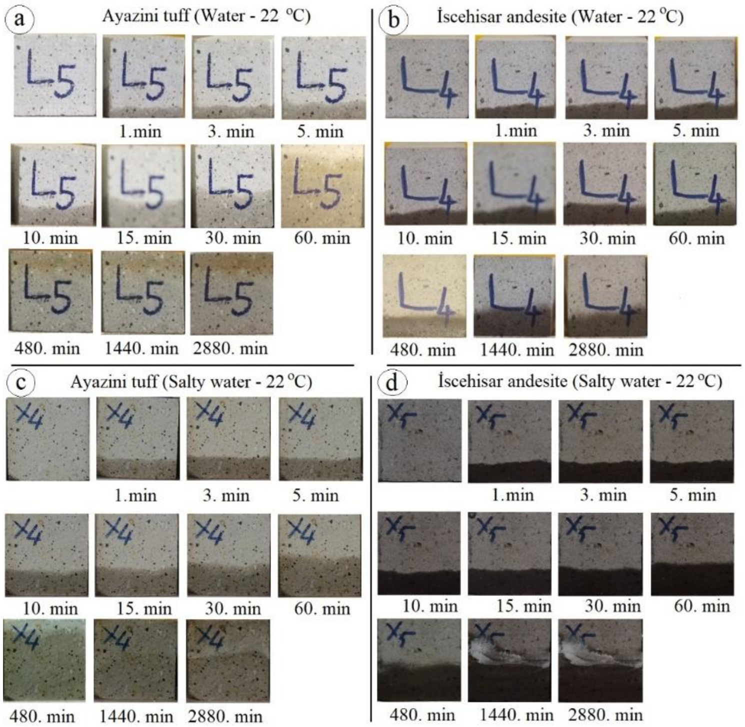

Figure 9. Time-dependent water absorption levels of 22 °C water and salty water in the CWA test of Ayazini tuff (a, c) and İscehisar andesite (b, d) samples).

3.4.2. Capillary water absorption (CWA) experiments at 30 °C

In the CWA test of the tested stone, time-dependent water absorption values in 30 °C water and salty water are given in Table 4, and the water absorption graph is shown in Figure 10. At 30 °C, at the end of 2880 min, Ayazini tuffs had 22.02 and 23.45 kg/m^2 capillary water absorption capacity, while Iscehisar andesites had 4.92 and 7.73 kg/m^2 capillary water absorption capacity in water and salty water. After 2880 min at 30 °C, Ayazini tuff absorbed 6.46% more capillary water in salty water than in water. This rate has been calculated as 57.21% for İscehisar andesite. This situation showed that salty water at a temperature of 30 °C is more effective in andesites. Ayazini tuff absorbed 7.59% and 3.68% more capillary water and andesites 4.77% and 20.49% more capillary water than 22 °C in 30 °C water and salty water. Accordingly, 30 °C temperature caused more water to be absorbed than at room temperature in both samples.

In the CWA test of the tested stone, elevation views of time-dependent water absorption levels in 30 °C water and salty water are given in Figure 11. It is observed that the Ayazini tuff and İscehisar andesite reach saturation earlier in salty water than the capillary water absorption level at 30 °C. However, the tuffs have much faster water absorption. Full saturation at 480 min in the Ayazini tuffs is only 50% at 2880 min in andesites. In andesites in salty water at 30 °C, fluorescence was observed again after 1440 min. No fluorescence was observed in Ayazini tuffs. This situation shows that salt crystals remain in the pores in tuffs, and in andesites, evaporation occurs on the sample surfaces. Cloudy structures formed due to evaporation in salty water are seen in Figure 11.

Table 4. In the CWA test of tested stone, time-dependent water absorption values in 30 °C water and salty water (kg/m^2) (AT: Ayazini tuff, İA: İscehisar andesite).

Time ($s^{0.5}$)	7.75	13.42	17.32	24.49	30.00	42.43	60.00	169.71	293.94	415.69
Water 30 °C (AT)	1.87	2.70	3.64	4.88	6.14	7.80	9.89	15.40	21.47	22.02
Salty water 30 °C (AT)	2.03	4.22	6.02	8.03	10.64	12.70	14.26	19.95	22.78	23.45
Water 30 °C (İA)	0.23	0.33	0.43	0.54	0.69	0.84	1.40	2.16	4.00	4.92
Salty water 30 °C (İA)	0.28	0.46	0.60	0.77	0.89	1.12	1.46	4.29	6.33	7.73

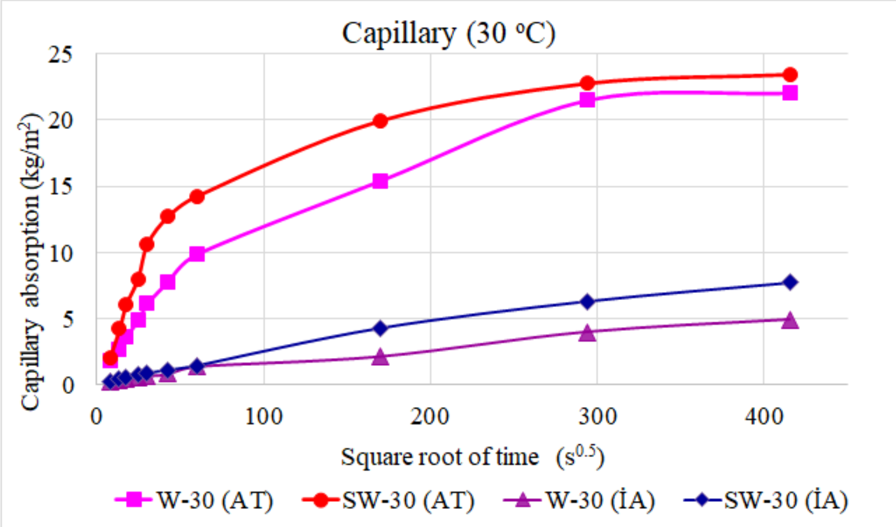

Figure 10. In the CWA test of tested stone, time-dependent water absorption graph in 30 °C water and salty water (W: water, SW: salty water, AT: Ayazini tuff, İA: İscehisar andesite).

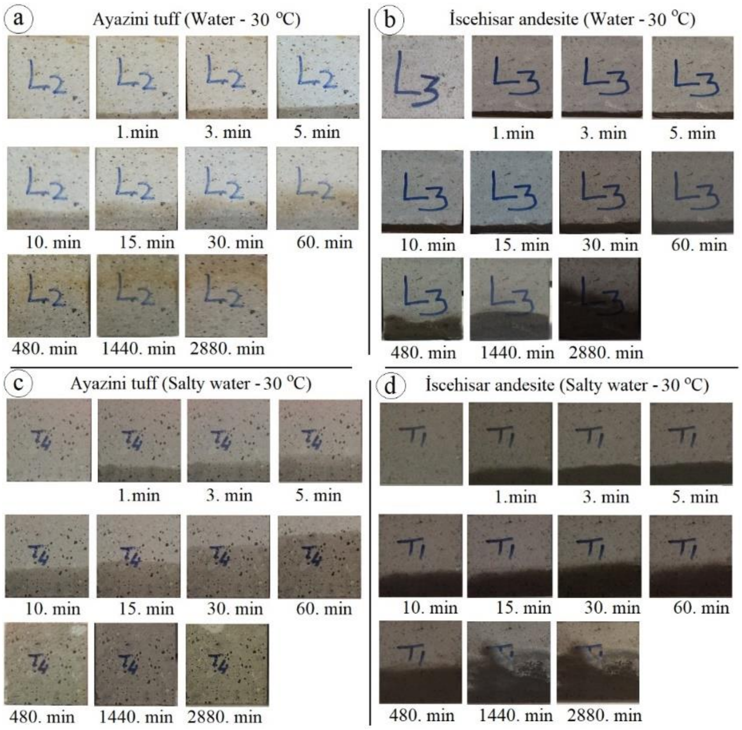

Figure 11. Time-dependent water absorption levels of 30 °C water and salty water in the CWA test of Ayazini tuff (a, c) and İscehisar andesite (b, d) samples).

3.4.3. Capillary water absorption (CWA) experiments at 40 °C

In the CWA test of the tested stone, time-dependent water absorption values in 40 °C water and salty water are given in Table 5, and the water absorption graph is in Figure 12. At 40 °C, at the end of 2880 min, Ayazini tuffs had 22.21 and 23.80 kg/m^2 capillary water absorption capacity, while İscehisar andesites had a capillary water absorption capacity of 5.24 and 6.67 kg/m^2 in water and salty water. When the experimental temperature increased to 40 °C, salty water absorbed 7.18% more water in Ayazini tuff and 27.42% more water in İscehisar andesite than water. Ayazini tuff absorbed 8.49% and 5.26% more water, and andesites absorbed 11.49% and 3.92% more water than 22 °C in water and salty water at 40 °C. Accordingly, it is seen that water is more active at 40 °C in both samples compared to room temperature. Ayazini tuff absorbed 0.83% and 8.08% more water in water, salty water at 40 °C than 30 °C, and andesites absorbed 6.41% more water in water. In andesites, 13.75% less water absorption occurred in 40 °C salty water than in 30 °C temperature. This situation may have increased NaCl precipitates in the experimental environment and decreased capillary water penetration into the material due to some evaporation of the salty solution depending on the temperature increase.

In the CWA test of the tested stone, the elevation views of time-dependent water absorption levels in 40 °C water and salty water are given in Figure 13. The Ayazini tuffs reached full saturation in 480 min in water, this situation occurred in 30 min in salty water. From these data, it can be said that the temperature of 40 °C, besides salinity is efficient in the amount of capillary water absorption in the tuffs. In İscehisar andesites, although the water absorption level in water increased slightly compared to the previous temperature, there was not much change in salty water. In 40 °C salty water, Ayazini tuffs fluorescence at 1440 min and andesites at 1440 and 2880 min. No physical damage was observed in the samples after the experiment in 40 °C water and salty water.

Table 5. In the CWA test of tested stone, time-dependent water absorption values in 40 °C water and salty water (kg/m^2) (AT: Ayazini tuff, İA: İscehisar andesite)

Time ($s^{0.5}$)	7.75	13.42	17.32	24.49	30.00	42.43	60.00	169.71	293.94	415.69
Water 40 °C (AT)	0.98	2.32	3.57	4.86	6.74	8.77	10.35	16.22	21.85	22.21
Salty water 40 °C (AT)	2.38	4.31	6.06	8.11	10.38	13.00	14.45	17.78	23.16	23.80
Water 40 °C (İA)	0.27	0.39	0.51	0.59	0.75	0.97	1.17	2.33	4.26	5.24
Salty water 40 °C (İA)	0.29	0.42	0.53	0.65	0.79	1.05	1.32	2.58	5.67	6.67

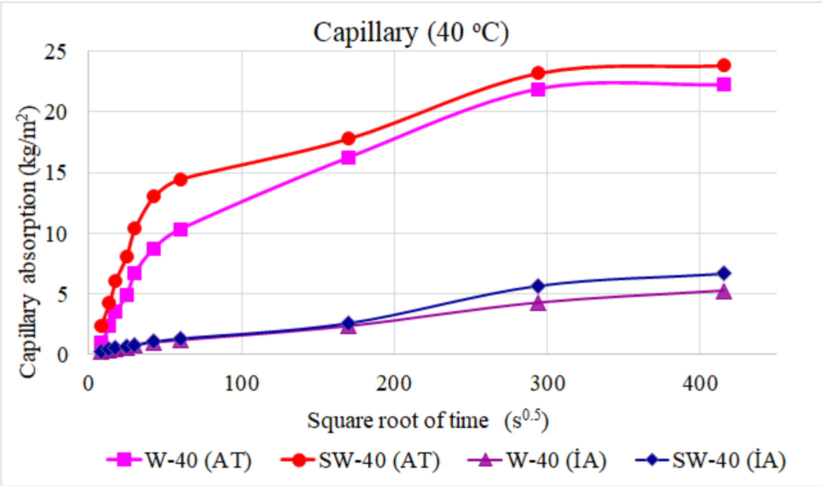

Figure 12. In the CWA test of tested stone, time-dependent water absorption graph in 40 °C water and salty water (W: water, SW: salty water, AT: Ayazini tuff, İA: İscehisar andesite)

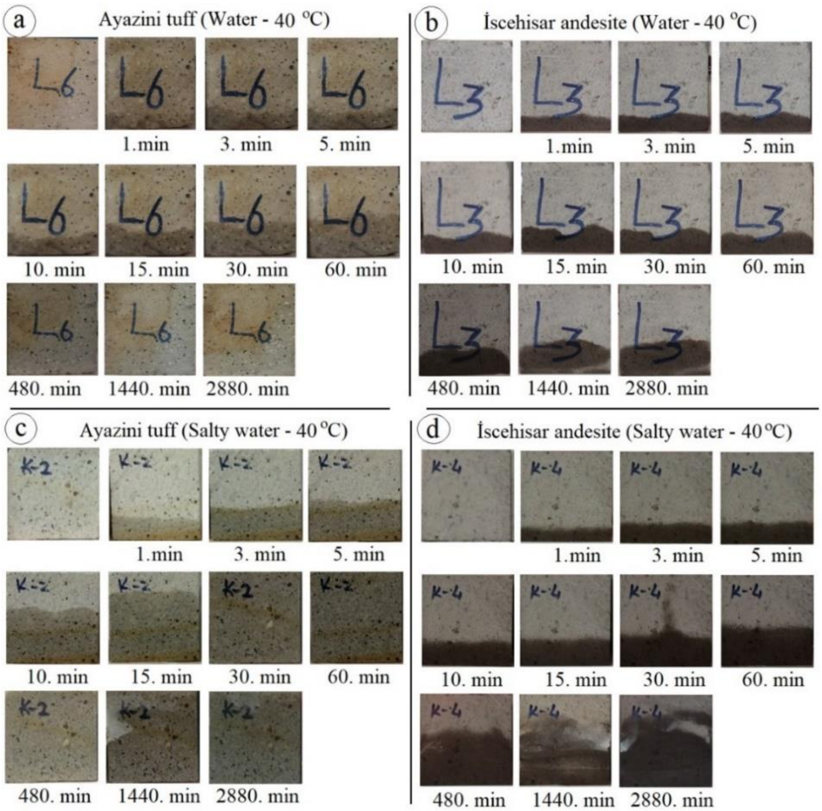

Figure 13. Time-dependent water absorption levels of 40 °C water and salty water in the CWA test of Ayazini tuff (a, c) and İscehisar andesite (b, d) samples).

3.4.4. Capillary water absorption (CWA) experiments at 50 °C

In the CWA test of the tested stone, time-dependent water absorption values in 50 °C water and salty water are given in Table 6, and the water absorption graph is in Figure 14. Ayazini tuffs absorbed 22.98, and 23.72 kg/m² in water and salty water at 50 °C after 2880 min, and İscehisar andesites absorbed 5.80 and 7.01 kg/m² of capillary water. Ayazini tuff absorbed 12.28% more water in water, while the amount of water absorbed at 50 °C at the end of 2880 min was 4.90% more water in salty water than at room temperature. This situation resulted in less water absorption due to the salt crystallization accumulated in the micropores in the tuffs. In İscehisar andesite, 23.55% and 9.21% more capillary water absorption occurred, respectively, compared to water and salty water. At 50 °C, at the end of 2880 min, the amount of water absorbed in tuffs increased by 3.49% in 40 °C water, while a 0.34% decrease was observed in salty water. According to 30 °C, an increase of 4.36% and 17.92% in water in tuff and andesites, an increase of 1.18%, and a decrease of 9.37% in salty water were observed.

In the CWA test of the tested stone, the elevation views of water absorption levels depending on the time in 50 °C water and salty water are given in Figure 15. While the Ayazini tuffs in water and salty water reach full saturation in 480 min, the water absorption level in İscehisar andesites barely exceeded 50% after 2880 min. While fluorescence in 50 °C salty water was observed in Ayazini tuffs at 1440 and 2880 min, it was not observed in andesites at this temperature. In 50 °C water and salty water, the water absorption height of the Ayazini tuffs in 60 min reached 2880 min for andesites. It is seen that the total porosity ratio being 36.64% in the Ayazini tuffs and 19.37% in andesites has a significant effect on this situation.

Table 6. In the CWA test of tested stone, time-dependent water absorption values in 50 °C water and salty water (kg/m²) (AT: Ayazini tuff, İA: İscehisar andesite).

Time (($s^{0.5}$)	7.75	13.42	17.32	24.49	30.00	42.43	60.00	169.71	293.94	415.69
Water 50 °C (AT)	1.57	2.83	4.16	5.80	7.16	9.05	11.21	18.03	22.13	22.98
Salty water 50 °C (AT)	2.87	4.59	5.99	7.47	8.52	10.54	13.02	18.92	22.68	23.72
Water 50 °C (İA)	0.22	0.37	0.47	0.60	0.73	0.87	1.29	2.64	4.42	5.80
Salty water 50 °C (İA)	0.40	0.56	0.69	0.82	0.98	1.22	1.55	2.69	5.78	7.01

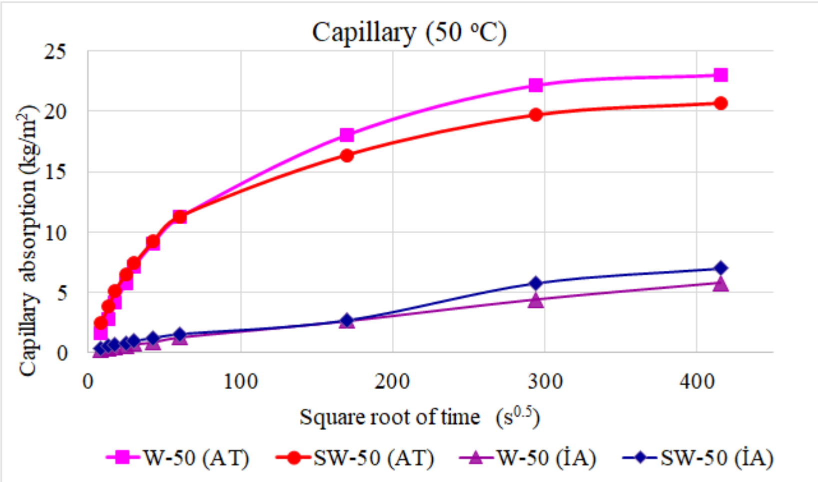

Figure 14. In the CWA test of tested stone, time-dependent water absorption graph in 50 °C water and salty water (W: water, SW: salty water, AT: Ayazini tuff, İA: İscehisar andesite)

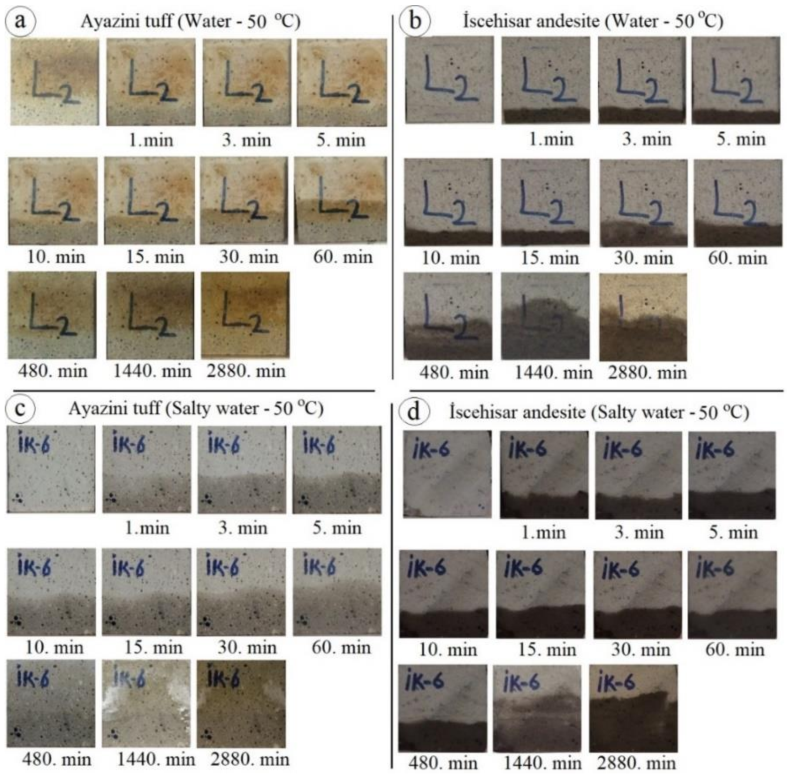

Figure 15. Time-dependent water absorption levels of 50 °C water and salty water in the CWA test of Ayazini tuff (a, c) and İscehisar andesite (b, d) samples)

3.4.5. Capillary water absorption (CWA) experiments at 60 °C

In the CWA test of tested stone, time-dependent water absorption values in 60 °C water and salty water are given in Table 7, and the water absorption graph is given in Figure 16. At the end of 2880 min, Ayazini tuffs absorbed 22.72, and 23.60 kg/m² of water is water and salty water at 60 °C, and these values were determined as 6.42 and 7.12 kg/m² for İscehisar andesites. The amount of water absorbed at 60 °C at the end of 2880 min was absorbed 3.86% more water in Ayazini tuff than water at 60 °C compared to room temperature, while this rate was 10.85% in andesites. The amount of water absorbed in water at 60 °C in Ayazini tuff has decreased steadily compared with 22, 30, 40, and 50 °C. Capillary water absorption rates were 11.02%, 3.18%, 2.33% and -1.12%, respectively. The same situation was determined in İscehisar andesite at 36.77%, 30.54%, 22.67%, and 22.67%, respectively.

In the CWA test of the tested stone, the elevation views of time-dependent water absorption levels in 60 °C water and salty water are given in Figure 17. Traces of evaporation were found in 60 °C water and salty water test samples. This situation is more pronounced, especially in water. In tuff and andesite samples, evaporation traces are intense at higher levels than water absorption levels. Because steam has a lower density than water, it rose before water and entered the pores. The evaporation traces seen in the tuffs until the 480th minute, when full saturation was reached, could not be seen after this time interval, as the water filled all the pores. Evaporation traces were observed in andesites at all time intervals until the end of the experiment. This situation was not the case for salty waters in either example. However, it was seen that the water absorption height was higher than the previous temperature values in both water and salty water at 60 °C. Especially in andesites, the water absorption level reached almost 90%. This situation shows that the increase in temperature leads to faster capillary absorption in water and salty water.

Table 7. In the CWA test of tested stone, time-dependent water absorption values in 60 °C water and salty water (kg/m²) (AT: Ayazini tuff, İA: İscehisar andesite)

Time ($s^{0.5}$)	7.75	13.42	17.32	24.49	30.00	42.43	60.00	169.71	293.94	415.69
Water 60 °C (AT)	1.62	3.17	4.52	6.08	7.39	8.99	10.86	18.00	21.96	22.72
Salty water 60 °C (AT)	2.81	5.14	7.09	9.98	12.06	13.98	15.83	20.34	22.22	23.60
Water 60 °C (İA)	0.21	0.36	0.47	0.82	0.99	1.14	1.86	3.37	5.74	6.42
Salty water 60 °C (İA)	0.29	0.46	0.62	0.76	0.89	1.24	1.68	3.02	5.79	7.12

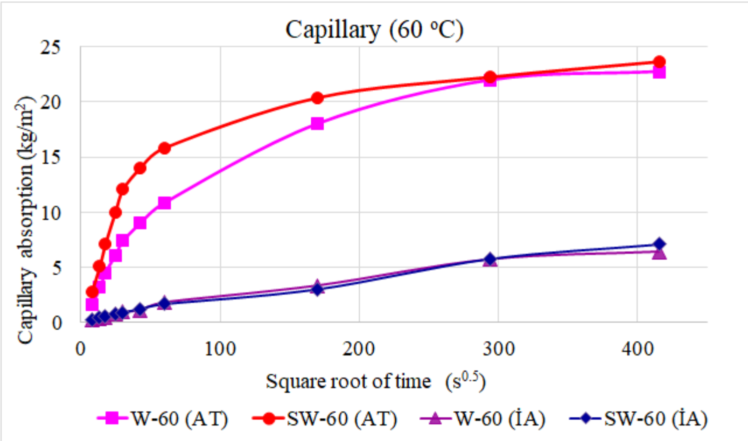

Figure 16. In the CWA test of tested stone, time-dependent water absorption graph in 60 °C water and salty water (W: water, SW: salty water, AT: Ayazini tuff, İA: İscehisar andesite)

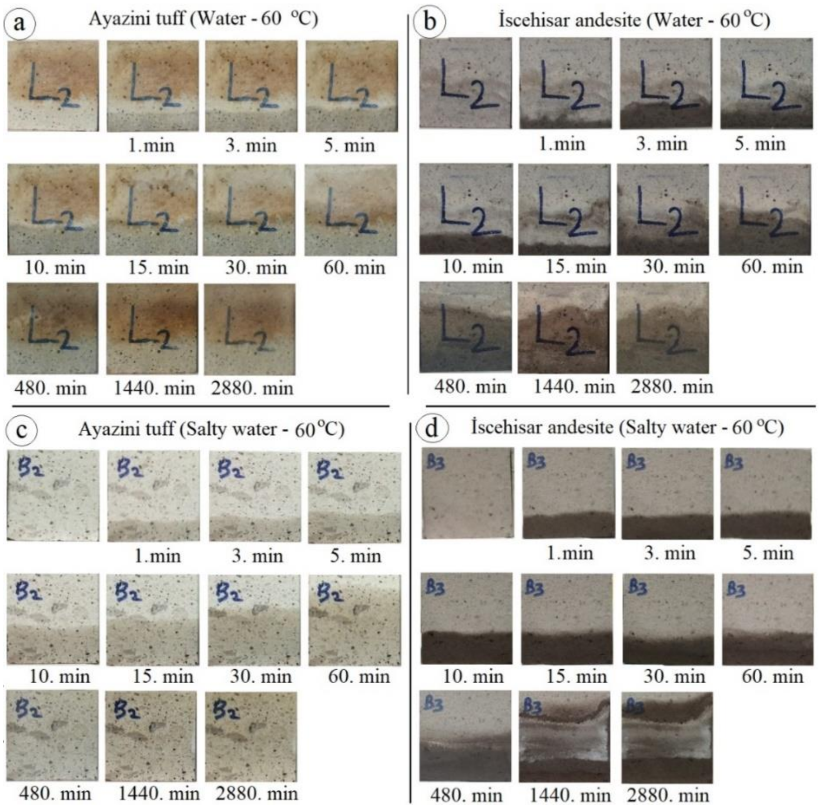

Figure 17. Time-dependent water absorption levels of 60 °C water and salty water in the CWA test of Ayazini tuff (a, c) and İscehisar andesite (b, d) samples)

4. Conclusions

The effect of water and saline solutions on the decomposition of natural building stones is known. One of the most effective ways of water entering the building stones is the capillary water absorption mechanism. In addition to water, the water absorption capacities of Ayazini tuff and İscehisar andesite in salty waters were investigated depending on temperature. The results obtained from experimental studies on 5 different water temperatures (22, 30, 40, 50, and 60 ^{o}C) on the capillary water absorption capacity are given below.

In polarized microscope investigations, Ayazini tuff is formed of quartz, feldspar (sanidine), and hornblende. In contrast, İscehisar andesite is composed of quartz, plagioclase, and mafic minerals pyroxene and biotite. In XRD investigation of Ayazini tuff and İscehisar andesite samples, quartz, feldspar (andesine, oligoclase, and sanidine), pyroxene, biotite, hornblende, and montmorillonite minerals were determined.

The mercury porosimetry method determined the pore size distribution of the Ayazini tuff and İscehisar andesite samples. For the Ayazini tuffs, it shows a unimodal (single-topped) distribution between 0.01–0.8 μm, while andesite shows a multimodal (multi-topped) size distribution with multiple maximum values between 0.08 and 350 μm. In terms of porosity, Ayazini tuffs had 36.64% and andesite 19.46% total porosity.

At the end of the CWA test at 22 ^{o}C (2880 min), Ayazini tuffs in water and salty water have a capillary water absorption capacity of 20.47 and 22.61 kg/m^2, and İscehisar andesites 4.70 and 6.42 kg/m^2. Ayazini tuff absorbed 10.47% more water in salty water than in water. İscehisar andesite absorbed 36.70% more water in salty water than in water. This situation is because the surface tension of salty water is higher than that of water. Ayazini tuffs, with a total porosity of 36.64%, were found to have high capillary water absorption potential, as expected. According to these data, Ayazini tuffs and İscehisar andesite are in the class of stones with strong capillary water absorption since their capillary values are greater than 3.0 kg/m^2.

The graphs of the temperature and capillary water absorption value change relationship of Ayazini tuff and İscehisar andesite are given in Fig. 18 and 19. According to the test data, Ayazini tuff absorbed 10.47% more capillary water at 22 ^{o}C and 6.46% more at 30 ^{o}C at the end of 2880 min than water in salty water. When the water temperature rises to 40 ^{o}C, it was calculated that 7.18% more water is absorbed in salty water than water, 3.22% at 50 ^{o}C, and 3.86% at 60 ^{o}C. In terms of salty water absorption rate, the increase in water temperature to 50 and 60 ^{o}C decreased capillary water absorption. Here, the increase in salt crystallization due to the evaporation of water was adequate. In İscehisar andesites, at the end of 2880 min, salty water absorbed 36.70% more water at 22 ^{o}C and 57.21% more water at 30 ^{o}C than water. It has been calculated that when the water temperature rises to 40 ºC, salty water absorbs 27.42% more capillary water than water, 20.84% at 50 ºC, and 10.85% at 60 ºC. Likewise, depending on the increase in water temperature, there is a decrease in the rate of absorbed water at 50 and 60 ºC.

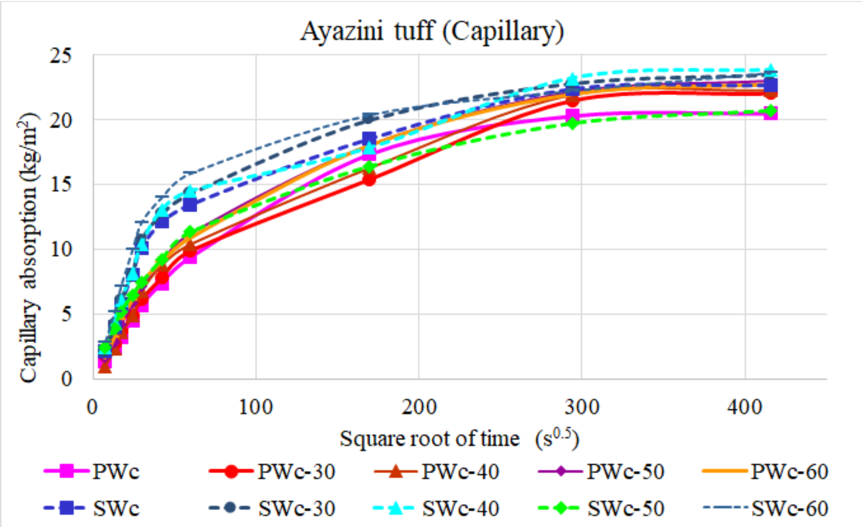

Figure 18. The graphs of the temperature and capillary water absorption value change the relationship of Ayazini tuff.

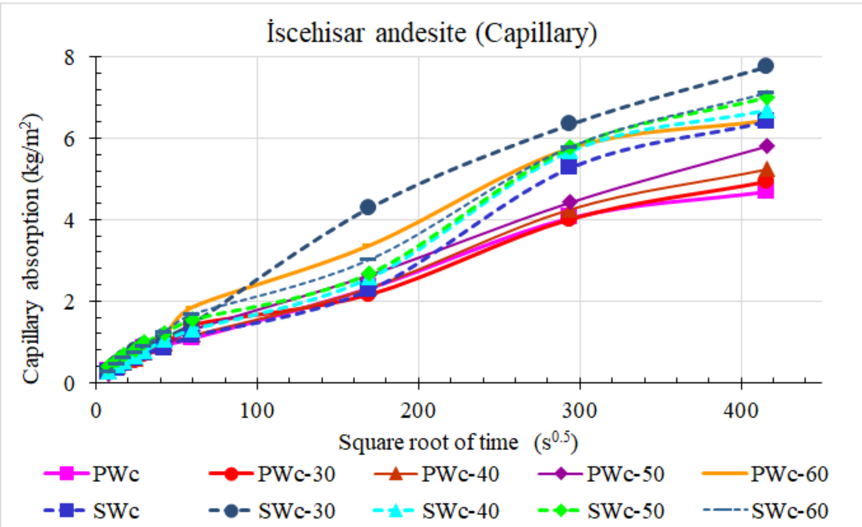

Figure 19. The graphs of the temperature and capillary water absorption value change the relationship of İscehisar andesite.

The fluorescence formed by the salts that crystallize on the outer surface of the natural building stones may cause decomposition in cases where the stone surface is not cleaned for a long time. In the capillary water absorption experiments, fluorescence was observed only at 40 and 50 °C in Ayazini tuffs. In İscehisar andesite, fluorescence occurred at all temperatures except 50 °C. However, no decomposition impairing physical integrity was observed in either group of samples at all temperature values.

Other data obtained from experimental studies show traces of evaporation in test samples in 60 °C water and salty water. This situation, which is more pronounced, especially in waters, was seen as evaporation traces at higher levels than water absorption levels in tuff and andesite samples. This situation occurred when the steam with a lower density rose before the water and entered the pores.

As a result, it has been determined that the Ayazini tuff, which is used as a building stone in many historical and cultural artifacts, has a higher capillary water absorption capacity than İscehisar andesite. It was observed that salty water effectively absorbed more capillary water than water in both stones. Experimental studies have shown that the capillary water absorption effect decreases when the temperature values reach 50 and 60 °C.

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